DRAFT
FEASIBILITY REPORT
DELIVERY PACKAGE

Caño Martín Peña Ecosystem Restoration Project

SEPTEMBER 2015

US Army Corps of Engineers

U.S. ARMY CORPS OF ENGINEERS
JACKSONVILLE DISTRICT

PROYECTO ENLACE DEL CAÑO MARTÍN PEÑA

CORPORACIÓN DEL PROYECTO
ENLACE DEL CAÑO MARTÍN PEÑA

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The Draft Feasibility Report Delivery Package contains 11 TABS as required by U.S. Army Corps of Engineers Planning Regulation ER 1105-2-100, Appendix G, Amendment #1, dated 30 June 2004.

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Acronyms and Abbreviations

ac	acres
AAHU	Average Annual Habitat Unit
ACGIH	American Conference on Governmental Industrial Hygienists
ACI	American Concrete Institute
ACM	Articulated concrete mat
ADCP	Acoustic Doppler Current Profilers
adICPR	advanced Interconnected Pond Routing
ADS	Autoridad de Desperdicios Sólidos
ALOHA	Areal Locations of Hazardous Atmospheres
AMC	Antecedent Moisture Condition
ASTM	American Society for Testing Materials
ATSDR	Agency for Toxic Substances and Disease Registry
ATR	Agency Technical Review
B2EHP	Bis (2-ethylhexyl) phthalate
BA	Biological Assessment
BACT	Best Available Control Technology
BDL	Below Detection Limit
BI	Benthic Index
BMP	Best Management Practice
C&D	Construction and demolition debris
°C	degrees Celsius
CAA	Clean Air Act
CAD	Confined Aquatic Disposal
CBIA	Coastal Barrier Improvement Act
CBRA	Coastal Barrier Resources Act
CBRS	Coastal Barrier Resources System
CCMP	Comprehensive Conservation & Management Plan for the San Juan Bay Estuary
CDLUP	Comprehensive Development and Land Use Plan
CDRC	Ciudad Deportiva Roberto Clemente
CE/ICA	Cost Effectiveness/Incremental Cost Analysis
CEM	Conceptual Ecological Model
CEQ	President’s Council on Environmental Quality
CERCLA	Federal Comprehensive Environmental Response, Compensation and Liability Act

CERCLIS	Federal Comprehensive Environmental Response, Compensation and Liability Information System
CFMC	Caribbean Fisheries Management Council
CFR	*Code of Federal Regulations*
CFU	Fecal coliform bacteria units
CH3D-WES	Curvilinear Hydrodynamics in 3 Dimensions, WES version
CHDO	Community Housing Development Organization
CM	Construction Management
cm	centimeters
CMP	Caño Martín Peña
CMP-CLT	Caño Martín Peña Community Land Trust
CMP-ERP	Caño Martín Peña Ecosystem Restoration Project
CMP-MTZ	Caño Martín Peña Maritime Terrestrial Zone
CO	Carbon monoxide
CO_2	Carbon dioxide
COC	Contaminants of Concern
CORRACT	Federal Corrective Actions List
CPI	Consumer Price Index
CRIM	Municipal Tax Revenue Collection Center
CSD	Combined Sewer Discharge
CSO	Combined Sewer Overflow
CSRA	Cost Schedule Risk Analysis
CSS	Combined Sewer System
CVM	Contingent Valuation Method
CWA	Clean Water Act
cy	cubic yards
CZMP	Coastal Zone Management Program
dB	decibel
dB(A)	A-weighted decibel
dbh	diameter at breast height
DDD	Dichlorodiphenyldichloroethane
DDE	Dichlorodiphenyldichloroethylene
DDT	Dichlorodiphenyltrichloroethane
DMMP	Dredged Material Management Plan
DNER	Puerto Rico Department of Natural and Environmental Resources
DO	Dissolved oxygen

DSS	Decent, Safe and Sanitary housing
DTPW	Puerto Rico Department of Transportation and Public Works
EA	Environmental Assessment
EC	Engineering Circular
ECC	ENLACE's Community Committee
ECO-PCX	Ecosystem Restoration Planning Center of Expertise
EDR	Environmental Data Resource, Inc.
EFH	Essential Fish Habitat
EGM	USACE Economic Guidance Memorandum
EIS	Environmental Impact Statement
EMF	Electromagnetic field
ENLACE	Corporación del Proyecto ENLACE del Caño Martín Peña
ENLACE Project	Caño Martín Peña ENLACE Project
EO	Executive Order
EPG	Emergency Power Generator
EQ	Environmental Quality Account
ER	USACE Engineering Regulation
ER	Engineering Report
ERAMPT	Ecosystem Restoration Adaptive Management Planning Team
ERDC	USACE's Engineer Research and Development Center
ERL	Effects Range–Low
ERM	Effective Range–Median
ERNS	Federal Emergency Response Notification System
ERP	Ecosystem Restoration Project
ERPG	Emergency Response Planning Guidelines
ESA	Endangered Species Act
ESI	Environmental Sensitivity Index
EUA	Ecological Uplift Assessment
°F	degrees Fahrenheit
FDA	Food and Drug Administration
FEIS	Final Environmental Impact Statement
FEMA	Federal Emergency Management Agency
FHWA	Federal Highway Administration
FIRM	Flood Insurance Rate Map
FIS	Flood Insurance Study
FMC	Fishery Management Council

FMP	Reef Fish Fishery Management Plan
FONSI	Finding of Non-Significant Impact
fps	feet per second
FR	Feasibility Report
FR	*Federal Register*
FRM	Flood Risk Management
FRP	Federal Recreation Plan
ft	feet
ft/s	feet per second
ft/y	feet per year
ft^2	square feet
ft^3	cubic feet
FWCA	Fish and Wildlife Coordination Act
FWPRA	Federal Water Project Recreation Act
FY	Fiscal year
g	grams
G-8	Group of the Eight Communities bordering the Caño Martín Peña
GHG	Greenhouse gas
GIS	Geographic Information System
GPS	Global Positioning System
H	Hybrid
H&H	Hydrology and Hydraulics
H_2S	Hydrogen sulfide
ha	hectare
HAP	Hazardous Air Pollutant
HAPC	Habitat Areas of Particular Concern
HDPE	High-density polyethylene
HEC	Hydraulic Engineering Circular
Hg	Mercury
HHW	Household Hazardous Waste
HIA	Health Impact Assessment
HTRW	Hazardous, Toxic, and Radioactive Waste
HU	Habitat Unit
HW	Household Waste
IA	Initial Assessment
IBC	International Building Code

IDC	Interest During Construction
IEPR	Independent External Peer Review
in	inches
in/yr	inches per year
INCICO	Instituto de Ciencias para la Conservación de Puerto Rico
IPCC	Intergovernmental Panel on Climate Change
IPRC	Institute of Puerto Rican Culture
IWR	USACE Institute for Water Resources
kg	kilograms
JD	Jurisdictional Determination
km^2	square kilometers
kV	kilovolt
L_{10}	Noise value exceeded 10% of the time
LBC	Level Bottom Capping
LC	Los Corozos
LEERD	Lands, Easements, Rights-of-Way, Relocations, and Disposal Area
L_{eq}	Equivalent (or average) noise level
LI	liquidity index
LL	liquid limit
LLC	Los Corozos Lagoon
LMM	Luis Muñoz Marín
LSJ1	Water Quality Station San José Lagoon 1
LSJ2	Water Quality Station San José Lagoon 2
LUST	State Leaking Underground Storage Tank
M	Million
m/s	meters per second
m^2	square meters
m^3/d	cubic meters per day
m^3/s	cubic meters per second
MCACES	Micro-Computer Aided Cost Engineering System
mg/kg	milligrams per kilogram
mg/L	milligrams per liter
mg/mg^3	milligrams per cubic milligrams
MGD	million gallons per day
MHHW	mean higher high water
MHW	mean high water

mi	miles
mi^2	square miles
mL	milliliters
MLLW	mean lower low water
MLW	mean low water
mm/yr	millimeters per year
MOA	Memorandum of Agreement
MP	Monitoring Plan
mph	miles per hour
MPRSA	Marine Protection, Research, and Sanctuaries Act
MRF	Material Recovery Facility
MSFCMA	Magnuson-Stevens Fishery Conservation and Management Act
msl	mean sea level
MTL	Mean Tide Level
MTZ	Maritime Terrestrial Zone
MTZ-CMP	Public Domain lands within the Caño Martín Peña Maritime Terrestrial Zone
NAAQS	National Ambient Air Quality Standards
NAD 83	North American Datum 1983
NCDC	National Climatic Data Center
NED	National Economic Development
NEP	USEPA's National Estuary Program
NEPA	National Environmental Policy Act
NER	National Ecosystem Restoration
NH_3	Ammonia
NMFS	National Marine Fisheries Service
NO_2	Nitrogen dioxide
NOA	Notice of Availability
NOAA	National Oceanic and Atmospheric Administration
NOI	Notice of Intent
NO_x	Nitrogen oxides
NPDES	National Pollutant Discharge Elimination System
NPL	National Priority List
NRC	Natural Research Council
NRCS	Natural Resource Conservation Service
NRHP	National Register of Historic Places
NTP	Notice to Proceed

NGVD 29	National Geodetic Vertical Datum 1929
NWI	National Wetland Inventory
O&M	Operation and Maintenance
O_3	Ozone
ODMDS	San Juan Bay Ocean Dredged Material Disposal Site
OGPe	Puerto Rico Permit Management Office (for its Spanish acronym)
OMRR&R	Operation and Maintenance, Repair, Replacement and Rehabilitation
OPA	Otherwise Protected Areas
OSC	On-Scene Coordination
OSE	Other Social Effects Account
OSHA	Occupational Health and Safety Administration
P&G	U.S. Water Resources Council Principles and Guidelines
PAH	Polycyclic aromatic hydrocarbons
Pb	Lead
PCBs	Polychlorinated biphenyls
PDI	Comprehensive Development Plan for the Caño Martín Peña Special District (Plan de Desarrollo Integral y Uso de Terrenos para el Distrito de Especial del Caño Martín Peña)
PDR	Project Design Report
PDT	Project Delivery Team
PED	Preconstruction Engineering and Design
PEL	Probable Effect Level
PI	plasticity index
PL	Public Law
PL	plastic limit
PM	Particulate Matter
PMP	Project Management Plan
PM_{10}	Particulate matter with an aerodynamic diameter less than or equal to a nominal 10 microns
$PM_{2.5}$	Particulate matter with an aerodynamic diameter less than or equal to a nominal 2.5 microns
PPA	Project Partnership Agreement
ppm	parts per million
ppt	parts per thousand
PR (P.R.)	Commonwealth of Puerto Rico
PRASA	Puerto Rico Aqueduct and Sewer Authority
PRCCC	Puerto Rico Climate Change Council

PRCZMP	Puerto Rico Coastal Zone Management Program
PREPA	Puerto Rico Electric Power Authority
PREQB	Puerto Rico Environmental Quality Board
PRGAP	Puerto Rico Gap Analysis Project
PRHTA	Puerto Rico Highway and Transportation Authority
Project Channel	2.2 miles of the Eastern CMP associated with the CMP-ERP
PRPB	Puerto Rico Planning Board
PR SCORP	Puerto Rico State Comprehensive Outdoor Recreation Plan
PRWQSR	Puerto Rico Water Quality Standards Regulation
psu	Practical salinity unit
PUD	Permanent Upland Disposal
RCRA	Federal Resource Conservation and Recovery Act
RCRA-G	RCRA Generators List
RCRA-TSD	RCRA Treatment, Storage, or Disposal List
REC	Recognized Environmental Conditions
RED	Regional Economic Development
REP	Real Estate Plan
RfC	Reference Concentration (for Chronic Inhalation Exposure)
ROD	Record of Decision
ROW	Right-of-Way
SAV	Submerged Aquatic Vegetation
SCS	Soil Conservation Service
SGC	Subaqueous geotextile confinement
SHPO	State Historic Preservation Office(r)
SHWS	State Hazardous Waste Site
SIP	State Implementation Plan
SJ	San José
SJ1	Artificial Pit San José 1
SJ2	Artificial Pit San José 2
SJ3/4/5	Artificial Pit San José 3/4/5
SJB	San Juan Bay
SJBE	San Juan Bay Estuary
SJBEP	San Juan Bay Estuary Program
SJHP	San Juan Harbor Project
SJL	San José Lagoon
SJMA	San Juan Metropolitan Area

SLR	Sea Level Rise
SO_2	Sulfur dioxides
SO_x	Sulfur oxides
SQG	Sediment quality guidelines
SQUIRT	Screening Quick Reference Tables
STAC	Scientific and Technical Advisory Committee
SV	Screening Value
SWMA	Puerto Rico Solid Waste Management Authority
T&E	Threatened and Endangered Species
TC	Technical Committee to the Project
TCLP	Toxicity characteristic leaching procedure
TCM	Travel Cost Method
TEL	Threshold Effect Level
TKN	Total Kjeldahl Nitrogen
TLV	Threshold Limit Value
TM	Thermal Stability Analysis
TN	Total nitrogen
TOC	Total Organic Carbon
tpy	tons per year
TSCA	Toxic Substances Control Act
TSD	RCRA Treatment, Storage, or Disposal List
TSP	Tentatively Selected Plan
TSS	Total Suspended Solids
UDV	Unit Day Value
µg/g	micrograms per gram
µg/L	micrograms per liter
URA	Uniform Relocation Act of Assistance and Real Property Acquisition Policies Act as amended, P.L.91-646; 42 U.S.C. 4601 et seq.
U.S.	Unites States of America
USACE	U.S. Army Corps of Engineers
U.S.C.	United States Code
USCG	U.S. Coast Guard
USDA	U.S. Department of Agriculture
USEPA	U.S. Environmental Protection Agency
USFWS	U.S. Fish and Wildlife Service
USGS	U.S. Geological Survey

UST	Underground storage tank
UWFP	Urban Waters Federal Partnership
VCS	State Voluntary Cleanup Site
VES	Visual Encounter Survey
VOC	Volatile Organic Compounds
WES	Waterways Experiment Station
WRDA	Water Resources Development Act
WQC	Water Quality Certification
yr	year
Zn	zinc

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Feasibility Report & Environmental Impact Statement for the Caño Martín Peña Ecosystem Restoration Project

MARCH 201

SEPTEMBER 2015

US Army Corps of Engineers

PROYECTO ENLACE DEL CAÑO MARTÍN PEÑA

Volume I

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Draft
Feasibility Report
Caño Martín Peña Ecosystem Restoration Project
San Juan, Puerto Rico

Main Report

September 2015

Prepared by:
Corporación del Proyecto ENLACE
del Caño Martín Peña

For review by:
U.S. Army Corps of Engineers

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FEASIBILITY REPORT
CAÑO MARTÍN PEÑA ECOSYSTEM RESTORATION PROJECT
SAN JUAN, PUERTO RICO

Responsible Agencies: The lead agency is the U.S. Army Corps of Engineers, Jacksonville District. The *Corporación del Proyecto ENLACE del Caño Martín Peña* is the non-Federal cost-sharing partner for the project. Operations, Maintenance, Repair, Rehabilitation, and Replacement will be the responsibility of the Puerto Rico Department of Natural and Environmental Resources (DNER).

Abstract: This Draft Feasibility Report and Environmental Impact Statement document the study for the Caño Martín Peña Ecosystem Restoration Project, in accordance with the requirements of Section 5127 of the Water Resources Development Act of 2007. The Project is essential to achieve the rehabilitation of the San Juan Bay Estuary System, which is the only tropical estuary within the Environmental Protection Agency's National Estuary Program. It addresses the need to restore the natural hydraulic connection between the San José Lagoon and the San Juan Bay, which has been eliminated through years of backfilling, sedimentation, and other factors. The proposed project, a key component of the Comprehensive and Conservation Management Plan for the San Juan Bay Estuary, is necessary to restore fish habitat, species diversity, and overall health of the system. The restored conveyance of tidal flow through the Caño Martín Peña will decrease water residence time within the San José Lagoon, returning salinity and dissolved oxygen to more natural levels and restoring benthic habitat in several of the San Juan Bay Estuary water bodies. In addition to restoring connectivity in the estuary, mangrove habitat for aquatic invertebrates and other native species will be restored, providing important nursery grounds for commercial fish species such as snapper and grouper. The Caño Martín Peña Ecosystem Restoration Project is also critical for the revitalization of eight impoverished communities settled along the Martín Peña tidal channel, and restoration of this system will significantly improve human health and safety in the area by reducing residents' frequent contact with highly polluted floodwaters. Recreational navigation will also be re-established in the area, allowing for increased public and commercial use of the entire estuary.

This Draft Feasibility Report and Environmental Impact Statement describe public and agency involvement in Project development, explains the plan formulation, evaluation, and selection process, and documents the National Ecosystem Restoration Plan features, including costs and environmental benefits.

THE OFFICIAL CLOSING DATE FOR THE RECEIPT OF COMMENT IS 45 DAYS FROM THE DATE ON WHICH THE NOTICE OF AVAILABILITY OF THIS EIS APPEARS IN THE *FEDERAL REGISTER*.

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DRAFT
FEASIBILITY REPORT
CAÑO MARTÍN PEÑA ECOSYSTEM RESTORATION PROJECT
SAN JUAN, PUERTO RICO

EXECUTIVE SUMMARY

The non-Federal sponsor, the *Corporación del Proyecto ENLACE del Caño Martín Peña* (ENLACE), has completed a Draft Feasibility Study and Environmental Impact Statement (FR/EIS) for the Caño Martín Peña Ecosystem Restoration Project (CMP-ERP). In accordance with Section 5127 of the Water Resources Development Act of 2007 and the subsequent implementation guidance, ENLACE submits this FR/EIS to the U.S. Army Corps of Engineers (USACE) for review and approval of the Assistant Secretary of the Army (Civil Works). This draft main report describes the purpose and need, location, National Ecosystem Restoration (NER) Plan, and other alternatives considered. It also includes the data that were collected and generated, analyses, and evaluations made with regards to the alternatives that were formulated leading to the selection of the NER plan for implementation. A draft Environmental Impact Statement (EIS) has also been prepared for the proposed project. It has been prepared to satisfy documentation requirements of the National Environmental Policy Act of 1969, as amended (NEPA), as well as the Commonwealth of Puerto Rico Environmental Policy Act of 2004.

Purpose and Need for the Study

The CMP-ERP is an urban ecosystem restoration project to restore the Caño Martín Peña (CMP) and surrounding areas of the San Juan Bay Estuary (SJBE). Restoration of the CMP would re-establish the tidal connection between the San José Lagoon and the San Juan Bay, which would improve dissolved oxygen levels and reduce salinity stratification, increase biodiversity by restoring fish habitat and benthic conditions, and improve the functional value of mangrove habitat within the estuary.

The CMP is a tidal channel 3.75 miles long in metropolitan San Juan, Puerto Rico. It is an integral part of the SJBE, the only tropical estuary included in the U.S. Environmental Protection Agency (USEPA) National Estuary Program (NEP). The SJBE's watershed covers 97 square miles. It is heavily urbanized, with a population density of over 5,000 people per square-mile. The SJBE includes over 33 percent of the mangrove forests on the island with over 124 species of fish and 160 species of birds. The eastern half of the CMP, historically between 200 and 400 feet wide and navigable, currently ranges in depth from 3.94 feet to 0 foot towards San José Lagoon. Due to years of encroachment and fill of the mangrove swamps along the CMP, the channel no longer serves as a functional connection between San Juan Bay and San José Lagoon. Sedimentation rates within the

CMP are nearly two orders of magnitude higher than in other parts of the SJBE. Open waters in areas closer to the San José Lagoon have been lost, as the area has started transitioning into a wetland. A combination of sediment and solid waste is found in the CMP, of which the solid waste accounts for approximately 10 percent of its composition. In some sites, the solid waste extends to depths 10 feet below the sediment surface.

The conditions within the eastern CMP have led to degradation within the entire estuary. Connectivity of the ecosystem has been severed and the biodiversity within the lagoons has been compromised, as more individuals of a reduced number of species are found when compared with other lagoons throughout the SJBE. The reduction in biodiversity in turn decreases the ability of fish and invertebrates to respond to natural changes, disease and other factors, resulting in a depletion of fish stock and losses of economic and recreational resources.

Water residence time in the San José Lagoon is of 16.9 days, much higher than a normal residence time, estimated to be about 3 days. The lack of tidal flushing causes strong salinity stratification and in turn leads to low oxygen or no oxygen levels in the 702 acres of lagoons with depth below 4 to 6 feet, severely affecting benthic habitats. Mangrove habitat, extremely important for native aquatic invertebrates, has been severely impacted, reducing habitat where important commercial fish species spend their juvenile life stages.

Ecological degradation within the estuary has also begun to affect socio-economic conditions of local human population surrounding the CMP. Inability to improve local drainage infrastructure due to the lack of conveyance capacity in the CMP leads to substantial flooding with the surrounding neighborhoods. Fecal coliform levels within these floodwaters are alarmingly high, and subsequent human contact with the waters of the CMP has been associated with higher rates of asthma and gastrointestinal disease. Recreational navigation within the estuary has also been severed, restricting public and commercial waterborne traffic within the capital city.

Initial Array of Alternatives

The plan formulation process built directly upon previous planning and design efforts. Structural management measures for the channel dredging, erosion control, dredged material disposal, mangrove planting and construction, recreation, as well as non-structural measures were identified and screened. An Initial Array of Alternatives consisting of rectangular channel cross sections ranging between 75- and 200-foot widths with 10-foot depths was then developed and evaluated. Screening criteria such as completeness, acceptability, cost effectiveness, and secondary effects on adjacent communities, were then used to eliminate unfavorable plans and develop a final array of alternatives.

Final Array of Alternatives, Plan Comparison, and Selection

Final Array: The final array of alternatives consisted of four alternative plans:

<u>No Action Alternative Plan</u>: Involves no further Federal actions.

Alternative Plan 1: Consists of a 75-foot-wide by 10-foot-deep channel; articulated concrete mats along the entire channel bottom for erosion control; an elongated weir under the Martín Peña, Tren Urbano, and Luis Muñoz Rivera bridges involving a 115-foot-wide by 6.5-foot-deep channel with riprap on side slopes and articulated concrete mats at the channel bottom; dredging approximately 680,000 cubic yards (cy) of mixed materials along 2.2 miles of the eastern CMP; construction of a vertical concrete-capped steel sheet pile with hydraulic connections with the surrounding lands; and, restoration of 20.42 acres of open water and 39.62 acres of wetland.

Alternative Plan 2: Consists of a 100-foot-wide by 10-foot-deep natural bottom channel; an elongated weir under the Martín Peña, Tren Urbano, and Luis Muñoz Rivera bridges involving a 115-foot-wide by 6.5-foot-deep channel with riprap on side slopes and articulated concrete mats at the channel bottom to reduce water velocity and erosion, and to control scour; dredging approximately 762,000 cy of mixed materials along 2.2 miles of the eastern CMP; and construction of a vertical concrete-capped steel sheet pile with hydraulic connections with the surrounding lands; restoration of 25.57 acres of open water and 34.48 acres of wetland.

Alternative Plan 3: Consists of a 125-foot-wide by 10-foot-deep natural bottom channel; an elongated weir under the Martín Peña, Tren Urbano, and Luis Muñoz Rivera bridges involving a 115-foot-wide by 6.5-foot-deep channel with riprap on side slopes and articulated concrete mats at the channel bottom to reduce water velocity and erosion, and to control scour; dredging approximately 872,000 cy of mixed materials along 2.2 miles of the eastern CMP; and construction of a vertical concrete-capped steel sheet pile with hydraulic connections with the surrounding lands; restoration of 30.97 acres of open water and 29.08 acres of wetland.

For Alternative Plans 1, 2, and 3, total construction time would be approximately 27 months; maintenance dredging would be required; and dredged material disposal would be divided between upland landfill for solid waste and disposal in the San José Lagoon pits for dredged sediment.

Evaluation and Comparison: Performance measures for Benthic Habitat, Fish Habitat, and Mangrove Habitat were developed to measure alternative output, and ecosystem restoration measure benefits were calculated for each alternative. A cost effectiveness and incremental cost analysis (CE/ICA) was conducted based on a project life of 50 years and a Federal Discount Rate of 3.5 percent and a base year of 2019. Each alternative was considered to be independent and not combinable with the other alternative. Due to weir restrictions to prevent erosion at bridges and other structures for all three action alternatives, average annual habitat units (AAHUs) would be nearly identical among alternatives, totaling 6,133 AAHUs per alternative. As a result, Alternative 2, with an average annual equivalent cost of $8,700,000, was determined to be cost effective and best buy when compared to Alternatives 1 and 3 with average annual equivalent costs of $9,300,000 and $9,100,000, respectively.

Additional considered criteria included project objectives and constraints, a comparison of the Four Accounts, and criteria contained in the "Principles and Guidelines" (P&G) for water resources planning adopted by the Water Resources Council.

Selection: Alternative 2, the 100-foot-wide channel, was identified as the Tentatively Selected Plan (TSP). It is the National Ecosystem Restoration Plan (NER) plan and is both cost effective and a best buy. In accordance with the P&G criteria, Alternative 2 provides a complete solution to the problems identified for the study. It is also the most effective plan and meets the project objectives. The NER Plan is acceptable and has been determined to be in the national and public interest and can be constructed while protecting the human environment from unacceptable impacts.

National Ecosystem Restoration Plan Elements

Channel

Alternative Plan 2 consists of dredging approximately 2.2 miles of the eastern half of the CMP to a width of 100 feet and a depth of 10 feet, with slight variations in channel width and depth at the 4 bridges to the west, the Barbosa Bridge to the east, and at the terminus of the CMP with the San José Lagoon. The walls of the Project Channel would be constructed with vertical concrete-capped steel sheet piles with hydrologic connections to the surrounding lands. The sill depth of the window would be set at mean low water so that tidal exchanges are facilitated to the mangrove beds. Rip rap would be placed at the four bridges. At the terminus of the Project Channel with the San José Lagoon, an extended channel would be dredged east into the San José Lagoon (over a distance of approximately 4,300 feet) as a hydraulic transition from the CMP. This extended channel would transition from the 10-foot-deep Project Channel to the 6-foot-deep areas of San José Lagoon. The extended channel would maintain the Project Channel's 100-foot width but replace its steel sheet pile walls with a trapezoidal configuration with 5-foot to 1-foot earthen side slopes.

Disposal

Materials within the Caño Martín Peña include various types of solid waste, debris, and other materials. Such materials will require further testing prior to and/or during project construction, as appropriate, in accordance with an agreed sampling plan. If the testing determines that any materials contain hazardous substances at levels that are not suitable for unregulated disposal, they will be managed in accordance with the applicable laws and regulations of the relevant regulatory agencies.

A barge-mounted mechanical clamshell dredge would be used to widen and deepen the CMP channel, and would place dredged material into dump scows. Approximately 76,200 cy of solid waste would be screened from the 762,000 cy of dredged material and transported from the CDRC staging area to the Humacao landfill site, which is located approximately 32 miles from the CMP-ERP site.

After screening and removal of solid waste debris, the remaining sediment and smaller pieces of solid waste would be encapsulated within geotextile fabric bags, and transported by shallow draft barges to the San José Lagoon artificial subaqueous pits. Sediments would be placed utilizing contained aquatic disposal (CAD) in the SJ1 and SJ2 pits. Prior to disposal operations, both of these sites would be modified to increase capacity to accommodate the majority of dredged sediments and the required 2-foot sand cap. Approximately 517,581 cy of material would be removed from SJ1 and SJ2 and deposited within the SJ 3/4/5 artificial subaqueous pits. During the CMP-ERP disposal operations, approximately 648,000 cy of in situ sediments would be placed in the SJ1 and SJ2; however, additional water quality and sediment testing, such as bioassays, would be conducted prior to placement to ensure their suitability for disposal. Approximately 37,800 cy of in-situ sediments would be used to complete the sheet pile construction and mangrove bed restoration.

The SJ1 and SJ2 CAD sites would be capped with a 2-foot layer of sand. Material for the sand cap will be quarried from upland quarry sites and transported by trucks to the construction staging area for transfer to dump scows for placement. Silt curtains would also be employed around the pits in the San José Lagoon. In critical areas, the curtains may double ring the active area for additional precautions. The curtains would be constructed to the full depth of the water where they are placed.

For activities related to the installation of the weir in the western end of the Project Channel, an upland staging area near the four western bridges would be used to temporarily stockpile and transfer the collected sediment and solid waste excavated during the dredging process. Equipment and materials would be staged on floating barges. After the construction of the weir, and once the dredging from the eastern portion of the Project Channel opened the CMP, the temporary coffer dam would be removed, and the stockpiled solid waste would be placed into shallow-draft barges for transport to the Ciudad Deportiva Roberto Clemente (CDRC) staging area. At the CDRC staging area, the material would be off-loaded, placed into trucks, and hauled for disposal at the Humacao upland landfill. Stockpiled sediment would be transported by barge to the San José Lagoon pits for CAD.

Erosion Control

A weir would be constructed at the western end of the Project Channel to mitigate water flows into the adjacent western CMP waterway. The weir would be constructed with an articulated concrete bottom, while the remainder of the Project Channel would be earthen bottom.

Non-Structural Measures

As an aquatic ecosystem restoration project, there are no non-structural measures for the dredging of the CMP. Non-structural measures related to structure acquisitions and relocations within the public domain boundary (and confines of the Federal project), as well as activities outside of the project that would be conducted by the non-Federal sponsor included structure acquisition and relocation, increased enforcement of illegal dumping, and community education. There are 434 residential structures that would be acquired and 390 relocations that would occur as part of the proposed project.

Mangrove Restoration

Approximately 34.48 acres of mangrove wetlands would be restored by grading lands adjacent to the CMP and planting four native species of mangrove.

Secondary Project Components

Secondary project components are as follows: Recreation Plan, Project Monitoring and Adaptive Management Plan, Nuisance and Exotic Vegetation Control, and Draft Project Operating Manual. The proposed Federal recreation plan includes numerous water access areas that would replace lost functions within the project area.

Cost of the Plan

The total estimated project first cost is $230,280,000, estimated at October 2014 price levels. Operations, Maintenance, Repair, Rehabilitation, and Replacement (OMRR&R) costs are estimated at $59,423,000 for a total estimated cost of $289,703,000. The cost share for the ecosystem restoration features of the project will be 65 percent Federal and 35 percent non-Federal. Recreational features would be cost shared at 50 percent Federal and 50 percent non-Federal. The Local Sponsor will be responsible for 100 percent costs of lands, easements, rights-of-way, relocations, and disposal areas (LERRDs), ecosystem restoration maintenance, and recreation OMRR&R. Thus, the Federal estimated cost share is $148,139,000 and the non-Federal cost share is $141,564,000.

Environmental Operating Principles

The proposed project is consistent with the USACE "Environmental Operating Principles" and is intended to achieve a sustainable, healthy CMP and SJBE ecosystem as well as the surrounding communities. Planning for the CMP-ERP was based on over a decade of intense work to engage the public and stakeholders in developing management plans, creating a platform for a successful, collaborative planning effort. The planning process fully considered the relationship of a restored ecosystem to the socioeconomic wellbeing of the surrounding neighborhoods. It has been open and transparent, and has fully leveraged the scientific, economic, and social knowledge of the project's stakeholders, and government agencies.

Areas of Controversy and Unresolved Issues

Throughout the informal public participation process carried out by the Sponsor, several issues have been raised and are addressed in the FR/EIS. The most important areas of concern are related to water quality, dredging, and disposal of dredged material, including potentially contaminated sediments. Alternatives presented in the FR/EIS were discussed and analyzed with stakeholders. The public has also raised concerns regarding temporary impacts during construction such as noise, odors, vibrations and structure stability, and vectors. The EIS discusses recommendations to reduce these impacts.

Public concerns also include the acquisition of structures and relocation of families living along the CMP and the possibility of gentrification once the project is completed. The Sponsor has worked closely with the organized communities along the CMP to ensure participation in the decision making process, leading to the design of strategies to address such concerns incorporated within the Comprehensive Development and Land Use Plan for the District and in Puerto Rico Law 489 of September 24, 2004, as amended. Strategies include the relocation plan, the creation of a citizens' relocation committee to comply with applicable policies, as well as the creation of the Fideicomiso de la Tierra del Caño Martín Peña, a community land trust.

Agency Technical Review

An Agency Technical Review (ATR) has been performed on the Draft FR/EIS. The ATR was conducted by a multidisciplinary team consisting of technical staff from USACE Districts across the nation, and was completed in accordance with recent USACE policy regarding coordination with the National Ecosystem Center of Expertise and the National Cost Engineering Directorate of Expertise.

Independent External Peer Review

An Independent External Peer Review (IEPR) has been performed on the Draft Feasibility Report and Environmental Impact Statement (EIS). The Sponsor contracted a multi-disciplinary panel of experts from the public to perform the IEPR. The Review was conducted in accordance with USACE policy regarding coordination with the National Ecosystem Planning Center of Expertise.

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Acronyms and Abbreviations

AAHU	Average Annual Habitat Units
ACM	Articulated Concrete Mat
ATR	Agency Technical Review
B2EHP	Bis (2-ethylhexyl) phthalate
BI	Benthic Index
BMPs	Best Management Practices
C&D	Construction and Demolition
CAD	Contained Aquatic Disposal
Cantera Company	*Compañía para el Desarrollo Integral de la Península de Cantera*
Commonwealth	The Commonwealth of Puerto Rico
CCMP	Comprehensive Conservation & Management Plan for the San Juan Bay Estuary
CDLUP	Comprehensive Development Land Use Plan
CDRC	Ciudad Deportiva Roberto Clemente
CE/ICA	Cost Effectiveness/Incremental Cost Analysis
CEM	Conceptual Ecological Model
CERCLA	Comprehensive Environmental Response, Compensation, and Liability Act
CFR	Code of Federal Regulations
CH3D-WES	Curvilinear Hydrodynamics in 3-Dimensions-Waterways Experiment Station model
CHDO	Community Housing Development Organization
CMP	Caño Martín Peña
CMP-ERP	Caño Martín Peña Ecosystem Restoration Project
CSRA	Cost Schedule Risk Analysis
cy	cubic yard
dB	decibels
DDT	dichloro-diphenyl-trichloroethane
District	CMP Special Planning District
District's Plan	CMP Special Planning District's Land Use and Comprehensive Development Plan
DNER	Puerto Rico Department of Natural and Environmental Resources
DO	dissolved oxygen
DTPW	Puerto Rico Department of Transportation and Public Works
EC	Engineering Circular
ECO-PCX	USACE Ecosystem Restoration Planning Center of Expertise
EFH	Essential Fish Habitat
EIS	Environmental Impact Statement
ENLACE	Corporación del Proyecto ENLACE del Caño Martín Peña

ENLACE Project	Caño Martín Peña ENLACE Project
EQ	Environmental Quality Account
ER	Engineering Regulation
ERDC	USACE Engineer Research and Development Center
ERP	Ecosystem Restoration Project
ESA	Endangered Species Act
FEMA	Federal Emergency Management Agency
FIRM	Flood Insurance Rate Map
FMP	Reef Fish Fishery Management Plan
FR	Feasibility Report
FRM	Flood Risk Management
ft^2	square feet
ft/s	feet per second
ft/y	feet per year
IWR	USACE Institute for Water Resources
G-8	Grupo de las Ocho Comunidades Aledañas al Caño Martín Peña (Group of the Eight Communities bordering the Caño Martín Peña)
g	grams
GHG	Greenhouse Gas
GIS	Geographic Information System
H_2S	hydrogen sulfide
HW	Household Waste
HHW	Household Hazardous Waste
HTRW	Hazardous, Toxic, Radioactive Waste
HU	Habitat Unit
IDC	Interest During Construction
IEPR	Independent External Peer Review
in	inches
IPRC	Institute for Puerto Rican Culture
Juan Méndez	Quebrada Juan Méndez
LERRDs	Lands, Easements, Right-of-Way, Relocations, and Disposal Areas
Kg	kilograms
m	meters
MCACES	Micro-Computer Aided Cost Estimating System
mg/Kg	milligrams per kilogram
mg/L	milligrams per liter
mi^2	square mile
mL	milliliter
MLLW	mean low low water
mm/yr	millimeters per year

MOA	Memorandum of Agreement
mph	miles per hour
MSL	mean sea level
MTZ-CMP	Public Domain lands within the Caño Martín Peña Maritime Terrestrial Zone
NED	National Economic Development Account
NEP	USEPA's National Estuary Program
NEPA	National Environmental Policy Act
NER	National Ecosystem Restoration
NGVD 29	National Geodetic Vertical Datum 1929
NH_3	Ammonia
NMFS	National Marine Fisheries Service
NOAA	National Oceanic and Atmospheric Administration
NOI	Notice of Intent
NRC	Natural Research Council
O&M	Operations and Maintenance
ODMDS	San Juan Bay Ocean Dredged Material Disposal Site
OMRR&R	Operations, Maintenance, Repair, Rehabilitation, and Replacement
OSE	Other Social Effects Account
P&G	United States Water Resources Council Principles and Guidelines
PAH	polycyclic aromatic hydrocarbons
PCBs	polychlorinated biphenyls
PDT	Project Delivery Team
PED	Preconstruction engineering and design
PL	Public Law
PMP	Project Management Plan
PPA	Project Partnership Agreement
ppm	parts per million
PR	Puerto Rico
PRASA	Puerto Rico Aqueduct and Sewer Authority
PREQB	Puerto Rico Environmental Quality Board
PRHTA	Puerto Rico Highway and Transportation Authority
Project Channel	2.2 miles of the Eastern CMP associated with the CMP-ERP
PRPB	Puerto Rico Planning Board
PRWQSR	Puerto Rico Water Quality Standards Regulation
PUD	Permanent Upland Disposal
RCRA	Resource Conservation and Recovery Act
REC	Recognized Environmental Condition
RED	Regional Economic Develop Account
ROD	Record of Decision

ROW	Right-of-Way
SHPO	State Historic Preservation Office
SJBE	San Juan Bay Estuary
SJBEP	San Juan Bay Estuary Program
SJHP	San Juan Bay Harbor Project
T&E	Threatened and Endangered Species
TC	Technical Committee to the Project
TN	Total Nitrogen
TSP	Tentatively Selected Plan
µg/g	micrograms per gram
URA	Uniform Relocation Act of Assistance and Real Property Acquisition Policies Act as amended, P.L.91-646; 42 U.S.C. 4601 et seq.
USACE	United States Army Corp of Engineers
U.S.C.	United States Code
USEPA	United States Environmental Protection Agency
USFWS	United States Fish and Wildlife Service
USWRC	United States Water Resources Council
UWFP	Urban Waters Federal Partnership
WQC	Water Quality Certification
WRDA	Water Resources Development Act

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1.0 INTRODUCTION

The Caño Martín Peña (CMP) is a considerably degraded tidal channel in the heart of heavily urbanized San Juan, Puerto Rico. Due to years of infill in the surrounding communities, the CMP no longer serves as a functional connection between San Juan Bay and San José Lagoon. The resulting loss of tidal circulation has led to decreased functional value of the region's fish, wildlife, and mangrove habitat, degraded water and sediment quality, and extensive human health impacts in the surrounding communities. This feasibility report documents the feasibility study process used to develop, evaluate, compare, and recommend a tentatively selected plan to improve the CMP for the benefit of the natural and human communities.

1.1 STUDY AUTHORITY

The Puerto Rico Department of Natural and Environmental Resources (DNER), custodian authority of the Maritime-Terrestrial Zone of the Caño Martín Peña (MTZ-CMP) and the USACE have performed preliminary technical analyses concerning the dredging of the CMP under a Support for Others Memorandum of Agreement (MOA) dated March 3, 1996, and amended on May 24, 1999. This work concluded with the report "Dredging of Caño Martín Peña, Project Design Report and Environmental Impact Statement (EIS)" (USACE, March 2001).

After the Caño Martín Peña Ecosystem Restoration Project (CMP-ERP) was assigned to the Puerto Rico Highway and Transportation Authority (PRHTA), the USACE prepared the "Reconnaissance Report Section 905(b) Water Resources Development Act of 1986 (WRDA 86) Analysis, Caño Martín Peña, Puerto Rico Ecosystem Restoration." This report was prepared under a Congressional Resolution by the Committee on Transportation and Infrastructure of the U.S. House of Representatives, Docket 2702, dated September 25, 2002, which reads as follows:

> *Resolved by the Committee on Transportation and Infrastructure of the United States House of Representatives, That the Secretary of the Army is requested to review the report of the Chief of Engineers on the Puerto Nuevo River, Puerto Rico, and other pertinent reports to include the dredging of Caño Martín Peña Project Design Report and Environmental Impact Statement, dated March 2001, to determine whether modifications to the recommendations contained therein are advisable at the present time in the interest of environmental restoration and protection and related purposes at the Martín Peña Canal, San Juan, Puerto Rico.*

The purpose of the reconnaissance study was to determine whether there was a Federal interest in the USACE participating in a cost shared feasibility phase study for ecosystem restoration and other related purposes along the CMP in San Juan, Puerto Rico. This Reconnaissance Report, which was completed in 2004, presented the results of studies for the CMP ecosystem restoration and concluded that there was a strong Federal interest in continuing the study into the feasibility phase. This conclusion was based on the likelihood that a Federal ecosystem restoration project would be environmentally and economically justified and implementable.

The 110th Congress enacted Public Law (PL) 110–114, known as the "Water Resources Development Act of 2007," or WRDA 2007, on November 8, 2007. Section 5127 directed that:

> *The Secretary shall review a report prepared by the non-Federal interest concerning flood protection and environmental restoration for Caño Martín Peña, San Juan, Puerto Rico, and, if the Secretary determines that the report meets the evaluation and design standards of the Corps of Engineers and that the project is feasible, the Secretary may carry out the project at a total cost of 150,000,000.*

On October 27, 2008, the Director of Civil Works issued an implementation guidance memorandum for Section 5127 of the WRDA 2007, which established that the feasibility study "will follow the requirements set forth in Appendix H of Engineering Regulation (ER) 1105-2-100 for projects authorized without a report and be submitted for approval by the Assistant Secretary of the Army (Civil Works)."

As indicated above, the proposed CMP-ERP was authorized as multi-purpose Ecosystem Restoration and Flood Risk Management project. Prior to embarking on the Feasibility Report, an appraisal of potential Flood Risk Management (FRM) benefits was conducted for the proposed project. Initial analysis indicated that the FRM National Economic Development (NED) benefits would not be equivalent to those that would be generated from a National Ecosystem Restoration (NER) analysis. As a result, it was concluded that the project would be more aptly formulated as a single-purpose, Ecosystem Restoration project with incidental FRM benefits. A qualitative analysis has been conducted for FRM and those benefits are identified within the Economic and Environmental Principles and Guidelines for Water and Related Land Resources Implementation Studies (P&G) Four Accounts description and NER Plan sections of this Report. Federal recreation features have also been included in the CMP-ERP consistent with ER 105-2-100.

1.2 NON-FEDERAL SPONSOR

The *Corporación del Proyecto ENLACE del Caño Martín Peña* (ENLACE) is a public agency created under the Commonwealth of Puerto Rico (the Commonwealth) Law 489-2004 of September 24, 2004, for the implementation of the Comprehensive Development of the Caño Martín Peña Special Planning District, as amended (PR Law 489-2004). ENLACE is the non-Federal sponsor for the feasibility study effort of the CMP-ERP. As such, it initiated the feasibility phase of the study in September 2010. In June 2012, ENLACE and the Department of the Army executed a contributed funds agreement for the revision of the Feasibility Report and Environmental Impact Statement for the CMP-ERP. ENLACE performed the planning and technical analyses for the feasibility report according to USACE regulations using a combination of in-house and contracted staff resources. The USACE Jacksonville District provided oversight and technical review of the process to ensure the final feasibility report complied with ER 1105-2-100.

1.3 PROJECT AREA

The CMP is a tidal channel 3.75 miles long in metropolitan San Juan, Puerto Rico. It is part of the San Juan Bay Estuary (SJBE), the only tropical estuary included in the U.S. Environmental Protection Agency (USEPA) National Estuary Program (NEP). The SJBE and its associated marine ecosystems are considered the "Study Area," because the proposed CMP-ERP is expected to have direct, indirect, and cumulative beneficial effects on this whole region (Figure 1). The "Project Area", which mostly lays out the construction footprint, has been defined as the Project Channel, where dredging would take place, and the adjacent delimitation of the public domain lands within the MTZ-CMP where relocations are scheduled to occur. Also included in the Project Area is the 6-acre dredged material staging area within the 35-acre Ciudad Deportiva Roberto Clemente (CDRC) site, the boating routes from the eastern limit of the CMP to the CDRC and the nearby San José Lagoon pits, and the five pits in San José Lagoon (Figure 2).

Eight communities are adjacent to the eastern CMP including Barrio Obrero Oeste y San Ciprian, Barrio Obrero Marina, Buena Vista Santurce, Parada 27, Las Monjas, Buena Vista Hato Rey, Israel-Bitumul, and Peninsula de Cantera (Figure 3). In addition, there are three major utilities that are located within the project area: a 115-kV Power Line, the Borinquen Water Transmission Line, and the Rexach Sewer Line (Figure 4). Another major utility, the San José Sewer Line, is adjacent to the CMP-ERP Project Area.

The SJBE, along the northern coast of Puerto Rico, is the largest system of its kind on the island. Located within the largest urbanized and most densely populated region in Puerto Rico, the SJBE's watershed includes the municipalities of Toa Baja, Cataño, Bayamón, San Juan, Guaynabo, Carolina, Loíza, and Trujillo Alto. The system is characterized by a network of lagoons, channels, man-made canals, permanently and seasonally flooded woody and herbaceous wetlands, and the San Juan Bay, which is home to Puerto Rico's busiest port.

Figure 1. The San Juan Bay Estuary Study Area.

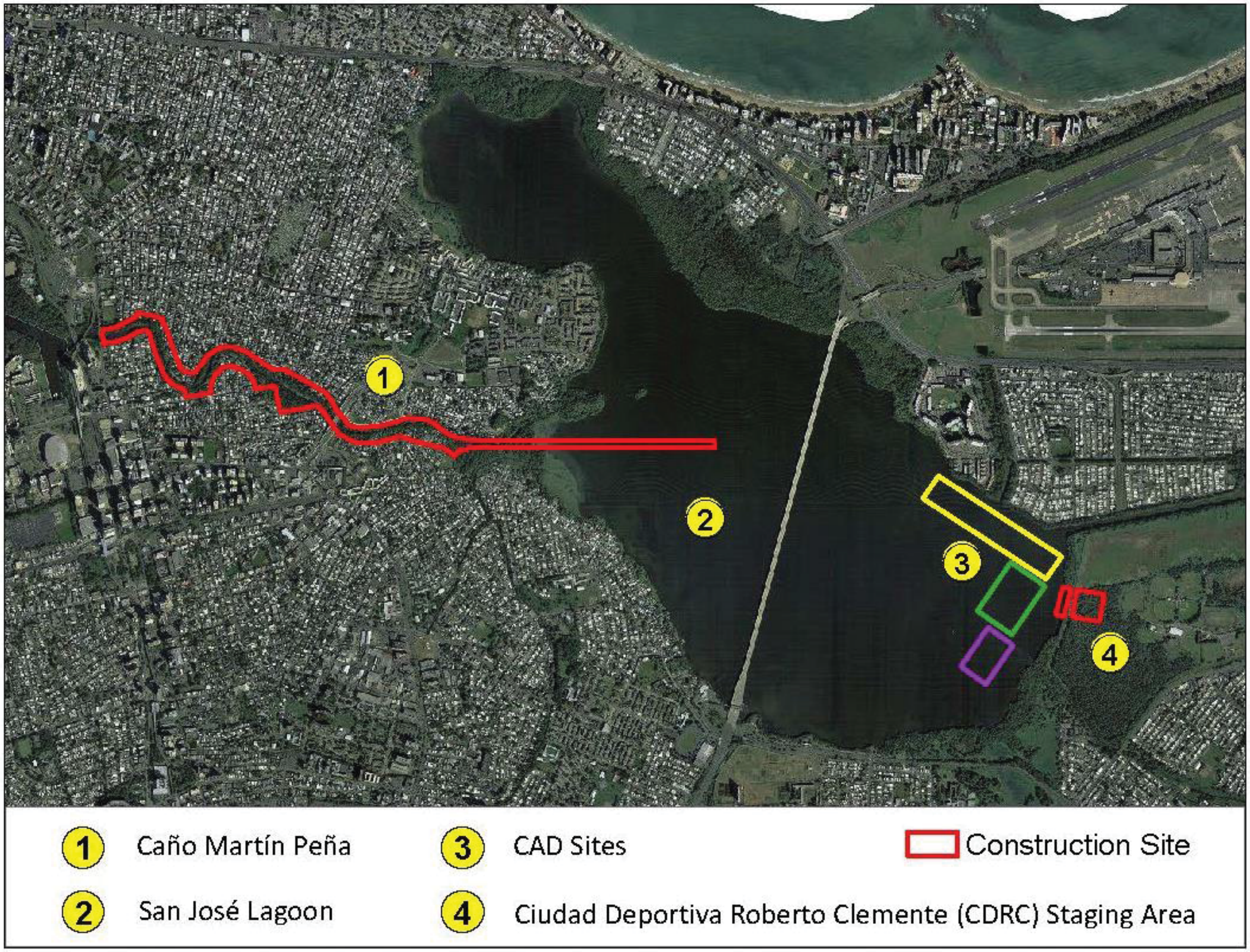


Figure 2. The Caño Martín Peña Ecosystem Restoration Project Area

Figure 3. Communities Adjacent to the Caño Martín Peña

The SJBE includes the San Juan Bay, the Condado, San José, Los Corozos, La Torrecilla, and Piñones lagoons, the interconnecting CMP, San Antonio Channel, and Suárez Canal, as well as the Piñones mangrove forest and Las Chucharillas Swamp. Fresh water flows into the system from the creeks and rivers flowing mostly north from its watershed, covering approximately 97 square miles (see Figure 1). These include the Río Piedras (Puerto Nuevo) River, Juan Méndez, San Antón, and Blasina creeks, and the Malaria Canal. During medium to extreme flood events, fresh water is also received from the Río Grande de Loíza River located east of the Piñones State Forest. Several flood control pump stations as well as storm water sewers discharge fresh water into the system. Ocean water enters the SJBE through three openings or outlets: Boca del Morro at the San Juan Bay, El Boquerón at the Condado Lagoon, and Boca de Cangrejos at La Torrecilla Lagoon. The Puerto Nuevo River, whose drainage area is of about 25 square miles, flows into the western end of the CMP, close to the San Juan Bay. The western half of the CMP was dredged during the 1980s as part of a waterway transportation project. This portion of the CMP is navigable and has a channel width and depth of 200 feet and 10 feet, respectively. The total drainage area of the CMP is about 4 square miles (2,500 acres).

Source: ENLACE & Puerto Rico Planning Board

Figure 4. Major Utilities Within and Adjacent to the Project Area

1.4 PURPOSE AND SCOPE FOR THE PROJECT

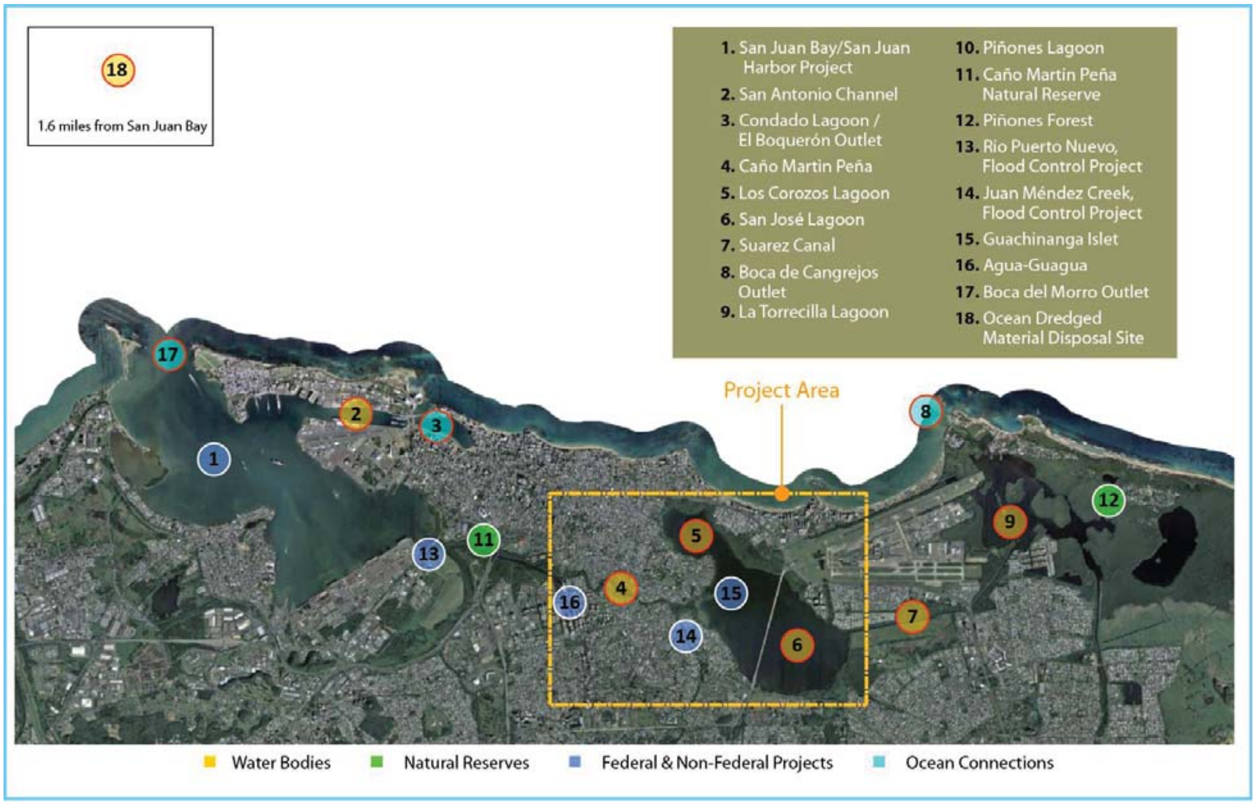
The project has been formulated and evaluated as a single-purpose ecosystem restoration project for the purpose of environmental restoration for the Caño Martín Peña, San Juan, Puerto Rico. The national significance of the resource (e.g., public, institutional, and technical significances) is further discussed in Section 6.1.1 (*Significance of Ecosystem Restoration Benefits*) of this report. The feasibility report directly builds on the following previous technical and planning efforts by incorporating those previous technical and plan formulation considerations into the current feasibility study:

- San Juan Bay Estuary Program (SJBEP) Comprehensive Conservation and Management Plan (CCMP) (2000);
- USACE Dredging of Caño Martín Peña, Project Design Report and Environmental Impact Statement, Jacksonville District (2001);
- USACE Reconnaissance Report Section 905(b) Analysis, Caño Martín Peña, Puerto Rico Ecosystem Restoration (2004);
- PRHTA Comprehensive Development and Land Use Plan for the Caño Martín Peña Special Planning District (2006); and,

- Puerto Rico Planning Board (PRPB) Comprehensive Development Plan for the Cantera Peninsula (1995).

1.5 RELATIONSHIP TO OTHER USACE, FEDERAL, AND NON-FEDERAL PROJECTS

There are several related Federal and non-Federal projects and other efforts in the Study Area that have been or are being implemented. Their locations are shown in Figure 5.



Source: ENLACE & Puerto Rico Planning Board

Figure 5. Existing Projects Related to the Caño Martín Peña Ecosystem Restoration Project

1.5.1 San Juan Harbor Project

San Juan Harbor, which is part of the SJBE system, has the Commonwealth's main port, handling over 15 million tons (or 80 percent) of waterborne commerce moving through the harbor annually.

The San Juan Harbor Project (SJHP), west of the CMP, is a completed Federal Deep-Draft Navigation Project with congressional authorizations dating back to 1917, the most recent included in the Water Resources Development Act (WRDA) of 1996, to deepen the navigation channels. The current project consists of a Bar Channel with depths from 56 to 49 feet, a 40-foot-deep Anegado entrance channel, a 40-foot-deep Army Terminal Channel, a 39-foot-deep Puerto Nuevo Channel, a 34-foot-deep Sabana

Approach, a 36-foot-deep Graving Dock Channel, a 30-foot-deep Graving Dock Turning Basin, a 36-foot-deep San Antonio Channel, a 30-foot-deep extension to the San Antonio Channel, two 30-foot-deep Cruise Ship Basins, a 36-foot-deep Anchorage Area E, and a 30-foot-deep Anchorage Area F. Maintenance dredging works for the navigational channels is performed on a regular basis. The basic channel structure of the SJHP is complete; however, there may be requirements in the future for basin or wharf improvements or modifications.

Dock and storage facilities in the San Juan Bay (SJB) led to the elimination of almost all of the mangrove basin forests that existed in this waterbody, such as those associated with the outlets of the CMP, the Puerto Nuevo River, and the San Fernando Channel, and especially those that used to fringe the San Antonio Channel, including most of what is today the Isla Grande Península. Dredging works have caused the temporary resuspension of sediments and concomitant impacts to the Bay's water quality, including the mechanical destruction of benthic communities. The USACE has proposed to mitigate the latest impacts to submerged aquatic vegetation by filling two artificial dredged pits in the Condado Lagoon in order to promote its restoration with seagrasses (USACE, 2014; Tetra Tech, 2011).

Overall, beneficial effects resulting from the CMP-ERP are anticipated within San Juan Harbor. The CMP-ERP would help offset some of the SJHP short- and long-term impacts of the ports operations and maintenance by restoring mangrove forests and open waters along the eastern CMP, and improving overall water quality and benthic habitat conditions within the SJBE.

1.5.2 Agua-Guagua Project (AcuaExpreso)

In 1982, the Puerto Rico Department of Transportation and Public Works (DTPW) requested the USACE to conduct engineering and design studies for a waterway along the western half of the CMP, from the San Juan Bay to the Hato Rey Financial District, as part of the mass transportation Agua-Guagua Project. A Final Report was completed in August 1983. The Urban Mass Transit Administration provided funding for this project.

The USACE began construction in 1984 and completed it in 1988 at a cost of $20 million. Work consisted of dredging the western CMP to 200 feet wide and 10 feet deep, ocean disposal of over 1.3 million cubic yards (cy) of material dredged from the channel, and construction of 13,000 feet of concrete retaining bulkhead. Docking facilities were designed and built by the Commonwealth. The completed mass transportation waterway project was inaugurated in March 1991. The Agua Guagua (now AcuaExpreso) Project created substantial environmental and recreational benefits along the western half of CMP in addition to its use by the public as a transportation system. The Enrique Martí Coll Linear Park was built above the bulkheads along the northern shore of the CMP, connecting the Hato Rey Financial District to the Parque Central. A pedestrian bridge to cross over to the southern shore, next to the AcuaExpreso docking facilities in Hato Rey, was also built. The infrastructure associated with this project was considered in the CMP-ERP FR/EIS as increased tidal flows through the entirety of the CMP may affect it.

In section III.A.5 of the 1983 EIS, it is stated that the western CMP had been plagued by water quality problems, mostly due to the construction of structures over the water, untreated wastewater discharges, and garbage and debris disposal. Elevated levels of contaminants were also found from water samples taken in this area. Even though contaminants were found in the western CMP, the report states that dredged material would be preferably disposed at the ocean (given that requirements of Section 103 of the CWA were met), while non-dredging waste would be disposed in the municipal dump. Upon completion of appropriate testing, dredged sediments were in fact disposed of in the ocean, while solid waste was disposed of in a landfill.

1.5.3 Juan Méndez Creek Flood Control Project

Juan Méndez Creek, whose outlet originally discharged into the eastern end of the CMP, is a small drainage system that lies within one of the most densely developed residential sectors of San Juan. Prior to constructing the flood control project, encroachment on the creek by informal settlements and fill deposition, as well as a lack of maintenance of the upstream channel led to the formation of a shoal at the mouth. This shoal impeded drainage and became colonized by mangroves. It became a major cause of upstream flooding and associated health hazards to the occupants of 290 residential and commercial structures near the creek's outlet. It extended about 1,640 feet upstream from the outlet at San José Lagoon, with an average depth of about 3 feet in this area.

The project for the clearing of the Juan Méndez Creek outlet was conducted under the authority of Section 208 of the Flood Control Act of 1954, as amended. The Municipality of San Juan was the non-Federal sponsor for the project. During the 3 years prior to construction of the project, the Municipality of San Juan invested $2.5 million to relocate 35 families that were living in areas required for construction and maintenance.

The project consisted of removing the existing shoal to restore the natural channel cross section. Excavation work was performed by a long arm backhoe working from the southeast channel bank. Channel cleaning activities generated about 15,700 cy of dredged material that was hauled by truck to a sanitary landfill. Also, the creek's outlet was rerouted through the excavation of a trapezoidal channel with an average top width of 89 feet and a depth of 3.3 feet. It runs now south and parallel to the CMP for about 1,214 feet into the San José Lagoon (USACE 2004). Sediment inputs from this creek have the potential to affect the eastern outlet of the CMP into the San José Lagoon.

1.5.4 Puerto Nuevo River Flood Control Project

The Puerto Nuevo River Flood Control Project, currently under construction and estimated to be completed in the next 10-15 years, is located on the north coast of Puerto Rico within the San Juan Metropolitan Area and the SJBE. The Puerto Nuevo River (Río Piedras) used to flow into the San Juan

Bay, and now flows into the western end of the CMP. Project construction was authorized under Section 202 of WRDA 1986 (PL 99-662). Improvements to the CMP were not included as part of this authorization. The improvement plan protects against the 100-year flood (the flood with a 1 percent likelihood of occurring in any year) through the construction of 1.7 miles of earth lined channel, 9.5 miles of concrete lined channels (5.1 of which are high velocity), and two debris basins in the Puerto Nuevo River and its tributaries. The plan also requires the construction of five new bridges, the replacement of 17 bridges, and the modification of eight existing bridges.

Concerns have been expressed over whether the construction of the Puerto Nuevo River Flood Control Project, as currently conceptualized (e.g., construction of enlarged, paved, high-velocity channels) might have detrimental effects on the CMP-ERP. It is understood that the Corps modeled 10 scenarios resulting in hydrologic and water quality changes as part of the Hydrodynamic and Water Quality Model Study conducted for the SJBE Program in 2000. At least one of the scenarios, with a comparable configuration as the TSP for CMP-ERP, did not point to problems or issues such as backflow into the San José Lagoon, or significant increases in flood levels to those communities fringing the Eastern CMP. The model showed that levels in the San José Lagoon increased due to tidal influence.

It is recommended that this and other modeling conducted as part of the Puerto Nuevo Flood Control Project be further reviewed to determine whether the simulations accounted for the Eastern CMP's proposed configuration, if there are any problems or issues such as backflow into the San José Lagoon, or a significant increase in flood levels resulting from the Puerto Nuevo Flood Control Project that would affect those communities fringing the Eastern CMP or others nearby once it is dredged. Dependent upon the results of the review, further modeling may be warranted.

The 1984 Survey Report associated with this project effort states that elevated levels of contaminants were found in the waters of the project site. Solid waste and sediments were also found at the site; however, these were not deemed hazardous and were disposed at the ocean in the EPA-approved ocean disposal site in San Juan, pursuant to Section 103 of the Clean Water Act (CWA).

1.5.5 San Juan Bay Estuary Comprehensive Conservation and Management Plan

In 1992, and in recognition of the continued threats facing the SJBE system, the Governor of Puerto Rico nominated it for the USEPA's NEP. The NEP is a place-based program established under Section 320 of the 1987 Clean Water Act Amendments that works to protect and restore the water quality and ecological integrity of 28 estuaries across the United States. The USEPA approved the nomination, and Federal funds were made available in 1993 to develop a Comprehensive Conservation and Management Plan (SJBEP 2000). With its inclusion in the NEP, the SJBE was designated as an "estuary of national significance" (SJBEP 2000).

On August 2000, the SJBE Program completed a CCMP for the SJBE that identified problems and recommended solutions to guide future management of the SJBE resources. The SJBE's CCMP is a long-term plan that contains 49 specific actions designed to address: (1) water and sediment quality; (2) habitat, fish, and wildlife; (3) aquatic debris; and (4) public education and involvement solutions to the estuary's priority problems. Six actions related to water and sediment quality improvements were identified as high priority or "urgent", as they "deserve immediate attention and should be initiated as soon as possible or within 0 to 5 years after CCMP approval" (SJBEP 2000). Three of these priority actions are directly related to the CMP-ERP:

- **Action WS-2**: Relocate families living adjacent to the CMP.
- **Action WS-5**: Improve flow in the Martín Peña Channel.
- **Action WS-6**: Fill artificial depressions at the Suárez Canal and at the San José, and La Torrecilla lagoons.

1.5.6 Cantera Peninsula Project

The Cantera Peninsula is one of the eight communities adjacent to the CMP. The portion of the CMP south of the Cantera Peninsula and north of the Israel–Bitumul neighborhood is the most affected by accumulation of trash and debris, and encroachment. In partnership with others, the *Compañía para el Desarrollo Integral de la Península de Cantera* (Cantera Company) has developed several housing projects to allow for relocation alternatives within the community. Both the PRHTA and the Cantera Company have relocated over 200 families, over 100 of which lived adjacent to the CMP. Moreover, a vacuum sanitary sewer and other vital infrastructure have been built. The Cantera Company already completed the first segment of the Paseo del Caño, the street proposed to be developed along the MTZ-CMP as a public space that separates the eight communities from the CMP and its mangroves and prevents future encroachment. The Paseo del Caño is envisioned to be built on both the northern and southern boundaries of the CMP.

The future without-project condition and CMP-ERP design assume that the relevant aspects of Cantera Peninsula project are fully implemented. If the remaining features are not constructed, there should be little to no impact on the physical features of the Project and no diminution of benefits.

1.5.7 Guachinanga Islet

Located north of the CMP eastern end, the Guachinanga Islet is a small haystack hill that used to be surrounded by San José Lagoon waters, but debris and sedimentation closed the small channel that separated it from the Cantera Peninsula. Partly due to its isolation, the Guachinanga Islet is a nesting paradise for coastal birds and is home to a very unique biodiversity in the midst of the San Juan Metropolitan Area. The Cantera Company has organized several cleanup activities in the Guachinanga Islet and is currently working together with the SJBE Program in the restoration of the small channel that separated it from the Cantera Peninsula. The Guachinanga channel restoration is not expected to impact or influence the CMP-ERP, but rather the latter is expected to have a net positive effect on the Guachinanga project goals.

1.5.8 Villas El Paraíso

The Israel-Bitumul community organized the first Community Housing Development Organization (CHDO) in Puerto Rico under U.S. Department of Housing and Urban Development regulations. As such, this CHDO developed the Villas El Paraíso project located in the community. With the support of the Municipality of San Juan, 108 families were relocated from the MTZ-CMP to Villas El Paraíso. The second phase of this project, which will provide housing for 120 families, is currently on the predevelopment stages. The CMP-ERP will benefit from completion of the second phase, as a relocation alternative for families living within the MTZ-CMP who which to remain in their communities.

1.5.9 Project Design Report for the Dredging of Caño Martín Peña (USACE 2001)

In 2001, the Planning Division of the USACE (Jacksonville District), under the Support for Others Program, prepared the *Project Design Report and Environmental Impact Statement for the Dredging of Caño Martín Peña* at the request of the DNER (USACE 2001). According to this report, various alternatives were evaluated on the basis of their construction method and cost, environmental impacts, real estate requirements, etc. All alternative plans proposed dredging the Project Channel following its current alignment, beginning at the San José Lagoon and extending for about 11,600 feet to end west of the Luis Muñoz Rivera Avenue Bridge.

USACE's 2001 Design Report also evaluated three alternatives for the disposal of CMP's dredged material, a recommendation of in-bay disposal within the largest artificial pits located at Los Corozos and San José Lagoons. In 2002, the USACE further evaluated the in-bay disposal alternative through the *Design of Contained Aquatic Disposal (CAD) Pits for Martín Peña Canal, San Juan, Puerto Rico* study developed by the U.S. Army Engineer Research and Development Center (ERDC).

1.5.10 Caño Martín Peña Comprehensive Development Plan

In 2001, the DTPW assumed the inter-agency leadership of the CMP dredging and established what became the Caño Martín Peña ENLACE Project (ENLACE Project) under the Puerto Rico Highway and Transportation Authority (PRHTA). On May 17, 2002, the PRPB designated the CMP Special Planning District (District) and delegated the elaboration of the District's Land Use and Comprehensive Development Plan (District's Plan) to the PRHTA. The District includes the following seven communities: (1) Barrio Obrero (West and San Ciprián); (2) Barrio Obrero-Marina; (3) Buena Vista-Santurce; (4) Parada 27, (5) Las Monjas; (6) Buena Vista-Hato Rey; and (7) Israel-Bitumul (see Figure 3).

As part of the planning process, the ENLACE Project held over 700 community participation activities between 2002 and 2004, including round table discussions, public assemblies, workshops, presentations, and educational activities at local schools. The CMP's dredging, channelization, and ecosystem restoration is only one of the principal elements of the District Plan strategies, which also integrate the design and implementation of a number of environmental, infrastructure, housing development, family relocation, urban revitalization, land tenure, and socioeconomic development strategies before, during, and after the channel's dredging and restoration phase.

The District's Plan focuses its vision, goals, and policies on four principal areas: (1) environment; (2) socioeconomic development; (3) institutional capacities; and (4) mobility, transportation, and tourism development. It included the following relevant critical components:

- The CMP-ERP with a recommended channel configuration alternative of a 150-foot width and a depth of 10 feet following the existing channel alignment, as a reference for the future establishment of the MTZ-CMP and for the relocation and infrastructure strategies.
- A mangrove conservation area within the MTZ-CMP along the proposed channel.
- Recreational access areas, proposed as formal interaction public spaces between the CMP and its users located within the conservation area. They are critical to avoid disturbance to the mangroves and as recreational components that will also provide the District with economic development opportunities.
- The Paseo del Caño, a proposed street along the MTZ-CMP as a public space that separates the eight communities from the CMP and its mangroves and prevents future encroachment. It also provides a bicycle lane and pedestrian amenities, as well as access to the recreational access areas.
- A relocation plan as required under the Uniform Relocation Act of Assistance and Real Property Acquisition Policies Act as amended, P.L.91-646; 42 U.S.C 4601 et seq. (URA).
- Construction of new housing units and rehabilitation of existing ones, primarily to provide relocation alternatives within the District.
- Construction of critical infrastructure and relocation of several infrastructure facilities, including 66-inch-diameter San José and Rexach sewer trunks, the 36-inch-diameter Borinquen water distribution line, and the 115-kV power transmission line.
- New streets to provide for public space that can be used to locate critical infrastructure, as needed to address the lack of sewer systems.

ENLACE is implementing the following CMP-ERP related initiatives.

- Acquisition of 98 structures to date within the MTZ-CMP, which includes the relocation of 55 eligible occupants, and demolition of structures. All acquisition and relocation efforts have been made in compliance with the URA, as required under PR Law PR 2004-489. Together with the efforts of the Cantera Company, the Israel-Bitumul CHDO, and the PRHTA, approximately 500 households have been relocated from the MTZ-CMP and adjacent areas and the remaining 336 structures located within the MTZ-CMP still need to be acquired. No more than 5 percent of the total remaining relocations are expected to be mandatory, with the remaining relocations to be voluntary. Real estate acquisition in other areas of the District, and housing rehabilitation to serve as relocation opportunities within the District.

- One-on-one orientation to families living within the MTZ-CMP in the District.
- Design of improvements to the San José Trunk in the segment within the Israel-Bitumul communities. The project will be built by the Puerto Rico Aqueduct and Sewer Authority (PRASA).
- Development of the FR/EIS for the CMP-ERP.
- Design of the Israel-Bitumul segment of the Paseo del Caño, the street along the MTZ-CMP designed, in part, to prevent future encroachment of the CMP.
- Environmental awareness activities targeting mainly school children.
- A microbusiness incubator that provides support to recycling and ecotourism community owned businesses.

The following relevant initiatives are or have been implemented by other Commonwealth government agencies, most under the coordination of ENLACE.

- Relocation of the Barbosa Bridge over the CMP, elevating it to allow access for the barges, as part of the future CMP dredging (PRHTA).
- Two surface debris clean-up activities in areas adjacent to the CMP, which resulted in the removal of over 885 tons of debris and the recuperation of over 1,500 pounds of recyclable material.
- Construction of the Barrio Obrero Marina vacuum sewer system, north of the CMP. Evaluation of alternatives for the relocation of the San José and Rexach 66-inch-diameter sewer trunks and the Borinquen 36-inch-diameter potable water distribution line (PRASA).
- Conceptual design for a sewer system in northern Israel-Bitumul (PRASA).
- Delineation of the public domain lands associated to the MTZ-CMP within the District (DNER).

The activities and projects being implemented by ENLACE are vital to the success of the CMP-ERP. An immense public outreach campaign for such a project is necessary to inform and educate the public of the importance of a healthy ecosystem in the area, discouraging future secondary effects that could occur. Utility and other infrastructure improvements that have been conducted are also vital, and debris removal, sewer construction and other activities guarantee the effectiveness of the CMP-ERP. Additionally, the *Fideicomiso de la Tierra del Caño Martín Peña*, a community land trust, was created under PR Law 489-2004 to prevent gentrification as a result of the CMP-ERP.

1.5.11 Urban Waters Federal Partnership

On May 2013, USEPA designated the CMP as one of 18 sites nationwide that participate in the Urban Waters Federal Partnership (UWFP). This initiative seeks to revitalize urban waters and the communities that surround them, transforming overlooked assets into treasured centerpieces and drivers of urban revival. The USACE is one of 13 federal agencies that are part of the partnership, together with ENLACE and other local agencies and organizations. The CMP-ERP is key to the objectives of the UWFP around the CMP.

2.0 EXISTING CONDITIONS

2.1 HISTORIC CONDITIONS

2.1.1 Caño Martín Peña

For centuries, the SJBE has been affected by dredging, channelization, the mining and placement of fill material, and sedimentation (SJBEP 2000). The first known intervention in the CMP consisted of a "paso," or causeway. "Pasos" were typically made by piling rocks or stones at the bottom of a shallow waterbody, hardening the soft sediments found at the bottom, reducing its depth to facilitate its crossing, and while still allowing flow. In the area, various bridges have been built up to this date, including the historic Martín Peña Bridge at Ponce de León Avenue.

The construction of the tram and the train bridges over the CMP during the 1890s signaled the beginning of profound changes in the surrounding natural landscape of the SJBE. Many areas previously occupied by fresh water wetlands and marshes adjacent to the San José and Los Corozos lagoons, the Suárez Canal, and those lands south of La Torrecilla and the Piñones lagoons were converted to agricultural use. In Puerto Rico, mangroves were overexploited during the 1900s for firewood and charcoal. In 1918, Governor Arthur C. Yager proclaimed mangrove swamps as Insular Forests, and recognized that charcoal was an article of prime necessity. In 1927, the Puerto Rico Senate resolved that mangroves could be sold to raise funds for the completion of the Capitol Building, and they were erroneously associated with the propagation of the malaria mosquito. The sale was conditioned to the declaration of a public health problem by the Health Commissioner, and to the drainage and fill of the mangrove lands (Legislatura de Puerto Rico 1927).

In the late 1910s and early 1920s, the wetlands adjacent to the San Juan Bay and along CMP were used as disposal sites for the material that was dredged from the SJHP affecting or eliminating more than 80 percent of the original mangrove acreage found in this area of the SJBE. Most of the filled area adjacent to the San Juan Bay was then developed for the construction of port and storage facilities.

The western section of the CMP was dredged and straightened, further eliminating mangroves and replacing these with open water areas. These works created two mangrove "islands" between the segments of the original and dredged channel (Sepúlveda 2003). Mangroves were basically confined to these islands, and to a fringe in the southern shores of this segment of the CMP, lands that at that time were under the U.S. military control.

During the 1920s, the government built 260 houses in Barrio Obrero, a workers neighborhood, thus starting encroachment towards the mangrove forests at the northeastern area of the CMP, delimited by what today is the Rexach Avenue (Sepúlveda 2003). The downfall of the sugar cane industry and Hurricanes San Felipe and San Ciprián, two of the worst in Puerto Rico's recent history, destroyed agricultural production and left thousands of people homeless. Migrants fled rural communities for

San Juan, and there, lacking the resources for anything else, informally settled the wetlands around the CMP. Residents made the swamps habitable first by building their homes on stilts, and afterwards, by depositing solid waste such as vegetative material, garbage, and debris into the swamp until it became firm enough to support the makeshift homes they built from salvaged wood and corrugated tin. By the end of the 1930s, the limestone hills or "mogotes" found at both shorelines of the CMP and east of the Barbosa Avenue Bridge began to be mined for the production of construction aggregates and as a source of material to fill the adjoining mangroves. By 1948, informal settlements replaced the mangrove swamps along the north shore of the CMP and on the eastern half of its southern shore. An aerial photograph of 1936 shows a 200- to 400-foot-wide natural channel in the 2.2 miles of the eastern CMP (Project Channel), as well as the first settlements in the area (USACE 2004; Figure 6).

Most, if not all of the housing on former mangrove forests was built without basic utilities such as a sanitary sewer system, resulting in discharges of untreated sewage directly into the CMP, or indirectly, as in the case of older dwellings built on uplands, through the combined storm and sewer system that serviced the Santurce-Cangrejos area north of the CMP. These communities lacked proper access to other public services, such as garbage collection. Residents disposed of their refuse in the channel or used it as fill material to extend their properties (SJBEP 2000). Eventually, the Municipality of San Juan contributed to the process with fill material, and built a storm sewer system in the communities adjacent to the Project Channel.

In 2004, the eastern segment of the CMP was described as follows:

> "A 1962 aerial photograph of the eastern half of the CMP shows a reduced canal width, no more than 200 feet, with dense urban development all the way to the edge of both banks. A 2000 aerial photograph shows, in the remaining 2.2 miles of unimproved eastern segment of the channel a minimum canal width near the bridges, a very dense urban development all the way, and a completely filled up canal, which is impeding water flow between the San José Lagoon and the San Juan Bay.
>
> "Today, the canal's ability to convey flows has been almost completely blocked as a result of siltation, trash and debris accumulation, and structure encroachments along the eastern segment. Recent subsurface investigations in the canal and both banks along the eastern half of Caño Martín Peña found trash and debris down to 9 feet below the surface. As a result of the progressive clogging, there is very little tidal exchange between the San José Lagoon and the San Juan Bay and the water quality is very poor" (USACE 2004).

Source: ENLACE & Puerto Rico Planning

Figure 6. Historic and Existing Conditions within the Caño Martín Peña

The unsanitary and unsafe conditions suffered by the 26,000 inhabitants of the eight communities living near the eastern CMP have prompted a concerted effort with the community to restore its ecological functions and values, starting in the early 1990s. After Hurricane Hugo, the Cantera Peninsula neighborhood organized itself, promoted the creation of the Cantera Peninsula Special Planning District and started implementing its Land Use Plan. The Israel-Bitumul neighborhood to the south organized the first community housing development organization that allowed them to receive funds from the US Department of Housing and Urban Development. In 2001, the eight communities adjacent to the CMP created the G-8, Inc., a grassroots nonprofit, while the ENLACE Project flourished as an alternative that brings together the community, the private sector and the government around the CMP-ERP, among other environmental justice and comprehensive development initiatives. The CMP Land Trust was created as an innovative land titling initiative, intimately related to the new regularization approach. Also under PR Law 489-2004, the DNER established the limits of the public domain lands associated to the MTZ-CMP within the District.

These initiatives have resulted in the relocation of 500 families that lived along the CMP shoreline, the construction of new sewer systems for the Barrio Obrero Marina and the Cantera Peninsula neighborhoods, the creation of recycling microbusinesses, an environmental awareness program, and several debris clean-up activities, among others. In 2007, a new bridge at Barbosa Avenue was built with much higher clearance over the CMP than the previous one to allow the navigation of barges and other machinery that will be used in the CMP-ERP. Actions continue today that are geared towards a fully restored and functioning CMP.

2.2 EXISTING CONDITIONS

The eastern segment of the CMP found within the Project Area has an approximate length of 2.2 miles, up to its outlet to the San José Lagoon. The widest open water section of the CMP in the Project Area is approximately 131.2 feet wide just east of the Martín Peña Bridge. Its depth ranges from approximately 3.94 feet about 328 feet west of the Barbosa Avenue Bridge, to essentially 0 feet east of that bridge. Wherein that area, mangroves and other wetland vegetation, including aquatic weeds, have grown over sediments and solid waste used as fill material over the past decades (Webb, R. and F. Gómez-Gómez 1998), obstructing most water exchange between the channel and the San José Lagoon. Maximum elevations along the CMP's northern watershed are approximately 98 feet (30 meters) above mean sea level (MSL), and street slopes are approximately 4 percent. Elevations along the communities located south of the CMP are gentler, with maximum elevations of approximately 32 feet (10 meters) above MSL and street slopes averaging 1 percent. The San José Lagoon is divided, hydrologically, into two sections: Los Corozos Lagoon to the northwest and the San José Lagoon to the southeast. These have a combined surface area that ranges from approximately 1,129 acres (SJBEP 2000) to approximately 1,242 acres (Appendix A – NER Benefits Appendix). There is no direct connection between these lagoons and the ocean. The natural average depth of the San José and Los Corozos lagoons was 6 feet; it did not exceed 8.2 feet (Ellis 1976); however, the lagoons were dredged for sand and fill mining, between the late-1950s and 1960s, altering about 17 percent of their combined bottom surface, and as a result, several depressions or dredge pits are found today.

The dredge pit at Los Corozos Lagoon is known to have an approximate depth of 17.5 feet. Two dredged areas can be distinguished in the San José Lagoon. The first depression extends from the outlet of the Suárez Canal, towards the northwest and parallel to the lagoon's shores, until halfway to the Teodoro Moscoso Bridge. This area consists of three dredge pits, with depths varying from approximately 15 to 28.4 feet, and named San José pits 3, 4, and 5. The second depression is found south of the Suárez Canal outlet, extending along the southeastern shore of the lagoon, next to the Quebrada San Antón creek's outlet. It consists of two dredge pits that approximately 28.4 to 32 feet deep. They are named San José pits 1 and 2.

The western segment of the Suárez Canal has an approximate length of 1.39 miles. Most of the canal has an average width of approximately 90 feet. The canal has a section, approximately 541 feet wide by 2,346 feet long, that was deepened and widened towards its northern bank during the 1960s for the development of a never completed yacht basin. The deepest site within this area of the Suárez Canal has an approximate depth of 30 feet (SJBEP 2000).

2.2.1 Abiotic Characteristics

Existing conditions are described for abiotic characteristics, biotic characteristics, and socio-economic conditions.

2.2.1.1 Climate

The National Weather Service's Luis Muñoz Marín International Airport automated weather station, collects data on rainfall and temperature that is representative to the Project Area's climatic conditions. It is located at an approximate elevation of 9 feet above MSL, at approximately 0.53 mile northeast of the San José Lagoon. Table 1 displays the average monthly conditions in the Project Area, including temperature, rainfall, humidity, and winds. Additional information on the Study Area climate can be found in Section 3.1 of the EIS and Section 4.1 in the Engineering Appendix.

Table 1. Study Area Climate

Parameter	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec
Average High Temp (°F)	83.2	83.7	84.9	86.2	87.5	88.9	88.7	89.2	89.2	88.4	85.9	83.9
Average Low Temp (°F)	72.0	72.0	72.9	74.4	76.3	77.7	78.1	78.2	77.8	76.9	72.2	73.4
Average Rainfall (in)	3.76	2.39	1.95	4.68	5.90	4.41	5.07	5.46	5.77	5.59	6.35	5.02
Average Humidity (%)	75	71.5	69	69	72	71	73	73.5	73	73.5	74.5	74.5
Average Wind Direction	E	ENE	ENE	ENE	ENE	ESE	E	E	E	ESE	E	ENE
Average Wind Speed (mph)	8.3	8.7	9.1	8.8	8.3	8.9	9.6	8.7	7.5	6.6	7.4	8

2.2.1.2 Geology

Puerto Rico's geology can be divided into two, broad formations belonging to rocks of volcanic or sedimentary origin. Those of sedimentary origin consist mostly of limestone, and are normally found underlying the northern coastal plains. The coastal plain of the San Juan Metropolitan Area shows a surficial geology dominated by lagoon and estuary environments, covered by fluvial and eolian deposits that have dictated the geomorphologic evolution of this region. The estuary areas are characterized by low-lying flat land that has evolved to its present conditions by erosion, deposition, compaction, and subsidence, all of which are still active. In the CMP, east of the José Celso Barbosa Bridge, limestone can be found at depths as shallow as 10.5 feet (Atkins 2011d). Additional information on the Study Area's geology can be found in Section 3.2 of the EIS.

2.2.1.3 Soils

Today, most of the soils of the Project Area have been severely altered, mainly composed of artificial fill consisting of sand, limestone and volcanic rock. In those areas once occupied by wetlands or open water where substandard housing has been established, such as the eastern section of the CMP, the western shores of Los Corozos Lagoon, and the southwestern shores of the San José Lagoon, the superior soil layers are composed of a combination of sediment and solid waste.

The sediments that characterize the first 10 feet of depth of the Project Channel are generally soft to very soft black organic mud, clays and silts with some lenses of sandy material. The sediments that characterize the first 40 feet on the channel banks show a large range of geotechnical conditions from soft to very soft black organic mud, clays, silts with some lenses of sandy material, consistent with the channel, then become stiff sandy clays and stiff silty clays, sandy gravels and clayey gravels. Silica sands and alluvium appear to be most unconsolidated deposits in this region of the CMP. Gravels, cobbles and boulders may be present east of the José Celso Barbosa Avenue Bridge (Atkins 2011d). Most areas now covered by artificial fill are under laid by swamp deposits. Additional information on the Study Area's soils can be found in Section 3.3 of the EIS.

2.2.1.4 Solid Waste

Solid waste is any discarded material, abandoned, inherently waste-like, and not excluded by law such as domestic sewage. All waste classified as solid waste are regulated by the Resource Conservation and Recovery Act (RCRA) and in Puerto Rico is also regulated by the Puerto Rico Solid Waste Management Regulation. RCRA excluded waste are regulated by different laws. An example is domestic waste that is regulated under the Clean Water Act.

Materials within the Caño Martín Peña include various types of solid waste, debris, and other materials, which will require further testing prior to and/or during project construction, as appropriate, in accordance with an agreed sampling plan to determine whether any materials contain hazardous substances at levels that are not suitable for unregulated disposal.

These findings are supported by several previous studies and investigations, including:

- a 1997 Preliminary Site Characterization of the CMP that was prepared by Roy F. Weston, Inc. for the USACE;
- an Environmental Site Assessment report prepared by ECG, Inc. for the USACE in 1998,
- a Draft Phase 1 Environmental Site Assessment prepared by CMA Architects and Engineers, LLP. for the Puerto Rico Highway and Transportation Authority in 2002; and
- a 2011 Initial Assessment prepared by PBS&J for the CMP-ERP feasibility study.

Household waste is any material, garbage, trash, sanitary waste derived from single and multiple-family residences, hotels and motels, bunkhouses, ranger stations, crew quarters, campgrounds, picnic grounds, and day-use recreation areas. Bulky wastes such as household appliances, furniture, large auto parts, trees, branches and stumps are all considered household waste.

Construction and Demolition (C&D) materials consist of the debris generated during the construction, renovation, and demolition of buildings, roads, and bridges. C&D debris often contain larger, heavy materials, such as concrete, asphalt, wood, metals, glass, and salvaged building components. Disposal of C&D debris is only regulated to the extent that solid waste landfills must follow a few basic standards outlined at 40 CFR parts 257.

Hazardous Radioactive Toxic Waste (HTRW) is a solid waste with a listed hazardous substance, is listed as a hazardous waste, or presents characteristics of ignitability, corrosivity, reactivity, or toxicity and is not considered a household waste. Some wastes are excluded by law from being a hazardous waste. Household waste including Household Hazardous Wastes (HHW) are excluded from being classified as hazardous waste under 40 CFR 261.4(b)(1). HHW are leftover household products that may contain corrosive, toxic, ignitable, or reactive ingredients. Examples are paints, cleaners, fluorescent light bulbs, oils, batteries, automotive products, and pesticides. Segregation of HHW from the municipal waste is encouraged but not required by law. HHW are classified as household waste independent of the chemical composition.

Dredged material, as defined by 40 CFR 323.2(d), is any material dredged from Waters of the U.S. and sediments proposed for management under Sections 404 of the Federal Water Pollution Control Act (33 United States Code [U.S.C.]1344) and 103 of the Marine Protection, Research, and Sanctuaries Act (MPRSA) of 1972 (33 U.S.C. 1413), and the dredged material would only qualify as HTRW if they are within the boundaries of a site designated by the USEPA, or a state, for a response action under CERCLA, or if they are a part of a National Priority List (NPL). Dredged material under Waters of the United States are also excluded from being classified as hazardous waste under 40 CFR 261.4(g). Therefore, the solid waste and sediments dredged from beneath the Waters of the United States within the CMP-ERP would not be considered HTRW. It is recognized that there may be disagreement as to the extent of the characterization of Waters of the United States as it applies to the CMP-ERP Project Channel at the time of this report development.

2.2.1.5 Hydrology

2.2.1.5.1 General characteristics

The SJBE receives direct fresh water inputs from several small streams, storm water pump stations, storm water runoff, drainage canals, and untreated sanitary sewage outfalls. Upland steep topography and the nearly complete urbanization of most of the SJBE drainage basin result in extremely flashy rainfall-runoff events (Webb and Gómez-Gómez 1998).

Tides in the Study Area are mixed semidiurnal with two highs and two lows of unequal height every day. The tidal range between the mean elevation of the lower of the two waters and the mean of the higher of the two high waters is 19.2 inches. The magnitude of daily tidal oscillations varies within the SJBE and is controlled primarily by the hydraulic characteristics of the channels and surface areas of each water body. Tidal oscillations in the San José Lagoon, for example, are limited to about 1.97 inches (Webb and Gómez-Gómez 1998).

Webb and Gómez-Gómez (1998) reported that it is common for river and storm-water discharges to dominate tidal flow patterns in the SJBE, especially in regions such as the CMP that have restricted connections to the open sea. Salt water reaches the Project Channel through its western section, which connects to the ocean by means of the San Juan Bay's Boca del Morro outlet. Ocean waters have access to the San José and Los Corozos lagoons, and the Suárez Canal, through the Boca de Cangrejos outlet by means of La Torrecilla Lagoon. There is a constricted section at the middle of the Suárez Canal, which is limited by the pilings of the Ramón Baldorioty de Castro Expressway (Road PR-26) Bridge. It takes, on average, about 16.9 days for the San José lagoon to renew its waters (Atkins 2011a).

The San José Lagoon receives fresh water discharges from the Juan Méndez Creek, in its southwestern end, and from the San Antón Creek, in its southeastern shore. Several small drainage canals, both unpaved and paved, discharge into the southern shores of the lagoon. A relatively large unpaved drainage canal coming from the Luis Muñoz Marín International Airport, flows into the northeastern corner of the lagoon. The estimated in-fill rate within the CMP's outlet at San José Lagoon is 6.7 feet per year (ft/yr). Discharges in the lower reaches of the Juan Méndez Creek are the primary contributor of sediments deposited within the channel's outlet. The sedimentation rate for the entire CMP was estimated to be 1.5 in per year, with illegal filling and dumping, as well as combined sewer discharges, identified as the primary sources for sedimentation in the entire CMP. Sedimentation rates within the CMP, are thus more than 50 times higher than in other parts of the SJBE (SJBEP 2000).

Main fresh water inputs to Los Corozos Lagoon come from two storm water pump stations that discharge into its northern shores. One, operated by the Municipality of Carolina, services the Villamar residential community. The second one, managed by the DNER, services a larger area, and receives combined sewer overflows from a section of the Ramón Baldorioty de Castro Expressway and neighboring sectors.

Ground water discharges from the upper aquifer to the SJBE are limited to a segment of about 8.7 miles from the San Juan Bay to the San José Lagoon, and estimated at 43,162 cy/day (Webb and Gómez-Gómez 1998). Additional information on the Study Area hydrology can be found in Section 3.4 of the EIS and Sections 4.2 and 4.3 of the Engineering Appendix.

2.2.1.5.2 Domestic sewage discharges

Much of the developed lands adjoining the CMP do not have the necessary infrastructure to properly collect and convey sewage effluent to treatment facilities. In several communities in and around the Project Area, a sanitary sewer system is nonexistent. A 2002 study effort on potable water and sanitary sewer installations concluded that 1) the existing transmission and distribution potable water system, as well as the sanitary sewer system, had deteriorated; 2) both systems were neither adequate nor reliable; and 3) both systems were not in compliance with standards of the agencies having jurisdiction (ENLACE 2002).

Because the sanitary sewer system was combined with the storm water system, the hydraulic capacity of both was reduced. Storm events can overwhelm the sewer lines with limited capacities, resulting in the overflow of the combined effluent into the community and the CMP. Some sanitary sewer mains outfall untreated sewage effluent directly into the existing CMP channel. For example, the combined sewer/stormwater trunk serving areas of Hato Rey and Río Piedras continues to discharge raw sewage adjacent to the Mercantil Plaza Building next to the Martín Peña Bridge. The eastern segment of the CMP is the Project Area's section that receives the most direct discharges of untreated sewage coming from the adjoining communities that lack a proper sanitary sewer system, as well as overflow of combined sewers serving other urban areas during heavy rainfall. The Rexach storm water pump station, managed by the Municipality of San Juan, discharges west of the José Celso Barbosa Avenue Bridge.

The adjoining communities have ongoing and proposed projects to construct new sanitary sewers to collect and convey effluent to treatment facilities, and new storm sewers that will collect and treat stormwater prior to its discharge it into the channel. As part of the Comprehensive Development Plan, relocations (e.g., the Rexach Sewer Line and the Borinquen Water Transmission Line) and the construction of these improvements (e.g. San José Sewer Line) would precede completion of the CMP and precede dredging operations. For example, the PRASA is working on a project to separate the combined sewer/stormwater trunk serving the areas of Hato Rey and Río Piedras into sanitary and storm water sewers. In addition, the San José Sewer Line would be reinforced in-place and, with the planned repairs and improvements, would help mitigate sewage discharges that currently affect the Israel-Bitumul community. Another example of a sanitary sewer system project nearby the Project Area is the construction of the Barrio Obrero Marina vacuum sewer system, which is located to the north of the CMP in the adjacent Barrio Obrero Marina community. Relocations of the Rexach Sewer Line and the Borinquen Water Transmission Line are requisite for the construction of the CMP-ERP, and thus are considered an element of the CMP-ERP.

ENLACE continues to work with numerous government agencies, such as the USEPA and PRASA, and the Municipality of San Juan to facilitate the removal, reduction, and/or remediation of sewage discharges into the project and study areas. The elimination of sewage discharges into other parts of the SJBE would be part of a greater island-wide effort that PRASA is undertaking.

2.2.1.5.3 Flooding

Historically, low-lying areas along the CMP have been subject to frequent flooding from several sources. Sources of flooding include urban runoff from rain events over the CMP basin. Existing storm sewer inlets along Borinquen, A, and Rexach avenues are frequently clogged with sediment or garbage, and runoff that fails to enter these inlets continues south along the streets until it reaches CMP. Flood waters flow along the Juan Méndez Creek on the southeastern end of the CMP and a much attenuated storm surge through the San Juan Bay to the west of the CMP and/or the Suárez Canal into San José Lagoon to the east of the CMP.

Due to the CMP's lack of conveyance to manage storm water discharges, the communities bordering the CMP continually suffer flooding events. This situation becomes critical because of the significant amount of untreated sewage water that is also discharged to the CMP, causing the flood waters to be contaminated with extremely high bacterial concentrations, far exceeding established water quality standards.

According to the Federal Emergency Management Agency (FEMA) Flood Insurance Rate Map (FIRM) panel number 720000-0051D and 0054D, a significant portion of the CMP banks are located within a flood prone area with 100-year base flood elevation of 6.56 feet above MSL. The 100-year floodplain extends up to 350 meters (1,148 feet) south and up to 550 meters (1,804 feet) north from the channel. These base flood levels are influenced by the storm surges at San José Lagoon and San Juan Bay.

An examination of the bathymetries conducted in San José lagoon during the past decade demonstrates that it has been losing depth. Its ability to convey storm water has decreased, and neighboring areas such as the Vistamar and Los Angeles communities in the Municipality of Carolina have experienced an increase in flooding. One of the main drainage channels of the Luis Muñoz Marín International Airport flows into the northeastern San José Lagoon.

Additional information regarding flooding in the Study Area can be found in Section 3.4.1 of the EIS and 4.2.6 of the Engineering Appendix.

2.2.1.6 Navigation

The CMP has been used since prehistoric times to provide an inland route to navigate the north coast of the island and for fishing and collection of crustaceans, wood, and other products. Historically, the CMP had an average width of at least 200 feet and a depth between 6 and 8 feet, and provided tidal exchange between San Juan Bay and San José Lagoon. Modifications of the channel and its wetlands that led to significant reduction of its section, significant loss of open waters and to a transition to a wetland ecosystem in areas closer to San José Lagoon, preclude navigation for all types of watercraft through the eastern CMP. The western half of the CMP is navigable, and is used intermittently as a mass transportation waterway.

2.2.1.7 Air Quality

Hydrogen sulfide is a gas with a characteristic rotten egg smell. The gas is commonly found in volcano explosions, mangrove wetlands and other natural habitats. It is heavier than normal air so it remains within the atmosphere for longer periods of time and affects smaller stature populations such as children with more ease. The gas can remain in the atmosphere for about 18 hours (USEPA 2003). Recent air samples by the USEPA (2011) in areas near or on the CMP revealed concentrations of hydrogen sulfide between 0.002 parts per million (ppm) and 0.062 ppm. The reference concentration for chronic inhalation of the hydrogen sulfide, which is also the reference value used for chronic exposure among children, is 0.001 ppm (USEPA 2003). Chronic exposure is defined as contact with a substance over a long period of time (over a year). All of the samples in referenced places exceeded the minimum reference levels acceptable for inhalation of hydrogen sulfide in a chronic exposure situation. Chronic exposure potential effects include is difficulty breathing, particularly in vulnerable populations as asthmatics, other negative effects to the respiratory system, lethargy, lack of coordination, headaches, loss of short term memory and motor dysfunction due to an affected nervous system (ATSDR 2006). Additional information on air quality in the Study Area can be found in Section 3.6 of the EIS.

2.2.1.8 Water and Sediment Quality

The water quality of the SJBE has been significantly altered from its natural state not only by land-use activities, but also by the modification of its hydraulic properties through the dredging and filling of many of its water bodies. Water quality within both the Caño Martín Peña and San José Lagoon has been previously documented as being degraded (Kennedy et al. 1996, Webb and Gomez-Gomez 1998, San Juan Bay Estuary Program 2000, Puerto Rico Environmental Quality Board 2008) and data suggest that the Caño Martín Peña is a source of turbidity and bacteria to the waters of San José Lagoon; however, the Caño Martín Peña does not appear to be a source of nutrients for the San José Lagoon (Atkins 2011a).

Impacts to the water quality of the Caño Martín Peña and San José Lagoon include inflows from combined storm sewer overflows, inflows from areas lacking sanitary sewers, untreated industrial discharges, surface runoff and subsurface seepage over areas with household waste, and from direct dumping of household waste. While water quality concerns remain within both the Caño Martín Peña and San José Lagoon, there is ample evidence of substantial improvements in water quality within San José Lagoon in recent decades, due mostly to improvements in the collection and treatment of wastewater loads in the San Juan Bay region (Webb and Gomez-Gomez 1996 and 1998; Webb et al. 1998). In western San José Lagoon, in the part of the Lagoon closest to the Caño Martín Peña, phosphorus concentrations have decreased more than 50 percent since the late 1970s to early 1980s, and water clarity (as measured by Secchi disk depth) has doubled since the early 1980s (Atkins 2011a).

The recent trends of improved water quality in much of the San Juan Bay Estuary have been achieved only after the investment of substantial time and resources. Since the late 1980s alone, the USEPA has awarded in excess of $650 million to the Commonwealth via the Clean Water State Revolving Fund program (Caribbean Business Journal 2012). As a result of these and other coordinated actions, there is an obvious trend of improving water quality in the San José Lagoon, as outlined in the report "Technical Memorandum for Task 2.6 – Water and Sediment Quality Studies" (Atkins 2010b). Similar findings of improving water quality in the greater San Juan Bay estuary system have been previously reported by Webb and Gomez-Gomez (1996 and 1998) and by Webb et al. (1998). Webb and Gomez-Gomez (1998) concluded that "these records document the improved water quality that has resulted from implementing pollution control measures established in the 1970s."

The ongoing and reduced ecological integrity of the San José Lagoon, despite substantial reductions in pollutant loads, appears to be mostly due to salinity stratification and the development of hypoxic conditions (low levels of dissolved oxygen) in waters deeper than 4 to 6 feet (Atkins 2011b). Model results lead to the conclusion that restoration of the tidal exchange capacity of the Caño Martín Peña would increase salinity in the surface waters of the San José Lagoon, which would decrease salinity stratification and thus reduce the spatial extent and severity of hypoxic conditions (Atkins 2011b). Although acceptable levels of dissolved oxygen exist in those portions of the San José Lagoon that are shallower than approximately 4 feet, hypoxic to anoxic conditions are encountered throughout approximately 700 acres of the Lagoon where the water depths are greater than 4 feet. One of the most severe water quality problem in the Caño Martín Peña is levels of dissolved oxygen. Also, Webb and Gomez-Gomez (1998) found ammonia concentrations up to 2.3 milligrams per liter (mg/L) (as nitrogen) and orthophosphate concentrations of 0.22 mg/L (as phosphorus) as well as anoxic conditions within the Caño Martín Peña water column. Also in the Caño Martín Peña, recent studies have documented from 2,000,000 to 6,000,000 fecal coliform bacteria colonies per 100 milliliters (ml) well above guidance criteria of 200 colonies per 100 ml (SJBEP 2012). Additionally, levels as high as 1,200,000 for Enterococci bacteria colonies per 100 ml, where the guidance criteria of 35 colonies per 100 ml (SJBEP 2012).

Detected levels of lead and mercury and lesser concentrations of polycyclic aromatic hydrocarbons (PAH), oil and grease, and residual pesticides were noted in CMP sediments (Webb and Gómez-Gómez 1998). Substantial quantities of Polychlorinated biphenyls (PCBs), PAHs, pesticides, Bis (2-ethylhexyl) phthalate (B2EHP), lead, and mercury were measured within the sediments of the CMP. Sediment cores from six sites in the SJBE and CMP (Webb and Gómez-Gómez 1998) representing time periods of 1925–1949, 1950–1974, 1975–1995, show increases in concentrations of:

- Lead from 30 to 745 micrograms per gram (μg/g)
- Mercury from 0.16 to 4.7 (μg/g)
- PCBs from 12 to 450 micrograms per kilogram (μg/kg)

In contrast to increasing trends for lead, mercury and PCBs, DDT and its derivatives decreased over time, from 46 μg/kg in sediments during the years 1950 to 1974 to 14.6 μg/kg in sediments dated to the years 1975 to 1990.

In 2002 and 2011, elutriate testing of the eastern CMP sediments and sediment pore water confirmed the presence of heavy metals such as lead and mercury, PAHs, PCBs, oil and grease and residual pesticides (Atkins 2013). Table 2 documents average sediment chemical characteristics from the CMP (and Lagoon Pit sites for comparison), representing time periods from 2002 and 2011. Both the sediments and the sediment pore water of the CMP are characterized by elevated levels of various contaminants. Levels in excess of sediment quality guidelines, as defined in the National Oceanic and Atmospheric Administration (NOAA) Screening Quick Reference Tables, were found for anthracene, antimony, arsenic, copper, dieldrin, lead, mercury, selenium, silver and zinc, along with others (Buchanan 2008). The pore water within the sediments of the eastern CMP also exceeded criteria for multiple parameters. Problematic results were found for chromium, copper, lead, mercury, nickel, and zinc. Complicating this issue, the surface waters of the CMP and the San José Lagoon already exceed relevant criteria for copper and mercury.

The effects of these contaminants on the health of exposed organisms could be of concern depending on the type and concentration of the pollutants and the degree of exposure; however, these contaminants are now less abundant in surface waters and surface sediments than in the past. Additional information on sediment quality in the Study Area can be found in Section 3.5 of the EIS.

Channel and lagoon sediment results from the 2011 monitoring event were compared to the toxicity characteristic values of hazardous waste under 40 CFR 261.24, the Universal Treatment Standards (Land Disposal Restrictions for hazardous waste) under 40 CFR 268.48, and the Comprehensive Environmental Response, Compensation, and Liability Act (CERCLA) Regional Screening Levels for groundwater protection. This evaluation of existing analytical data provided a scientific basis for estimating approximate locations and concentrations of affected sediment areas within the CMP-ERP project area and disposal locations. Approximate toxicity characteristic leaching procedure (TCLP) values were calculated from the 2011 data using the approved method described in EPA Method 1311. When a waste is 100 percent solid as defined under the TCLP method, then the results of the total constituent analysis may be divided by twenty to convert the total results into a maximum leachable concentration. Dry weight samples were not reviewed during this initial screening, and since the Method 1311 calculation is performed on wet samples in this TM analysis, the determined TCLP values serve only as a rough estimate. Screening of the total metals concentrations via EPA Method 1311 suggested that lead may be the only total metal present in the canal sediments with a hazardous concentration.

Furthermore, hazardous debris, including household hazardous waste items and universal wastes that are extracted from the CMP-ERP during dredging activities, may not meet the exclusion criteria described above. Materials containing hazardous substances at levels that are not suitable for unregulated disposal will be managed in accordance with the applicable laws and regulations of the relevant regulatory agencies. More detail on the approach to handling of such contaminated material is included in Sections 6.2.2 and 7.2

2.2.1.9 Noise

The Study Area is found within a densely populated area that includes residential, recreational, commercial, and industrial elements. A heavy rail train and two 4-lane avenues divide the CMP in half. Two expressways cross over the western half of the CMP and the José Celso Barbosa Avenue over the eastern half. Vehicular traffic, commerce and industry all contribute to the background noise in the area. Additionally, aircraft approaching the Luis Muñoz Marín International Airport also represent an important source of noise. A noise study conducted within the District and the Cantera Peninsula in 2003 concluded that main sources of noise pollution came from these sources. The study estimated noise levels were of 60 decibels (dB) during daytime and 50 dB during nighttime. Speed and distance from source was the main influencing factor on the receiver. Additional information on the existing noise conditions can be found in section 3.7 of the EIS.

Table 2. Study Area Sediment Quality

	Sediment average concentrations (mg/kg)			Elutriate average concentrations (mg/L)*		PREQB Water Quality Standards (2010)	Dilution needed to meet PREQB (2010) criteria
Contaminant[1]	**CMP 2002[2]**	**CMP 2011**	**Lagoon Pits 2011**	**CMP 2002[2]**	**CMP 2011**		
TOC	9,300.000	35.800	7.108	4.50000	11.5980	NA	NA
Ammonia (NH_3) [3]	-	73.180	24.950	-	**9.79200**	5.00000	**2.0**
Antimony-Total	1.170	BDL	BDL	0.01200	0.00435	0.64000	NA
Aroclor 1260	-	0.020	ND	-	ND	NA	NA
Arsenic - Total	12.400	6.591	7.324	0.03100	BDL	0.03600	NA
Berylium	-	BDL	BDL	-	0.0002	NA	NA
Cadmium - Total	9.590	0.723	BDL	-	BDL	0.88500	NA
Chromium (Cr)	47.500	23.985	33.304	< 0.0010	0.00450	0.05035	NA
Chromium (Cr +3)	-	23.985	33.304	< 0.0010	BDL	NA	NA
Chromium (Cr +6)	-	BDL	BDL	-	BDL	0.05035	NA
Copper - Total	181.000	45.730	14.550	< 0.001	**0.06814**	0.00373	**18.3**
Cyanide - Total	-	0.452	BDL	-	**0.00188**	0.00100	**1.9**
Lead	281.000	67.960	3.074	0.00400	**0.01226**	0.00852	**1.4**
Mercury	2.440	0.550	0.120	< 0.00010	**0.00020**	0.00005	**3.9**
Nickel - Total	32.300	7.752	2.426	0.00500	**0.00930**	0.00828	**1.1**
Selenium	1.000	1.576	BDL	**0.10100**	BDL	0.07114	**1.4**
Silver - Total	3.400	1.481	0.866	< 0.002	BDL	0.00224	NA
TPH-DRO	-	456.000	ND	-	ND	NA	NA
TPH-GRO	-	0.000	0.025	-	0.21900	NA	NA
TPH-ORO	-	2,857.000	ND	-	ND	NA	NA
Zinc - Total	1,050.000	230.000	14.000	0.00000	0.00000	0.08562	NA
Thalium [4]	0.300	0.900	0.800	< 0.002	BDL	0.00047	NA
Sulfide [4]	696.000	573.000	-	< 1	-	0.00200	NA
Di-n-butyl phthalate	-	0.554	15.666	-	ND	4.50000	NA
Di(2-ethylhexyl) phthalate	-	ND	-	-	**0.03000**	0.02200	**1.4**
Total Solids (%)	-	52.000	62.000	-	-	NA	NA

BDL Below Detection Limit; ND Not Detected; - Data not available

[1] List of contaminants contains only those detected in the sediment composite and elutriate of 2011 sampling effort.

[2] Design of Contained Aquatic Disposal Pits for Martín Peña Canal, December 2002 report, Appendix B-Elutriate Testing.

[3] No ammonia criteria for the Class SB waters of CMP and San José Lagoon. However, ammonia is a component of Total Nitrogen (TN) and existing criteria for TN of 5 mg/l would apply

[4] Potential for lab minimum detection limit to be problematic

* **Bold Red** values indicate exceedance in the allowed maximum concentration established by the Puerto Rico Water Quality Standards Regulation (PRWQSR).

2.2.1.10 Hazardous, Toxic, and Radioactive Waste

Materials within the Caño Martín Peña include various types of solid waste, debris, and other materials. Such materials will require further testing prior to and/or during project construction, as appropriate, in accordance with an agreed sampling plan. If the testing determines that any materials contain hazardous substances at levels that are not suitable for unregulated disposal, they will be managed in accordance with the applicable laws and regulations of the relevant regulatory agencies. More detail on the approach to handling such contaminated materials is included in Sections 6.2.2 and 7.2, as well as Section 3.8 in the EIS.

2.2.2 Biotic Characteristics

2.2.2.1 Freshwater Aquatic, Wetland, and Terrestrial Plant Communities

The Project Channel, even though severely degraded, still harbors one of the most valuable ecological areas in Puerto Rico. Four major habitat types were identified within the CMP: swamps (forested wetlands/mangroves); marshes (emergent wetlands); open water; and transitional secondary forests (Figure 7). Based on the Cowardin classification (1979), the forested wetlands could be classified as estuarine and palustrine, and the emergent wetlands as palustrine (Figure 8). Additional information on freshwater aquatic, wetland, and terrestrial plant communities can be found in Section 3.9 of the EIS.

2.2.2.1.1 Estuarine Open Water

Open water areas in the Project Area consist of the CMP, San José lagoon, and the San Juan Bay. Floating vegetation was present within some of the open water areas, specifically in the areas where the CMP channel is clogged. The dominant species within these areas are *Eichhornia crassipes* (water hyacinth), *Lemna aequinoctialis* (duckweed), and *Pistia stratiotes* (water lettuce). The Cowardin classification (1979) for these areas is estuarine, sub tidal, unconsolidated bottom, and sub tidal (E1UBL). Within the eastern CMP Project Area, there are 7.40 acres of estuarine open water.

2.2.2.1.2 Estuarine Forested Wetland

Estuarine forested wetlands within the Project Area are tidally influenced. These wetlands consist of a mangrove forest fringe along most areas of the CMP bank and a large area on the eastern end of the CMP, near the connection with the San José Lagoon. Mangroves also populate the banks of the western half of the CMP, in an area that was declared a natural reserve by the PRPB. The dominant species within the estuarine, forested wetlands are *Avicennia germinans* (black mangroves), *Laguncularia racemosa* (white mangroves) and *Rhizophora mangle* (red mangroves). Other abundant species include *Terminalia catappa* (tropical almond), *Cocos nucifera* (coconut palm) and *Thespesia populnea* (seaside mahoe). The Cowardin classification (1979) for these areas is estuarine, intertidal, forested, broad-leaved evergreen, and irregularly exposed (E2FO3M). Within the eastern CMP Project Area, there are 15.53 acres of estuarine forested wetlands.

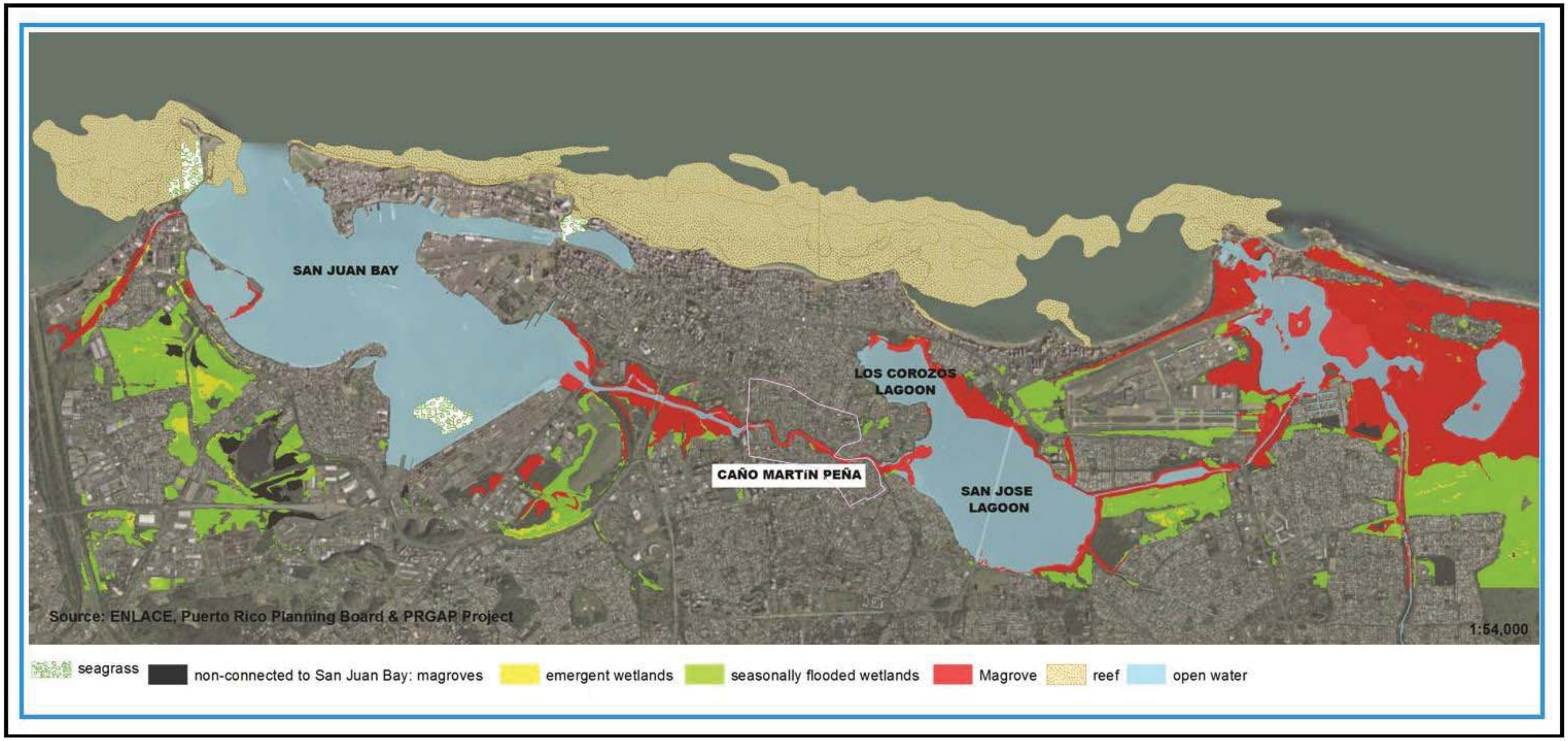
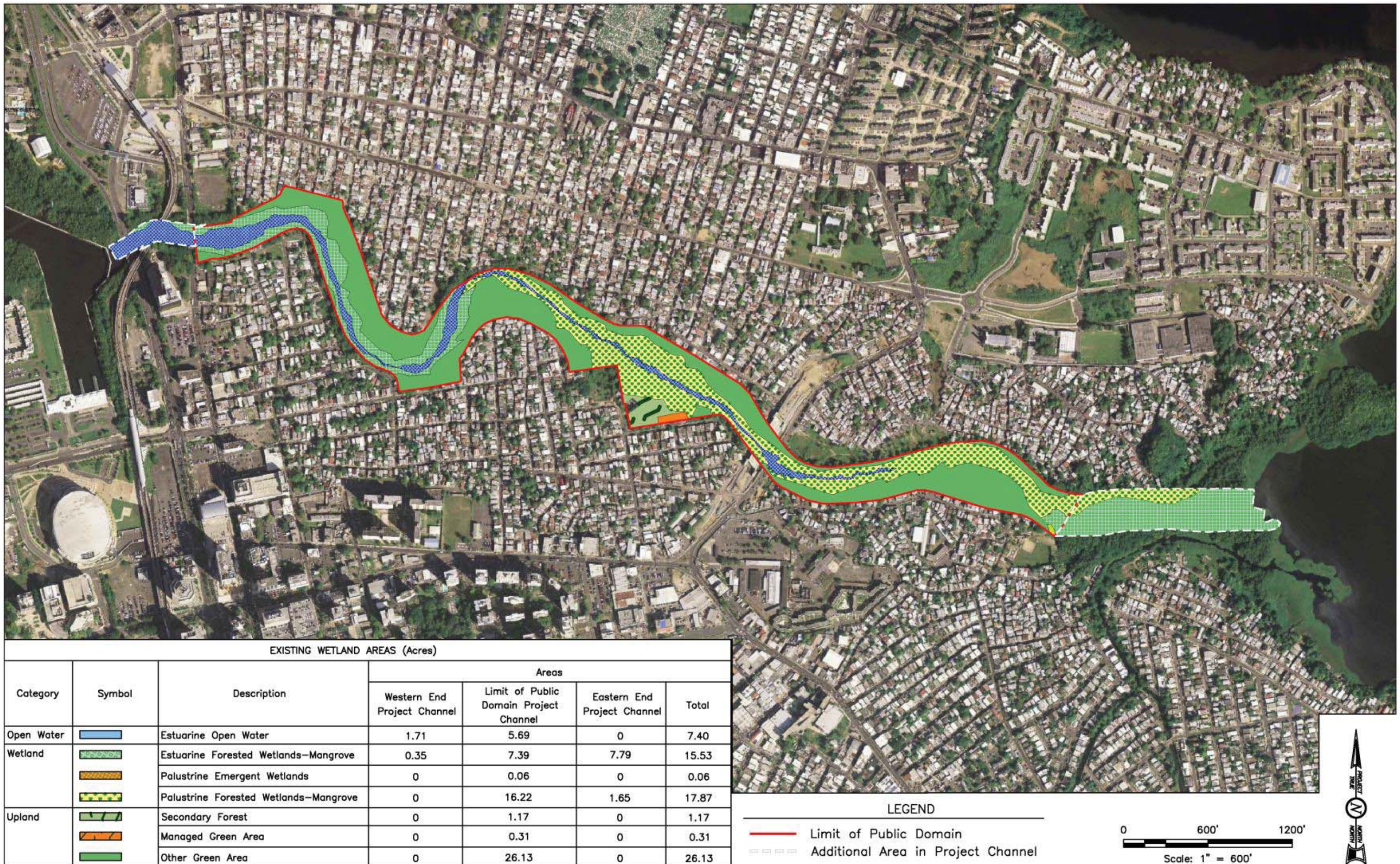


Figure 7. Freshwater Aquatic, Wetland, and Terrestrial Plant Communities in the CMP-ERP Study Area



EXISTING WETLAND AREAS (Acres)

Category	Symbol	Description	Areas			
			Western End Project Channel	Limit of Public Domain Project Channel	Eastern End Project Channel	Total
Open Water		Estuarine Open Water	1.71	5.69	0	7.40
Wetland		Estuarine Forested Wetlands–Mangrove	0.35	7.39	7.79	15.53
		Palustrine Emergent Wetlands	0	0.06	0	0.06
		Palustrine Forested Wetlands–Mangrove	0	16.22	1.65	17.87
Upland		Secondary Forest	0	1.17	0	1.17
		Managed Green Area	0	0.31	0	0.31
		Other Green Area	0	26.13	0	26.13
TOTALS			2.06	56.97	9.44	68.47

Figure 8. Existing Condition Wetland Analysis

2.2.2.1.3 Palustrine Forested/ Emergent Wetlands

Palustrine forested/emergent wetlands are tidally influenced and share the same vegetation composition as the estuarine forested wetlands, with some differences in their structure. While estuarine forested wetlands were dominated by *Avicennia germinans* (black mangrove), the palustrine forested/emergent wetlands had a relatively low abundance of this species. In addition, the abundance of emergent vegetation, mostly *Acrostichum aureum* (golden leatherfern), is substantial. The Cowardin classification (1979) for these areas is palustrine, forested, broad-leaved evergreen/emergent, persistent, seasonally flooded (PFO3/EM1C). The seasonal wetlands can be described as having surface water present for extended periods, especially early in the growing season, but absent by the end of the growing season in most years. The water table after flooding ceases is variable, extending from surface saturated to a water table well below the ground surface. Within the eastern CMP Project Area, there are 17.87 acres of palustrine forested/emergent wetlands.

2.2.2.1.4 Palustrine Emergent Wetlands

Palustrine emergent wetlands are mostly dominated by *Colocasia esculenta* (malanga), *Brachiaria purpurascens* (para grass), *Commelina diffusa* (climbing dayflower), *Paspalum fasciculatum* (mexican crowngrass), and various *Ipomoea* spp. These areas are located mostly between the mangroves and the houses on the north bank of the CMP, specifically in its easternmost portion. The Cowardin classification (1979) for these areas is palustrine, emergent, persistent, seasonally flooded (PEM1C). Within the eastern CMP Project Area, there are 0.06 acre of Palustrine emergent wetlands.

2.2.2.2 Invasive Species

As part of the habitat characterization study conducted in 2011, one hundred fifty-two species of vascular plants were identified among 61 plant families. Of the plant species, sixty-eight (44.74%) are introduced to Puerto Rico and 84 (55.26%) are native to the island. Invasives such as water hyacinth and duck weed can be found in parts of the SJBE, particularly in the CMP towards the San José Lagoon. Additional information on invasive species can be found in Sections 3.10.1.1 and 3.10.2.1 of the EIS.

2.2.2.3 Benthic Habitat

Benthic habitats are those that support plants and animals on or in the bottom of water bodies, also known as the benthos. Twenty-one distinct benthic habitat types are found in Puerto Rico, including: unconsolidated sediments, submerged vegetation, mangrove forests, coral reef and hard bottom (NOAA 2001). Differences in these habitats are dictated by the chemical and physical characteristics of the substrate and of the water column above.

The existing high sedimentation rates, presence of contaminants within the sediments, low dissolved oxygen levels, and salinity stratification within the CMP and/or the San José lagoon do not provide a healthy ecosystem for benthic organisms (e.g., infauna, meiofauna, epifauna) or organisms relying upon the estuarine water column (e.g., fish and invertebrates; Kennedy et al. 1996, Otero 2002, SJBEP 2000, Puerto Rico Environmental Quality Board [PREQB] 2008). Benthic habitats in and around the Project Channel area are highly degraded due to the contaminant loads and reduced tidal flushing present, which result in limited light penetration, poor water quality, and anoxic, highly organic sediments.

Soft bottoms in these shallow areas, the mangrove roots that line the lagoons, seawalls, rip-rap and other surfaces at these depths are covered with a thriving community dominated by mussels. Rivera (2005) estimated 66.7 acres of this mussel reef within the San José lagoon, which he hypothesized, is a “large source of food for the Lagoon” and provides a water filtering function “which must help maintain the water quality.”

Species abundance and diversity (important indicators of healthy habitats) of the encrusting community of red mangrove prop roots is higher in the La Torrecilla Lagoon (closest to the Atlantic Ocean), becomes less diverse and less abundant within the San José Lagoon (farthest from the flushing source), and is non-existent or limited (severely limited flushing) within the CMP. This could be related to dissolved oxygen and salinity concentrations.

This macrofauna follows a general pattern of reduced diversity and abundance along a gradient from Torrecilla Lagoon to Suárez Canal, to the San José Lagoon to the CMP. In general, sponges, crabs, worms and mussels become less abundant to absent along a gradient from the eastern end of Suárez Canal, along San José Lagoon and into the CMP.

In summary, the results of the benthic habitat survey in the shallow portions of San José Lagoon indicate that diverse and healthy biological communities are restricted to the shallowest (less than 4 feet) regions, where salinity stratification does not occur, and where sufficient levels of dissolved oxygen exist. These are the conditions that support a healthy benthic habitat, that type that would support sustenance and recreational fishery in the Lagoons; however, at the minimal dissolved oxygen conditions found in 702 acres of waters deeper than 4 feet in San José lagoon, the presence of hydrogen sulfide in the sediments is a strong indicator that the water layer above the sediments is also hydrogen sulfide laden. Therefore, these areas of the bottom of the lagoons cannot sustain a benthic habitat. Additional information on benthic habitat can be found in Section 3.9.2 of the EIS.

2.2.2.4 Fish and Wildlife Resources

Some of the 124 species that have been documented in the SJBE system have been locally identified as important target species for both recreational and commercial fisheries. The important target species of common snook (*Centropomus undecimalis*) and tarpon (*Megalops atlanticus*) are caught within San José Lagoon itself (Yoshiura and Lilyestrom 1999). The commercially important offshore fishery for mutton snapper (*L. analis*) is dependent, in part, on the maintenance of a healthy inshore, lower-salinity mangrove habitat for post-larval and juvenile phases (Faunce et al. 2007). Out of the

124 species of fish documented within the SJBE system, fifteen of these are also found within the 84 managed species included in the Caribbean Fishery Management Council's Fisheries Management Program (FMP) (Yoshiura and Lilyestrom 1999).

Due to the current clogging of the eastern CMP, there is essentially no tidal exchange between San Juan Bay and the San José Lagoon. As a result, fish within San Juan Bay cannot directly access the mangroves, seagrass meadows, and open water habitats of San José Lagoon, Los Corozos Lagoon, the Suarez Canal, La Torrecilla Lagoon, and Piñones Lagoon, just as fish within those waterbodies cannot directly access the habitats afforded by San Juan Bay. Additional information on fish and wildlife resources can be found in Section 3.10 of the EIS.

2.2.2.5 Study Area Threatened and Endangered Species

There were no Commonwealth or federally listed terrestrial flora species found during the survey in the Project Channel within the Project Area. The Flora Gentry Transect Survey results were as follows: Within 616 flora individuals and 15 species identified among 11 families, thirteen are tree species and 2 are palm trees.

There are four federally listed plant species in the Study area: 2 threatened, *Schoepfia arenaria* and *Stahlia monosperma*; and 2 endangered, *Banara vanderbiltii* and beautiful goetza (*Goetzea elegans*).

There are 19 federally listed species of fauna in the Study Area:

Reptiles: Four federally listed reptiles have been documented in the Study Area, but none within the Project Area: 1 threatened, Green sea turtle (*Chelonia mydas*); and 3 endangered, Leatherback sea turtle (*Dermochelys coriacea)*, Hawksbill sea turtle (*Eretmochelys imbricata)* and the Puerto Rican boa *(Epicrates inornatus).* Indeed, of the four species of sea turtles known to inhabit Puerto Rican waters, three have been reported in the nearshore waters at the Study Area. Juvenile green and hawksbill turtles may be found off the northern shore of Puerto Rico, associated with rafts of *Sargassum.*

Mammals: One federally endangered marine mammal has been documented in the Study Area. The Antillean manatee (*Trichechus m. manatus*), could be found west of the Project Area, at the juncture between the western half of the CMP and the Puerto Nuevo River Channel.

Birds: Three listed species of bird are found in the Study Area. The federally threatened yellow-shouldered black bird (*Agelaius xanthomus*) has been documented in the Study Area mangroves; the closest to the Project Area has been at the western half of the CMP. Federally threatened species such as the roseate tern (*Sterna d. dougallii*) and the red knot (*Calidris canutus)* were also sighted with other shorebirds on the mudflats that once existed in the western end of the CMP, at its outlet to the SJB.

Corals: Seven threatened coral species inhabit the nearshore marine waters in the Study Area. All identified in marine waters, north of the SBJE. Two belong to the *Acropora* genus: elkhorn coral (*A. palmata)* and the staghorn coral (*A. cervicornis)*; three to the *Orbicella* genus: Lobed star coral *(O. anularis),* Mountainous star coral (*O. faveolata)* and Knobby star coral (*O. franksi*), along with the rough cactus coral (*Mycetophyllia ferox) and the* Pillar coral *(Dendrogyra cylindrus*).

Critical habitat for *A. palmata* and *A. cervicornis* has been designated and include nearshore reefs within the Study Area, north of the SJBE, as well as other coastal areas around the Island with suitable requirements for these to thrive (e.g. heavy surf, clear-low nutrient ocean-water salinity conditions). As a result, none of these species are found in the CMP or the San José Lagoon.

The Puerto Rico Regulation 6766 for the Threatened and Endangered Species of the Commonwealth of Puerto Rico (created under the Puerto Rico Wildlife Law, Law No. 241 of August 15, 1999) also identifies other 19 species of special concern in the Study Area, in addition to those that have been federally listed: two species of seahorses *Hippocampus erectus (*lined seahorse) and *Hippocamus reidi (*longsnout seahorse); 12 species of birds: one species is listed as endangered, Masked duck (*Nomonix dominica*); 3 are listed as threatened, Ruddy duck (*Oxyura jamaicensis*), White-cheeked pintail (*Anas bahamensis*) and Caribbean coot (*Fulica caribaea*); 3 are listed as critically endangered, West Indian whistling duck (*Dendrocygna arborea*); the Snowy plover (*Charadrius alexandrinus)*, and the Peregrine falcon (*Falco peregrinus*); 1 is listed as low risk, the Puerto Rican vireo (*Vireo latimeri*); and 4 species are listed as data deficient due to lack of data on its population status: Grasshopper sparrow (*Ammondramus savanarum*), Black cowled oriole (*Icterus dominicensis*), Least tern (*Sterna a. antillarum*) and White-crowned pigeon (*Patagioenas leucocephala*).

Other data deficient species is the reptile, Puerto Rican slider (*Trachemys s. stejnegeri*) that can be found in the Study and Project areas. Likewise, two species of crustaceans are listed as data deficient, the Fiddler crab (*Uca sp.)* and the Mangrove tree crab (*Aratus pisonii*). Three other species of crab are listed as low risk: the Mangrove root crab (*Goniopsis cruentata*), the Common land crab (*Cardisoma guanhumi*) and the Swamp ghost crab (*Ucides cordatus*).

2.2.2.6 Essential Fish Habitat

Four types of Essential Fish Habitat (EFH) have been identified within the Study Area: mangrove wetland EFH (2,240 acres), sea grass EFH (11 acres), reef and hard bottom community EFH (3,564 acres), and estuarine water column EFH (5,759 acres). Of these four, only two exist within the Project Area: mangrove wetland EFH and estuarine water column EFH. The existing mangrove habitat within the Project Channel and along the shoreline of the San José lagoon is degraded as a consequence of extensive human encroachment, the massive amount of fill material, scrap and trash deposited within the mangroves, the severely degraded water quality from wastewater discharges, and the limited tidal flushing. Likewise, the estuarine water column is impaired by the existing high sedimentation rates, presence of contaminants within the sediments, low dissolved oxygen levels, and salinity fluctuations. Additional information on essential fish habitat can be found in Section 3.9 of the EIS.

2.2.3 Socioeconomic Conditions

Historically, neighborhoods along the CMP have a disproportionate adverse economic and environmental burden compared with the surrounding area of the municipality of San Juan and with Puerto Rico. The precarious economic situation of these disadvantaged communities has exacerbated the degradation of the surrounding environment. These circumstances have continued for decades, subjecting residents to conditions that adversely affect their health, safety and their quality of life. Despite these challenges, the CMP communities have a strong sense of belonging and social cohesiveness. Additional information on socioeconomic conditions can be found in Section 3.13 of the EIS.

2.2.3.1 Infrastructure

The present infrastructure along the Project Channel consist of three main avenues with bridge crossings, a pedestrian bridge, limited paved local access streets, water lines on bridge crossings, very limited storm and sanitary sewers, one trunk sewers and one water transmission line with cannel under-crossings, storm water system pumps, telephone and power supply network, limited cable TV, and limited recreation facilities. Recent additions to the existing infrastructure in the surrounding areas, including: the relocation of the José Celso Barbosa Avenue Bridge that makes feasible the access of dredging barges to a significant portion of the Project Area, Tren Urbano Sagrado Corazón station and its bridge crossing over the CMP, new vacuum sewer systems serving Barrio Obrero Marina and the Cantera Peninsula, new housing in the Cantera Peninsula and Israel-Bitumul, the José Miguel Agrelot Puerto Rico Arena, new recreational parks, community gardens, and associated facilities. The PRASA also deviated the continuous raw sewage discharge adjacent to the Mercantil Plaza Building next to the Martín Peña Bridge, related to a combined sewer trunk serving areas of Hato Rey and Río Piedras. PRASA is working on a project to separate this trunk into sanitary and storm water sewers, but in the meantime, overflow continues to occur. There are many ongoing studies and other efforts for improving and/or providing new storm and sanitary sewers to areas with deficient or non-existent sewers.

A segment of the San José Trunk Sewer runs from east to west adjacent to the Project Area. It is one of the principal San Juan area trunk sewers. This trunk sewer conveys wastewater from Trujillo Alto, Santurce, Barrio Obrero, Isla Verde, and Hato Rey to the Puerto Nuevo Wastewater Treatment Plant. While improvements to the San José Trunk Sewer are not a part of the CMP-ERP, it is located within the Study Area.

The Rexach Trunk Sewer is one of the main San Juan area trunk sewers, is located within the Project Area, and conveys wastewater from areas that include Isla Verde, Santurce, and Barrio Obrero to the

San José Trunk Sewer. The Rexach Trunk Sewer flows from north to south along Street 13 of the Barrio Obrero-Marina community, crosses the CMP, and continues along the Luna Street of the Parada 27 community until it connects to the San José Trunk Sewer. The Rexach Trunk Sewer has a diameter of 48 inches when it crosses the CMP and is encased in concrete. The crown of the trunk sewer in the CMP is at an elevation of 7.5 feet below MSL. The design and relocation of the Rexach Trunk Sewer is ongoing and will be completed prior to the dredge of the CMP.

The Borinquen Water Transmission Line is a 36-inch diameter pipe that travels from south to north along the Uruguay and Gardel Streets of the Parada 27 community, crosses the CMP, and continues on Argentina Street of the Barrio Obrero-Marina community. This transmission line has only 3 feet of cover where it crosses the CMP. Additional information on infrastructure in the Project Area can be found in Section 3.12 of the EIS and Sections 5.14 in the Engineering Appendix. The design and relocation of the Borinquen Water Transmission Line is ongoing and will be completed prior to the dredge of the CMP.

A 115-kV overhead transmission line ran from a substation near the Tren Urbano guiderail on the western end of the CMP-ERP, east via Rexach Avenue, and then south to the channel and San José Lagoon. The 115-kV overhead transmission line has been relocated as a component of the CMP-ERP.

2.2.3.2 Recreation

Recreation in the Project Channel is impaired and unsafe compared to the CMP channel to the west of the bridges (the western CMP). There are no areas where residents may access the canal for fishing, bird watching, or other recreation activities except at the three bridges which cross the canal. Navigation is impaired in the Project Channel as water depths are shallow and the easternmost section is completely filled in with sediment and solid waste. There is an existing basketball and volleyball court within the Public Domain Limit. Additional information on recreation resources can be found in Section 3.16 in the EIS.

2.2.3.3 Cultural Resources

At present, no previously recorded sub-aquatic prehistoric cultural resources have been identified in the area, and there is no historic evidence of smaller marine vessels encountered in the CMP; however, the investigations conducted in the area have been limited due to restricted access and solid waste in the Project Channel. Based on initial consultations with the State Historic Preservation Office (SHPO), the possibility of encountering submerged cultural remains within the CMP and Project Area still exists, and is considered to be high. It concluded that the accumulation of household and construction debris deposited within the Eastern CMP since early in the twentieth century could be considered an archeological site. There is also a probability of encountering cultural remains from the old bridges constructed in the area, as well as the remains of fishing corrals from the early twentieth century.

The Martín Peña Bridge is a historic structure because of its architectural value, and its location is an historic site, as several bridges that constituted the main crossing between Hato Rey and Santurce towards Old San Juan have been built in the area since the 1500s. This location is also the site of one of the key battles that led to the defeat of the British invasion of San Juan in 1797, led by Admiral Ralph Abercrombie. Community efforts to preserve the bridge led to Law 110 for the Declaration of the CMP Bridge as a Historic Monument, which was signed on August 15, 2007. The bridge is also listed in the National Register of Historic Places. Additional information on cultural resources can be found in Section 3.15 of the EIS.

2.2.3.4 Socioeconomics and Environmental Justice

The eastern CMP is mostly lined by a very narrow fringe of mangrove-dominated forest, which is completely encroached by high-density urban development, consisting in many instances of substandard residential units. From west to east, those communities found along this entire section of the CMP include, in its northern bank, Barrio Obrero Marina, Barrio Obrero Obrero Oeste and San Ciprián), and Cantera Peninsula. Parada 27, Las Monjas, Buena Vista Hato Rey, and Israel-Bitumul are found in the southern bank (Figure 3). The following information summarizes the socioeconomic characteristics of these communities:

- Approximately 23,420 inhabitants (Census 2010), representing about 6 percent of San Juan's population.
- Population density (8,775 people/km^2) is very high — more than twice that of San Juan's (3,417) and significantly higher than Puerto Rico's (419). Communities with the highest population density are Barrio Obrero Oeste (11,244) and Buena Vista-Santurce (10,264).
- Median household income for the communities adjacent to eastern CMP is $12,268, considerably lower than Puerto Rico's ($18,791).
- Most households (59%) fall below the poverty level, being Cantera Península the community with the highest proportion of the population below poverty level (72%). These values are greater that the percentage for the Municipality of San Juan (37%).
- Only 6 percent of the residents of these communities have obtained a college degree, a proportion lower than Puerto Rico's (20%). The community with the largest proportion of residents with a college degree is Parada 27/Las Monjas with 10 percent, followed by Buena Vista Santurce with 8 percent.
- Housing occupancy rate in the communities adjacent to the eastern CMP is 84.8%, slightly larger than Puerto Rico's (84.2%). Nonetheless, in Barrio Obrero Oeste, Buena Vista Santurce, and Buena Vista Hato Rey the occupancy rate is a little lower than Puerto Rico's.

Additional information on socioeconomics can be found in Section 3.13 of the EIS.

2.2.3.5 Human Health and Safety

2.2.3.5.1 Exposure to Contaminated Waters

The CMP's environmental degradation has impacted the adjacent communities' public health. As the Project Channel has significantly decreased its capacity to convey water, a regular rain event will cause flooding in nearby residences. In addition to the frequent floods due to the CMPs decreased capacity, the communities bordering the CMP have significant infrastructure problems such as poor quality housing, lack of a sanitary sewer system, decreased or inefficient trash collection services due to poor access, among others (PRHTA 2004). Sanitary discharges flow directly into the already compromised CMP with about 40 percent of the structures neighboring the CMP completely lacking a sanitary sewer (PRHTA 2004).

Recent surface water samples by the USEPA and the SJBE Program have revealed fecal coliform counts ranging from 2,100 colonies per 100 ml of water to 2,000,000 colonies per 100 ml of water. These concentrations indicate that CMP waters have from 10 to 10,000 times the permitted standard for indirect contact with water according to the PREQB. The maximum standard permitted by the PREQB for indirect contact is 200 fecal coliforms (PREQB 2010). Fecal coliforms in the water may signify the potential presence and risk of contracting diseases transmitted through warm bodied animal waste. Levels of *Enterococci* bacteria have been reported at 11,000 colonies per 100 ml of water and up to 1,200,000 colonies per 100 ml of water. The maximum permitted standard for *Enterococci* bacteria for indirect water contact is 35 colonies per 100 ml of water. Colony levels surpass the permitted standard over 35,000 times. These findings reveal the presence of microbes indicative of human contagious diseases. *Enterococci* are more precise indicators of pollution of human waste origin. The levels of *Enterococci* bacteria are the most worrisome pollution parameter with regards to its public health risks. Finding these significant levels of colonies confirms the presence of direct human waste pollution. Residents have already expressed concern about exposure to contaminated waters and the polluted waters potential mixing with the potable water lines at each flood event, (PRHTA 2004). The community census carried out by the ENLACE Project in 2002, which interviewed all community households, revealed that nearly 40 percent of residents that answered replied that their residence or nearby areas flooded between 1 and 20 times during the previous year (PRHTA 2003).

In 2011, the Ponce School of Medicine and Health Sciences carried out an investigation to measure the level of gastrointestinal symptoms within the populations of CMP-adjacent communities and establish if there was a correlation between documented symptoms and flood events in the past three months. The conclusion, with a statistically significant population sample, showed that residents within the CMP adjacent communities had a higher prevalence of gastroenteritis symptoms (31 percent in the CMP communities, as opposed to 22 percent within the rest of the island population) and that residents exposed to flood waters (whether it entered their home or just reached the street) were twice as likely to develop gastrointestinal symptoms than residents not exposed to flood waters. Stagnant waters, such as the ones in the CMP, with such high bacteria levels may indicate the presence of other bacteria. Other risks to which community residents are exposed include the Hepatitis A virus, the bacteria *Vibrio colerae*, and shigella, a close relative of salmonella.

There is very limited human consumption of fish from the CMP and from the flood waters, as well as consumption of fish and crustaceans in the San José lagoon. Also, there is consumption of crops exposed to flood waters.

2.2.3.5.2 Exposure to Environmental Degradation

In addition to the decreased conveyance capacity offered by the CMP, the CMPs environmental degradation is exemplified by the clogging up of the waterway due to waste from the surrounding areas and area contractors that dispose of construction debris within the CMP. As such, the environmental degradation of the Project Channel is exacerbated by the amount of trash deposited within the area including paper, plastics, tires, junk cars, domestic appliances, construction debris among others (PRHTA 2004). Inadequate trash disposal promotes environments that increase proliferation of rats, insects, flies and other animals that transmit disease. Among the many diseases that could be transmitted are Leptospirosis and dengue fever. Concentration of trash in particular areas also becomes a source of dust and leaching from the trash becomes another potential source of pollution for adjacent waters.

Children under five years old living within the CMP adjacent communities have double the prevalence of asthma than that reported for the island of Puerto Rico (44.5 percent for CMP children over 21.5 percent for Puerto Rico), and there is a clear trend of a higher number of cases as distance from the residence to the CMP decreases (Departamento de Bioestadística y Epidemiología 2012). Additional information on health and safety conditions can be found in Section 3.14 of the EIS.

2.2.3.6 Aesthetics

Only the western half of the CMP is used extensively for bird watching, cycling, and other recreational activities and has high aesthetical value. The eastern half of the CMP is not well defined and views into the CMP are obstructed due to encroachment. Limited access to the eastern half of the CMP has fostered its use for illegal dumping, which coupled with decades of filling with various vegetative material and solid waste, has negatively affected the view to the CMP. Additional information on aesthetics can be found in Section 3.17 of the EIS.

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3.0 FUTURE WITHOUT-PROJECT CONDITIONS

3.1 "WITH AND WITHOUT" COMPARISONS

The U.S. Water Resources Council's Principles and Guidelines provide the instructions and rules for federal water resources planning (USWRC 1983). One Principles and Guidelines requirement is to evaluate the effects of alternative plans based on a comparison of the most likely future conditions with and without those plans in place. In order to make this kind of comparison, descriptions must be developed for two different future conditions: the future without-project condition and the future with-project condition.

The future without-project condition describes what is assumed to be in place if a study's alternative plans are not implemented. The without-project condition is the same as the alternative of "no action."

Future with-project conditions describe what is expected to occur as a result of implementing each alternative plan being considered in a study. With-project conditions are developed for each alternative plan; therefore, there are as many with-project conditions as there are alternative plans. The differences between the without-project condition and the with-project condition are the effects or impacts of the plan.

3.2 "WITH AND WITHOUT" VERSUS "BEFORE AND AFTER" COMPARISONS

Many people typically think about the effects of alternative plans in terms of "before and after"; that is, they compare the condition that exists now or before it is changed by a plan, to the condition they expect will exist in the future after it has been changed by a plan. For example, if a proposed channel dredging project were to disturb four acres of an existing ten-acre wildlife habitat, then using a before-and-after comparison, the project could be said to result in a loss of four acres of that habitat.

Another way to think about effects is to compare expected future conditions if no alternative plan is implemented (the without-project condition), to expected future conditions if a particular plan is implemented (the with-project condition). Returning to the example, assume that the ten-acre wildlife habitat is already included in a residential development plan that would convert three of its acres to residential sites. Now suppose the proposed dredged channel would cover four acres of the ten-acre site, including the same three acres that would be converted to residential sites. Using a with and without comparison, the channel would be said to result in a loss of only one acre since three of the four acres would be affected even if the channel were never constructed. With-and-without comparisons recognize that the future is often different from the existing condition; and unlike before-and-after comparisons, account for future changes in the comparison.

3.3 PLANNING HORIZON

The period of analysis for the study is of 50 years, from calendar year 2020 through calendar year 2070. Although most project objectives will be reached within the first 3 to 15 years, construction costs and maintenance costs presented in this report are based on a project life of 50 years.

3.4 FORECASTED WITHOUT-PROJECT CONDITIONS

Federal improvements to the CMP would not be conducted. Under the future without-project condition, the non-Federal sponsor, ENLACE, and its partners would still conduct planned improvements to the area surrounding the CMP. These efforts would include:

- the Cantera Peninsula Project (Section 1.5.6 of this report);
- the partial construction of the Paseo del Caño with important limitations regarding storm sewer management (ENLACE CMP Project; Section 1.5.10 of this report);
- improvements to the San José Trunk Sewer Line;
- relocation of all residents that would be affected by construction of the Paseo del Caño (outside of the CMP Public Domain limit);
- housing acquisition and rehabilitation in eight CMP neighborhoods outside of the MTZ-CMP to improve the stock of standard housing units; and
- sewer system upgrades in the eight CMP neighborhoods to eliminate discharge of untreated sewage into the CMP.

Although these efforts could improve socioeconomic conditions for the residents in the area, these efforts would not provide any ecological restoration of the CMP. The actions listed above would not serve to alleviate the current problems that are occurring in the estuary such as fragmentation, poor dissolved oxygen levels, increased sedimentation, etc. In fact, many future projects by the non-Federal sponsor to further improve socio-economic conditions are contingent on restoring tidal flow and environmental conditions within the CMP.

3.4.1 Future Abiotic Characteristics

San José lagoon is expected to continue to lose depth. The CMP would continue to fill in due to channel sedimentation and illegal dumping, leading to a further decrease in open water area. Water quality in the CMP and the western San José lagoon would continue to degrade due to continued isolation from significant tidal influences. Estuarine open waters would continue to be persistently hypoxic or anoxic below 4 to 6 feet depth in San José lagoon, precluding the establishment of submerged aquatic vegetation and healthy benthic communities. Salinity stratification within the lagoon would likely continue to degrade with fish kills becoming more prevalent.

Flooding of residential and commercial structures in the Project Area would become more frequent with the continued loss of outlet capacity in the CMP. While certain contaminant concentrations may decrease in the greater SJBE, bacterial counts would remain high in the CMP, and contaminants from untreated runoff will remain consistent with today's unhealthy levels. Air quality would continue to be a problem due to elevated levels of hydrogen sulfide (H_2S), particularly in areas adjacent to the waters of the Project Channel. Table 4 summarizes the future without-project abiotic conditions.

3.4.1.1 Sea Level Change

The effect of sea level change (SLC) on the CMP project provides information guided by the U.S. Army Corps of Engineers recommending that sea level change be calculated and reported as a low, intermediate, and high rate for consideration of project impacts. The following analysis is made consistent with Engineer Regulation (ER) 1100-2-8162 "Incorporating Sea-Level Change Considerations in Civil Works Programs," released in December 2013.

The "low" sea level change rate is defined as the historic rate of relative sea level change at the local tide station. NOAA has evaluated sea level change trends for each tide station (NOAA 2008) and provides the data for the mean sea level trend at the San Juan tide gauge, station 9755371. The mean sea level trend has been calculated by NOAA to be 0.00541 feet/year.

The "intermediate" sea level change rate is defined as the rate of local mean sea level change using the modified Natural Research Council (NRC) Curve I. The "high" sea level change rate is defined as the rate of local mean sea level change using the modified Natural Research Council (NRC) Curve III. Both the "intermediate" and "high" rates include a consideration for the future acceleration of sea level change that is not considered when evaluating the historical ("low") rate of relative sea level change.

Assuming a project life of 50 years, with construction beginning in 2018 and completing in 2020, sea level change was calculated. Using the updates to the NRC Equations and extending the calculation 50-years from a construction completion date of 2020, Table 3 provides the summary of all estimated sea level change rates. As further reference, the Puerto Rico Climate Change Council (PRCCC 2013) recommends planning for a rise of 0.5–1.0 meter (1.64–3.28 feet) by 2100.

Table 3
Summary of Sea Level Change Estimates
(U.S. Army Corps of Engineers 2013)

SLC Estimate (feet)	Method	Estimate
0.36	Tide Gauge Trend	Low
0.76	NRC Curve I	Intermediate
2.03	NRC Curve III	High

Table 4. Summary of Future Without-Project Abiotic Conditions

Resource	Future Without-Project Condition
Climate Change and Sea Level Change	The filled condition of the CMP translates to greater impacts of storm surge, more frequent and severe storms, and sea level change in the Project Area, i.e. more flooding and land loss, and erosion. Continued trends in increased greenhouse gas (GHG) emissions.
Geology	There would be continued accumulation of debris and sediments over the historic channel bottom and adverse impacts to the physical geological features that affect water conveyance and runoff in the Study Area, including reduced depth and width of channel. No significant adverse impacts to underlying geology are anticipated.
Soils	Soils would remain significantly altered by urbanization and human settlement. In areas converted for human habitation, soils include debris, rip rap, rubble, household waste, vegetation, discarded furniture, abandoned cars, and other waste. Debris would remain >10% of the soil.
Hydrology	Channel depth and width would continue to be reduced with continued debris and sediment accumulation from watershed. Continued disruption of historic hydrologic connection between San José Lagoon and San Juan Bay. Constricted CMP would continue to exacerbate flooding in the watershed due to flashy runoff and poor drainage, whose waters are likely to be contaminated. Poor water quality would continue to be manifested as health issues in the adjacent communities
Flooding	Inadequate drainage would continue to result in flooding. The risk of flooding in adjacent communities as a result of continued filling in and sedimentation within the CMP and sea level change would increase.
Navigation	Navigation and watercraft access would continue to be precluded through the eastern CMP.
Coastal Processes	Lagoons in the Study Area have been dredged or mined. Average tidal range in San Juan Bay would remain consistent with existing condition, 19.2 inches compared with 2.0 inches in San José Lagoon because of reduced tidal influence. Estimated sedimentation rates among lagoons (ranging from 0.1 inches/yr to 0.2 inch/yr), would remain much lower than San José Lagoon (1.5 inches/yr) due to tidal exchange.
Air Quality	Hydrogen Sulfide would continue to be a problem in the area, likely worsening with continued filling of the eastern CMP.
Water Quality	Negligible tidal exchange in the CMP would persist, and this condition would continue to cause salinity stratification and poor dissolved oxygen in depths from 4-6 feet, thus contributing to poor habitat for benthic and fish and wildlife communities. Water quality would continue to violate existing federal and local water quality standards, and would remain as a major health hazard. Plan to improve local drainage and sewer would be limited by lack of conveyance capacity in the CMP.
Sediment Quality	The sediments deposited in the SJBE system would continue to be upland sediments mixed with anthropogenic inputs.
Noise	No significant adverse impacts are anticipated since no new activities would occur.
Hazardous, Toxic, and Radioactive Waste	No additional evidence of HTRW sites in the CMP, and the potential for new HTRW in the Project Area would be minimal.

3.4.2 Future Biotic Characteristics

A functional CMP is critical to the health of the entire SJBE. If the project is not carried out, environmental conditions would continue to worsen within the entire estuary. Degraded mangrove habitats would decrease habitat for water birds and migratory fowl. Increased sedimentation would be expected to bury pneumatophores and roots, compromising the health of the mangrove and leading to decreased growth and survival. A lack of tidal flushing can result in future algal blooms in the surrounding areas becoming more intense due to increased nutrients and lack of light filtration. These factors may decrease germination and survival of mangrove seedlings, reducing canopy coverage and preventing colonization of new areas.

Estuarine open waters would continue to be persistently hypoxic and/or anoxic below 4 feet in depth throughout the Project Channel and the San José Lagoon, precluding the establishment of submerged aquatic vegetation or healthy benthic communities. Estuarine fish species dependent on healthy benthic communities and wetland habitats would remain absent from these water bodies due to low habitat suitability and insufficient tidal access, also reducing populations and impacting nesting success of water-dependent birds. The existing condition for benthic, fish, and mangrove habitat would persist into the future. Table 5 summarizes the future without-project biotic conditions.

3.4.3 Future Socioeconomic Conditions

The inhabitants of neighboring communities to the CMP would continue to suffer the social stresses associated with substandard living conditions, deteriorated air and water quality, frequent flooding events, and numerous public health hazards. The low education, employment, and home ownership rates would continue to be consistent with today's rates, and population density will remain unsustainably high. The subsistence fishermen that use fish and shellfish caught in San José a lagoon would continue to ingest the contaminants present in the seafood and may pass those contaminants to unsuspecting consumers when they sell their catch (Atkins 2011b).

In general, residents would continue to experience disproportionate adverse economic and environmental burden compared to surrounding areas of San Juan, the rest of Puerto Rico and the United States with respect to health, safety and quality of life. Table 6 summarizes the future without-project socioeconomic conditions.

Table 5. Summary of Future Without-Project Biotic Conditions

Resource	Future Without-Project Condition
Freshwater Aquatic, Wetland, Terrestrial Habitats	The approximately 33.46 acres of wetland areas within the Project Channel would remain primarily mangrove swamp of comparatively low functional value as a result of disturbed conditions due to human habitation of the area, and poor water quality due to flooding and untreated waste and stormwater. The fish and mangrove habitat conditions would persist similar to the existing condition.
Invasive Species	The 152 invasive plant and animal species documented as occurring in Puerto Rico would persist, with some possible increase with disturbances. Invasive species often become established due to disturbance of native habitats and would continue to expand in the Project Area without management.
Benthic Habitat	Benthic Index (BI) for the San José Lagoon was 1.55, reflecting salinity stratification and poor DO in -4 to -6 feet of depth due to poor tidal exchange along CMP. This existing condition is expected to persist into the future
Fish and Wildlife Resources	Some fish and wildlife species would likely decline, in population and geographic distribution within the Study Area; overall species diversity would decline.
Threatened and Endangered Species (T&E)	T&E species population numbers losses are not anticipated to significantly change due to existing regulations and lack of quality, available habitat in the project area. There is no critical habitat for listed species in the Project Area and no T&E plant species have been found in the area of the proposed disposal sites.
Essential Fish Habitat	The Project Area includes mangrove wetland EFH and estuarine water column EFH. Mangrove habitat in the Project Channel and along the San José lagoon would remain functionally degraded due to extensive human encroachment, wastewater discharges, and severely limited tidal exchange along the CMP. Estuarine water column EFH in the CMP would remain impaired and functionally degraded by the existing high sedimentation rates, sediment toxins, low DO levels, and salinity fluctuations and stratification.

Table 6. Summary of Future Without-Project Socioeconomic Conditions

Resource	Future Without-Project Condition
Land Use and Infrastructure	Plans for improving sanitary sewer infrastructure, independent of the proposed project, would partially and perhaps temporarily improve health conditions in some areas. The feasibility of improved storm water infrastructure will be seriously impaired, due to the lack of water conveyance at the CMP. Thus, CMP and storm sewer related flooding is expected to continue, limiting land use opportunities.
Recreation	Recreation opportunities would remain very limited due to lack of transportation and recreation infrastructure. Commercial (e.g. tarpon anglers who presently fish borrow pits) and recreational fishing, as well as other water related activities, would be precluded in the CMP due to little to no tidal flow through it. The 4 existing basketball/volleyball courts within the CMP Public Domain limit would be relocated to areas within the surrounding communities along the CMP.
Cultural Resources	The Martín Peña Bridge would remain as the only designated Historic Monument under Law 110. No additional resources eligible for the National Register of Historic Places are listed as occurring in the Project area.
Socioeconomics	Adverse economic impacts to commercial and recreational fishing, tourism and land values in the communities and region would continue.
Environmental Justice	Historic neighborhoods along the CMP would continue to experience disproportionate adverse economic and environmental burden compared with the surrounding areas of the San Juan and the rest of Puerto Rico with respect to health, safety, and quality of life. Although local projects would alleviate some of these problems, the communities bordering the CMP would continue to experience the degraded environmental conditions and health hazards, and have limit economic development opportunities.
Human Health and Safety	Communities along the CMP would continue to experience adverse health impacts directly related to the ecological conditions of the CMP. Although some progress may be made through future sewer and infrastructure improvement projects, local asthma and disease rates are not expected to improve significantly.

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4.0 IDENTIFICATION OF PLANNING OBJECTIVES

4.1 PROJECT GOALS

The project goal is defined as environmental restoration of the Caño Martín Peña.

4.2 PROBLEMS AND OPPORTUNITIES

4.2.1 Problems

The health of the SJBE has been compromised by the lack of tidal interchange between the San Juan Bay and the San José Lagoon, resulting from habitat destruction and the near-complete blockage of the Caño Martín Peña. The fragmented estuary has functionally been divided in half, which can cause such severe ecological effects as crowding, increased competition, and loss of population density and species diversity. The habitat fragmentation leaves the ecosystem extremely susceptible to changes in climate or shifts in available resources, which can have devastating effects on the community and can alter the overall species composition of the estuary.

The SJBE, being in an area of relatively low tidal amplitude, now suffers from a lack of tidal flushing that has led to decreases in dissolved oxygen and adverse changes in salinity stratification. The poor water quality conditions cause disruptions to the normal levels of species evenness and richness, leading to poor benthic habitat. These conditions have also led to poor species distribution and populations density within the mangrove root community. Research within the estuary has indicated that the mangrove root habitat decreased in overall quality with closer proximity to the Caño Martín Peña. Specifically, the current conditions within the Caño Martín Peña have led to the following problems:

1. Aquatic habitat in the SJBE has been fragmented due to the near complete obstruction of the CMP, eliminating connectivity throughout the entire estuary.
2. Severe hypoxic/anoxic bottom water conditions and poor salinity stratification exist in the San José lagoon due to a lack of tidal flushing and resulting in decreased habitat for benthic species in the estuary.
3. Mangrove wetland habitat in the CMP, the San José lagoon, and the Suárez Canal has been adversely impacted due to the lack of tidal flow and the subsequent reduction in density of native species that use this habitat.

These problems are anticipated to remain under the future-without project condition.

4.2.2 Opportunities

Opportunities to provide ecological improvements within the Caño Martín Peña and also the surrounding SJBE have been recognized by numerous groups and agencies. Although the CMP and associated SJBE have been severely impacted by the problems identified above, most of the damage that has occurred is reversible. Based on this fact, there are opportunities to:

1. Reconnect estuarine areas within the SJBE and restore fish habitat;
2. Improve conditions for benthic species within the SJBE, and;
3. Improve mangrove habitat within the historic CMP and surrounding SJBE areas.

4.3 OBJECTIVES AND CONSTRAINTS

4.3.1 Objectives

Planning objectives are statements that describe the desired results of the planning process by solving the problems and taking advantage of the opportunities identified. The planning objectives must be directly related to the problems and opportunities identified for the study and will be used for the formulation and evaluation of plans. Objectives must be clearly defined and provide information on the effect desired (quantified, if possible), the subject of the objective (what will be changed by accomplishing the objective), the location where the expected result will occur, the timing of the effect (when would the effect occur) and the duration of the effect.

The following objectives have been developed for the CMP-ERP. Unless otherwise noted, the objectives are intended to begin being met immediately upon construction of the project and deliver ecosystem restoration benefits throughout the life of the project.

1. Improve fish habitat in the SJBE system by increasing connectivity and tidal access to estuarine areas.
2. Restore benthic habitat in San José Lagoon by increasing dissolved oxygen in bottom waters and improving the salinity regime to levels that support native estuarine benthic species.
3. Increase the distribution and population density and diversity of native fish and aquatic invertebrates in the mangrove community by improving hydrologic conditions in the SJBE.

The timing and duration for the objectives would occur over the period of analysis, beginning with project implementation in year 2020 and continuing for 50 years.

4.3.2 Constraints

The following constraints were identified as a basis for development of a solution to the identified problems. The CMP-ERP must:

1. Comply with all Federal, state, and local laws, regulations and policies, including those for floodplain management, environmental protection, and historic preservation;

2. Avoid increasing sedimentation, algal growth, and other impacts to near-shore reefs adjacent to the Study Area;

3. Avoid induced flooding and other secondary effects such as noise, odors, release of H_2S, and damage to structures resulting from vibration within the communities adjacent to the CMP; and,

4. Avoid damage to existing sheet piles, bridges, and other structures in the Study Area.

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5.0 FORMULATION, EVALUATION, AND COMPARISON OF ALTERNATIVE PLANS

5.1 PLAN FORMULATION OVERVIEW

The Feasibility Report for the CMP-ERP followed the USACE 6-step planning process and was conducted by a Project Delivery Team (PDT) consisting of ENLACE, USACE, and consultant personnel. ENLACE also convened a Technical Committee (TC) (see Table 30) to assist it with conducting the feasibility study as part of the public engagement process. The rational, systematic and flexible analysis the process that relied directly on these previous planning and design efforts:

- San Juan Bay Estuary Program Comprehensive Conservation and Management Plan (2000)
- USACE Dredging of Caño Martín Peña, Project Design Report and Environmental Impact Statement, Jacksonville District (2001)
- USACE Reconnaissance Report Section 905(b) Analysis, Caño Martín Peña, Puerto Rico Ecosystem Restoration (2004)
- PRHTA Comprehensive Development and Land Use Plan for the Caño Martín Peña Special Planning District (2004)

Section 5 of the Feasibility Report documents the last four steps of the USACE Planning Process: Formulation, Evaluation, Comparison and Plan Selection.

5.2 PLAN FORMULATION

5.2.1 Plan Formulation Strategy

Management measures were initially created to address planning objectives for the proposed project. A management measure is a feature (a structural element that requires construction or assembly on-site) or an activity (a nonstructural action) that can stand alone or be combined with other management measures to form alternative plans. Most management measures were derived from a variety of sources including prior studies, the NEPA public scoping process, and the TC (see Table 30). Four categories of Management Measures were created:

- Channel Dredging
- Beneficial Use of Dredged Material
- Mangrove Planting Bed Construction
- Non-Structural Measures

Measures were then screened based on factors such as constructability, exposure to wind and wave actions, environmental impacts, conflict with planning objectives, elimination of subaqueous, benthic habitat within the estuarine system, capacity in landfills or other available sites in San Juan, engineering/infrastructure considerations such as proximity next to flowing water or insufficient roadways, impacts to adjacent communities by noise or air pollution or by undiluted containment of solid waste, and potential for unacceptable erosion. In addition to the measures, dredged material disposal options and erosion control features were also evaluated, as these components were necessary for the channel dredging measures to function. Afterwards, different scales of the channel dredging measure were combined with other measures as well as the appropriate disposal options and erosion control features to create alternatives. The alternatives were then compiled into an Initial Array to proceed with plan evaluation, comparison, and selection.

5.2.2 Planning Assumptions

Due to the large amount of heterogeneous nature of the dredged material as well as the unique island location of the project, several assumptions were established to guide initial plan formulation. First, due to the large amount of sediment and solid waste that would be dredged, capacity was not available at existing disposal facilities within the San Juan area to dispose of both the sediment and solid waste together. This assumption was verified with local landfills. Second, solid waste would need to be removed or filtered from sediment to the maximum extent practicable before potential disposal at any aquatic site. Third, based on surveys, testing and historical data, solid waste at the site was assumed to be eligible for disposal at a municipal landfill. Coordination with the Humacao landfill in San Juan indicated that the solid waste would be acceptable for disposal.

For aquatic disposal measures formulated, sediment testing and concurrence from the USEPA would be necessary in accordance with Section 103 of Public Law 92-532 (the Marine Protection, Research, and Sanctuaries Act of 1972) for ocean disposal. For inland aquatic disposal, sediment testing and concurrence from the PREQB would be necessary in accordance with Section 404 of the Clean Water Act. Due to resource limitations for the non-Federal sponsor, Section 103 and/or Section 404 testing would not be conducted until the preconstruction engineering and design (PED) phase, at the latest, if aquatic disposal is included as part of any recommended alternative. Initial assessments of sediment and solid waste and coordination with regulatory agencies have been conducted.

Dewatering of the solid waste is not considered necessary for the disposal process in light of the planning assumption that the solid waste would air dry during transportation from the CMP to the landfill.

5.2.3 Alternatives Considered but Not Carried Forward for Further Evaluation

Two alternatives to enhance tidal influence and reduce residence time in the San José Lagoon were also considered that did not involve restoring the hydrologic connection between San Juan Bay and San José Lagoon via the CMP. Both alternatives involved modifications to the cross section or configuration of specific areas within some of the water bodies found in the eastern half of the SJBE.

The first alternative involved increasing the water conveyance capacity of the Suarez Canal with ocean waters through La Torrecilla Lagoon by addressing the flow constriction at the Ramón Baldorioty De Castro's expressway (Road PR-26) caused by the bridge pilings. The action would be to dredge a section of the Suárez Canal found underneath the expressway, from 50 ft. wide and 3 ft. deep, to 100 ft. wide and 9 ft. deep. This modification was also one of the scenarios (Scenario 3) considered and evaluated as part of the Hydrodynamic and Water Quality Model Study for the SJBE performed by the USACE in 2000 (Bunch et al. 2000). The 2000 USACE study concluded that this modification "did little to improve overall water quality" in the SJBE, and thus, the San José Lagoon and the CMP, when compared to existing conditions. The study team for this feasibility study effort concurs with the USACE's original conclusion, and recognizes that this alternative would not meet the project purpose and objectives of the CMP-ERP.

The second alternative would require the construction of a new, man-made channel to provide for a direct connection between the San José Lagoon and the Atlantic Ocean, through the narrowest point north of the lagoon. The land mass that separates these two waterbodies, however, is densely urbanized, and includes sensitive sites or infrastructure such as a cemetery and the Ramón Baldorioty De Castro's expressway; the latest is the main access road that connects the municipality of San Juan with the northeastern region of the Island. Even if these constraints could be properly handled, the new channel would require very frequent dredging to counter sediment and sand deposition, especially at its outlet in the ocean. In addition, flow exiting the San José Lagoon would most probably affect nearby coral reef communities that are not accustomed to the high turbidity, rich nutrient waters that characterized this and other coastal lagoons in the Island. In light of these impacts, and considering that the alternative would not meet the project purpose and objectives of the CMP-ERP, it was not carried forward for further evaluation.

Other projects involving additional structural measures to improve tidal flow, such as placing a box culvert or pipeline between the western half of the CMP and the San José Lagoon along the channel's historic alignment, were also briefly considered. These alternatives were not carried forward for further evaluation because none would meet the project's purpose and objectives of the CMP-ERP. Each of these alternatives would result in additional man-made modifications to the SJBE without restoring its connectivity and the ecological health of the CMP, nor achieving system wide improvements to water and habitat quality.

5.2.4 Management Measures

This section provides a brief description of the management measures that were developed and also describes the screening process that was conducted. For full descriptions of the measures, please refer to the Engineering Appendix.

5.2.4.1 Channel Dredging

In order to increase the connectivity and tidal access within the SJBE and also restore benthic habitat and the mangrove root community, a connection must be re-established between San Juan Bay and the San José Lagoon. The construction of a new channel outside of the historic alignment is not feasible due to the high density of housing in the area and topography (higher elevations), so dredging of the existing channel of the CMP would be a necessary feature for any structural alternative that is formulated.

Two types of channel cross sections were considered for the Project Channel, rectangular cross-section and a hybrid design. A rectangular channel would utilize sheet piles with concrete caps along the entire length to prevent erosion. The hybrid channel employs sheet pile in areas that would be subject to erosive conditions and 5- to 1-foot earthen slopes in other areas. Based on initial calculations, the hybrid design would add 50 to 75-feet to the channel width and would only be feasible within the widest portions of the area.

Based on construction of the Rio Puerto Nuevo Flood Control Project, the construction of a sloped bank in the Project Channel is not likely feasible. Sloped banks were constructed as part of the Margarita Channel and were later replaced with sheet pile walls after consistent sloughing of fluvial sediment was causing poor project performance. The CMP project is located within a similar part of San Juan within the SJBE, and sloughing of material would also be anticipated within the Project Channel. A 5- to 1-foot sloped bank would also reduce the area available for mangrove restoration. For these reasons, the rectangular cross-section channel dredged design was retained and the hybrid design was eliminated for use in the Project Channel. Steel sheet pile was the selected structural treatment for the vertical edge, chosen over concrete sheeting due to its ease of handling and ability to be installed without the need for tie-backs. Although gabions are used for construction of vertical edges, they were not chosen due to their difficulty of construction underwater and their susceptibility to damage or wear.

5.2.4.2 Beneficial Use of Dredged Material

Several different possibilities were considered for this measure: expanding existing islands/habitat, constructing new diked or undiked islands, and constructing new marsh areas. All of these measures were eliminated due to sediments with possible high concentrations of contaminated pollutants being exposed to environmental conditions. Although the dredged material could be capped, the proximity and exposure to wave action and high winds could prompt failure of the structure during tropical weather. Unlike contained aquatic disposal (CAD) within anoxic borrow pit areas, these sites would be completely exposed to weather events, and given the high likelihood of experiencing future tropical events, there could be a significant risk of containment failure. In addition, the volume of material is extremely large, and, if constructed within a lagoon, it would eliminate a substantial area of open water and benthic habitat similar to the lagoon level measure. Other areas to construct ecological features are unavailable due to the densely populated nature of San Juan. As a result, this measure was eliminated from further consideration due to possible environmental impacts and acting conversely to project objectives.

5.2.4.3 Mangrove Planting Bed Construction

There are still some mangrove wetlands, albeit of extremely low functional quality, along the CMP. If the CMP was dredged, much of these wetlands would be within the construction area and impacted by the project. In order to maintain a mangrove fringe of wetlands along the CMP for habitat, nutrient reduction, water quality, and other wetland functions, mangrove wetlands could be re-established in areas along a dredged canal. This measure would provide immediate restoration within the project area, as the existing low quality mangrove areas would be removed along the CMP channel for construction purposes and replaced by high functioning mangrove wetlands. The north and south slopes of the channel above the sheet pile would be graded to receive tidal influence and then planted with appropriate mangrove species. Microtopography would be added to diversity habitat. A minimum of approximately 32 feet was considered as the recommended width for mangrove fringe (Fischer and Fischenich 2000). This measure was retained.

5.2.4.4 Non-Structural Management Measures

As an aquatic ecosystem restoration project, there are no non-structural measures for the dredging of the CMP. Non-structural measures related to structure acquisitions and relocations within the public domain boundary (and confines of the Federal project) have been retained and included in the development of alternatives, as well as activities outside of the project that would be conducted by the non-Federal sponsor. Overall the non-structural measures considered and used in the development of alternatives included:

- Structure acquisition and relocation
- Increased enforcement of illegal dumping
- Community education

Structure acquisition and relocation was retained as a measure that would be considered in all action alternatives under the Federal project. There are a substantial number of residential buildings that have been constructed within the Project Area (within the Public Domain limit), including within the actual footprint of the pre-existing channel, and acquisition and demolition of these structures would be necessary for any restoration of tidal flow, and the families would need to be relocated. Notwithstanding the need to remove the structures because they are within the Public Domain limit, the removal of these structures would help reduce the potential for the deposition of solid waste and sewage discharges into the CMP.

Additionally, ENLACE has an extensive community education program that focuses on explaining the benefits of restoration to the CMP, and preventing future harm to the watershed. Along with ENLACE, the community has also banded together to erect barriers to prevent illegal dumping. These areas are patrolled by the residents to ensure that future dumping and degradation of the CMP does not occur. The USACE does not have authority to implement and/or cannot enforce these two measures; however, they would be necessary in conjunction with any alternative that is selected.

5.2.4.5 Elements other than Management Measures

Elements other than management measures described here include dredged material disposal options and erosion control features.

5.2.4.5.1 Dredged Material Disposal

Five categories of dredged material disposal options were considered: CAD, Landfill Disposal, Permanent Upland Disposal (PUD), Ocean Disposal, and Onsite Disposal. Beneficial Use of Dredge Material was considered as a management measure and eliminated earlier in this section. All the disposal options are dependent on dredging of the existing CMP channel. Table 7 displays the different Dredged Disposal Management Options and reasons for elimination. Disposal options were eliminated for a number of reasons, including:

- Insufficient capacity at the site;
- Extent of sediment and solid waste mixing;
- Engineering/infrastructure considerations such as proximity next to flowing water or insufficient roadways;
- Impacts to adjacent communities by noise or air pollution or by undiluted containment of solid waste;
- Elimination of subaqueous, benthic habitat within the estuarine system; and,
- Exposure to wind and wave action that could cause failure of containment.

Table 7. Summary of Elimination of Dredged Disposal Options

Dredged Material Disposal Options	Reason for Elimination					
	Insufficient capacity	Extent of Sediment and Solid Waste Mixing	Engineering/ infrastructure considerations	Impacts to adjacent communities	Elimination of benthic habitat	Exposure to current or wind and wave action
Suarez Canal CAD (sediment and small pieces of debris)	X		X			X
Los Corozos Lagoon CAD pit disposal (sediment and small pieces of debris)	X			X		
Lagoon level bottom capping/containment (sediment and small pieces of debris)					X	X
San José Lagoon CAD with geotextile containment (sediment and small pieces of debris)						
Landfill disposal (sediment and solid waste)			X	X		
Landfill disposal (solid waste only)						
Permanent Upland Disposal (sediment and small pieces of debris)						
Ocean disposal (sediment only)		X				
Onsite Disposal	X		X	X		
Non-Structural	Refer to text for discussion					

5.2.4.5.1.1 Contained Aquatic Disposal

Contained aquatic disposal refers to the placement of dredged sediments within the aquatic environment, then capping of the material with clean sand. Based upon a CAD analysis performed by the USACE ERDC in 2002 for the CMP-ERP, sand is the recommended sediment to be used as the capping material. Capping would involve the placement of the dredged sediments and capping them with a 2-foot sand layer to contain the migration of any potential contaminants. The overall performance objective for a CAD alternative is to control direct exposure of benthic organisms to potentially contaminated sediments such that toxicity or unacceptable levels of bioaccumulation do not occur. To meet this objective, a cap must be placed on the dredged materials at a thickness designed to isolate potentially contaminated materials from the water column and benthic environment, and to be maintained over the long term. Furthermore, the materials should be placed in the CAD site in a manner such that water column impacts from potential contaminant losses during placement are acceptable, and the loss of dredged material from the site is minimal.

The Suarez Canal location is an indention along the waterway that could possibly be backfilled to align with the rest of the shoreline. It was eliminated due to insufficient capacity for sediment at the location, and the fact that it would require containment of the material behind a sheet pile bulkhead that would be exposed to currents and possible wave action during storms and tropical events. The Los Corozos location, an anoxic borrow area in the bottom of the lagoon, was eliminated as there is insufficient capacity within the pits at the location, and also because the pits are immediately adjacent to the shoreline, which would likely interfere with the adjacent communities, docks and navigation, and other shoreline activities. Lagoon level placement would be established on existing benthic habitat rather than placement in anoxic borrow areas as in other options. This option would impact an area of rare island habitat, and other options could be utilized to avoid these detrimental effects. As a result, lagoon level placement was eliminated from consideration.

The San José Lagoon pits disposal option could occur within 5 existing artificial, subaqueous anoxic pits in the bottom of the lagoon. They include (Figure 9):

- San José Lagoon 1 – Maximum depth at this site is -27 feet MSL with a surface area of 897,190 ft^2. In order to minimize environmental impacts, the fill depth of the site would be limited to -16 feet MSL, resulting in a total available capacity of 260,516 cubic yards.

- San José Lagoon 2 – Maximum depth at this site is -27 feet MSL with a surface area of 956,000 ft^2. In order to minimize environmental impacts, the fill depth of the site would be limited to -16 feet MSL, resulting in a total available capacity of 245,450 cubic yards.

- San José Lagoon 3/4/5 – Maximum depth at this site is -24 feet MSL with a surface area of 1,591,070 ft^2. In order to minimize environmental impacts, the fill depth of the site would be limited to -16 feet MSL, resulting in a total available capacity of 275,373 cubic yards.

There is sufficient capacity, and impacts to habitat would be extremely low. These areas would be protected from most wave action, and impacts to existing communities would be lower than the Los Corozos option. As such, the San José Lagoon option was retained. Monitoring and possibly adaptive management techniques would likely be necessary to avoid any water quality impacts from CAD due to the possible concentrated levels of any contaminants in dredged sediment.

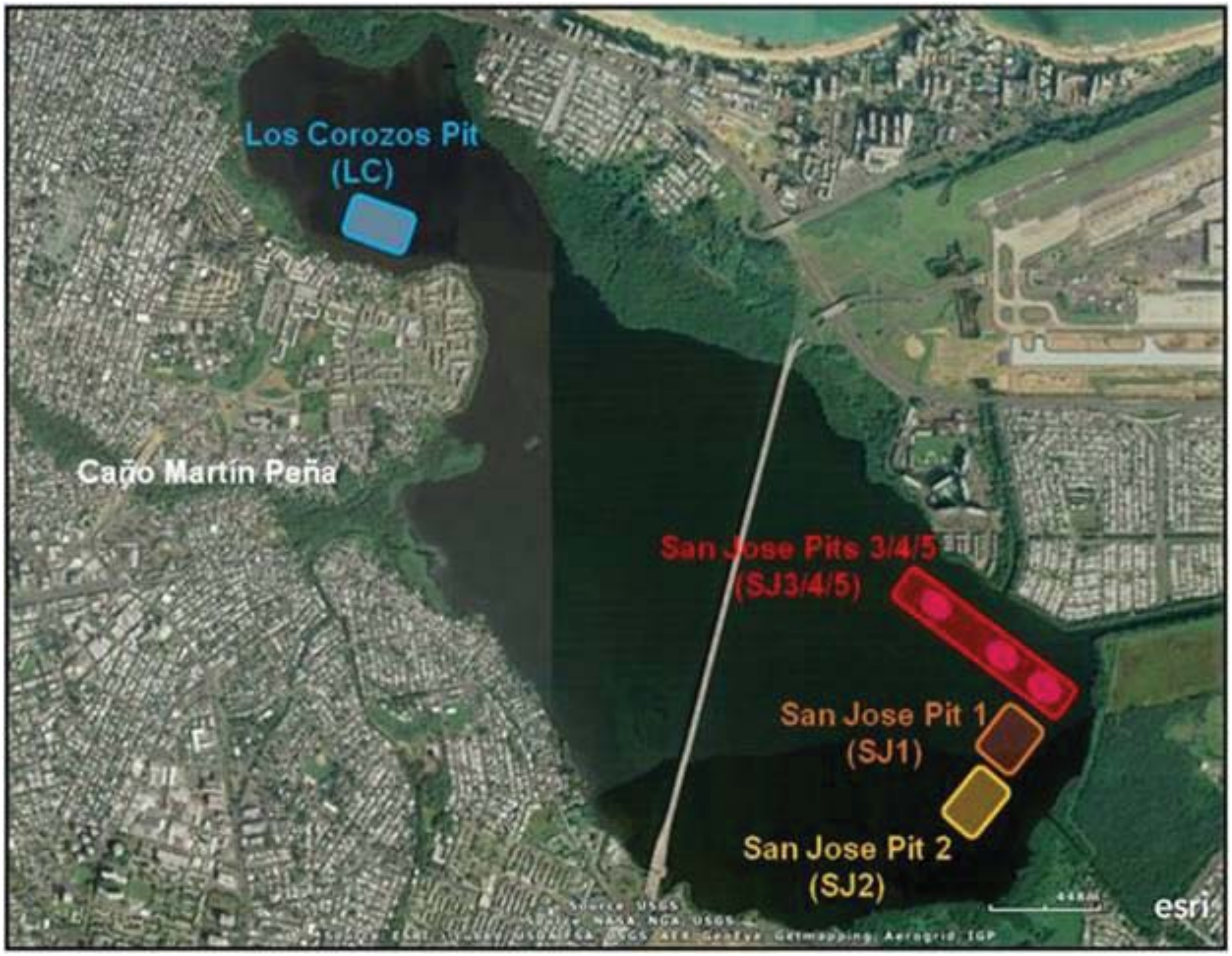

Figure 9. Artificial Pit Locations – San José & Los Corozos Lagoons

5.2.4.5.1.2 Landfill Disposal

Landfill disposal was evaluated for both dredged sediment and solid waste, and also for solid waste only. Analysis indicated that the entire volume of sediment and solid waste together is too great to be considered for existing landfills within the San Juan area, as the capacity is not available. As Puerto Rico is an island, there is an extremely limited area for landfill disposal. While there is capacity at existing landfills elsewhere on the island, the distance between the project site and these landfills (as much as 70 miles) is great enough that the disposal of both sediment and solid waste is not feasible. Additionally, the infrastructure (roads) adjacent to the CMP cannot accommodate large dump trucks. All material would need to be pumped or barged to a staging area, and then trucked to the disposal site, leading to immense cost increases. Noise, traffic, and air quality impacts would be expected due to the large number of trucks that would be constantly traveling to and from the site. Landfill disposal for both sediment and solid waste was subsequently eliminated.

Landfill disposal for solid waste only would require a much smaller capacity that is available at current landfills in the San Juan area. The material would need to be transported to a staging area and trucked to the landfill. There would be some noise and air concerns with the dump truck traffic, but levels (and duration of impacts) would be more acceptable than those associated with disposal of both sediment and solid waste. As such, landfill disposal for solid waste only was retained as an option, but would need to be combined with a sediment disposal option to be viable.

5.2.4.5.1.3 Permanent Upland Disposal

This option would be similar to landfill disposal, but would rely on acquiring and constructing a new area for single use upland disposal, essentially a new private landfill. Any PUD would need to be located within 10-miles of San Juan (and the project site). Similar to landfill disposal, PUD would impact infrastructure and create noise, traffic, and air quality impacts. Several potential sites have been identified with sufficient acreage and configurations to accommodate the volume of dredged material from the project. Permanent Upland Disposal was retained as an option.

5.2.4.5.1.4 Ocean Disposal

Ocean disposal would occur at a currently EPA-approved ODMDS located approximately 1.6 miles from the mouth of San Juan Bay. Section 103 testing would need to be completed and approved for use of the site consistent with the EPA/USACE *Evaluation of Dredged Material Proposed for Ocean Disposal, Testing Manual* as amended (otherwise known as the "Green Book"). Preliminary testing of the sediment has indicated ocean disposal could be a viable option; however, after coordination with the USEPA on the issue of ocean disposal of sediments for the CMP-ERP, it was determined that sediment mixed with small pieces of solid waste/debris would not be suitable for ocean disposal. After analysis of the existing geotechnical information associated with the dredged material from the CMP-ERP, a conservative apportionment was determined such that, for planning purposes, fifty-five percent of the dredged material would be pure sediment, while 45 percent would be a mixture of sediment and solid waste. At such a ratio, the effort to transport the sediment/solid waste mixture to an approved landfill coupled with the cost to mobilize for ocean disposal would result in costs well beyond the 902 (b)(1) authorized cost. More importantly, there would be significant problems associated with infrastructure and noise, traffic, and air quality impacts associated with the hauling of dredged material. As a result, ocean disposal of sediment was not retained as an option.

5.2.4.5.1.5 Onsite Disposal

Onsite disposal would consist of placement of dredged material within upland areas outside of the planned channel. Onsite disposal would reduce the amount of onsite mangrove restoration that could occur, and would also have impacts to recreation opportunities in the area by eliminating available lands. This option could also require additional acquisition and demolition of structures, as well as more relocations if impacts to recreation were to be avoided. Sediment would likely be stockpiled high on the banks and capped, leading to aesthetic impacts by creating large berms along each side of the CMP. The local sewer and drainage system would also likely need to be modified to account for the changes in land contours and elevation. As a result of these factors, this option was eliminated.

5.2.4.5.2 Erosion Control Features

Preliminary hydrologic modeling for different channel configurations indicated that if the channel dredging measure was implemented, erosion control features would be necessary to protect the CMP channel from scouring, and to protect existing bridges and shoreline stabilization structures in the western CMP such as sheet piles. Three erosion control features were formulated, evaluated, and retained for these purposes. These erosion control features are all dependent on dredging of the existing CMP channel. First, articulated concrete mats (ACMs) would be required to provide scour protection for any high velocity dredged channel configurations. The soils in the CMP Project Channel are predominantly hard silts and clays at a depth of 10 to 15 feet below the existing bottom, and these soils could be subject to scour at velocities greater than approximately 4.0 feet per second. Table 8 provides within-channel bottom velocities that could be produced by the different channel dimensions. Those indicated in red would require ACM to prevent channel scouring. The other configurations are considered wide enough to slow within-channel velocities to an acceptable rate, and a 100-foot-wide channel would be the most marginal that could be acceptable.

Table 8. Maximum Bottom Velocities
Within the CMP Project Channel

Channel Dimensions (feet wide x feet deep)	CMP Bottom Velocity (ft/s)
(75 x 10)	4.22
(100 x 10)	4.09
(125 x 10)	3.95
(125 x 15)	3.45
(150 x 10)	3.85
(150 x 15)	3.13
(200 x 10)	3.13

Second, riprap would be a necessary feature for protection along any structures such as bridges. Lastly, initial hydrologic analysis for the project determined that a weir would be necessary to slow velocities in the western portion of the CMP above channel dimensions greater than 75 x 10 feet.

Two main project constraints for the proposed project is that the plan should not damage the shoreline and sheet pile structures in the downstream western CMP, and that the foundations of the existing four bridges in the western portion of the Project Channel must be protected. During recent years, three bridges and shoreline stabilization projects have been constructed in the western CMP, and these structures were not designed with a wider, higher velocity CMP channel in mind. Preventing erosion is essential to maintaining a functional project as any effects to the structures in the western CMP could require major construction and cost for repairs in the future, thus impacting funding for general channel maintenance. To evaluate this constraint, western CMP velocities were calculated and evaluated for the potential to damage bridges and sheet pile structures (Table 9). With the exception of the 75-x-10-foot channel, every other channel dimension would be considered unacceptable.

Table 9. Maximum Bottom Velocities within the CMP and the Adjacent Western Channel

Channel Dimensions (feet wide x feet deep)	Western CMP Bottom Velocity (ft/s)
(75 x 10)	2.20
(100 x 10)	2.80
(125 x 10)	3.25
(150 x 10)	3.65
(200 x 10)	4.09

Because a 75-foot-wide by 10-foot-deep channel was the only dimension that resulted in a bottom velocity that was low enough to prevent unacceptable scour in the western CMP, every larger channel dimension that was modeled (e.g., 100-, 125-, 150-, and 200-foot widths) must include a design component to reduce water flow at the western end of the Project Channel consistent with the model output for the 75-x-10-foot channel if they were to be retained as viable, feasible dimensions. The inclusion of a weir (115-foot-wide by 6.5-foot-deep) would enable the larger channels to replicate the cross-sectional area of the smaller 75-x-10-foot channel, and, in turn, maintain the same flow characteristics. With such a weir in place, the potential for unacceptable scour in the western CMP would be resolved while accommodating wider channel widths in the rest of the Project Channel.

In order to protect the structural integrity of the four bridges in the western portion of the Project Channel, it was recommended that channel depths in their vicinity do not extend below 6.5 feet in depth, which is consistent with the weir depth; however, in light of this depth restriction around the bridges, the 75-x-10-foot channel must also include the 115-x-6.5-foot weir. Thus, the inclusion of the weir in the 75-x-10-foot channel is in response to the protection of the existing bridges, not because of the need to reduce water flows to an acceptable bottom velocity in the western CMP, as is the case with the 100, 125, 150, and 200-foot-wide channels.

Although the western and eastern CMP channel segments have different cross-sectional areas and bottom elevations, water flow through a tidal system such as the CMP is, and would continue to be, restricted by the smallest cross-sectional area. More specifically, the water flow characteristics of potential wider channel configurations with the weir would be not significantly different than those associated with that narrower channel configuration of 75 feet.

5.2.5 Formulation of the Initial Array of Alternatives

To create an Initial Array of Alternatives from management measures, appropriate scales for channel dredging were formulated as this would determine the number of alternatives. The following section describes the bracketing analysis that was conducted to create scales of channel widths and depths for inclusion in alternatives.

5.2.5.1 Channel Dimension Bracketing Analysis

Several considerations were identified that limited channel widths to distances between 75 feet and 200 feet, and channel depths to 10 feet. These factors included: geotechnical, hydrodynamics, scour potential, dredging volumes, mangrove restoration, recreation, navigation, and constructability.

5.2.5.1.1 Width

When considering channel widths, hydrodynamics, scour potential, mangrove restoration, recreation, navigation, and constructability were primary factors.

Greater than 200 feet wide – Mangrove restoration is an essential element of the project. The project is being conducted with the confines of the public domain and the area available for restoration is extremely limited. There has been substantial public participation in the project and there is a strong desire to maintain the overall aesthetics of the CMP, which includes wetland areas that were historically present along the canal. Channel designs with smaller widths would allow for more mangrove restoration potential than those designs with greater widths, especially considering the need for a minimum of approximately 32 feet of mangrove fringe on each side of the CMP (Fisher and Fischenich 2000). Additionally, enlarging the CMP to widths greater than 200 feet could create a much wider CMP than has historically existed, and would essentially create an artificial waterway that would not meet the definition of restoration.

Recreation is an important secondary element of the project and is essential to maintain recreational opportunities in the highly urbanized area. Channel designs with smaller widths provide more area for recreational elements than those designs with greater widths. Continued navigational access is essential for public acceptance of the proposed project, and elimination of recreation in the area would be viewed as a secondary project impact. As a result of these factors, channel widths greater than 200 feet were not considered for the proposed project.

Less than 75 feet wide – A restored CMP would provide opportunities for recreational and some commercial navigation, primarily small vessels, travelling between San Juan Bay and San José Lagoon. The waterway should be wide enough for safe two-way passage of vessels while also accommodating the mooring of vessels along possible bulkheads and marginal wharves. Channel footprints at least 75-feet wide would be the minimum necessary to ensure safe navigation through any restored CMP channel.

Constructability is also of concern in determining channel design as two barges would be required to work side-by-side during the operation. These barges would need enough room for maneuverability to pass one another, and wider channel footprints would allow more space for these construction vessels to operate.

As 75 feet was determined to produce unacceptable scouring, channel widths were bracketed at this limit and only alternatives at 75 feet or wider were included. Navigational safety and constructability were also considered factors in maintaining alternative widths at 75 feet or wider.

Another factor in restricting channel widths to those 75 feet or greater is the ability of the area to mimic natural conditions. The CMP was historically 200-400 feet wide, and much smaller dimensions would not reflect prior conditions. During public coordination, members of the community expressed an opinion for the CMP to be restored nearest to historical conditions as possible, making dimensions at least 75 feet wide more acceptable.

Conclusion – As a result of these factors, channel widths greater than 200 feet were eliminated from consideration due to loss of restoration potential and recreational impacts. Widths less than 75 feet were eliminated due to navigational safety, scour potential, constructability, and ability to mimic historic conditions.

5.2.5.1.2 Depth

Geotechnical issues and secondary impacts were primary considerations for channel depths.

Less than 10 feet deep – In regards to geotechnical considerations, the CMP and channel banks contain solid waste from the surface to -10 feet. Thus, channel depths less than 10 feet could leave behind waste in the proposed channel's side slopes and bottom, which could work loose over time and be released into the estuary.

Greater than 10 feet deep – There are portions of the CMP channel, notably near the eastern end adjacent to the San José Lagoon, where limestone can be found at depths of -10.5 feet. In these areas, it is likely that substantial rock removal through blasting and disposal would have to be considered for parts of the channel. As this project site is within a highly urban setting, substantial amounts of blasting would likely violate the constraint of avoiding secondary impacts within the communities adjacent to the CMP. While historic depths within the CMP are unknown, it is believed that depths were not greater than 10 feet based on the presence of limestone rock at -10.5 feet in deth and in light of the fact that solid waste can be found as deep as -10 feet. Increasing depths to 10-15 feet would cause irreversible change to the CMP by the removal of rock, further altering the tributary and creating a much deeper CMP that does not mimic the natural conditions that previously existed.

Conclusion – Water depths were scaled at 10 feet. Depths less than 10 feet would likely leave solid waste to be carried downstream and into other aquatic habitat. Depths greater than 10 feet would likely require blasting, violating a primary project constraint. Also, depths greater than 10 feet would not reflect the natural, historical depths of the CMP.

5.2.5.2 Initial Array of Alternatives

After the bracketing analysis, five combinations of widths and depths were chosen for an Initial Array: 75 x 10 feet, 100 x 10 feet, 125 x 10 feet, 150 x 10 feet, and 200 x 10 feet. The mangrove planting bed measure and all four non-structural measures were combined with each width and depth combination. Erosion control features were also added to each alternative, as appropriate. All measures contain riprap and a weir, and the 75-x-10-foot alternative contains ACM through the Project Channel due to the higher bottom velocities it would create in the Project Channel. Lastly, in order to incorporate the two different disposal options, the number of alternatives was doubled into Series 1-5, and Series 1B-5B. Series 1-5 contains the San José Lagoon pits disposal option, while Series 1B-5B contains the permanent upland disposal option.

5.2.5.2.1 No Action Alternative

Federal planning guidelines require the evaluation of the "No Action" alternative plan. Taking no additional Federal actions would result in the future without-project condition (Section 3) occurring over the planning horizon. The No Action alternative plan provides a basis for comparing the project effects of alternative plans to conditions that can reasonably be expected to occur without constructing the project. As part of the No-Action Alternative, ENLACE would undertake other elements of the CDLUP, but would not continue with the demolition of existing structures within the Public Domain Limit of the CMP Project Area, and the associated relocation of families, unless living conditions required so.

5.2.5.2.2 Alternative Plan 1 – 75-Foot Channel Width, 10-Foot Depth

Alternative Plan 1 includes the following measures: 1) 75-foot-wide, 10-foot-deep rectangular channel with concrete-capped steel sheet pile walls (with variations in channel width and depth at the 4 bridges in the western portion of the Project Channel, the Barbosa Bridge, and terminus of the CMP with the San José Lagoon); 2) trapezoidal channel with 5:1 earthen side slopes exiting from the CMP and extending approximately 4,300 feet into San José Lagoon, 3) disposal of dredged material in the San José Lagoon pits; 4) a weir in the western end of the Project Channel with articulated concrete mat bottom and rip rap protection for the bridges, 5) ACM paving throughout the Project Channel, 6) mangrove planting along the channel margins; and 7) non-structural measures.

5.2.5.2.3 Alternative Plan 2 – 100-Foot Channel Width, 10-Foot Depth

Alternative Plan 2 includes the following measures: 1) 100-foot-wide, 10-foot-deep rectangular channel with an earthen bottom and concrete-capped steel sheet pile walls (with variations in channel width and depth at the 4 bridges in the western portion of the Project Channel, the Barbosa Bridge, and terminus of the CMP with the San José Lagoon); 2) trapezoidal channel with 5:1 earthen side slopes exiting from the CMP and extending approximately 4,300 feet into San José Lagoon; 3) disposal of dredged material in the San José Lagoon pits; 4) erosion control weir in the western end of the Project Area with associated rip rap for bridges and ACM for the channel bottom; 5) mangrove planting along the channel margins; and 6) non-structural measures.

5.2.5.2.4 Alternative Plan 3 – 125 Foot Channel Width, 10-Foot Depth

Alternative Plan 3 includes the following measures: 1) 125-foot-wide, 10-foot-deep rectangular channel with an earthen bottom and concrete-capped steel sheet pile walls (with variations in channel width and depth at the 4 bridges in the western portion of the Project Channel, the Barbosa Bridge, and terminus of the CMP with the San José Lagoon); 2) trapezoidal channel with 5:1 earthen side slopes exiting from the CMP and extending approximately 4,300 feet into San José Lagoon; 3) disposal of dredged material in the San José Lagoon pits; 4) erosion control weir in the western end of the Project Area with associated rip rap for bridges and ACM for the channel bottom; 5) mangrove planting along the channel margins; and 6) non-structural measures.

5.2.5.2.5 Alternative Plan 4 – 150-Foot Channel Width, 10-Foot Depth

Alternative Plan 4 includes the following measures: 1) 150-foot-wide, 10-foot-deep rectangular channel with an earthen bottom and concrete-capped steel sheet pile walls (with variations in channel width and depth at the 4 bridges in the western portion of the Project Channel, the Barbosa Bridge, and terminus of the CMP with the San José Lagoon); 2) trapezoidal channel with 5:1 earthen side slopes exiting from the CMP and extending approximately 4,300 feet into San José Lagoon; 3) disposal of dredged material in the San José Lagoon pits; 4) erosion control weir in the western end of the Project Area with associated rip rap for bridges and ACM for the channel bottom; 5) mangrove planting along the channel margins; and 6) non-structural measures.

5.2.5.2.6 Alternative Plan 5 – 200-Foot Channel Width, 10-Foot Depth

Alternative Plan 5 includes the following measures: 1) 200-foot-wide, 10-foot-deep rectangular channel with an earthen bottom and concrete-capped steel sheet pile walls (with variations in channel width and depth at the 4 bridges in the western portion of the Project Channel, the Barbosa Bridge, and terminus of the CMP with the San José Lagoon); 2) trapezoidal channel with 5:1 earthen side slopes exiting from the CMP and extending approximately 4,300 feet into San José Lagoon; 3) disposal of dredged material in the San José Lagoon pits; 4) erosion control weir in the western end of the Project Area with associated rip rap for bridges and ACM for the channel bottom; 5) mangrove planting along the channel margins; and 6) non-structural measures.

5.2.5.3 B-Series Alternatives

The B-Series of alternatives is identical to the five above, except that disposal of dredged material would occur within a permanent upland disposal site within 10 miles of the project site instead of the San José Lagoon pits.

5.2.6 Screening of Initial Array

5.2.6.1 Screening of Permanent Upland Disposal Alternatives (B-series)

In order to determine an appropriate Final Array, a screening analysis was conducted to determine whether one of the disposal methodologies was preferable for reasons other than cost. A comparison of the Principles and Guidelines (P&G) Criteria indicated that the Permanent Upland Disposal alternatives (1B-5B) were less acceptable than San José Lagoon pits alternatives (1–5). The permanent upland disposal alternatives would result in significant amounts of heavy truck use through the San Juan area and secondary roads and neighborhoods to reach the upland disposal site(s). The impacts to infrastructure as well as associated noise, air quality, and community impacts would be significant and controversial.

Public input, particularly from recreational and commercial fisherman within the San José Lagoon area, has also indicated that there are concerns with lagoon disposal; however, the temporary closure of the San José Lagoon pits is considered more acceptable than sustained trucking impacts to a broad group of residents and businesses along the hauling routes to the permanent upland disposal site(s). As a result, it was determined that San José Lagoon was more acceptable than permanent upland disposal. There are no significant differences between San José Lagoon and permanent upland disposal in regards to meeting the objectives and constraints, the P&G four accounts (see Section 5.4.2 for more information), or any other factors that could be considered. Therefore, alternatives 1B, 2B, 3B, 4B, and 5B were screened as these plans, based on the P&G Criteria of acceptability, would not have been selected as a Tentatively Selected Plan (TSP).

5.2.6.2 Screening of Larger Channel Alternatives

Benefits for the CMP-ERP are directly related to water flow, which controls differences in residence time and tidal range. With respect to benefits derived from the various channel alternatives, there is a significant benefit to the San José Lagoon (based on the benthic index score) once the CMP channel is widened to 75 feet due to tidal amplitude, or volume of water flowing into and out of the lagoon. Increasing channel widths to 100, 125, 150, and 200 feet would progressively result in additional, albeit marginal, benefits as a result of the increased water flows and reduced water residence times (Table 10). The model could only run in increments of 3 feet, hence the differences between descriptions of model runs as they relate to alternatives (9 feet) versus tables that identify alternatives being considered in the feasibility report (10 feet). Velocities in 10-foot-deep channels would be slightly higher than the modeled 9-foot-deep channels.

Table 10. Channel Configuration Comparisons

	Channel Configuration (depth by width)						
	3 by 33*	9 by 75	9 by 100	9 by 125	9 by 150	9 by 175	9 by 200
Area (ft^2)	99	675	900	1,125	1,350	1,575	1,800
Hydraulic Conveyance	184.2	2,530.4	3,487.2	4,450.0	5,416.1	6,384.0	7,353.3
Residence Time (days)	16.90	3.86	3.23	2.87	2.66	2.49	2.38
Benthic Index Score	1.33	2.84	2.90	----	2.96	----	2.98
Max. Bot. V-CMP-East (ft/s)	1.25	4.22	**4.09	**3.95	3.85	3.52	3.13
Max. Bot. V-CMP-West(ft/s)	0.74	**2.20	2.80	3.25	3.65	3.89	4.09
Tide Range (feet)	0.33	1.36	1.61	1.75	1.85	1.96	2.05

* [note to be provided]

** [note to be provided]

If these benefits were used for project justification, it is likely that Alternative 5, at 200 x 10 feet, would be selected as a cost effective plan and best buy; however, once a weir is included in channel alternatives, water flow is restricted for all alternatives in the Initial Array to the level identified for the 75-x-10-foot channel. This results from the fact that water flow in the CMP is tidal and peaks every 12 hours before reversing direction. As a result, large accumulations of flow or head beyond the channel restriction or weir do not occur. This is different than flow in a riverine system not influenced by tides, as water flow would normally be traveling in one direction and the restricting channel would raise the head upstream from a channel constriction, thereby raising water flow. As a result, the flow and thus benefits resulting from larger alternatives with a weir is essentially identical to the flow and benefits identified for the 75-x-10-foot alternative, and larger, costlier alternatives would not be cost effective as they would produce the same benefits as smaller, cheaper alternatives.

Additionally, alternatives with smaller channel configurations would not require as many difficult Real Estate actions as larger alternatives. Once the project footprint becomes larger than that presented for Alternative 3 (125-x-10-foot channel), additional acquisitions and relocations become necessary, and the ability to meet the recommended minimum for mangrove fringe (~32 feet) is not feasible. As a result of the larger channel alternative screening analysis, Alternatives 4 and 5 were eliminated from consideration. None of these alternatives would be cost effective if a Cost Effectiveness/Incremental Cost Analysis was conducted, and they would be difficult to implement due to public acceptability and feasibility related to mangrove restoration minimums. Alternatives 1, 2, and 3 were retained to carry forward into a Final Array.

5.2.6.3 Further Bracketing of Alternatives

As there would only be three alternatives within the Final Array (excluding the No-Action), concerns were raised that additional alternatives could have been established to provide an even more comprehensive comparison. In regards to possible alternatives with channel dimensions between 100 and 125 feet wide, these alternatives would have the same benefits due to the weir restrictions, and cost would increase as channel width increases. As a result, nothing would be gained by adding another plan, as the 125-x-10-foot alternative successfully brackets a high end cost alternative that would not have better performance.

Alternative 2, with channel dimensions of 125 x 10 feet, is considered to be the largest channel configuration that would not cause detrimental within-channel scouring. Although numerous alternatives could have been formulated with channel dimension sizes between Alternatives 1 and 2, all of these plans would have required concrete matting to prevent erosion in the Project Channel, would cost more than Alternative 2, and would produce the same benefits as Alternative 2. No new information would be gained from including these additional plans in the analysis.

5.2.7 Final Array of Alternative Plans

The Final Array of Alternative Plans consisted of the No-Action Plan and Alternatives 1, 2, and 3. The following sections provide a more thorough description of each alternative plan, and are followed by plan evaluation, comparison, and selection.

5.2.7.1 No Action Alternative Plan

No further Federal actions will be implemented under the No Action Alternative.

5.2.7.2 Alternative Plan 1 – 75-Foot Channel Width, 10-Foot Depth

Total construction time for Alternative Plan 1 is approximately 27 months, including mobilization, site preparation, construction, and demobilization.

Channel

Alternative Plan 1 consists of dredging approximately 2.2 miles of the eastern end of the CMP to a width of 75 feet and a depth of 10 feet (Figure 10), with slight variations in channel width and depth at the four bridges in the western portion of the Project Channel, the Barbosa Bridge, and terminus of the Project Channel with the San José Lagoon. The walls of the Project Channel would be constructed with vertical concrete-capped steel sheet piles with hydrologic connections to the surrounding lands. The sill depth of the window would be set at mean low water so that tidal exchanges are facilitated to the mangrove beds.

At the terminus of the Project Channel with the San José Lagoon, an extended channel would be dredged east into the San José Lagoon (over a distance of approximately 4,300 feet) as a hydraulic transition from the CMP. This extended channel would transition from the 10-foot-deep Project Channel to the 6-foot-deep areas of San José Lagoon. The extended channel would maintain the Project Channel’s 100-foot width but replace its steel sheet pile walls with a trapezoidal configuration with 5-foot to 1-foot earthen side slopes.

A barge-mounted mechanical clamshell dredge would be used to widen and deepen the CMP, and would place dredged material into dump scows. Of the 680,000 cy of mixed materials, screens would separate solid waste debris (estimated at 68,000 cy) from sediments. It is estimated that the dredged debris would make up 10 percent of the total material to be dredged from the CMP, and the dredged sediments would bulk up to 126 percent of their in situ volume. Solid waste debris would be transported by shallow-draft barge to a staging area for subsequent landfill disposal. A majority of the sediments would be transported by barge for aquatic disposal, while some sediment would be used to complete the sheet pile construction and mangrove bed restoration.

A weir would be constructed at the western end of the project area to protect the structural integrity of the existing four bridges in the western portion of the Project Channel. The dimensions of the weir (115 x 6.5 feet) would replicate the cross sectional area of the rest of the channel configuration (75 x 10 feet), which would prevent scour around bridges, bulkheads, and other marine structures west of the project area by providing a transition area to reduce unacceptable bottom velocities between the project area and the adjacent channels. The weir would be constructed with an articulated concrete bottom.

Erosion Control

Articulated concrete mats would be placed along the entire length of the dredged channel bottom to mitigate for high channel velocities that would occur in the Project Channel. This feature is expected to prevent scour along the bottom of the channel, which may threaten the stability of the sheet pile walls and increase sedimentation. Rip rap would be placed at the four western bridges and adjacent slopes, and at the Barbosa Bridge.

Disposal

Materials within the Caño Martín Peña include various types of solid waste, debris, and other materials. Such materials will require further testing prior to and/or during project construction, as appropriate, in accordance with an agreed sampling plan. If the testing determines that any materials contain hazardous substances at levels that are not suitable for unregulated disposal, they will be managed in accordance with the applicable laws and regulations of the relevant regulatory agencies. Solid waste and debris would be transported from the CDRC staging area to the Humacao landfill site, which is located approximately 32 miles from the CMP-ERP site. A total of 6 acres are included within the project footprint of the CDRC staging area on the southeast shore of San José Lagoon. Of these 6 acres, five acres are upland habitat and 1 acre is mangrove fringe. The staging area includes a dock for loading/unloading the dredged material to be transported to the landfill. The five upland acres are within a previously disturbed 35-acre parcel. After all solid waste has been disposed in the upland landfill, the 5-acre staging area would be restored with native upland vegetation, and the 1 acre of mangrove fringe would be restored with mangroves.

After screening and removal of solid waste debris, the remaining sediment and smaller pieces of solid waste would be encapsulated within geotextile fabric bags, and transported by shallow draft barges to the San José Lagoon artificial subaqueous pits. Sediments would be placed utilizing CAD in the SJ1 and SJ2 pits. Prior to disposal operations, both of these sites would be modified to increase capacity to accommodate the majority of dredged sediments and the required 2-foot sand cap. Approximately 517,581 cy of material would be removed from SJ1 and SJ2 and deposited within the San José 3/4/5 artificial subaqueous pits. During the CMP-ERP disposal operations, approximately 574,200 cy of in situ sediments would be placed in the SJ 1 and SJ2; however, additional water quality and sediment testing, such as bioassays, would be conducted prior to placement to ensure their suitability for disposal. Approximately 37,800 cy of in-situ sediments would be used to complete the sheet pile construction and mangrove bed restoration.

The SJ1 and SJ2 CAD sites would be capped with a 2-foot layer of sand. Material for the sand cap will be quarried from upland quarry sites and transported by trucks to the construction staging area for transfer to dump scows for placement. Silt curtains would also be employed around the CAD pits in the San José Lagoon. In critical areas, the curtains may double ring the active area for additional precautions. The curtains would be constructed to the full depth of the water where they are placed.

For activities related to the installation of the weir in the western end of the Project Channel, an upland staging area near the four western bridges would be used to temporarily stockpile and transfer the collected solid waste excavated during the dredging process. Equipment and materials would be staged on floating barges. After the construction of the weir, and once the dredging from the eastern portion of the Project Channel opened the CMP, the temporary coffer dam would be removed, and the stockpiled solid waste would be placed into shallow-draft barges for transport to the CDRC staging area. At the CDRC staging area, the material would be off-loaded, placed into trucks, and hauled for disposal at the Humacao upland landfill.

Mangrove Restoration

Approximately 34.46 acres of wetlands would be disturbed for construction activities, including 33.46 acres within the Project Channel and 1 acre at the CDRC staging area. Restoration of the disturbed mangrove fringe would be accomplished by grading the site to between 0 foot MLLW and 2 feet above MLLW, and planting with native vegetation. The width of the planting beds would vary depending upon the land availability, but in general would extend from the channel wall to the limit of the MTZ-CMP, excluding only areas set aside for recreation elements. Four species of mangrove would be considered for use in the mangrove planting beds depending on micro topography and the associated levels of tidal inundation, period, and salinity. After dredging and construction of mangrove planting beds, the CMP would consist of 20.42 acres of open water and 39.62 acres of mangrove wetland.

Non-Structural Measures

In addition to the 98 structure acquisitions and 55 relocations already completed as part of the Federal project, the plan would include the acquisition and removal of an additional 336 residential structures, along with relocation of affected families. Enforcement of illegal dumping regulations, stormwater and sewage improvements, and community education would be implemented by the non-Federal sponsor outside of the Federal project. Relocation of the Borinquen Water Transmission Line, the Rexach Trunk Sewer, and the 115-kV overhead transmission line would also be components of the CMP-ERP.

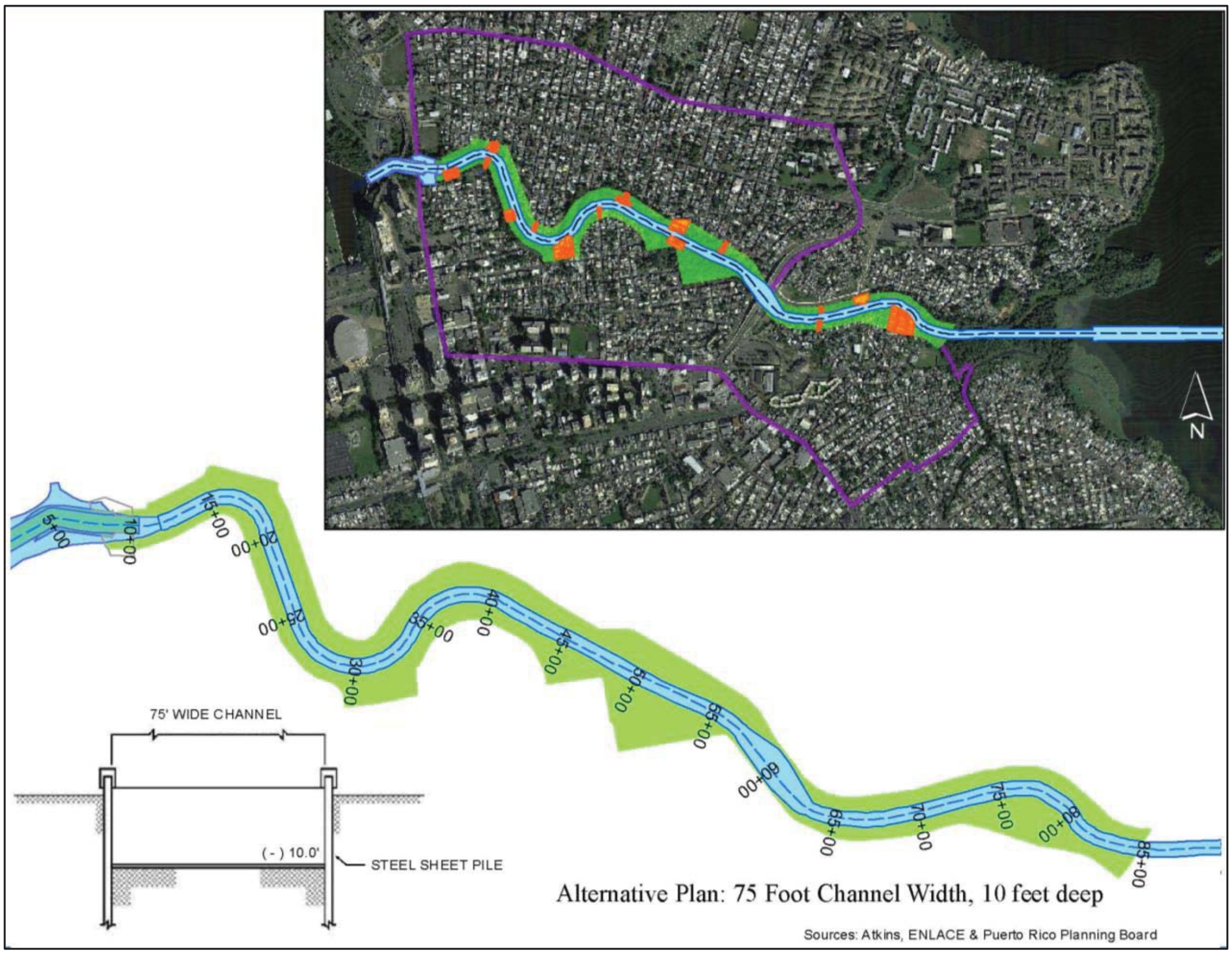

Figure 10. Alternative Plan 1 – 75-Foot Channel Width, 10-Foot Depth

5.2.7.3 Alternative Plan 2 – 100-Foot Channel Width, 10-Foot Depth

Total construction time for Alternative Plan 2 is approximately 27 months, including mobilization, site preparation, construction, and demobilization.

Channel

Alternative Plan 2 consists of dredging approximately 2.2 miles of the eastern end of the CMP to a width of 100 feet and a depth of 10 feet (Figure 11), with slight variations in channel width and depth at the 4 bridges in the western portion of the Project Channel, the Barbosa Bridge, and terminus of the CMP with the San José Lagoon. The walls of the Project Channel would be constructed with vertical concrete-capped steel sheet piles with hydrologic connections to the surrounding lands. The sill depth of the window would be set at mean low water so that tidal exchanges are facilitated to the mangrove beds.

At the terminus of the Project Channel with the San José Lagoon, an extended channel would be dredged east into the San José Lagoon (over a distance of approximately 4,300 ft) as a hydraulic transition from the CMP. This extended channel would transition from the 10-foot-deep Project Channel to the 6-foot-deep areas of San José Lagoon. The extended channel would maintain the Project Channel's 100-foot width but replace its steel sheet pile walls with a trapezoidal configuration with 5-foot to 1-foot earthen side slopes.

Figure 11. Alternative Plan 2 – 100-Foot Channel Width, 10-Foot Depth

A barge-mounted mechanical clamshell dredge would be used to widen and deepen the CMP channel, and would place dredged material into dump scows. Of the 762,000 cy of mixed materials, screens would separate solid waste debris (estimated at 76,200 cy) from sediments. It is estimated that the dredged solid waste debris would make up 10 percent of the total material to be dredged from the CMP, and the dredged sediments would bulk up to 126 percent of their in situ volume. Solid waste debris would be transported by barge to a staging area for subsequent landfill disposal. Sediments would be transported by shallow-draft barge for aquatic disposal.

Erosion Control

A weir would be constructed at the western end of the project area to mitigate water flows into the adjacent waterways, in addition to the need to protect the structural integrity of the four bridges in the western portion of the Project Channel. The dimensions of the weir (115 x 6.5 feet) would replicate the cross sectional area of Alternative 1 (75 x 10 feet), and would prevent scour around bridges, bulkheads, and other marine structures west of the project area by providing a transition area to reduce unacceptable bottom velocities between the project area and the adjacent channels. The weir would be constructed with an articulated concrete bottom, while the remainder of the project channel would be earthen bottom. Rip rap would be placed at the four western bridges and adjacent slopes, and at the Barbosa Bridge.

Disposal

Materials within the Caño Martín Peña include various types of solid waste, debris, and other materials. Such materials will require further testing prior to and/or during project construction, as appropriate, in accordance with an agreed sampling plan. If the testing determines that any materials contain hazardous substances at levels that are not suitable for unregulated disposal, they will be managed in accordance with the applicable laws and regulations of the relevant regulatory agencies. Solid waste debris would be transported from the CDRC staging area to the Humacao landfill site, which is located approximately 32 miles from the CMP-ERP site. A total of 6 acres are included within the project footprint of the CDRC staging area on the southeast shore of San José Lagoon. Of these 6 acres, five acres are upland habitat and 1 acre is mangrove fringe. The staging area includes a dock for loading/unloading the dredged material to be transported to the landfill. The five upland acres are within a previously disturbed 35-acre parcel. After all solid waste has been disposed in the upland landfill, the 5-acre staging area would be restored with native upland vegetation, and the 1 acre of mangrove fringe would be restored with mangroves.

After screening and removal of solid waste debris, the remaining sediment and smaller pieces of solid waste would be encapsulated within geotextile fabric bags, and transported by shallow draft barges to the San José Lagoon artificial subaqueous pits. Sediments would be placed utilizing CAD in the SJ1 and SJ2 pits. Prior to disposal operations, both of these sites would be modified to increase capacity to accommodate the majority of dredged sediments and the required 2-foot sand cap. Approximately

517,581 cy of material would be removed from SJ1 and SJ2 and deposited within the San José 3/4/5 artificial subaqueous pits. During the CMP-ERP disposal operations, approximately 648,000 cy of in situ sediments would be placed in the SJ 1 and SJ2; however, additional water quality and sediment testing, such as bioassays, would be conducted prior to placement to ensure their suitability for disposal. Approximately 37,800 cy of in-situ sediments would be used to complete the sheet pile construction and mangrove bed restoration.

The SJ1 and SJ2 CAD sites would be capped with a 2-foot layer of sand. Material for the sand cap will be quarried from upland quarry sites and transported by trucks to the construction staging area for transfer to dump scows for placement. Silt curtains would also be employed around the CAD pits in the San José Lagoon. In critical areas, the curtains may double ring the active area for additional precautions. The curtains would be constructed to the full depth of the water where they are placed.

For activities related to the installation of the weir in the western end of the Project Channel, an upland staging area near the four western bridges would be used to temporarily stockpile and transfer the collected solid waste excavated during the dredging process. Equipment and materials would be staged on floating barges. After the construction of the weir, and once the dredging from the eastern portion of the Project Channel opened the CMP, the temporary coffer dam would be removed, and the stockpiled solid waste would be placed into shallow-draft barges for transport to the CDRC staging area. At the CDRC staging area, the material would be off-loaded, placed into trucks, and hauled for disposal at the Humacao upland landfill.

Mangrove Restoration

Approximately 34.46 acres of wetlands would be disturbed for construction activities, including 33.46 acres within the Project Channel and 1 acre at the CDRC staging area. Restoration of the disturbed mangrove fringe would be accomplished by grading the site to between 0 foot MLLW and 2 feet above MLLW, and planting with native vegetation. The width of the planting beds would vary depending upon the land availability, but in general would extend from the channel wall to the line of public domain, excluding only areas set aside for recreation elements. The minimum width for mangrove fringes would be approximately 32 feet on either side of the CMP. Four species of mangrove would be considered for use in the mangrove planting beds depending on micro topography and the associated levels of tidal inundation, period, and salinity. After dredging and construction of mangrove planting beds, the Project Channel would consist of 25.57 acres of open water and 34.48 acres of mangrove wetland.

Non-Structural Measures

In addition to the 98 structure acquisitions and 55 relocations already completed as part of the Federal project, the plan would include the acquisition and removal of an additional 336 residential structures, along with relocation of affected families. Enforcement of illegal dumping, stormwater and sewage improvements, and community education would be implemented by the non-Federal sponsor outside of the Federal project. Relocation of the Borinquen Water Transmission Line, the Rexach Trunk Sewer, and the 115-kV overhead transmission line would also be components of the CMP-ERP.

5.2.7.4 Alternative Plan 3 – 125-Foot Channel Width, 10-Foot Depth

Total construction time for Alternative Plan 1 is approximately 27 months, including mobilization, site preparation, construction, and demobilization.

Channel

Alternative Plan 3 consists of dredging approximately 2.2 miles of the eastern end of the CMP to a width of 125 feet and a depth of 10 feet (Figure 12), with slight variations in channel width and depth at the four bridges in the western portion of the Project Channel, the Barbosa Bridge, and terminus of the Project Channel with the San José Lagoon. The walls of the Project Channel would be constructed with vertical concrete-capped steel sheet piles with hydrologic connections to the surrounding lands. The sill depth of the window would be set at mean low water so that tidal exchanges are facilitated to the mangrove beds.

At the terminus of the Project Channel with the San José Lagoon, an extended channel would be dredged east into the San José Lagoon (over a distance of approximately 4,300 ft) as a hydraulic transition from the CMP. This extended channel would transition from the 10-foot-deep Project Channel to the 6-foot-deep areas of San José Lagoon. The extended channel would maintain the Project Channel's 100-foot width but replace its steel sheet pile walls with a trapezoidal configuration with 5-foot to 1-foot earthen side slopes.

A barge-mounted mechanical clamshell dredge would be used to widen and deepen the CMP, and would place dredged material into dump scows. Of the 872,000 cy of mixed materials, screens would separate solid waste debris (estimated at 87,200 cy) from sediments. It is estimated that the dredged solid waste debris would make up 10 percent of the total material to be dredged from the CMP, and the dredged sediments would bulk up to 126 percent of their in situ volume. Solid waste debris would be transported by barge to a staging area for subsequent landfill disposal. Sediments would be transported by shallow-draft barge for aquatic disposal.

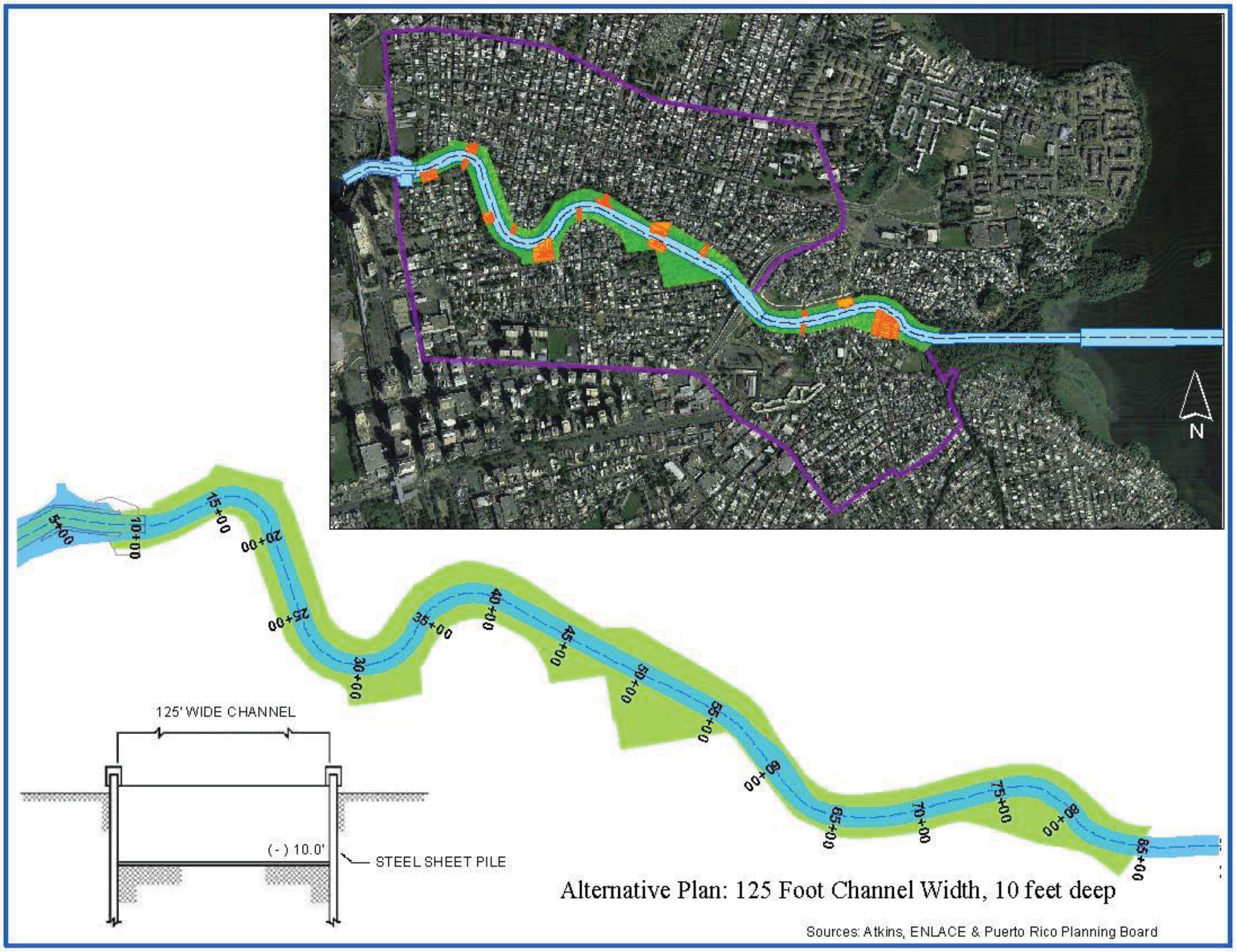

Figure 12. Alternative Plan 3 – 125-Foot Channel Width, 10-Foot Depth

Erosion Control

A weir would be constructed at the western end of the project area to mitigate water flows into the adjacent waterways, in addition to the need to protect the structural integrity of the four bridges in the western portion of the Project Channel. The dimensions of the weir (115 x 6.5 feet) would replicate the cross sectional area of Alternative 1 (75 x 10 feet), and would prevent scour around bridges, bulkheads, and other marine structures west of the project area by providing a transition area to reduce unacceptable bottom velocities between the project area and the adjacent channels. The weir would be constructed with an articulated concrete bottom, while the remainder of the project channel would be earthen bottom. Rip rap would be placed at the four western bridges and adjacent slopes, and at the Barbosa Bridge.

Disposal

Materials within the Caño Martín Peña include various types of solid waste, debris, and other materials. Such materials will require further testing prior to and/or during project construction, as appropriate, in accordance with an agreed sampling plan. If the testing determines that any materials contain hazardous substances at levels that are not suitable for unregulated disposal, they will be managed in accordance with the applicable laws and regulations of the relevant regulatory agencies. Solid waste debris would be transported from the CDRC staging area to the Humacao landfill site, which is located approximately 32 miles from the CMP-ERP site. A total of 6 acres are included within the project footprint of the CDRC staging area on the southeast shore of San José Lagoon. Of these 6 acres, five acres are upland habitat and 1 acre is mangrove fringe. The staging area includes a dock for loading/unloading the dredged material to be transported to the landfill. The five upland acres are within a previously disturbed 35-acre parcel. After all solid waste has been disposed in the upland landfill, the 5-acre staging area would be restored with native upland vegetation, and the 1 acre of mangrove fringe would be restored with mangroves.

After screening and removal of solid waste debris, the remaining sediment and smaller pieces of solid waste would be encapsulated within geotextile fabric bags, and transported by shallow draft barges to the San José Lagoon artificial subaqueous pits. Sediments would be placed utilizing CAD in the SJ1 and SJ2 pits. Prior to disposal operations, both of these sites would be modified to increase capacity to accommodate the majority of dredged sediments and the required 2-foot sand cap. Approximately 517,581 cy of material would be removed from SJ1 and SJ2 and deposited within the San José 3/4/5 artificial subaqueous pits. During the CMP-ERP disposal operations, approximately 747,000 cy of in situ sediments would be placed in the SJ 1 and SJ2; however, additional water quality and sediment testing, such as bioassays, would be conducted prior to placement to ensure their suitability for disposal. Approximately 37,800 cy of in-situ sediments would be used to complete the sheet pile construction and mangrove bed restoration.

The SJ1 and SJ2 CAD sites would be capped with a 2-foot layer of sand. Material for the sand cap will be quarried from upland quarry sites and transported by trucks to the construction staging area for transfer to dump scows for placement. Silt curtains would also be employed around the CAD pits in the San José Lagoon. In critical areas, the curtains may double ring the active area for additional precautions. The curtains would be constructed to the full depth of the water where they are placed.

For activities related to the installation of the weir in the western end of the Project Channel, an upland staging area near the four western bridges would be used to temporarily stockpile and transfer the collected solid waste excavated during the dredging process. Equipment and materials would be staged on floating barges. After the construction of the weir, and once the dredging from the eastern portion of the Project Channel opened the CMP, the temporary coffer dam would be removed, and the stockpiled solid waste would be placed into shallow-draft barges for transport to the CDRC staging area. At the CDRC staging area, the material would be off-loaded, placed into trucks, and hauled for disposal at the Humacao upland landfill.

Mangrove Restoration

Approximately 34.46 acres of wetlands would be disturbed for construction activities, including 33.46 acres within the CMP and 1 acre at the construction staging area. Restoration of the disturbed mangrove fringe would be accomplished by grading the site to between 0 foot MLLW and 2 feet above MLLW, and planting with native vegetation. The width of the planting beds would vary depending upon the land availability, but in general would extend from the channel wall to the limit of the MTZ-CMP, excluding only areas set aside for recreation elements. The minimum width for mangrove fringes would be approximately 32 feet on either side of the CMP. Four species of mangrove would be considered for use in the mangrove planting beds depending on micro topography and the associated levels of tidal inundation, period, and salinity. After dredging and construction of mangrove planting beds, the CMP would consist of 30.97 acres of open water and 29.08 acres of mangrove wetland.

Non-Structural Measures

In addition to the 98 structure acquisitions and 55 relocations already completed as part of the Federal project, the plan would include the acquisition and removal of an additional 336 residential structures, along with relocation of affected families. Enforcement of illegal dumping, stormwater and sewage improvements, and community education would be implemented by the non-Federal sponsor outside of the Federal project. Relocation of the Borinquen Water Transmission Line, the Rexach Trunk Sewer, and the 115-kV overhead transmission line would also be components of the CMP-ERP.

5.3 EVALUATION OF FINAL ARRAY OF ALTERNATIVE PLANS

5.3.1 Benefit Evaluation

5.3.1.1 Federal Objective

Ecosystem restoration is one of the primary missions of the USACE Civil Works program. The USACE objective in ecosystem restoration planning is to contribute to national ecosystem restoration. Contributions to national ecosystem restoration, or NER outputs, are increases in the net quantity and/or quality of desired ecosystem resources. Measurement of NER is based on changes in ecological resource quality as a function of improvement in habitat quality and/or quantity and expressed quantitatively in physical units or indexes (but not monetary units). These net changes are measured in the planning area and in the rest of the Nation. As a single purpose ecosystem restoration feasibility study, the alternative plans were evaluated in terms of their net contributions to increases in ecosystem value, expressed in non-monetary habitat units. Results of the NER analyses are presented in Section 5.3.1.2, Habitat Units.

With respect to benefits derived from the various channel alternatives, modeling concludes that there is a significant benefit to the San José Lagoon (based on the benthic index score) once the CMP channel is widened to 75 feet due to tidal amplitude, or volume of water flowing into and out of the lagoon. Increasing channel widths to 100 and 125 feet would progressively result in additional, albeit marginal, benefit as a result of the increased water flows and reduced water residence times. Although the western and eastern segments of the Project Channel have different cross-sectional areas and bottom elevations for the 100- and 125-foot alternatives with the weir, water flow through a tidal system such as the CMP is, and would continue to be, restricted by the smallest cross-sectional area. Accordingly, once the weir is included in the larger channel configurations, there is no further benefit to residence time in San José Lagoon with channel widths wider than 75 feet, and thus no additional national ecosystem restoration benefits. Therefore, the NER benefits related to ecological uplift for all alternatives would be the same as the 75-foot channel alternative. The only difference would be the variation in habitat scores as it related to open water and mangrove habitat within the Project Channel.

The performance metrics/models for the benefits analysis were mostly based on assessments developed from existing efforts and from the relationships and hypotheses developed in the Conceptual Ecological Model (CEM) contained in the NER Benefits Evaluation Appendix (Appendix A). These prior efforts include a hydrodynamic model originally produced for San Juan Bay by Bunch et al. (2000), which was recreated with various potential tidal reestablishment scenarios by Atkins (2011a). The hydrodynamic model used was the Curvilinear-grid Hydrodynamics model in 3 Dimensions, developed by USACE researchers from the Waterways Experimental Station model (i.e., Curvilinear Hydrodynamics in 3 Dimensions, WES version = CH3D-WES). The physical boundaries of the hydrodynamic model (Bunch et al. 2000) are consistent with the physical boundaries of the estuary and nearshore waters used by the San Juan Bay Estuary Program in developing its various resource management programs. The hydrodynamic model is an approved model by USACE Headquarters, and the habitat models have been evaluated by the USACE Ecosystem Restoration Planning Center of Expertise (ECO-PCX) and approved for single-use by the Model Certification Team, USACE HQ.

5.3.1.2 Habitat Units

In order to calculate habitat units, performance metrics were developed from project planning documents, and relationships and hypotheses developed in the CEM. The CEM displays relationships demonstrating that the planned CMP-ERP would result in:

1. Improved fish habitat in the SJBE system by increasing connectivity and tidal access to estuarine areas;

2. Restored benthic habitat in San José and Los Corozos lagoons by increasing dissolved oxygen in bottom waters and improving the salinity regime to levels that support native estuarine benthic species; and
3. Increased the distribution and population density and diversity of native aquatic fish and invertebrates in the mangrove community by improving hydrologic conditions in the SJBE system.

These parameters were then associated with the appropriate attributes of benthic habitat, fish habitat, and mangrove habitat.

5.3.1.2.1 Fish Habitat Model

The restoration of the inter-connectedness of mangrove forests, seagrass meadows, open water and coral reefs as the “seascape” is essential to improving the health, viability and number of fish within the SJBE. Currently, fish within San Juan Bay cannot directly access the mangroves, seagrass meadows, and open water habitats of San José Lagoon, the Suarez Canal, La Torrecilla Lagoon and Piñones Lagoon, just as fish within those waterbodies cannot directly access the habitats afforded by San Juan Bay (located to the west of the western end of the CMP). Due to the current condition of the CMP, there is essentially no tidal exchange between San Juan Bay and the San José Lagoon, i.e. the eastern and western sides of San Juan Bay Estuary system, creating essentially two estuary systems connected independently to the ocean waters by inlets.

The restoration of the CMP is not only expected to benefit water quality and fish habitat within the Caño Martín Peña, San José Lagoon, and Los Corozos Lagoon (Atkins 2011a), it would benefit fisheries outside of these water bodies by allowing easier access to the variety of fish habitat (i.e., open water, seagrass meadows, hard bottom, mangrove fringes) found throughout the newly inter-connected waters of San Juan Bay, San José Lagoon, the Suarez Canal, La Torrecilla Lagoon and Piñones Lagoon (i.e., the entire San Juan Bay Estuary system).

The quantification of benefits to the fish habitats that constitute the seascape features of the SJBE is based on a two-step process. The first step involves the use of existing Geographic Information System (GIS) maps to quantify acreage associated with the habitats of open water, seagrass meadows, and nearby coral reefs. Model boundaries were those previously delimited by the SJBEP. The acreage estimates for the combined areas of open water and seagrass habitat were quantified using GIS for each of the following waterbodies: 1) Los Corozos Lagoon, 2) San José Lagoon, 3) Caño Martín Peña (from the existing condition and project alternatives), 4) eastern San Juan Bay, 5) western San Juan Bay, 6) Suarez Canal, 7) La Torrecilla Lagoon, 8) Piñones Lagoon, and 9) Condado Lagoon. For the reef tract, GIS coverage was divided between West Near Inlet, East Near Inlet, and Central Reef Tract portions.

The second step was to scale the habitats. The fish habitats associated with open waters and seagrass meadows (if present) in Caño Martín Peña, San José Lagoon, the Suarez Canal, and Los Corozos Lagoon would directly benefit from the restoration of the historical tidal connection between San Juan Bay and San José Lagoon, and therefore the anticipated ecological uplift with project implementation is calculated by multiplying acres of open water habitat by a scaling factor of 1.0. For areas other than San José Lagoon, an approach was used whereby the relative degree of connectivity between a given location and San José Lagoon would be the basis for scaling habitat uplift estimates. The scaling factor decreased in increments of 0.25 for every intervening waterbody between a location and San José Lagoon, until reaching the farthest locations for any reasonable expectations of environmental benefit. Thus, the fish habitat benefits associated with open waters and seagrass meadows (if present) in San Juan Bay and La Torrecilla Lagoon are less direct than in San José Lagoon, and the anticipated ecological uplift is calculated by multiplying their acres of habitat by the scaling factor of 0.75. For Condado and Piñones Lagoons, the fish habitat uplift associated with open waters and seagrass meadows (if present) are less direct still, and the anticipated ecological uplift with project implementation is calculated by multiplying habitat acres by a scaling factor of 0.50.

Although it is anticipated that reef habitats will benefit from the restored water quality that would occur in San José Lagoon and the CMP, a conservative approach to quantifying anticipated ecological uplift is appropriate. Consequently, the fish habitat uplift associated with the reef tract upon project implementation is calculated by multiplying reef acreage estimates in the eastern near inlet and western near inlet regions by a scaling factor of 0.25. For the Central Reef Tract, a scaling factor of 0.125 is used.

Table 11 displays the location, acreage, scaling factor, and resulting habitat units for the open water habitat model. Table 12 provides the open-water habitat units for the existing condition and proposed channel alternatives for the CMP-ERP.

The construction of the CMP-ERP would result in the eventual benefit to open water and reef habitat of additional net habitat units based upon the scaling factors and the proposed Caño Martín Peña channel alternatives (5,154.0 HUs for the 75-foot Alternative; 5.159.2 HUs for the 100-foot Alternative with weir; and 5,164.6 HUs for the 125-foot Alternative with weir). The net average annual Habitat Units (AAHUs) for the Fish Habitat Model varies between the proposed Caño Martín Peña channel alternatives (Table 13) (5,050.9 AAHUs for the 75-foot Alternative; 5,056.0 AAHUs for the 100-foot Alternative with weir; and 5,061.3 AAHUs for the 125-foot Alternative with weir) and is based upon the recovery time of 3 years (linearly from the existing condition to the predicted, modeled score) and a project period of 50 years.

Table 11. Quantification of Open Water/Seagrass and Reef Habitat Unit Benefits with Project Implementation

Location / Habitat Feature	Acres of Habitat	Scaling Factor	Net Habitat Units
San Juan Bay	3,483.4	0.75	2,612.6
Condado Lagoon	77.6	0.50	38.8
San José Lagoon	1,039.9	1.00	1,039.9
La Torrecilla Lagoon	642.0	0.75	481.5
Piñones Lagoon	242.6	0.50	121.3
Suarez Canal	63.9	1.00	63.9
Caño Martín Peña	see Table 12	1.00	see Table 12
Los Corozos Lagoon	202.2	1.00	202.2
Western near Inlet Reef	773.0	0.25	193.3
Eastern near Inlet Reef	309.4	0.25	77.4
Central Reef Tract	2,481.9	0.125	310.2
SUBTOTAL			5,141.0
TOTALS	All totals include the added values above and the values in Table 12 for the project alternatives. See Table 12.		

Table 12. Quantification of Open Water Habitat Unit Benefits for the No Action and Project Alternatives within the Caño Martín Peña

Project Alternative	Acres Open Water Habitat in CMP	Net Habitat Units in CMP	Subtotal Net Habitat Units[1]	Total Net Habitat Units
No Action	7.4	0.0	0.0	0.0
75 feet wide	20.4	13.0	5,141.0	5,154.0
100 feet wide with weir	25.6	18.2	5,141.0	5,159.2
125 feet wide with weir	31.0	23.6	5,141.0	5,164.6

[1] Subtotal from Table 11

Table 13. Performance of Alternative Plans Against Planning Objective 1

Project Condition	Net Average Annual Habitat Units (AAHUs)
No Action Alternative	0.0
Alternative Plan 1 (75-x-10-foot Channel)	5,050.9
Alternative Plan 2 (100-x-10-foot with weir)	5,056.0
Alternative Plan 3 (125-x-10-foot with weir)	5,061.3

5.3.1.2.2 Benthic Index Model

Benthic habitat is evaluated using an index originally developed for the SJBE Program to report on the status and trends of the health of the SJBE and its individual component water bodies. The technique is consistent with the wider body of literature on how such indices should be constructed, and it is consistent with guidance provided by USEPA (2008) on the requirements of a benthic index which is a refinement of the standard diversity index for SJBE. The index combines information on benthic community diversity, the presence or absence of pollution-tolerant benthic taxa, and the presence or absence of pollution-sensitive taxa (PBS&J 2009). The Benthic index is designed to increase as beneficial factors (i.e., species richness [number of species present], species evenness [number of individuals present from each species is not dominated by one species in particular]), and presence of pollution-sensitive taxa increase. Conversely, if species richness and/or evenness decline and the proportion of pollution-tolerant taxa increases, the Benthic Index will decline. An extensive database on benthic species composition by Riviera (2005) was used to produce benthic index scores throughout SJBE. In the original report (PBS&J 2009), it was determined that benthic index scores were lowest in SJBE in the Caño Martín Peña, followed by the San José Lagoon and that distance from the Atlantic Ocean, used as a surrogate for tidal influence, was a better predictor of benthic index scores than water depth.

Output from the hydrodynamic model was used to determine whether the correlation between benthic index scores and distance from the Atlantic Ocean could be replicated with residence time. The model variables used for the linked hydrodynamic-Benthic Index Model are the hydrodynamic model (CH3D-WES) output of residence time (as an independent variable) and benthic index scores (as a potentially statistically significant independent response variable). The model assumptions are that residence time affects benthic index scores, and the derived mathematical equation reveals the direction of the relationship, the variability associated with the derived relationship, and the statistical significance of the relationship. The Benthic Index Model was properly associated with the residence time within San José Lagoon because the benthic index improvement in San José Lagoon depends upon the water within the Lagoon turning over with the reduced residence time and increased dissolved oxygen levels are anticipated in bottom waters of San José Lagoon as a function of decreased salinity stratification (which is currently occurring in the lagoon), brought about through increasing the exchange of more saline surface waters. Larger, deeper waterbodies like San Juan Bay proper will not experience a significant reduction in residence time with the opening of the Caño Martín Peña; whereas, smaller, fairly shallow waterbodies like San José Lagoon will experience significant reductions in residence time.

To estimate the spatial extent of benthic communities expected to benefit, with regard to the benthic index model, the water quality surveys conducted in the Hydrodynamic and Water Quality Modeling Effort (Atkins 2011a) were examined in greater detail. A close examination of the water column profiles contained in that report shows that salinity stratification and bottom water hypoxia/anoxia occurs at depths greater than about 4 feet. Waters shallower than 4 feet do not show evidence of salinity stratification. There are a number of deep dredge pits in the San José Lagoon, mostly in the southeastern portion of the lagoon. The deep waters of these dredge pits grade down to depths in excess of 20 feet from a more typical depth within the lagoon of approximately 6 feet. It was thus concluded that waters shallower than 4 feet would not likely benefit from enhanced tidal circulation, as they are too shallow to exhibit hypoxia/anoxia brought about by salinity stratification. Those bottom areas associated with deep dredge pits which will likely continue to be problematic in terms of hypoxia and anoxia.

Those portions of San José Lagoon that are between 4 and 6 feet in depth represent the portions of the lagoon that are anticipated to have improved benthic index scores upon restoration of the historical tidal connection between San Juan Bay and San José Lagoon. The spatial extent of the bay bottom to benefit in this manner is quantified at 702 acres.

The performance of the Benthic Index Model (Table 14) is based on achieving a Benthic Index value of 3.0, which would be approximately the maximum predicted value for the Benthic Index in San José Lagoon after restoring the CMP to its original width and depth of an estimated 200 feet by 10 feet. The Habitat Unit score is based upon the project performance and the maximum spatial extent of the area of San José Lagoon that would benefit from the opening of the CMP (702 acres). The net AAHUs (294.5 Habitat Units) for the Benthic Index Model is based upon the recovery of the area in San José Lagoon to the predicted, modeled Benthic Index HUs (663.8) starting from no action (363.0 Habitat Units) with the expected time of recovery of 3 years (linearly from the existing condition to the predicted, modeled score) and the project period of 50.

Table 14. Performance of Alternative Plans Against Planning Objective 2

Alternative Plan (feet wide x feet deep)	Residence Time (days)	Benthic Index	Scaled Benthic Index (based on a maximum of 3.0)	Habitat Units (relative benthic index x 702 acres)	Net Benthic Index HU	Net Average Annual HU
No Action	16.9	1.55	52%	363.0	0.0	0.0
Alternative Plan 1 (75 x 10)	3.9	2.84	95%	663.8	300.9	294.5
Alternative Plan 2 (100 x 10 with weir)	3.9	2.84	95%	663.8	300.9	294.5
Alternative Plan 3 (125 x 10 with weir)	3.9	2.84	95%	663.8	300.9	294.5

5.3.1.2.3 Mangrove Habitat Model

The Sport Fisheries Study (Atkins 2011b) includes an assessment of the red mangrove prop root community within the CMP and within zones in designated distances away from the CMP. It was found that the numbers and diversity of the attached (e.g., mussels and oysters) and mobile (e.g., crabs) organisms found on the roots increased from the CMP and western San José Lagoon out to La Torrecilla Lagoon, thus providing an indicator of water quality improvement that would likely respond to the improvements provided by the opening of the CMP. Through this preliminary study, a significant relationship was found between the number of crabs found on mangrove prop roots and distance from the CMP (Figure 13). This relationship uses the connectivity of habitat described above for fish habitat and may be expanded to further species individuals and groups or overall density and diversity of organisms with further data collection.

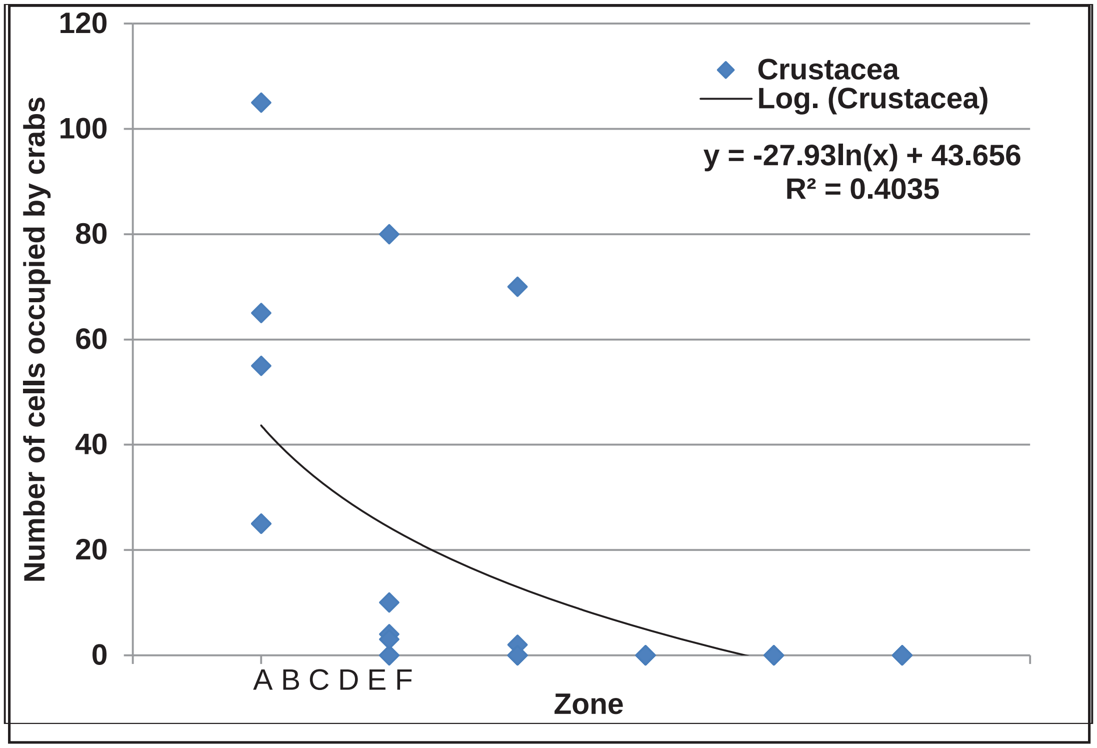

Figure 13. Relationship of the Number of Crabs and the Distance from the Caño Martín Peña (Atkins 2011c).

As with the fish habitats, existing GIS maps were used to quantify acreage associated with the mangrove habitats in SJBE. The scaling method for the Mangrove Habitat Model uses the differential in tide phase within San Juan Bay Estuary system reported by Fagerburg (1998) in the field data study for the hydrodynamic model calibration. Opening the Caño Martín Peña will nearly equilibrate the tidal phase within the central portion of the San Juan Bay Estuary system as tidal waters are able to enter the central portion of the estuary system from both the east and the west. The greatest benefits will occur within the Caño Martín Peña, San José Lagoon, and Los Corozos Lagoon. Suárez Canal and the western portion of the Caño Martín Peña will also benefit greatly, but less so, as evidenced by tidal phasing. The scaling factor decreased in increments of 0.125 based on the relative degree of similarity of tidal phases. The mangrove habitat (e.g., vegetation health and seed distribution) and the organisms (e.g., fish and invertebrate life stages) associated with that habitat in Caño Martín Peña and San José Lagoon would directly benefit from the restoration of the historical tidal connection between San Juan Bay and San José Lagoon. The mangrove habitat in eastern San Juan Bay and Suarez Lagoon is somewhat more distant, and the anticipated ecological uplift is less direct; benefits are calculated by multiplying acres of mangrove habitat by the scaling factor of 0.75. Mangrove uplift for La Torrecilla Lagoon is quantified as acreage multiplied by 0.25. For the more distant areas of western San Juan Bay, Condado Lagoon and Piñones Lagoon, anticipated ecological uplift of mangrove habitat is quantified by multiplying acres of mangroves by 0.125.

Table 15 displays the location, acreage, scaling factor, and resulting habitat units for the fish habitat model feature of mangroves. Table 16 provides the mangrove habitat units for the existing condition and proposed channel alternatives for the CMP-ERP. Note that the 125-foot alternative with a weir does indicate a net loss of 4.4 Habitat Units within the Caño Martín Peña.

Table15. Quantification of Mangrove Habitat Unit Benefits with Project Implementation.
(NM = none mapped / not shown in GIS data files)

Location	Acres of Habitat	Scaling Factor	Net Habitat Units
Western San Juan Bay	34.2	0.125	4.3
Eastern San Juan Bay	207.3	0.75	155.5
Condado Lagoon	NM	0.125	NM
San José Lagoon	157.5	1.00	157.5
La Torrecilla Lagoon	1,066.5	0.25	266.6
Piñones Lagoon	568.5	0.125	71.1
Suarez Canal	118.5	0.75	88.9
Caño Martín Peña	see Table 15	1.00	see Table 1 5
Los Corozos Lagoon	53.8	1.00	53.8
SUBTOTAL			797.6
TOTAL	All totals include the added values above and the values in Table 15 for the project alternatives. See Table 15.		

Table 16. Quantification of Mangrove Habitat Unit Benefits for the
Existing Condition and Project Alternatives within the Caño Martín Peña.

Project Alternative	Acres of Mangrove Habitat in CMP	Net Habitat Units in CMP	Subtotal Net Habitat Unit Score	Total Net Habitat Units
No Action	33.5	0.0	0.0	0.0
75 feet wide	39.6	6.2	797.6	803.8
100 feet wide with weir	34.5	1.0	797.6	798.6
125 feet wide with weir	29.1	-4.4	797.6	793.2

The net HUs would be those HUs (803.8 HUs for the 75-foot Alternative; 798.6 HUs for the 100-foot Alternative with weir; and 793.2 HUs for the 125-foot Alternative with weir) gained with each project alternative above the no action alternative. The net AAHUs for the Mangrove Habitat Model (Table 17) (787.7 for the 75-foot Alternative; 782.7 for the 100-foot Alternative with weir; and 777.4 for the 125-foot Alternative with weir) is based upon the recovery time of 3 years (linearly from the existing condition to the predicted, modeled score) and a project period of 50 years.

Table 17. Performance of Alternative Plans
Against Planning Objective 3

Project Condition	Net Average Annual Habitat Units (AAHUs)
No Action Alternative	0
Alternative Plan 1 (75-x-10-foot Channel)	787.7
Alternative Plan 2 (100-x-10-foot with weir)	782.7
Alternative Plan 3 (125-x-10-foot with weir)	777.4

5.3.1.2.4 Benefit Evaluation Result

The results of the benefit evaluation are presented in Table 18.

5.3.2 Cost Effectiveness/ Incremental Cost Analysis

Pursuant to the calculation of habitat units, planning level cost estimates were developed for the Final Array. As described below, a cost effective analysis was conducted to determine which plans reasonably maximize ecosystem restoration benefits compared to costs. Additionally, an incremental cost analysis was then conducted to identify the most efficient plan.

5.3.2.1 Average Annual Costs and Ecosystem Benefits

Construction and maintenance costs presented in this report are based on a project life of 50 years, a Federal Discount Rate of 3.5 percent, and a base year of 2019. All costs, construction and operation and maintenance, are estimated as year-end values. The costs discussed in this paragraph include ecosystem restoration; costs associated with recreation facilities are not included. Three alternatives, the 75-x-10-foot paved channel, the 100-x-10-foot channel, and the 125-x-10-foot channel were carried into the final array to be considered in this analysis. Because Micro-Computer Aided Cost Estimating System (MCACES) level costs were only developed for the 100-x-10-foot alternative, planning level cost estimates were used for the cost effectiveness/incremental cost analysis (CE/ICA). First costs range from $0 for the No Action Alternative to $171,700,000 for the 75-foot-wide by 10-foot-deep channel alternative. Average Annual Operation and Maintenance (O&M) costs range to $0 for the No Action alternative to $1,700,000 for the 75-foot-wide by 10-foot-deep alternative. Total average annual equivalent costs range from $0 for the No Action alternative to $8,700,000 for the 100-foot-wide by 10-foot-deep alternative. Total first cost, interest during construction, annual operation and maintenance, and average annual equivalent cost are presented in Table 19.

Table 18
Average Annual Habitat Unit Lift for the project alternatives

Project Condition	Residence Time (days)	Benthic Index[1]	Benthic Index Project Perfor-mance	Benthic Index Habitat Units (HU)[2]	Benthic Index Net HU	Net Benthic Index Net Average Annual HU[3]	Fish Habitat Model Net HU[4]	Fish Habitat Model Net Average Annual HU[3]	Mangrove Habitat Model Net HU[4]	Mangrove Habitat Model Net Average Annual HU[3]	Total Net Habitat Units	Total Net Average Annual HU[5]
No action	16.9	1.55	51.70%	362.95	0	0	0	0	0	0	0	0
75-ft-wide Alternative	3.9	2.84	94.56%	663.81	300.86	294.54	5,154.01	5,050.93	803.77	787.69	6,258.64	6,133.16
100-ft-wide Alternative with weir	3.9	2.84	94.56%	663.81	300.86	294.54	5,159.16	5,055.98	798.63	782.66	6,258.65	6,133.17
125-ft-wide Alternative with weir	3.9	2.84	94.56%	663.81	300.86	294.54	5,164.56	5,061.27	793.23	777.37	6,258.65	6,133.17

[1] Based upon a maximum Benthic Index Score of 3.0 (see text for further explanation).

[2] Based upon an expected area to benefit = those regions between -4 and -6 feet in water depth within San José Lagoon (= 702 acres maximum).

[3] Average annual habitat unit lift from existing condition based upon a 3-year recovery time after project construction.

[4] See text for explanation.

[5] Combined Benthic Index Average Annual HU lift, Fish Habitat Model Average Annual HU lift and Mangrove Habitat Model HU lift based upon a 3-year recovery time after project construction [Columns F + H + J = K].

Table 19. Project Costs for the Final Array of Alternative Plans

Alternative	Total First Cost w/o Recreation	Interest During Construction	Total Investment Costs (incl. IDC)	Avg. Ann. Total Costs	Avg. Ann. O&M @ 1% of Subtotal	Total Avg. Ann. Costs incl. O&M
No Action	$ -	$ -	$ -	$ -	$ -	$ -
75' x 10' Paved	$171,700,000	$5,800,000	$177,500,000	$7,600,000	$ 1,700,000	$ 9,300,000
100' x 10'	$ 161,300,000	$ 5,400,000	$ 166,700,000	$7,100,000	$ 1,600,000	$ 8,700,000
125’ x 10’	$167,200,000	$ 5,600,000	$172,800,000	$7,400,000	$ 1,700,000	$9,100,000

Notes: Costs do not include recreation features. Annualized over 50 years at 3.5%; Interest during construction (IDC) calculated based on 23-month construction schedule; 1% of total first cost (without recreation) assumed for annual O&M.

5.3.2.2 Cost Effectiveness and Incremental Cost Analysis

Traditional benefit-cost analysis is not appropriate for environmental preservation and enhancement projects since there is not a consistent national standard for monetary valuation of environmental outputs. CE/ICA procedures provide an evaluation approach that is consistent with the planning framework established in the P&G for Water and Related Land Resources Implementation Studies (U.S. Water Resources Council 1983). All CE/ICA procedures used in this report are based on the USACE Institute for Water Resources (IWR) Planning Suite User’s Guide, November 2006, and are consistent with the P&G.

Cost effectiveness analysis is conducted to ensure that the lowest cost alternative is identified for each possible level of environmental output, and that for any level of investment, the maximum level of output is identified. Cost effective means that for a given level of non-monetary output, no other plan costs less to produce the same output, and no other plans yields more output for less money. The analysis then identifies the subset of cost-effective plans that are superior investments through incremental cost analysis. These “best buys” provide an increase in output for the lowest average cost. The first best buy is the most efficient plan, producing output at the lowest average cost per unit. The next best buy is the most efficient plan for producing additional output, and so on. Each additional best buy is calculated starting from the previous “best buy.”

For the purpose of this project, average annual equivalent costs were compared to average annual habitat units to determine which alternatives are most cost-effective. Fish, mangrove, and benthic Index habitat units were considered to be combinable for purposes of the CE/ICA. Habitat units for each project alternative were compared to the No Action Alternative. The average annual equivalent cost and the average annual net habitat units (Fish, Mangrove, and Benthic Index) for each alternative are presented in Table 20.

Three with-project alternatives were analyzed. Each alternative was considered independent and not combinable with the other alternative. Each alternative provides the same level of output as a similarly sized weir is included in all alternatives, which serves to control the velocities in and out of the Caño Martín Peña, which in turn equates the flow-dependent habitat units. While the determination of the NER (National Ecosystem Restoration) Plan for this analysis could be explained as a least cost evaluation, a traditional cost effectiveness/incremental cost analysis was conducted. The 100-x-10-foot plan costs less than both the 75-x-100-foot and the 125-x-10-foot plans (see Table 20). Consequently, only the 10-x-100-foot plan is cost effective, and was also identified as a Best Buy in the ICA (Figure 13). The 100-x-10-foot plan yields 6,133 AAHUs at an average annual cost of \$8,700,000, with an average annual cost per average annual habitat unit of \$1,420.

Table 20. Average Annual Costs and
Habitat Units Used in Incremental Cost Analysis

Alternative	Avg. Ann. Cost	AAHU	Avg. Ann. Cost per HU	Cost Effective
No Action	$ -	0	Not applicable	Yes
75' x 10' Paved	$ 9,300,000	6,133	$ 1,510	No
100' x 10'	$ 8,700,000	6,133	$ 1,420	Yes
125’ x 10’	$9,100,000	6,133	$ 1,480	No

Note: 1) Mangrove wetland replacement acreage values for the CDRC staging area were not included in the CE/ICA, as these were not congruent values for comparison to Habitat Units, and also were only intended to replace impacted areas within CDRC rather than be utilized for project justification.

Note 2) Open water and mangrove habitat restoration within the Project Channel are included in the calculation of NER benefits for the alternatives; however, there would be a minor variation in habitat scores as it related to open water and mangrove habitat within the Project Channel between the alternatives, and as such, the benefits are assumed to be equal among the alternatives.

5.3.3 Principles and Guidelines Plan Evaluation Criteria

Although an initial evaluation was conducted during the B-series screening analysis, the Final Array was further evaluated using the P&G Criteria. The following section provides a more-detailed description of the merits of each alternative in regards to each criterion. As specified in ER 1105-2-100, the four P&G Criteria that were considered are: completeness, effectiveness, efficiency, and acceptability.

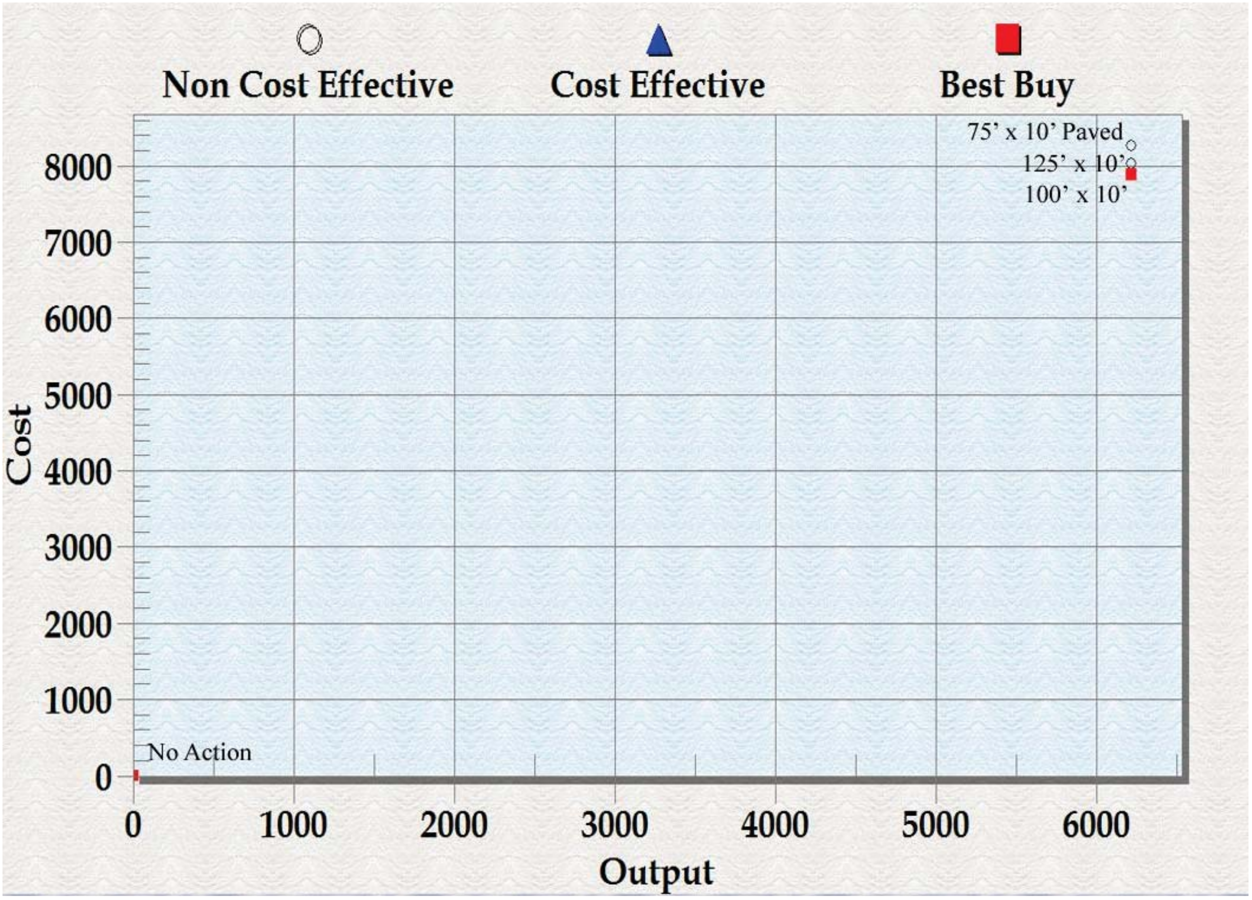

Figure 14. CE/ICA Analysis for the Final Array of Alternatives

5.3.3.1 Completeness

Completeness is the extent that an alternative plan provides and accounts for all investments and actions required to ensure the planned output is achieved. Completeness includes consideration of real estate issues, O&M, monitoring, and sponsorship factors. Adaptive management plans formulated to address project uncertainties may also to be considered.

The No Action Alternative plan is by definition an incomplete plan. Alternative Plans 1, 2, and 3 are complete plans. The plans address present and future restoration opportunities in the study area. Additionally, the plans provide for acquisition and removal of affected structures as well as relocation of affected families. Operations and maintenance has been analyzed and addressed for the period of analysis, and both a monitoring and adaptive management plan have been created.

5.3.3.2 Effectiveness

The No Action alternative plan is by definition ineffective in achieving the planning objectives as no Federal Action is proposed to address the identified problems. Alternative Plans 1, 2 and 3 are all equally effective in addressing the problems and realizing the opportunities, and all three plans would equally meet the project objectives.

5.3.3.3 Efficiency

Efficiency means the project is a cost effective means of addressing the problem and/or realizing the opportunities. The plan outputs cannot be produced more cost effectively by another institution or agency. The No Action Alternative plan is by definition an efficient plan, as it is both cost effective and a best buy. Alternative Plans 1 and 3 are not cost effective in relation to Alternative Plan 2. Alternatives 1 and 3 are more costly than Alternative 2 and produce less benefits. Alternative Plan 2 is considered cost effective and would also be considered a best buy.

5.3.3.4 Acceptability

Acceptability is the workability and viability of the alternative plan with respect to acceptance by Federal and non-Federal entities and the public, and compatibility with existing laws, regulations, and public policies. Two primary dimensions to acceptability are implementability and satisfaction. Implementability means that the alternative is feasible from technical, environmental, economic, financial, political, legal, institutional, and social perspectives. The second dimension to acceptability is the satisfaction that a particular plan brings to government entities and the public. The project should have evidence of broad-based public support and be acceptable to the non-Federal sponsor. Alternatives Plans 1, 2, and 3 are considered implementable and do not rely on any new technology, significant socio-economic factors, or other elements that could render the project infeasible. Additionally, Alternatives 1, 2, and 3 would be considered acceptable with regards to compatibility with existing laws, regulations, and public policies; however, extensive public involvement over the course of the study effort has determined a public preference for a wider, restored CMP. As such, Alternative Plan 3 is preferable to Alternative 2, as Alternative 2 would be considered preferable to Alternative 1.

5.4 COMPARISON OF ALTERNATIVE PLANS

5.4.1 Planning Objectives and P&G Criteria

Table 21 summarizes the effectiveness of the final array of alternative plans. Each alternative plan equally achieves Planning Objectives, and results in significant improvements to the natural and human communities in the region of the CMP and the SJBE. Each action alternative is complete, effective, and acceptable; however, Alternative Plan 1 and Alternative Plan 3 are not cost effective (efficient), whereas Alternative Plan 2 is cost effective (efficient).

Table 21. Comparison of Alternative Plans

Evaluation Metric	No Action Alternative Plan	Alternative Plan 1 (75' x 10' Channel)	Alternative Plan 2 (100' x 10' Channel)	Alternative Plan 3 (125' x 10' Channel)
Planning Objective 1 (Changes in Habitat Units for Fish Habitat in the SJBE)	There is no net change in habitat units of fish habitat over the planning horizon	A net increase of 5,050.9 AAHUs of fish habitat in comparison to the No Action Alternative.	A net increase of 5,056.0 AAHUs of fish habitat in comparison to the No Action Alternative.	A net increase of 5,061.3 AAHUs of fish habitat in comparison to the No Action Alternative.
Planning Objective 2 (Changes in Benthic Habitat Units)	There is no net change in benthic habitat area over the planning horizon.	A net increase of 294.54 benthic AAHUs in comparison to the No Action Alternative.	A net increase of 294.54 benthic AAHUs in comparison to the No Action Alternative.	A net increase of 294.54 benthic AAHUs in comparison to the No Action Alternative.
Planning Objective 3 (Changes in Habitat Units for Mangrove Habitat in the SJBE)	There is no net change in habitat units for mangrove habitat over the planning horizon	A net increase of 787.7 AAHUs of mangrove habitat in comparison to the No Action Alternative.	A net increase of 782.7 AAHUs of mangrove habitat in comparison to the No Action Alternative.	A net increase of 777.4 AAHUs of mangrove habitat in comparison to the No Action Alternative.
Cost Effectiveness/ Incremental Cost Analysis	Not applicable.	$1,510 annual cost/ annual habitat unit. Not as cost effective as Alternative Plan 2, which has the same benefits for a lower average cost per unit.	$1,420 annual cost / annual habitat unit. Cost effective. No other alternative plan produces the same benefits for lesser costs.	$1,480 annual cost/ annual habitat unit. Not as cost effective as Alternative Plan 2, which has the same benefits for a lower average cost per unit.
P&G Criteria: Completeness	Not complete.	Complete.	Complete.	Complete
P&G Criteria: Effectiveness	Not effective. Does not meet project objectives.	Meets the project objectives.	Meets the project objectives.	Meets the project objectives.
P&G Criteria: Efficiency	Cost effective and a best buy.	Not cost effective.	Cost effective and a best buy.	Not cost effective.
P&G Criteria: Acceptability	Not acceptable.	Acceptable.	More Acceptable.	Most Acceptable.

5.4.2 P&G System of Accounts

Four accounts are established by the P&G to evaluate and display effects of alternative plans, and can be used to produce a plan-by-plan comparison. The four accounts in the system of accounts are the: (a) national economic development (NED) account that displays changes in the economic value of the national output of goods and services; (b) environmental quality (EQ) account that displays non-monetary effects on significant natural and cultural resources; (c) regional economic development (RED) account that addresses changes in the distribution of regional economic activity; and (d) other social effects (OSE) account that addresses urban and community impacts (life, health, and safety factors; displacement; long-term productivity; and energy requirements and energy conservation from perspectives, not reflected in the other three accounts) (ER 1105-2-100, 22 Apr 2000).

Since this is an NER project, beneficial changes to the NED account would not be expected to significantly change, with the exception of recreation, and changes in the EQ account are captured in the NER benefit analysis documented in detail in the NER Benefits Evaluation Appendix (Appendix A). The CMP-ERP is evaluating ecosystem restoration and the System of Accounts analysis primarily focuses on the RED and OSE accounts. The analysis includes a description of the contributions to these accounts for the No Action Alternative (Without-Project), Alternative Plan 1 (75-x-10-foot Channel), Alternative Plan 2 (100-x-10-foot Channel), and Alternative Plan 3 (125-x-10-foot Channel).

5.4.2.1 NED

This section discusses the effects of No Action Alternative, Alternative Plan 1, and Alternative Plan 2 on the NED account.

5.4.2.1.1 No Action (Without-Project) Alternative

Under the No Action Alternative the Federal government would not participate in ecosystem restoration activities and no NED effects would be produced.

5.4.2.1.2 Alternative Plans

As the proposed project is a single-purpose, ecosystem restoration project, NED benefits were not produced for the primary project mission; however, the proposed project would produce recreation NED benefits and incidental flood risk management benefits. Recreation net benefits in the amount of $5,698,618 would occur with implementation of all three alternatives, reflecting a benefit/cost ratio of 6.4 to 1.0.

With respect to incidental flood risk management benefits, all three alternative plans would reduce potential flooding since they require flood prone structures to be removed from the floodplain. Additionally, all three alternatives would result in a restored tidal connection between San Juan Bay and the San José Lagoon, thus facilitating removal of storm water from the CMP. While this study effort did not calculate flood risk NED benefits associated with the CMP-ERP, relevant data associated with flooding in Puerto Rico indicates that average assistance from FEMA during past flood events in Puerto Rico has ranged from $3,000 to almost $14,000 per affected household. FEMA FIRM and GIS data from the Municipal Revenue Collection Center and the PRPB show that approximately 4,700 buildings adjacent to the CMP are within the 100-yr frequency AE Flood Zone (with storm surge). Real Estate sales records from previous relocations made by ENLACE show that property prices for flood-prone structures vary from $25,000 to $157,000. Past studies have estimated content value of buildings to be 55 percent of the value of the structure. Such figures point to the possibility that substantial or major damages would take place if a 100-yr flood with storm surge were to occur, and that a restored CMP should result in significant reductions in flood-related damages in the future (see Section 3.31 of the EIS for additional information). In addition, improved drainage conditions from a dredged CMP would reduce the duration that flood waters threaten developed areas.

In addition, recreational navigation benefits would be produced by the proposed project. Although the CMP is considered a navigable water of the United States, the waterway has become completely severed and can no longer serve navigational purposes. All three alternatives would result in re-opening this waterway, allowing for possible extension of the local river taxi and safe passage of other vessels. While no economic analysis was conducted and therefore no NED benefits were calculated, recreational navigation in adjacent waters that includes public boating and sport fishing suggests that these activities would increase with implementation of the proposed project.

5.4.2.2 EQ

This section discusses the effects of No Action Alternative, Alternative Plan 1, and Alternative Plan 2 on the EQ account, which is detailed in the NER Benefits Evaluation Appendix (Appendix A).

5.4.2.2.1 No Action (Without-Project) Alternative

Under the No Action Alternative the Federal government would not participate in ecosystem restoration activities. If the No Action Alternative were selected, there would be no effects on the EQ account from Federal participation in National Ecosystem Restoration, and the existing acreage (23.67 acres) of low functioning wetlands would remain.

5.4.2.2.2 Alternative Plans

EQ output for the proposed project was measured in terms of changes in the AAHUs for the Benthic Index, Fish Habitat, and Mangrove Habitat attributes. All three alternative plans would produce EQ output of 6,133 AAHU. Additionally, Alternative 1 would provide 39.62 acres of mangrove wetland replacement within the CMP, Alternative 2 would provide 34.48 acres of CMP mangrove wetlands, and Alternative 3 would provide 29.08 acres.

5.4.2.3 RED

EC 1105-2-409 states: “the regional economic development account registers changes in the distribution of regional economic activity that result from each alternative plan”. The RED account describes the effects alternatives would have on regional changes in jobs, income, and tax revenues. This section discusses the effects of No Action Alternative and Alternative Plans 1, 2, and 3 on the RED account.

5.4.2.3.1 No Action (Without-Project) Alternative

Under the No Action Alternative, the Federal government would not participate in ecosystem restoration activities. If the No Action Alternative were selected, there would be no increase in jobs, income, and tax revenues in the region from Federal participation in National Ecosystem Restoration.

5.4.2.3.2 Alternative Plans

The RED output from the implementation of Alternative Plans 1, 2, and 3 is practically identical with less than a 1 percent difference in the annual costs among the three plans. All three alternative plans would result in significant RED output through increases in jobs, income, and tax revenues in the region from construction expenditures and demand for construction labor and construction support services, providing short-term (over a 2-year period) regional economic benefits. In addition to construction labor demand and increased manufacturing labor demand, the private sector would benefit from the project through contracted construction management, architecture, and other construction related employment opportunities. Expenditures for construction materials, labor, and services should have secondary effects throughout the region as increased employment opportunities and higher overall earnings would generate spending and inter-industry economic activity.

Implementation of Alternative Plan 1 would result in the direct and indirect creation of 4,525 construction jobs, revenues to government generated from construction activities of $25.38 million, and salary income generated by construction activities of $103.43 million. Implementation of Alternative Plan 2 would result in the direct and indirect creation of 4,275 construction jobs, revenues to government generated from construction activities of $23.95 million, and salary income generated by construction activities of $97.72 million. Implementation of Alternative Plan 3 would result in the direct and indirect creation of 4,400 construction jobs, revenues to government generated from construction activities of $24.7 million, and salary income generated by construction activities of $100.5 million. Improvement in fish habitat will likely increase regional income from commercial and recreational fishing; however, computation of RED output for these parameters is not feasible due to a lack of reliable data.

The basis for the jobs and income figures presented in the report were the industry multipliers published by the PRPB (PRPB 2002). Government revenue was calculated by applying the corresponding effective average tax rates, including income taxes, sales taxes, and property and other municipal taxes to the construction expenditures. All figures are adjusted for inflation to prevent overestimation of benefits. RED impacts would only be for the period of construction.

5.4.2.4 OSE

A recently published OSE handbook by the USACE Institute for Water Resources entitled “Applying Other Social Effects in Alternatives Analysis” identifies the social factors recommended for consideration when evaluating the social effects of alternatives (USACE 2013). Under the No Action Alternative Plan, impacts from future conditions on the social factors shown below would be significantly adverse.

- Health and Safety – Perceptions of personal and group safety and freedom from risks
- Economic Vitality – Personal and group definitions of quality of life, which is influenced by the local economy’s ability to provide a good standard of living
- Social Connectedness – Community’s social networks within which individuals interact; these networks provide significant meaning and structure to life

- Identity – Community members' sense of self as a member of a group, in that they have a sense of definition and grounding
- Social Vulnerability and Resiliency – Probability of a community being damaged or negatively affected by hazards and its ability to recover from a traumatic event
- Participation – Ability of community members to interact with others to influence social outcomes
- Leisure and Recreation – Amount of personal leisure time available and whether community members are able to spend it in preferred recreational pursuits (USACE 2009)

One of the causes of the adverse social effects is the frequency of flooding in the neighborhoods surrounding the CMP. Under the No Action Alternative, the percentage of residents reporting flooding problems would be expected to remain unchanged or worsen. Interviews with 645 residents conducted in 2011 by the Ponce School of Medicine and Health Sciences included questions regarding flood frequency. Frequency of positive responses to various flooding question presented in Table 22.

Table 22. Frequency of Flooding Reported by CMP Neighborhood Residents

Flooding within or near the houses of study participants	Response Yes (%)
Does your house or backyard flood even if it has not rained?	16.4
Does your street flood even if it has not rained?	21.9
Does your house or backyard flood when it rains?	53.4
Does your street, or any house in the street, flood when it rains?	69.5
Did your house or backyard flood in 2011?	53.6
Did your house or backyard flood in the past three months?	33.1
Did your street flood in the past three months?	51.4

Another component parameter of adverse social effects evaluated in the interviews with neighborhoods adjacent to the CMP was the rates for gastroenteritis in the area population. The interviews were conducted between November 2011 and April 2012 using transversal sampling design included housing that had exposure to waste waters through flooding or the presence/absence of a sanitary sewer system. Results indicated that 31 percent of the population in the affected neighborhoods reported gastrointestinal symptoms as compared to the 22 percent background rate for Puerto Rico. People exposed to flood water were twice as likely to have gastrointestinal symptoms.

In June 2012, an interview effort was undertaken to evaluate the prevalence of asthma and atopic dermatitis with 122 adults responsible for children under 18 living adjacent to the CMP. A transversal design selected houses randomly for participation. Households included in the interview effort were selected from blocks of houses adjacent to and not adjacent to the CMP. The adult responsible for children under 18 was interviewed regarding the characteristics of the household. One minor was randomly selected from each household for an interview. Information requested about the minor included social, anthropometric and health characteristics, including a diagnostic test for asthma and atopic dermatitis. Bronchial asthma prevalence among children under 18 years of age living within the communities bordering the CMP was 23.2 percent. The number for children under five was 44.5 percent, more than double the 21.5 percent rate reported for that age group in Puerto Rico. Atopic dermatitis rates for children within the CMP communities was 35.3 percent, over 10 percent higher than the 24.8 percent rate reported for that age group in previous studies. Although not statistically significant, there is a clear trend that blocks closer to the CMP have a higher likelihood of suffering from one of the ailments focused on in this interview effort.

5.4.2.4.1 No Action (Without-Project) Alternative

Under the No Action Alternative rates for three identified conditions, Gastroenteritis, asthma in children and atopic dermatitis in children, are expected to remain similar or worsen from present rates. The communities surrounding the Caño Martín Peña in Puerto Rico reliant on the CMP for removal of floodwaters and other socio-economic factors such as subsistence fishing would continue to experience a very poor quality of life. The reduced drainage capacity would likely continue to worsen, along with the water quality in this area, already leading to high rates of disease in the community that continues to worsen. Members of the surrounding communities would continue to experience a disproportionately adverse economic and environmental burden compared to the surrounding areas of San Juan, the rest of Puerto Rico, and the United States with respect to health, safety, and quality of life.

5.4.2.4.2 Alternative Plans

The information above was used to derive an estimate of health care costs under current conditions within the CMP communities related to Gastroenteritis, asthma in children, and atopic dermatitis in children (Table 23). Under Alternative Plans 1, 2, and 3, prevalence rates are expected to drop to the Puerto Rico average, resulting in health care cost reductions of $775,927 per year, or $38,796,361 over the 50 year project life. Human health, safety and quality of life within the area surrounding the CMP would be expected to improve, not only with reduced rates of disease, but with reduced flooding effects and better water quality.

Table 23. Health Care Costs Related to Three Common Health Conditions in the CMP Neighborhoods

Condition	CMP Prevalence	Puerto Rico Prevalence[1]	CMP Population	Costs per year[2] ($/case/year)	Existing Population Affected	Existing Health Costs	Improved CMP Population affected[3]	Improved CMP Health Costs
Gastroenteritis	31%	21%	1,8074	$325	5,603	$1,820,956	3796	$1,233,551
Asthma (children under 5 years old)	44.5%	22%	1046	$654	465	$304,417	225	$147,078
Dermatitis (Children 5–9 years old)	35.3%	24.8%	958	$310	338	$104834	238	$73,651
					TOTAL	$2,230,207	TOTAL	$1,454,280

[1, 2] Source: Puerto Rico Department of Health

[3] Assumes prevalence rate drops to Puerto Rico prevalence rate.

5.5 PLAN SELECTION

5.5.1 Identification of the National Ecosystem Restoration Plan

For ecosystem restoration projects, a plan that reasonably maximizes ecosystem restoration benefits compared to costs, consistent with the Federal objective, shall be selected and designated as the NER Plan. The NER plan must be shown to be cost effective and justified to achieve the desired level of output. Alternative Plan 2, the 100-x-10-foot channel, was selected as the NER plan as it reasonably maximizes the amount of environmental restoration compared to costs. This alternative is an economically viable solution to the problems identified for the proposed project and would produce significant and meaningful improvements to the natural environment of the SJBE.

5.5.2 Tentatively Selected Plan

Alternative 2 is the NER plan and has been selected as the TSP for the CMP-ERP. Alternative 2 would meet all three of the project objectives and would not violate any project constraints. The TSP is both cost effective and a best buy, and has been demonstrated to be acceptable to state and local agencies as well as the public. The plan is also compatible with all applicable laws and policies.

Fish habitat within the SJBE would be restored with populations more resilient to change through increased genetic diversity. Commercial, recreational, and subsistence fishing would be improved as populations of native fish recover from currently degraded environmental conditions. The restoration of mangrove habitat will serve to provide increased habitat for juvenile fish, while increasing populations of native crabs and other invertebrates. Benthic habitat within the San José and Los Corozos Lagoons would be restored, with corresponding improvements to species such as wading birds that utilize the area for foraging grounds.

Alternative 2 would also provide a mechanism to evacuate floodwaters from the areas surrounding the CMP. Combined with ENLACE's Comprehensive Plan, rates of disease in the area should be reduced as the rate of flooding is reduced. Additionally, over 300 residences within flood prone areas would be removed as part of the CMP-ERP, providing non-structural improvements to the area.

A complete description of the TSP/NER Plan is found in Section 6.2.

5.6 RISK AND UNCERTAINTY

Potential areas of risk and uncertainty associated with the TSP/NER Plan were analyzed and have been addressed below.

5.6.1 Relative Sea Level Change

The increase in water level elevation as a result of sea level change (Section 3.4.1) will not affect future navigation or maintenance of the CMP since the depth of the channel is to be constructed and maintained as measured from the water surface. The proposed sheet pile wall's top (cap) elevation is 3.0 feet and present mean high high water (MHHW) elevation is 0.80 feet. With the estimated sea level changes presented in Table 24, mean high water elevations will remain below or near the top of wall for the low, intermediate, and high sea level change estimates. After construction, the MHHW elevation with SLC would rise 0.47 to 0.79 feet over the sheet pile cap. The main consequence associated with water levels overtopping the walls to this minor extent is a hazard to navigation as the tops of the wall will not be visible under certain tidal conditions. Channel markers may be required to adequately mark the position of the wall to minimize the hazard. With increases in tidal amplitude due to the proposed project, it is also likely that sea level change would further raise water levels within the CMP. The PRASA is the entity responsible for designing and constructing the sewer and drainage improvements as part of the Comprehensive Plan, and the Municipality of San Juan is responsible for designing and constructing the storm water improvements. Both entities are part of the TC that meets bi-yearly in San Juan. Coordination during the September 2013 meeting ensure that the Municipality of San Juan is aware of the potential water level changes due to the proposed project combined with sea level change, and future improvements to the basin will include proper design and construction to prevent induced flooding.

Table 24. Sea Level Change Estimates – Relative to Proposed Top of Sheet Pile Wall

Location	Top of Sheet Pile Cap	MHHW (preconstruction)	MHHW (SLC) (pre-construction)	MHHW (post-construction)	MHHW (SLC) (post-construction)
San Juan Bay	3.0	1.12	3.15	1.76	3.79
San Jóse Lagoon	3.0	0.80	2.83	1.44	3.47

5.6.2 Geotechnical Considerations

The geotechnical analyses presented in this feasibility report were based on maximizing the use of available data and minimizing new data collection in order to complete the planning level of analysis. This methodology was followed as conditions in the Project Area are relatively uniform and similar to projects previously constructed in the immediate vicinity. Additional geotechnical sampling and analysis will be performed during the PED phase, and it is possible, but not considered likely, that modifications to the project design would be required that significantly increase the project cost.

5.6.3 Water Quality

In preparation of the Water Quality sections, the best available data was used to characterize existing conditions, and best professional judgment was used to predict the project's impacts. Water quality parameters will be further modeled as part of the hydrologic modeling effort conducted during the PED phase. If the results of these modeling efforts suggest that the project's water quality impacts will differ from those currently anticipated, then a supplemental NEPA document may be prepared as appropriate. If further analysis during PED indicates that the project is likely to have significant adverse impacts to water quality, then the project's features and/or operation will be refined to mitigate the adverse impacts to the fullest extent possible, consistent with the project's overall goals. The project will also be adaptively managed post-construction to maximize the project's ability to meet its goals and objectives and minimize adverse impacts.

5.6.4 Suitability of Dredged Material

As mentioned in the assumptions for this section, sampling data was utilized to assess suitability of dredged material for disposal. Materials within the Caño Martín Peña include various types of solid waste, debris, and other materials. Such materials will require further testing prior to and/or during project construction, as appropriate, in accordance with an agreed sampling plan. If the testing determines that any materials contain hazardous substances at levels that are not suitable for unregulated disposal, they will be managed in accordance with the applicable laws and regulations of the relevant regulatory agencies. Although Section 404 testing could further confirm the suitability of dredged material for aquatic disposal, additional testing will not be conducted until the PED phase. As a result, although risk has been reduced by utilizing the existing sampling data and coordinating with the USEPA and the PREQB, there is a possibility that Section 404 testing could indicate unsuitable material within the CMP, potentially leading to a requirement for reformulation, which in turn could potentially lead to cost increases. If material were found unsuitable for aquatic disposal, the sediment/solid waste would need to be disposed of in an upland landfill or other approved location.

Prior to clearing, grubbing, and dredging activities, a sampling and remediation plan would be developed and approved by ENLACE, USACE, USEPA, and PREQB to ensure that hazardous substances are identified, managed, and disposed of according to applicable Federal, state, and local rules and regulations.

5.6.5 Ecosystem Response

Recovery of the SJBE is expected to follow a logarithmic scale, with substantial growth in fish, benthic, and mangrove communities due to an abundance of functional habitat and resources. Initial growth will be inevitably slow and will be followed by a more gradual, positive recovery as competition between resources begins to balance. Climatic or human-induced events such as chemical spills could slow the projected growth, particularly in certain geographic portions of the estuary that have been impacted in the past. During PED, an aquatic model will be used to further analyze the project's potential effects on fisheries resources; however, given the relative simplicity of the restorative actions of the project (i.e. dredging a clogged channel), no changes to the NER Plan are anticipated. Post-construction monitoring will be employed to maximize the project's ability to meet its goals and objectives, and any modifications to the project or it operation and maintenance would be conducted as part of the Adaptive Management process.

5.6.6 Potential for Induced Flooding During and After Construction

Existing flooding in the vicinity of the Project has been documented at various levels. During community meetings, residents have indicated observations of overflowing storm and sanitary sewers and flooding in streets and low-lying areas of the community. FEMA mapping places much of the adjoining community within the 100-year flood plain with a base flood elevation of 5.9 feet MSL.

Water levels along the CMP are directly influenced by the storm surge at San Juan Bay and San José Lagoon. Hydraulic analysis with storm surge compared the water levels in the channel prior to and during construction. During construction, the channel flow would be plugged. Storms lower than 25 years in return interval had virtually the same surface elevation for the existing and plugged condition. Storms 25 years or greater experienced maximum increases of 0.5 foot for the existing condition and 0.86 foot for the plugged condition. Storm events without storm surge are the ones most affected by the blocking of channel flow with the 100-year event increasing the water surface from 1.28 feet for the existing condition and 3.94 feet for the plugged condition, a change of 2.66 feet.

Modeling indicates that under the proposed condition, that is, after the channel has been constructed, storm surge elevations controls water levels for all return interval rainfall events. During rainfall events without storm surge, water levels are less than the existing condition due to the reestablishment of the direct connection between water levels at CMP, the San Juan Bay and San José Lagoon because standing water levels at CMP would be lower at the beginning of the storm event.

Tidal amplitude within the CMP and San José Lagoon would increase as a result of construction of the channel. The lagoon's tide range is expected to increase 1.28 feet after construction, which would equate to a 0.64-foot increase in average monthly water levels. The water surface rise may affect extremely low-lying structures around the SJL. In addition, storm sewers from the airport, at the north of the Suarez Canal, outfall into the SJL. The airport has been present for decades and presumably operating prior to the filling of the CMP. The airport is higher than its outfalls and thus may be able to build up a hydraulic head in its conduit to offset these monthly events.

The proposed Project Channel, along with its sheet pile walls and adjoining mangrove beds, are intended to form the floodway to contain the frequent storm events. Flood control measures, such as the construction of suitable protective structures between the channel waters and the adjoining low areas, will be incorporated to mitigate water backflow effect. Other alternatives may include the installation of a temporary sheet pile wall with local select backfill to buttress the structure. These temporary flood protection solutions would remain in place until the proposed sheet pile channel wall and upland embankment of the mangrove bed are installed. Proper construction (e.g., elevation) of the Paseo and related structures would provide additional, ancillary community flood protection.

Earthwork activities involving removal and placement of fill would probably be required for the foundations of the Paseo del Caño roadway. These works would be performed outside of the CMP-ERP footprint, and thus, would not be part of the Federal project. An elevated road could perform as an inland levee, depending on how high or elevated it is finally designed. Thus, it would help control flood waters rising from the dredged channel and its fringing mangroves that would be restored as part of the restoration project, protecting adjacent communities from these floods. However, if the elevation of the Paseo del Caño is higher than that of nearby areas, it could impact adjacent structures and cause runoff waters to pond in low lying areas. This would require additional infrastructure measures to address this potential problem.

Additional hydraulic and hydrologic (H&H) modeling and analyses are needed to confirm the potential for induced flooding as a result of the implementation of the CMP-ERP. This additional technical investigation would be completed before the conclusion of preconstruction engineering and design (PED).

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6.0 THE NATIONAL ECOSYSTEM RESTORATION PLAN

Alternative Plan 2, the 100-foot-wide by 10-foot-deep channel alternative (Figure 11), was identified as the NER Plan because: (1) it reasonably maximizes ecosystem restoration benefits compared to costs as a Cost Effective plan; (2) it would produce significant ecosystem restoration outputs that are recognized in terms of institutional, public, and/or technical importance; (3) it meets the four evaluation criteria of acceptability, completeness, effectiveness, and efficiency in the Economic and Environmental P&G for Water and Related Land Resources Implementation Studies; and (4) it fulfills the three study objectives. The NER Plan would result in restoration of tidal flow and circulation, which would improve water quality, and create, preserve, and restore fish and wildlife habitat in the CMP and the SJBE.

6.1 PLAN ACCOMPLISHMENTS AND RATIONALE FOR SELECTING THE NATIONAL ECOSYSTEM RESTORATION PLAN

The NER Plan would meet all the Goals and Objectives of the study. The improved conditions would reconnect the SJBE as one system with continuous and frequent renewal of ocean water (less than 4 days compared to approximately 17 days at present). Increased connection and conveyance would oxygenate the bottom waters of the shallow lagoons, improving the benthic habitat in the San José Lagoon for shrimp, crabs, mollusks, and other species vital to the health of the estuary. Fish habitat would be restored within the SJBE and offshore reef areas, as the increased connectivity would allow full movement and utilization of the estuary for juvenile stages of important species such as Nassau Grouper and Lane Snapper. The increased tidal flushing would improve water quality within mangrove habitat where 80 percent of commercially harvestable fish and shellfish spend part of their life cycle (USDA 2009).

The CMP-ERP would provide incidental flood risk reduction benefits by eliminating the blockage in the CMP that prevents local stormwater systems from properly draining. Just as the natural environment improves, the social environment will also benefit from the dredging of the CMP. Exposure to flood waters would be significantly reduced and the stresses related to frequent floods and infrastructure deficiencies will be diminished. Human health conditions would significantly improve to levels commensurate with Puerto Rico as a whole.

The removal of combined sewers, structure and household relocations, and construction of formalized access to the CMP (which would facilitate strict enforcement of trash-dumping regulations) should address the main sources of sedimentation within the CMP. Sedimentation resulting from discharges of the Juan Méndez Creek would be addressed by scheduled maintenance dredging in the CMP's outlet to the San José Lagoon.

6.1.1 Significance of Ecosystem Restoration Benefits

6.1.1.1 Public Significance

Although public significance can be recognized through authorization of the project in the WRDA 2007 and the statutes passed by the Government of Puerto Rico, perhaps more significant than the governmental recognition is the community adhesion and grassroots efforts that have contributed to the advancement of the project. Conditions in the CMP have worsened to the point that not only has fish and wildlife habitat been destroyed, but the ecosystem is actually causing deteriorating human health conditions in the adjacent areas. Human contact with the stagnant waters of the Caño Martín Peña has been shown to cause higher rates of gastrointestinal sickness, dermatitis and asthma; however, this problem would be alleviated by the proposed project, potentially saving over $38 million in associated public health care costs over the life of the project. Residents in these communities have actively been working to do what is possible to take care of the area, creating homemade blockades to prevent dumping and pollution, and have become an active voice for ecological restoration in Puerto Rico. The proposed project has the potential to improve habitat within the estuary, and perhaps just as important, improve socio-economic conditions for thousands of residents within the surrounding communities.

6.1.1.2 Institutional Significance

The San Juan Bay Estuary, at 93.44 square-miles, was the first tropical island estuary accepted into NEP in October 1992. The NEP was established in 1987 by amendments to the Clean Water Act to identify, restore, and protect estuaries of significance. The population of the coastal municipalities surrounding the SJBE was almost 1.18 million people in 2000, and the population density was 5,055 persons/mi2 (USEPA 2007), the highest observed for any of the 28 NEPs. The area is unique to the NEP due to the high density of population in the surrounding areas, and the severe poverty faced by those people inhabiting the project study area. Critical areas in the SJBE include coral communities, sea grass beds and mangrove forests, which would all be significantly restored by the proposed project.

Institutional significance can also be recognized by the Government of Puerto Rico through PR Law 489-2004, known as the Caño Martín Peña Special Planning District Comprehensive Development Act. Additionally, nearly the entire study area is considered EFH under the Magnuson-Stevens Fisheries Act. The proposed project will reverse a trend of direct and indirect habitat losses within the SJBE that have resulted in a diminished capacity to support existing fishing levels. Restoration of benthic areas, increased connectivity and improvements to mangrove habitat will in turn increase spawning, breeding, feeding and growth of fish within the SJBE, leading to a more sustainable regional commercial and recreational fishery.

6.1.1.3 Technical Significance

Thirty-three percent of the island's mangrove forests exist in the SJBE. Mangrove forests are one of the highest primary and associated secondary biologically productive ecosystems in the world, and form a base of the marine, arboreal and estuarine food webs. In 1995, over 324,500 lbs of finfish were landed in four municipalities within the SJBE (Cataño, San Juan, Loíza, and Carolina) (SJBEP 2000). Restoration of the mangrove habitat will boost numbers of sport and commercial fisheries through providing higher quality habitat and nursery grounds for juvenile marine and estuaries species. Increased connectivity within the estuary will also serve to increase biodiversity within the system, decreasing the effects of disease and eliminating the fragmentation that has caused severe degradation of the ecosystem. Increases in dissolved oxygen and the restoration of salinity levels within the San José Lagoon will benefit sport fisheries such as Tarpon, while providing food for a high number of sustenance fishermen in the area.

Endangered, threatened, endemic, and/or rare species in the estuary's watershed and associated areas include the Roseate Tern, the Yellow-shouldered Blackbird, the Leatherback Turtle, the Green Turtle, the Hawksbill Turtle, the West Indian Manatee, and 17 plant species. These species either reside in or utilize the project area and would experience direct benefits from the project as a result of water quality improvements, increases of prey species, and restoration of foraging, nesting and other habitat areas.

6.2 DESCRIPTION OF PLAN COMPONENTS

The descriptions below summarize the different components of the NER Plan. In addition to the channel dredging, disposal, non-structural measures, erosion control and construction of mangrove planting beds, the NER Plan also includes a number of secondary project components that did not factor into the primary formulation and evaluation of the proposed project. These components are as follows: Recreation Plan, Project Monitoring and Adaptive Management Plan, Nuisance and Exotic Vegetation Control, and Draft Project Operating Manual.

For additional engineering details, please refer to the Engineering Appendix. For additional information on the cost estimates for each of the plan features, please refer to the Cost Engineering Appendix.

6.2.1 Channel Dredging

The CMP-ERP consists of the dredging of approximately 2.2 miles of the eastern end of the CMP to a width of 100 feet and a depth of 10 feet (with the variations in channel width and depth for the Barbosa Avenue Bridge and terminus of the CMP with the San José Lagoon). The Project Channel would comprise 59.03 acres. The walls of the Project Channel would be constructed of vertical concrete-capped steel sheet pile embedded either 17 or 27 feet below the bottom of the channel. This depth is required for stability of the sheet pile as no connections to the surrounding lands are anticipated and to allow for some limited scour in channel bend areas. Typical sections for areas under bridges (Figure 15) and the main channel (Figure 16) are below; refer to the Engineering Appendix for additional sections. A temporary coffer dam would be constructed to parallel the shoreline at low-lying areas such as the bend at Barrio Obrero Marina to protect the area(s) until the dredging and permanent sheet pile construction was completed.

Dredging of the sediments would begin at the western end of the Project Channel to allow for the construction of the weir. Concurrently, mobilization for dredging at the confluence of the CMP and San José Lagoon would be undertaken, and subsequent dredging activities would commence from east to west in the Project Channel. Given the restricted physical environment within the CMP (shallow water, low bridge clearances), and the characteristics of the material to be dredged, the dredge type to excavate the CMP material would be a small clamshell mechanical dredge. The clamshell dredge could easily switch out between an open bucket (to excavate solid waste and stiff sediments) and an environmental bucket (to excavate unconsolidated contaminated sediments). The preparation and dredging of SJ1 and SJ2 would also commence during clearing and grubbing activities within the CMP. Both of these sites would be modified to increase capacity to accommodate the majority of dredged sediments and the required 2-foot sand cap. Approximately 517,581 cy of material would be removed from SJ1 and SJ2 and deposited within the San José 3/4/5 artificial subaqueous pits.

At the terminus of the Project Channel with the San José Lagoon, an extended channel would be dredged east into the San José Lagoon (over a distance of approximately 4,300 ft) as a hydraulic transition from the CMP. This extended channel would transition from the 10-foot-deep Project Channel to the 6-foot-deep areas of San José Lagoon. The extended channel would maintain the Project Channel's 100-foot width but replace its steel sheet pile walls with a trapezoidal configuration with 5-foot to 1-foot earthen side slopes. The extended channel would comprise 9.44 acres.

The Quebrada Juan Méndez (Juan Méndez) and the eastern end of the Project Channel meet at their confluence with San José Lagoon. The two channels are presently separated by a narrow band of mangroves, growing on built-up sediment deposits from the Juan Méndez (Figure 17). To minimize silt laden flow from the Juan Méndez entering the Project Channel, construction would include preserving and enhancing the sediment deposit berm between the channels. In this manner, sedimentation of the Project Channel would be reduced along with the subsequent need for maintenance dredging. To minimize potential damage to channel structures during maintenance dredging, the portion of the Project Channel paralleling the Juan Méndez would have a trapezoidal configuration with a 100-foot-wide bottom and 5-foot to 1-foot earthen side slopes, rather than the steel sheet pile walls.

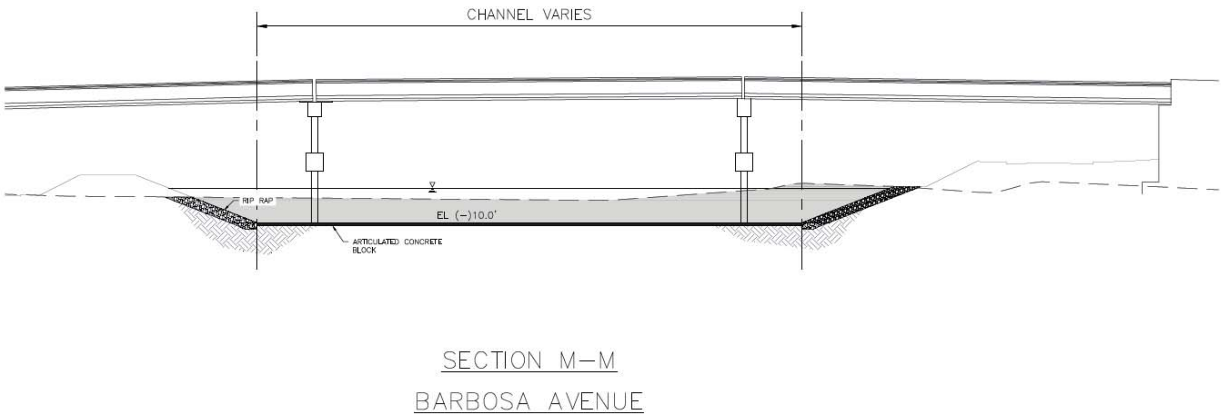

Figure 15. Typical Cross Section of the CMP Under Bridges

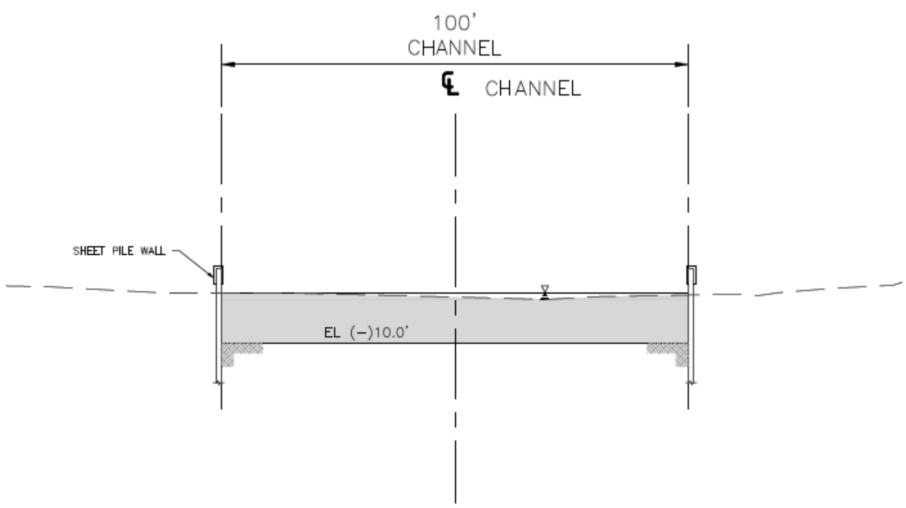

Figure 16. Typical Cross Section of the Open CMP

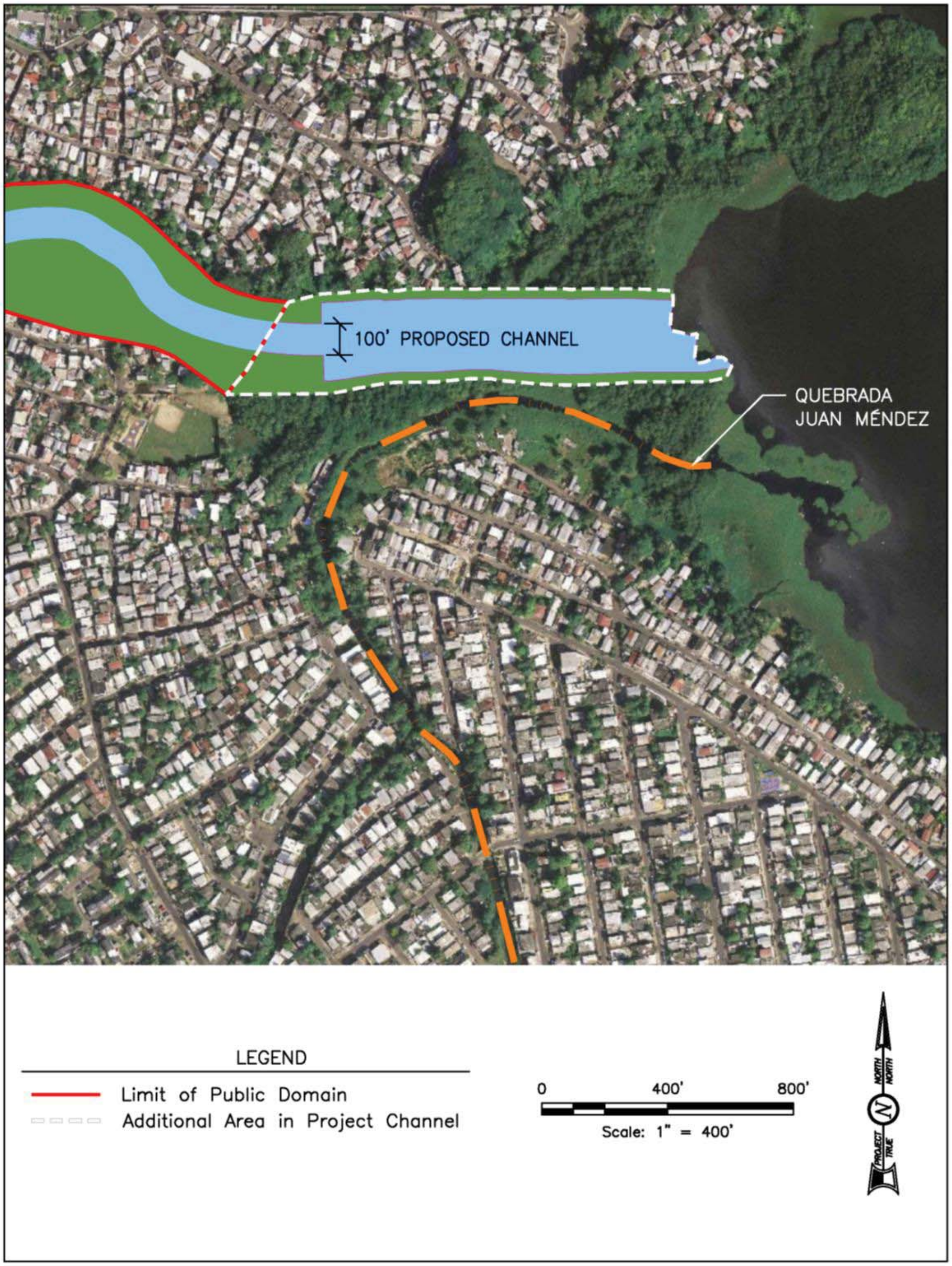

Figure 17. Quebrada Juan Méndez

6.2.2 Dredged Material Disposal

Approximately 10 percent of the dredged material is expected to be solid waste not suitable for aquatic disposal and will need to be screened. Metal sieves would be placed on top of the dump scows to allow for separation of the dredged material. The solid waste would be collected, processed, and transported to a 6-acre staging area at CDRC on the southeast shore of San José Lagoon. This staging area would be outfitted with a temporary dock for loading/unloading the dredged material prior to its transport to the Humacao landfill site, which is located approximately 32 miles from the CMP-ERP site. While there is not a dewatering component for the sediments or solid waste, the solid waste and associated debris would air dry during transport. After all solid waste has been disposed in the upland landfill, the 5-acre upland staging area would be restored with native upland vegetation, and the 1 acre of mangrove fringe would be restored with mangroves.

After screening and removal of solid waste debris, the remaining sediment and smaller pieces of solid waste would be encapsulated within geotextile fabric bags, and transported by shallow draft barges to the San José Lagoon artificial subaqueous pits. Sediments would be placed utilizing CAD in the SJ1 and SJ2 pits. During the CMP-ERP disposal operations, approximately 648,000 cy of in situ sediments would be placed in the SJ 1 and SJ2; however, additional water quality and sediment testing, such as bioassays, would be conducted prior to placement to ensure their suitability for disposal. Approximately 37,800 cy of in-situ sediments would be used to complete the sheet pile construction and mangrove bed restoration.

The SJ1 and SJ2 CAD sites would be capped with a 2-foot layer of sand. Material for the sand cap will be quarried from upland quarry sites and transported by trucks to the construction staging area for transfer to dump scows for placement. Silt curtains would also be employed around the CAD pits in the San José Lagoon. In critical areas, the curtains may double ring the active area for additional precautions. The curtains would be constructed to the full depth of the water where they are placed.

For activities related to the installation of the weir in the western end of the Project Channel, an upland staging area near the four western bridges would be used to temporarily stockpile and transfer the collected solid waste excavated during the dredging process. Equipment and materials would be staged on floating barges. After the construction of the weir, and once the dredging from the eastern portion of the Project Channel opened the CMP, the temporary coffer dam would be removed, and the stockpiled solid waste would be placed into shallow-draft barges for transport to the CDRC staging area. At the CDRC staging area, the material would be off-loaded, placed into trucks, and hauled for disposal at the Humacao upland landfill. Dredged sediment would be placed in barges for CAD within the SJL pits.

6.2.2.1 Applicability of Statutory and Regulatory Exclusions/Exemptions

The extent to which one or more potential exclusions or exceptions apply to the specific materials excavated during the project will depend upon the specific conditions and circumstances existing at the time of excavation.

For example, under the definition of HTRW in USACE Engineering Regulation 1165-2-132, dredged materials and sediments beneath navigable waters, including those that contain CERCLA hazardous substances or RCRA hazardous wastes, qualify as HTRW only if they are within the boundaries of a site undergoing a CERCLA response action or on the National Priorities List. Neither condition is considered applicable to this project. Further, under USEPA's hazardous waste exclusion for dredged material under RCRA, 40 C.F.R § 261.4(g), "dredged material that is subject to the requirements of a permit that has been issued under 404 of the Federal Water Pollution Control Act (33 U.S.C.1344) or section 103 of the Marine Protection, Research, and Sanctuaries Act of 1972 (33 U.S.C. 1413) is not a hazardous waste."

Final determination of the excavated materials' regulatory status will be made by the appropriate Federal and Commonwealth of Puerto Rico (the Commonwealth) regulatory authorities and would be a matter for discussion between the Commonwealth, as the responsible party, and those regulatory agencies.

6.2.2.2 Actionable Hazardous Substances

The CMP Ecosystem Restoration Federal project will not include costs associated with the management or disposal of any "Actionable Hazardous Substances," as defined herein. The Commonwealth shall be responsible for ensuring that the development and execution of Federal, State, Commonwealth, and/or locally required response actions to address Actionable Hazardous Substances are accomplished at 100 percent non-project cost. The Commonwealth also shall be responsible for and pay all costs associated with the generation, release, management, or disposal of any Actionable Hazardous Substances identified by sampling. The Commonwealth may request the services of the USACE to perform such actions outside of the Federal project.

All dredged or excavated materials will be tested for the presence of hazardous substances in accordance with a sampling plan to be agreed upon by the parties. All Actionable Hazardous Substances shall be segregated.

"Actionable Hazardous Substances" is defined for purposes of this project as any material that:

(1) contains a hazardous waste, as defined in USEPA's RCRA regulations;
(2) contains a hazardous substance as identified in 40 C.F.R. 302.3 and 302.4 in concentrations that pose a threat to human health or the environment as determined by USEPA; or,

(3) cannot, without additional treatment, be disposed of legally in a Subtitle D municipal solid waste landfill located within the Commonwealth of Puerto Rico, and is not environmentally appropriate, as determined by the Puerto Rico Environmental Quality Board, in consultation with USEPA, for disposal, without additional treatment, in open water or in the San José Lagoon Contained Aquatic Disposal areas.

Materials may constitute Actionable Hazardous Substances under the above definition regardless of whether such materials are subject to disposal pursuant to 33 U.S.C. 1344 or 33 U.S.C. 1413 or of such materials' jurisdictional status.

Disposal of classes or categories of materials determined not to be an "Actionable Hazardous Substance" as defined above shall be documented with an affirmative determination (by the appropriate regulator entity) supporting the proposed disposal methodology and location.

6.2.2.3 Establishment of Separate Memorandum of Agreement

In addition, prior to or concurrently with the execution of a Project Partnership Agreement (PPA) associated with the Federal project, the parties shall execute a separate MOA between the USACE and the Commonwealth. In accordance with the MOA, the Commonwealth shall be responsible for any Actionable Hazardous Substances encountered during the project. The MOA will explicitly provide that:

- All increased costs associated with the generation, release, management, and disposal of Actionable Hazardous Substances that exceed the cost of normal project design, engineering, and construction activities, and that are necessary to implement the Federal project features shall be excluded from total project costs and shall be paid by the Commonwealth under the terms of the MOA.
- After the discovery of Actionable Hazardous Substances, any further site characterization associated with the Actionable Hazardous Substances; development, planning, selection, and execution of appropriate response and disposal actions; and establishment and future management of disposal areas for all Federal, State, Commonwealth, and locally required actions to address those Actionable Hazardous Substances shall be paid 100 percent by the Commonwealth.
- The Commonwealth shall indemnify the Federal Government for any future liability associated with the generation, release, management, or disposal of any Actionable Hazardous Substances excavated or dredged during the project work.
- The Commonwealth may request USACE assistance in the removal and proper disposal of any Actionable Hazardous Substances necessary for the execution of the Federal project. Such work shall not be considered a Federal project cost and, as such, the only funds ultimately available shall be those funds provided by the Commonwealth under the MOA specifically for those purposes.

- Any future costs associated with such Actionable Hazardous Substances that exceed the scope of the MOA shall be the sole responsibility of the Commonwealth and shall be outside the Federal project.

6.2.2.4 Establishment of Escrow Account

Prior to the initiation of construction, the Commonwealth will establish an escrow account, with interest accruing to the Commonwealth, in an amount to be agreed upon that is sufficient to prevent delays in the execution of project work in the event that Actionable Hazardous Substances are encountered. Such escrow account will be maintained during the course of the project and will be used by the USACE in the execution of work relating to Actionable Hazardous Substances under the MOA, unless other funds are provided by the Commonwealth in time to prevent the suspension of work under the Federal project.

6.2.3 Erosion Control

The primary erosion control for the project is the construction of a weir at the western end of the project channel (Figure 18). This feature is expected to prevent scour around bridges, bulkheads, and other marine structures by providing a transition area to reduce flow, and unacceptable bottom velocities, between the Project Area and the western CMP. The weir, with a dimension of 6.5 x 115 feet, yields identical bottom velocities to Alternative Plan 1 (75 x 10 feet).

6.2.3.1 Turbidity Control

Turbidity controls will focus on minimizing dispersal of silt-laden waters from the project limits. To minimize dispersal of turbid water from the channel during dredging, a temporary coffer dam would be constructed west of the four bridges, and potentially at the channel's entrance to San José Lagoon (if access to the lagoon is not required for construction activities).

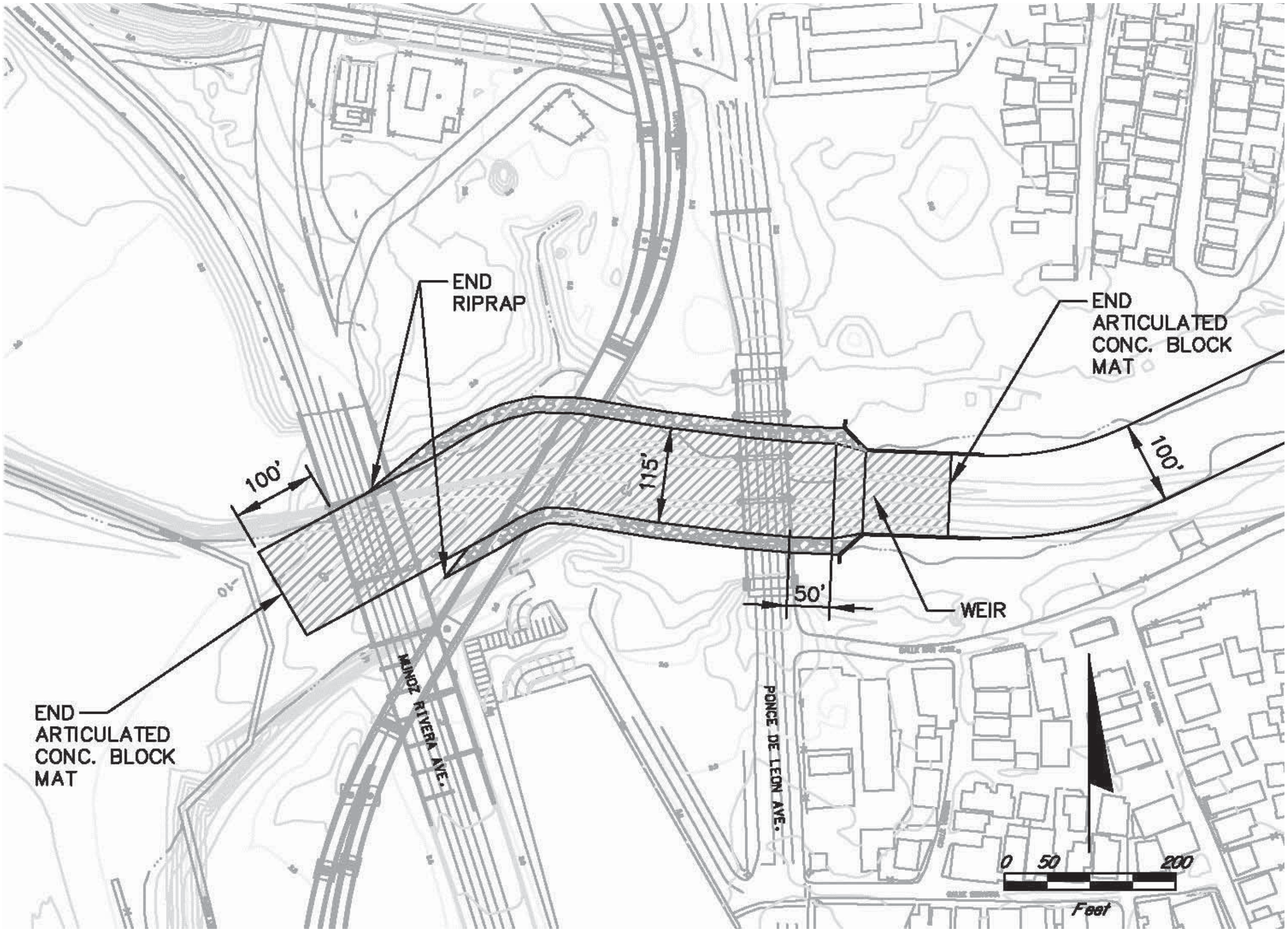

Figure 18. Weir, Overall Plan

Silt curtains would be employed within the channel corridor and around active dredging and excavations adjacent to the water; and around SJ1 and SJ2. Typically fabricated of flexible, polyester-reinforced thermoplastic (vinyl) fabric, the curtain is maintained in a vertical position by floatation material at the top and ballast chain along the bottom. In critical areas, the curtains may double ring the active area for additional precautions. The curtains would be constructed to the full depth of the water where they are placed; the coffer dam(s) would be sized and constructed in such a way as to prevent flooding impacts to adjacent areas.

During construction, best management practices (BMPs) would be used to minimize short-term and long-term sedimentation, erosion, turbidity, and total suspended solids (TSS). These BMPs during the construction phase would include seeding for temporary plant cover, retention blankets, silt fencing, and/or earthen diversions. Long-term turbidity and TSS management would be accomplished with storm water dispersion systems, paved discharges, blankets, matting, vegetative filter strips, and berms.

Sedimentation and erosion control devices would be deployed at the interface of the channel dredging and the uplands. Storm water from the project uplands would be filtered through these devices prior to discharge into the channel corridor. Storm water from existing community storm sewers would be directed into the channel corridor through temporary channels and flumes. Further treatment within the channel would be handled as turbidity control.

6.2.4 Mangrove Planting Bed Construction

Four species of mangrove would be considered for planting in the mangrove planting beds adjacent to the newly dredged CMP: *Rhizophora mangle* (red mangrove), *Avicennia germinans* (black mangrove), *Laguncularia racemosa* (white mangrove), and the associated species *Conocarpus erectus* (buttonwood). The flow of water from the channel to the mangrove planting beds would be facilitated by building hydraulic connections, or windows, in the bulkhead at regular intervals. The sill depth of the window would be set at mean low water so that tidal exchanges are facilitated to the mangrove beds. The width of the planting beds would vary depending upon the land availability, but in general would extend from the channel wall to the line of public domain, excluding only areas set aside for recreation elements of the NER Plan. The minimum width for mangrove fringes would be approximately 32 feet on either side of the CMP. Mangrove restoration would include 34.48 acres of wetlands.

Construction of the sheet pile walls would require the removal of existing soils along the channel. Care should be taken in the selection of replacement soils to ensure that they closely replicate the existing condition in a reference site for the project. Stockpile for reuse of excavated soils from dredging and bulkhead construction would be accomplished to maximize favorable conditions for natural recruitment and succession.

Monitoring of the mangrove restoration in both the CMP and CDRC planting areas has been included as part of the project cost.

6.2.5 Non-Structural Measures

Non-structural measures that would be implemented as a cost-shared part of the project would include structure acquisition and relocation. This measure is described more thoroughly in Section 6.5 and the Real Estate Appendix of this report. Increased enforcement of illegal dumping and community education would be implemented by ENLACE and the residents of the CMP outside the authority of this project. The community already has a program to erect barriers and patrol cleared areas to ensure illegal dumping is not conducted. ENLACE and the surrounding communities also have already implemented a community education program that informs the public on the importance of CMP health and effects on the local population. Continuation of the program is considered imperative to continue the environmental stewardship that has already begun and to encourage future generations in the area to prevent a return to present conditions.

6.2.6 Recreation Plan

The CDLUP and State Comprehensive Recreational Opportunity Plan are the foundation of recreational features selected for the project. The recreation features and final recreation measures that are identified in the Federal Recreation Plan were developed and selected through an intensive public participation and feedback process from the population in the surrounding communities. Over 700 public activities were conducted to promote effective participatory planning, decision making, and implementation over a two year period leading up to the initiation of the Feasibility Report.

Recreational features have been refined to ensure that they are in compliance with Exhibit E-3 of ER 1105-2-100, and thus allowable for use in the Federal recreation plan. The following is a list of the recreational features identified as acceptable for the Federal recreation plan.

- Trails
- Walks
- Steps/ramps
- Footbridges
- Picnic tables
- Trash receptacles
- Benches
- Entrance/Directional Marker
- Instructional signs
- Interpretive markers
- Gates
- Guardrails
- Lighting
- Handrails
- Walls

The non-Federal sponsor, ENLACE, will continue to work with the local community to implement the CDLUP. As part of the CDLUP, ENLACE proposes to include improvements to the aesthetic appearance and include additional opportunities in the Federal recreation plan areas. ENLACE will continue to refine the improvements and additional opportunities with the community in a timely manner to incorporate them into the construction of the Federal recreation plan, at 100 percent non-Federal cost. ENLACE is currently considering the addition of betterments to the lights, including figures or statues, and incorporating exercise stations, fishing, and kayak or canoeing opportunities. Navigation access would be provided through the Federal recreation access parks.

The Federal Recreation Plan would consist of 3 types of recreation access areas (Figure 19) on approximately 5 acres. The 3 types allow for major recreational use in some areas and median use in others. Two types would be adjacent to the proposed Paseo (whose construction is not a part of this federal ecosystem restoration project). This approach allows for large uninterrupted areas of restoration with major recreation areas that have access to the water, and median use areas along the smaller neighborhoods while connecting to the Paseo along the CMP.

1) **Linear Park**. This recreation area would consist of a trail, walk, and/or footbridge that extends the existing linear park located to the west of the Project Channel. The extended linear park trail would be constructed over the sheet pile bulk head in the channel (with the mangrove fringe between the linear park trail and the Paseo), and would be located on the southern side of the CMP, extending past the four western bridges in the project area and terminating at the first recreation access area in the Parada 27 community. In the vicinity of the western bridges, where the sheet pile wall is replaced with a riprap edge, the trail would be constructed on piles. If possible, benches may be placed in strategic locations to provide rest and or observation areas. The area would have an entrance sign, instructional signs and interpretive signs to educate the public on the CMP-ERP, proper use of the recreational area, and educational facts about the restored ecosystem. A gate and fence, or wall, would be placed along the CMP for safety and to discourage the disposal of materials into the CMP. Guardrails, handrails, steps, ramps, and lighting would be used, as appropriate, to maintain a safe and accessible recreation area. The linear park would fall within the navigational servitude.
2) **Recreation Access Park**. This type of recreational area would have open access to the restored CMP and would be scaled to accommodate more than 100 persons for passive recreation (Figure 20). The nine recreation access parks would provide visual openings through mangrove forest to the CMP, providing a strong community connection at these strategic locations. Each would be located strategically at the intersection of the Paseo del Cano walkway and an important community transportation artery. They would include picnic tables and benches to encourage educational gatherings and nature enthusiasts to enjoy the restored ecosystem. Each recreation access park would have an entrance sign, instructional signs and interpretive signs to educate the public on the CMP-ERP, proper use of the recreational area, and educational facts about the restored ecosystem. A gate and fence, or wall, would be placed along the CMP for safety and to discourage the disposal of materials into the CMP. Guardrails, handrails, steps, ramps, and lighting would be used, as appropriate, to maintain a safe and accessible recreation area. The recreation access parks would provide for navigation access to the CMP.

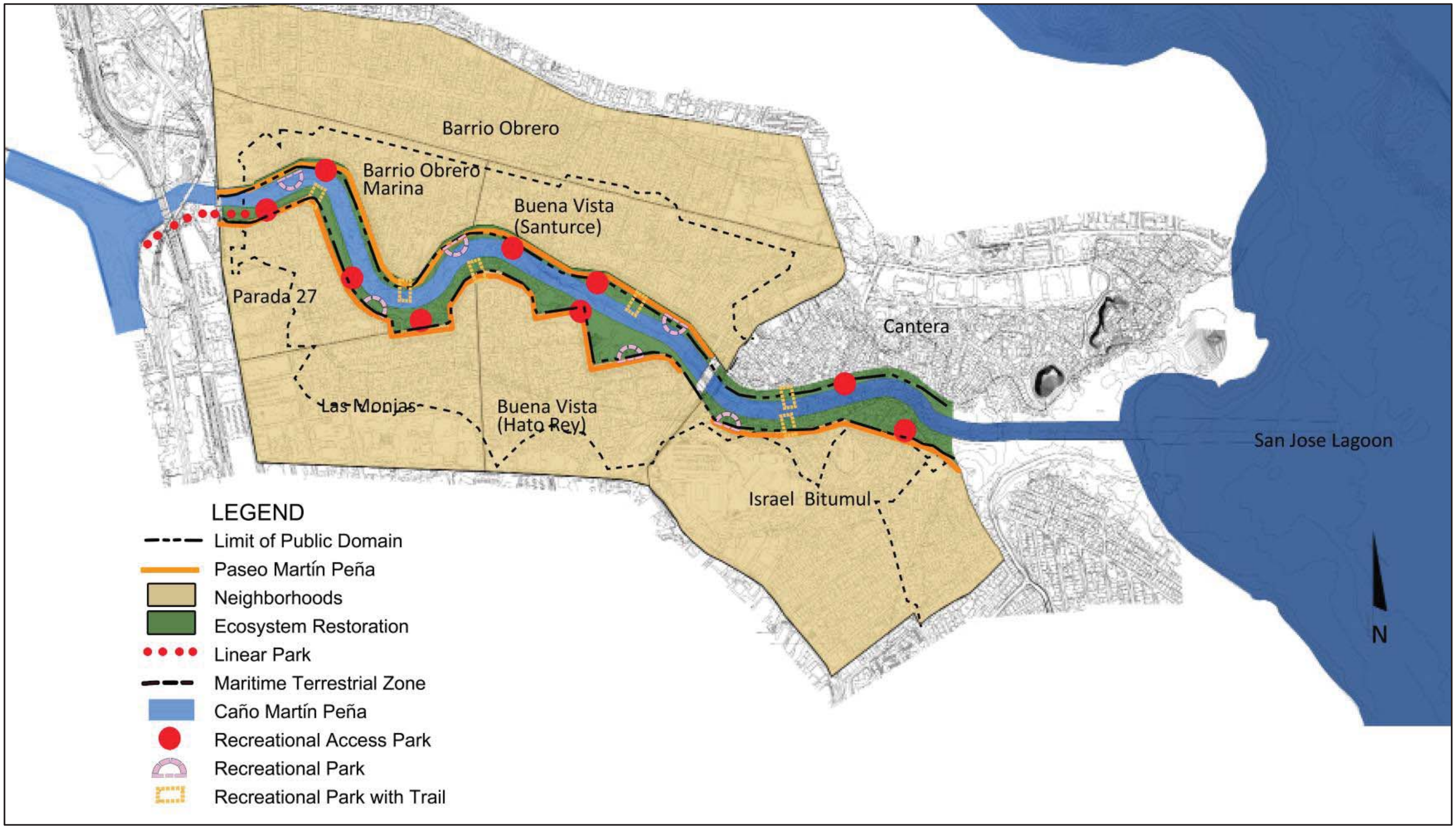

Figure 19. Proposed Federal Recreation Plan

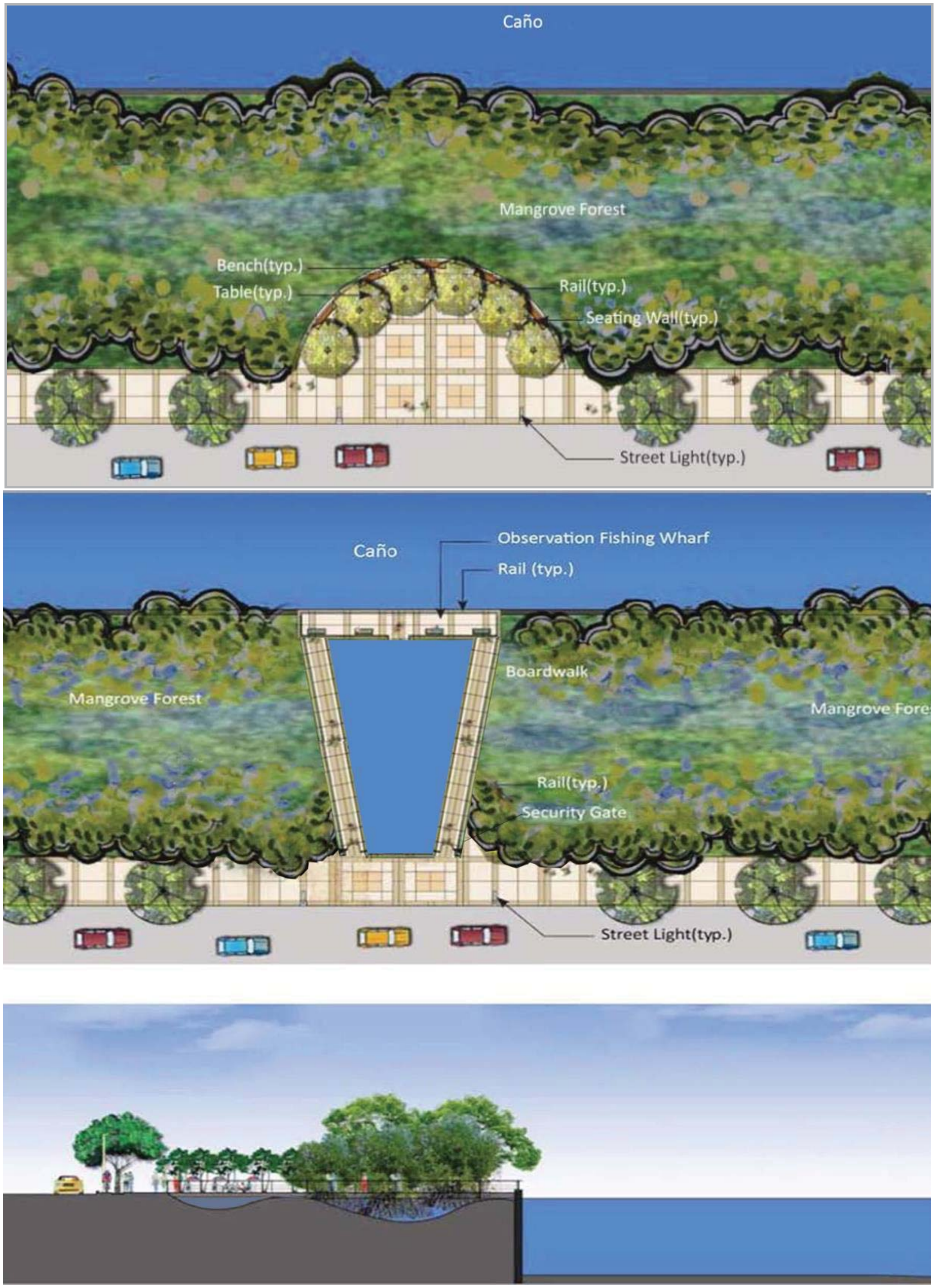

Figure 20. Prototype Recreation Park Design (a) no trail (b) with trail

3) **Recreation Park**. This type of recreational area would be smaller in scale than the proposed recreational access park, and would be scaled to accommodate less than 100 persons for passive recreation. With the natural mangrove forest serving as a backdrop, the twelve recreation parks would be strategically located along the Paseo del Cano walkway corridor to serve immediately adjacent blocks. In six of the recreation parks, a trail would be built through the forest to allow access to CMP (Figure 21). The recreation parks would include benches to create an outdoor classroom and be strategically positioned to enhance nature watching. They would have an entrance sign, instructional signs and interpretive signs to educate the public on the CMP-ERP, proper use of the recreational area, and educational facts about the restored ecosystem. A gate and fence, or wall, would be placed along the recreation park and CMP where applicable for safety and to discourage the disposal of materials into the CMP. Guardrails, handrails, steps, ramps, and lighting would be used as appropriate to maintain a safe and accessible recreation area.

There are no water-related recreation features currently within the Project Area, and as a result, there is no current or historic visitation information available for the types of proposed water-related recreational facilities. The existing land-related basketball/volleyball courts within the Project Area would be removed under the No-Action Alternative because they are in the public domain boundary. They will be replaced on a 1-1 usage basis and located outside the public domain using 100 percent non-Federal funds, and undertaken as part of the CDLUP. Their relocation is not associated with the CMP-ERP.

The Federal recreation plan is considered an essential component of the ecosystem restoration plan as it provides for a significant increase in recreational opportunities along the CMP, as well as helping alleviate the historic primary cause of ecosystem degradation in the area. The proposed recreational features are compatible with the ecosystem outputs for which the project is designed. They are compatible with the ecosystem restoration purpose by providing an appropriate interface within the urban environment and the aquatic environment. The features are appropriate in scale and have no impacts to the ecosystem restoration benefits that justify the CMP-ERP. The acreage necessary for the recreation features does not result in a loss of mangroves as the existing acreage of wetlands would be replaced with a net increase of higher functioning wetlands in the CMP, even with the 5 acres reserved for recreational features. In addition, the tidal connectivity for mangroves would still occur through the water, and the fish and wildlife that inhabit the mangroves would still be able to connect to other mangrove areas along the CMP through this water connection.

The recreational features are economically justified with a benefit to cost ratio of 6.9 to 1 and appropriately cost-shared 50 percent non-Federal and 50 percent Federal. The total recreation facilities first cost is $10,438,863 and the Federal share is $5,144,000 or 3.7 percent of the estimated non-recreation Federal cost share of $142,995,000 for the ecosystem restoration project. The 3.7 percent is in compliance with the requirement of not exceeding 10 percent of the non-recreation Federal project cost. The non-Federal sponsor would be 100 percent responsible for operation and maintenance of recreation features.

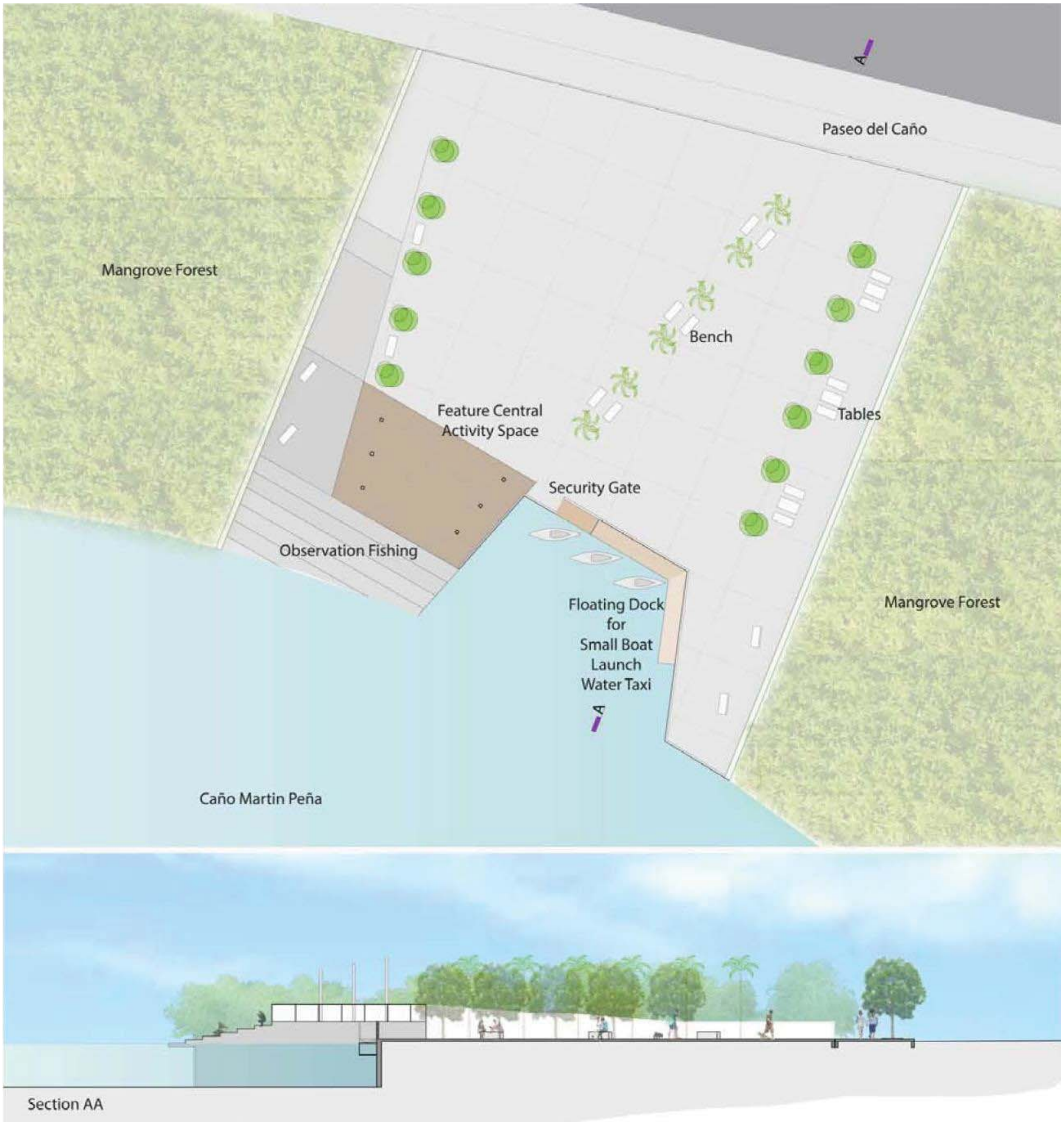

Figure 21. Sample design of recreation access park

The linear nature of the project area provides recreational uses for all eight neighboring communities; careful placement of these measures throughout the project area is also intended to protect the investment in ecosystem restoration by facilitating appropriate uses of the project area after the CMP-ERP is constructed. This approach facilitates the creation of larger, uninterrupted restored ecosystems, allows for easy access for project maintenance, and discourages improper and unmanaged uses of the area. It also aids education programs in increasing the environmental stewardship of this urban wetland. For example, improved and formalized access to the CMP and the resulting community engagement would facilitate strict enforcement of trash-dumping regulations and incentivize local conservation, thus avoiding future degradation in the process.

Provision of recreational access infrastructure has been demonstrated to foster community connection to the restored ecosystem and build and maintain a positive connection to their local landscapes (Golet et al. 2006; Ulrika Åberg & Tapsell 2013). Additionally, increases in recreational activities such as wildlife viewing, hunting, and fishing often translate to increases in support for conservation actions (Ulrika Åberg & Tapsell 2013). These activities provide the basis for new and existing community-based enterprises to flourish (e.g., Excursiones Eco, Bici-Caño).

6.2.7 Project Monitoring and Adaptive Management Plan

A Monitoring and Adaptive Management Program for the CMP-ERP has been developed to ensure the project achieves the desired restoration outcomes. The program focuses on project performance indicators that can be evaluated and predicted through modeling, and measured and monitored in the field.

The success of the project would be determined by initial physical changes in the system as a result of the opening of the CMP and eventual chemical (e.g., water quality) and biological changes. Project benefits are based upon a decrease in residence times within San José Lagoon following the dredging of the Project Channel, which would result in a decrease in the salinity stratification that currently is observed in the lagoon waters. The hydrodynamic and benthic index models suggest that increased flushing would decrease salinity stratification, increase the dissolved oxygen levels in bottom waters, and dramatically increase the ecological value of bottom waters in most of San José Lagoon. With increased dissolved oxygen within this area, benthic communities are expected to become more diverse, with a greater percentage of pollution-sensitive organisms and a smaller percentage of pollution-tolerant organisms. This series of changes outlines the parameters to be monitored that would reflect short-term and long-term response:

- Short-term: residence time (tidal exchange); water quality (dissolved oxygen)
- Long-term: fauna response; flora response

Based on previous studies, positive responses are "likely to occur" within a year of restoration of flushing and decrease in residence time, and substantial improvements in ecological health of the benthic and mangrove communities are "likely to occur" over a period of 2 or 3 years (Atkins 2011a).

Tidal velocities, estuarine residence time, water quality, Benthic Index scores, and diversity and function of the mangrove root community are performance indicators to be monitored and measured. The basic elements of the program include the following components.

1. Mangrove restoration – Ten 1,000 m^2 plots would be established along the restored CMP channel to assess seedlings survival.
2. Tidal and water quality stations – Four permanent tidal and water quality stations are proposed. The tidal stations would measure tidal fluctuations for translation into tidal exchange and residence time. The water quality stations would at minimum measure temperature, salinity/conductivity, dissolved oxygen, and pH.
3. Water quality profiles – Ten water quality profiles are proposed to be monitored on a monthly basis. Minimum parameters to be measure would be temperature, salinity/ conductivity, dissolved oxygen, and pH.
4. Benthic sampling stations – Thirty stations would be sampled (three grabs per station) and the organisms sorted and identified sufficient to create Benthic Index scores yearly at each station. The stations would be spaced through the SJBE with samples intensified within the 702 acres between -4 and -6-foot depth within San José Lagoon. Included in this effort are creel studies and interviews with recreational and commercial fisherman to help determine changes in fish abundance and diversity.
5. Mangrove prop root community study – Sampling of the stations in and around the Project Area to evaluate the encrusting community diversity and juvenile fish diversity.
6. Post-construction sedimentation rate – Bathymetric surveys to determine post-construction sedimentation rates and maintenance dredging requirements within the CMP.

The costs associated with implementing the monitoring program were estimated based on current available data and information developed during plan formulation (Table 25). Cost calculations for monitoring were calculated for a 5-year (maximum) period, consisting of 1-year pre construction, and 4-year post construction. If ecological success is determined earlier (prior to 4 years post construction), the monitoring program would cease and costs would decrease accordingly.

Table 25. Ecosystem Restoration Monitoring Plan Cost Estimate

Monitoring Plan Element	Estimated Equipment Cost	Estimated Annual Maintenance, Monitoring, and Reporting	Total Estimated Maintenance/ Monitoring/Reporting
Pre-construction baseline studies and mapping	$15,000	$60,000[1]	$60,000
Four permanent tidal/water quality stations	$40,000	$34,000[2]	$170,000
Inspection and bathymetric survey	–	$23,000[3]	$115,000
Ten water quality profile stations (Lab/field)	$10,000	$30,000[2]	$150,000
Thirty benthic sampling stations	$10,000	$80,000[2]	$400,000
Mangrove prop root community monitoring	–	$50,000[2]	$250,000
Creel survey	$5,000	$10,000	$50,000
End of monitoring period benthic mapping	–	$60,000[1]	$60,000
Data Analysis Evaluation and Assessment	–	$50,000[2]	$250,000
Equipment maintenance/transportation	–	$8,000[2]	$40,000
SUBTOTALS	**$80,000**	**$405,000**	
		Total Equipment and 5 Year Cost	**$1,625,000**
		Total 5-Year Cost with 3% Inflation	**$1,673,750**

[1]Single time cost / [2]Five year monitoring period / [3]1st. year for initial survey, $25,000; following 5 years, $18,000. Total of $115,000, or an annual average of $23,000.00.

The data collected through the proposed monitoring plan would provide information on whether selected targets have been achieved. Proposed adaptive management actions would be initiated if specific values for selected parameters or “triggers” are detected or measured during monitoring efforts.

Mangrove restoration success and water flow through the Eastern CMP are the two major uncertainties that would be addressed by several actions proposed as part of the Adaptive Management Plan. For mangrove restoration along the Eastern CMP, replanting mangrove species propagules has been proposed to replace those that could be lost due to natural or man-made factors. Increasing the area of the inlets (windows) in the sheet pile walls and/or conducting minor grading of the mangrove planting bed along the Eastern CMP would improve periodic tidal flow in case the topographic relief is unsuitable for the establishment of red mangrove trees. These actions would be triggered if the number of red mangrove propagules is reduced below 85% of those originally planted, and their implementation selected after first assessing and identifying those factors (natural or man-made) responsible for propagule mortality.

Adaptive management measures for tidal flow, bottom channel velocities and residence time would be triggered if (1) there is a decrease of 20% or more in tidal oscillation between the San Juan Bay and the San José Lagoon; (2) bottom velocities in the Eastern CMP are conducive to its sedimentation; and/or (3) result in scouring of the channel. These conditions would be addressed either by:

1. A one-time dredging event to provide a sump to store additional sedimentation at the confluence of the CMP and the Juan Méndez Creek prior to a 5-year cycle maintenance dredging scheduled.
2. Placement of boulders, rip rap, and/or other appropriate concrete structure at those sites that may result scoured in the Eastern CMP, including, if necessary, on either side of the weir's channel to constrict flow if flow velocities are stronger than expected.

Efforts to eliminate or reduce watershed based loadings from point and nonpoint sources of pollution would be encourage as a mean to improve water quality and overall habitat conditions in the event that adaptive actions to improve tidal flow and reduce water residence time prove to be insufficient to achieve expected targets or performance measures. The costs associated with implementing the Adaptive Management Program were estimated based on current available data and information developed during plan formulation (Table 26).

Table 26. Ecosystem Restoration Adaptive Management Plan Cost Estimate

Management Actions	Costs
One-time early dredging	$1,350,000
Placement of boulders, rip rap, and/or concrete structures in scoured areas	$750,000
Placement of rip-rap on either side of weir's channel to constrict flow	$1,005,890
Increase size of inlets within sheet piles	$52,500
Elevate mangrove planting bed relief	$175,000
Lower mangrove planting bed relief	$50,000
Replanting of mangrove planting bed	$42,000
Total	$3,425,390

Assumptions:

One-time early dredging would be performed as an adaptive management action. Subsequent dredging (annual dredging) is included in the O&M costs.

Mangrove re-planting would be carried out to replace dead mangroves propagules in order to increase up to 85% the number of trees initially planted.

Actions related to the implementation of best management practices to reduce erosion and sedimentation within San José Lagoon and the CMP watershed and eliminating/reducing raw sewage and polluted storm water discharges in coordination with related agencies would be funded by existing or future government watershed management programs.

Grading of mangrove planting beds could require either elevating or lowering its topography, or combining a limited scope of both actions. As such, total costs would be lower than those shown under any of these two cases for the total expenses related to the implementation of proposed management measures.

In light of the uncertainties remain as to the exact project features, monitoring elements, and adaptive management opportunities, the costs estimates may need to be refined in PED during the development of the detailed monitoring and adaptive management plans.

6.2.8 Nuisance and Exotic Vegetation Control

Initial control of invasive species would be provided during construction of the mangrove planting beds. Visual surveys and removal of identified invasive vegetation would be accomplished by physical removal or herbicide application as applicable. Over the life of the project, monitoring for invasive species establishment in the mangrove planting areas has been included as part of the project cost, and additional physical removal or herbicide application would be utilized as necessary. The project would be designed to provide optimal conditions for native vegetation, reducing the probability for establishment and spread of invasive species.

6.2.9 Draft Project Operating Manual

There are no day to day operating elements of the NER plan, so a draft operating manual has not been prepared at this time. An O&M Manual will be prepared during PED to guide project implementation to achieve project goals, purposes, and benefits outlined in this report and will encompass all reasonable foreseeable conditions that may be encountered during the project life. All costs associated with the maintenance of the project will be funded through O&M. At a minimum, the O&M manual would include discussions on maintenance requirements related to dredging, recreation, and mangrove restoration.

6.2.10 Description of Construction Activities and Sequence

Prior to the commencement of construction activities, all real estate activities would be completed, including the identification of real estate structures and issues, acquisition of structures, relocation of affected residents, and demolition and/or relocation of the structures. Concurrent with this activity would be the execution of agreements with one or more construction contractors to complete the CMP-ERP, typically preceded by a solicitation period to prospective bidders, receipt and review of bid submittals, selection of a successful bid, final negotiations and construction contract award.

Upon giving a Notice to Proceed to the selected contractor(s), the start and completion dates for the construction are finalized. Mobilization and site preparation activities would then commence. Mobilization is the period or periods during which the contractor deploys personnel and equipment to the site. These periods may take place in phases over various times during the construction. These activities would typically include the initial installation of construction fencing, sediment and erosion control devices, and the establishment of staging areas. Staging for the eastern end of the channel would be constructed at the CDRC. Staging for the western bridges would be a floating platform, comprised primarily of barge mounted equipment. The boats, barges, cranes, dredges, grizzlies, and other dredge equipment would be deployed. It is anticipated that equipment to be utilized for the dredging of the eastern channel would be brought in through San José Lagoon, and equipment slated for work under the western bridges would enter via the western branch of the Caño Martín Peña. This work would be performed in close conjunction with the clearing and grubbing activities. Should construction at the western bridges precede the eastern channel, the pits would have to be prepared and dredge equipment deployed overland.

During clearing and grubbing activities, trees, brush, root balls, and grasses would be stripped from the surface. All of the vegetation, sediment, and solid waste within an average of 12 inches throughout the Project Area would then be hauled to the upland landfill for disposal (Humacao). The stripped vegetation, including root balls, sediment, and solid waste evident on the surface and within the 12 inches, would be removed, loaded into trucks, and hauled to the upland landfill. Final adjustments to the construction fencing, sediment and erosion control devices, and staging areas would be completed during this activity. During clearing and grubbing activities, the turbidity curtain(s) would be installed by the SJ pits, and the preparation and dredging of the SJ1 and SJ2 would commence.

Upon completion of the above activities, staging areas and driveways for temporary placement of solid waste and dredged sediment from construction of the weir would be constructed near the western portion of the CMP project footprint. Temporary sheet pile dams would be placed to the west of the last of the four western bridges and along segments of low-lying areas along the Project Channel, particularly the bend at Barrio Obrero Marina.

With the completion of the temporary sheet pile dams, the excavation (dredging) and earthwork associated with the Project Channel would begin. Dredging activity would begin on both ends of the Project Channel concurrently. On the western end of the Project Channel by the four western bridges, dredging and related activities would take place to install the weir. Tasks associated with the installation of the weir include the preparation of the channel subgrade, placement of geotextile fabric, and the articulated concrete mat. Concurrent with this operation is the placement of scour protection (rip rap) around the bridge abutments, bridge pile caps and bridge columns, and along the channel side slopes. At the eastern end of the Project Channel, the 4,300-foot channel from the CMP into the San José Lagoon would be dredged, and dredging activities would take place in the Project Channel, from east to west, eventually connecting with the completed weir by the four western bridges. The equipment utilized for the installation of the weir would be scaled down for working near and under the bridge structures.

During the dredging of the channel, solid waste would be separated from the sediments and hauled by shallow-draft barge to the CDRC, where it would be offloaded onshore and reloaded into trucks for disposal at the upland landfill (Humacao). In the event that construction of of the weir begins prior to the eastern channel, all barge related activities would become overland trucking tasks. The remaining sediments and small pieces of debris would be encapsulated within geotextile fabric bags, moved by shallow-draft barges, and dumped in SJ1 and SJ2. Sediments that slough off the side of the channel would be dredged up and placed upland for use as backfill behind the sheet pile wall. In order to manage stormwater and tidal flows, the work under the bridges, including construction of the weir, must be completed prior to opening of the channel east of the weir.

In addition to the dredging, earthwork activities would be conducted upland of the dredged excavation to shape the surface of the soil along the project boundary and to collect and divert stormwater to a temporary protected outfall into the channel. Earthwork would also involve backfilling behind the sheet pile wall after the concrete wall cap for the sheet pile has been installed.

Following behind the dredging activity in the channel would be a concurrent process to install the sheet pile walls for bank stabilization starting from the east end of the Project Channel. After sufficient length of channel has been dredged, installation of the sheet pile would begin, with further dredging proceeding to the west. The sheet piles would be barged to the site and driven into place. After the wall construction has progressed sufficiently, forming and pouring of the concrete cap would occur, followed by the backfilling of the wall discussed above under earthwork. The wall openings for tidal conveyance to and from the mangrove bed would then be constructed. After the bank stabilization activities have been completed, the mangrove planting beds would be constructed.

Construction of the recreation areas would begin concurrently with the construction of the channel. The recreation component would include the upland recreational structures, paving and landscaping, and the walls and steps that form the interface between the parks and the sheet pile wall of the channel.

Upon notification by the construction contractor that substantial completion has been reached, the work would be inspected by those with oversight of the project. It is possible that the work would be broken into phases with each phase having separate and distinct inspections and close out activities. Work deemed incomplete or not constructed in accordance with the construction contract documents would be documented in the form of a punch list. The contractor would be required to perform the necessary corrective actions to remedy the items on the punch list. Follow-up inspections would be performed to ensure that all punch list items have been completed. Upon completion of the punch list items and delivery by the construction contractor of all documents required for closeout, project acceptance would be issued, ending the construction contract.

6.3 COST ESTIMATE

A breakdown of the cost of the CMP-ERP including construction, lands and damages, ecosystem restoration elements, PED costs, recreation and interest during construction is included in Table 27. The total estimated project first cost is $230,280,000. Project costs were estimated at 1 October 2014 price levels and rounded to the nearest $1,000. Refer to the Cost Engineering Appendix for the full MCACES cost estimate.

The NER Plan yields 6,133 AAHUs at an average annual cost of $10,829,000, with an average annual cost per average annual habitat unit of $1,766 (based on the MCACES and associated operations and maintenance cost estimates versus those developed with the Planning Level Cost Estimate for initial plan evaluation and comparison).

Table 27. Tentatively Selected Plan Cost Estimate

Feature	**Estimated Cost including contingency**	**Project First Cost-constant dollar basis (Effective Price Level Date 1 October 2014)**	**Total Project Cost fully funded**
Relocations (Cost to Date)	$263,000	$263,000	$263,000
Relocations	$17,105,000	$17,438,000	$18,429,000
Fish and Wildlife Facilities	$6,215,000	$6,346,000	$6,707,000
Channels and Canals	$49,576,000	$50,656,000	$53,533,000
Recreation Facilities	$8,852,000	$8,940,000	$9,447,000
Bank Stabilization	$66,735,000	$68,349,000	$72,230,000
Cultural Resources Preservation	$126,000	$127,000	$135,000
Construction Estimate Subtotal	$148,610,000	$152,120,000	$160,744,000
Lands and Damages (Cost to Date)	$6,038,000	$6,038,000	$6,038,000
Lands and Damages	$48,684,000	$49,428,000	$50,147,000
Planning, Engineering, and Design	$13,415,000	$13,616,000	$14,637,000
Construction Management	$8,944,000	$9,078,000	$10,104,000
Total Cost Estimate	$225,955,000	**$230,280,000**	$241,669,000
Interest During Construction (IDC)		$3,886,000	
Total Investment Cost		**$227,759,000**	
Average Annual Equivalent Cost		$9,759,396	
Average Annual OMRR&R		$1,070,000	
Total Average Annual Cost		**$10,829,000**	
Average Annual Cost per Average Annual Habitat Unit		**$1,766**	

Note: The TSP cost estimate includes several cost updates as compared to the Planning Level Cost Estimate that was used for the evaluation and comparison of the final array of alternatives. Updates/revisions included: inclusion/updates of utility relocations, updated Federal Discount rate, updated escalation table, updated AM/MP cost, updated quote for sheet pile wall, updated relocation costs, and inclusion of new mitigation measures. All of the cost updates and revisions associated with the TPCS would be common elements to the final array of alternatives, and as such, the result of the CE/ICA would not be affected. Thus these cost updates were not reflected in the Planning Level Cost Estimate.

6.4 DESIGN AND CONSTRUCTION CONSIDERATIONS

Design and construction of the CMP-ERP will be coordinated with adjacent construction activities that are not part of the federal project, including residential relocations, perimeter road construction and sanitary sewer, water, and electrical transmission line relocations. Ongoing planning efforts by ENLACE as part of the CDLUP would establish proposed elevations for the adjoining infrastructure are compatible. This effort must be carefully coordinated with the design of the Project Channel. This comparative analysis cannot be conducted without detailed engineering of these adjoining areas.

6.4.1 Engineering and Design

Additional technical investigations and studies are required for the CMP-ERP during PED. These investigations include items such as:

- Hydraulic and Hydrologic (H&H) modeling and/or analyses to:
  - Link tidal amplitude and flood surface elevations linearly from the western to the eastern ends of the channel to prepare a map that shows flood plain limits for various storm return periods. Based upon the topographic data, it is known that certain portions of the adjoining community are below base flood elevations. The preparation of a map that links tidal amplitude/flood elevations would provide a higher level of detail for determining where temporary flood protection of the adjoining community would be needed at the micro level while the project channel is under construction;
  - Update the existing H&H to determine allowable top of weir elevations for the installation of temporary cofferdams that will not cause the inundation of structures within the Project limits. The top of the temporary coffer dam at the western bridges must have a weir or spillway to control the maximum pool elevation of the water staging behind it. That elevation must be determined in conjunction with the top elevation of the temporary flood protection dams. This analysis would be a refinement of the work performed during the feasibility study;
  - Update the determination of scour rate through additional detailed sampling using FDOT procedure(s) for predicting scour rate for the type of material in the CMP. The soil investigation indicates that the silt clay material near the proposed channel bottom is predominantly hard and stiff, so there will be a time dependency for scouring. Extremely hard material can be very resistant to scour. Given that the peak tide velocities will only occur for several hours a day, this could be factored in to the design if the scour rate can be better predicted.
  - Perform bridge scour and analysis in accordance with the following documents:
    - Bridge Scour and Stream Instability Countermeasures: Experience, Selection, and Design Guidance-Third Edition
    - Publication No. FHWA-NHI-09-111 HEC-23, September 2009
    - FHWA Technical Advisory T 5140.23, Evaluating Scour at Bridges
    - NCHRP WEB only Document 107, Risk-Based Management Guidelines for Scour at Bridges with Unknown Foundations
  - Eastern CMP flows to and from the West is via the existing western channel, then into the Rio Puerto Nuevo and finally the San Juan Bay. The Rio Puerto Nuevo's drainage basin covers an area of approximately 24.2 square miles. A recent project to mitigate flooding in the Rio Puerto Nuevo's basin included the construction of enlarged, paved, high velocity channels. Concerns have been expressed over whether these improvements might have detrimental effects on the CMP-ERP. It is understood that the Corps modeled 10 scenarios resulting in hydrologic and water quality changes as part of the Hydrodynamic and Water Quality Model Study conducted for the SJBE Program in 2000. At least one of the scenarios, with a similar

configuration as the Tentatively Selected Plan for CMP-ERP, did not point to problems or issues such as backflow into the Lagoon, or significant increases in flood levels to those communities fringing the Eastern CMP. The model showed that levels in the San José Lagoon increased due to tidal influence.

It is recommended that this and other modeling conducted as part of the Puerto Nuevo flood control project be further reviewed to determine whether the simulations accounted for the Eastern CMP's proposed configuration, whether there are any problems or issues such as backflow into the San José Lagoon, or a significant increase in flood levels resulting from the Puerto Nuevo Flood Control Project that would affect those communities fringing the Eastern CMP once it is dredged. Dependent upon the results of the review, further modeling may be warranted.

- Geotechnical studies to:
    - Determine the depths of the piles supporting the Ponce de Leon and Luis Munoz Rivera Avenue bridge foundations. It is also recommended that a detailed structural conditions analysis be conducted for these two bridges and the existing Linear Park pedestrian bridge. Since as-built plans of the bridges were unavailable, the feasibility study was conducted without accurate information of the bridge pile cap elevations. Dredging under the bridges may not exceed the original construction depths. Otherwise, the bridge structures would become exposed and possibly require fortification. The additional studies would determine as-built pile cap elevations by performing non-destructive excavations (test pits and borings) to expose the bridge pile caps. Should it be determined that the preliminary plan for the channel under the bridges would expose bridge foundations, the proposed channel would be reconfigured around these structures and scour protection provided for their protection. It is anticipated that reconfiguration may widen the channel and adjust the channel invert in a manner that would maintain the cross sectional area required for the weir to function.
    - Determine the volume and location of dredged sediments that would be suitable and/or unsuitable for unconfined open water disposal, as well as to refine the current proportion of sediment to solid waste, 90 percent to 10 percent, respectively, using test pits or other suitable methods.
    - Characterize the stability of the pits during or after a disposal operation. With the use of the San José Lagoon pits as the recommended option for the aquatic disposal of dredged sediment, this issue should be investigated in more detail to prevent potential landslides, mainly slumps during the disposal.
    - Confirm sedimentation rates associated with the Juan Méndez, as the estimates used during the feasibility study are believed to be conservative. It is expected that a new investigation would identify a lower sedimentation rate because the 2003 study effort (Moffat and Nichol 2003) was conducted during the construction of 2 large developments along the Juan Méndez, and it is believed that the resulting sedimentation rates were elevated as a result of these activities. Moreover, the 2003 study effort did not account for mitigating factors such as improved tidal flow through the CMP, which may serve to disperse the sediments into lower energy

environments. If a lower sedimentation rate is confirmed, the operation and maintenance costs of the CMP-ERP would be reduced, perhaps significantly reduced.

- Surveys to:
    - Determine clearances underneath bridges and utilities to fully document and inform choice of dredge plans, sheet pile driving equipment, and other construction methods so that the likelihood or accidents occurring would be minimized;
    - Determine depth of cover over bridge pile caps in vicinity of the proposed project channel to prevent disturbing these existing bridge structures during dredging;
    - Ensure that the final design of the project fully complies with setback requirements from existing structures that will remain in areas adjacent to the project after construction; and
    - Determine whether structures adjacent to San José Lagoon would be impacted by restored tidal activity through the CMP. This effort would require topographic surveys of adjacent structures in conjunction with modeling of tidal action.
- Recreation feature studies to:
    - Ensure each recreational feature is developed in further detail in a manner that expresses the wishes, and reflects the character, of the neighborhood they represent.
- Environmental studies to:
    - Determine whether ground glass and/or dredged material from SJ1 and SJ2 can be used as an alternative to upland quarry sand. Due to present uncertainties in logistics, regulatory compliance, and ecological suitability, this option has not been recommended as part of the Tentatively Selected Plan. If further analysis during PED proves that this option is more reliable, cost efficient, and ecologically preferable, ground glass could be recommended to meet part or all of the cap sand requirements.
    - Additional chemistry data and bioaccumulation tests are required to verify the presence, concentrations, and toxicity of contaminants in the Project Channel (see Section 6.4.2, *Section 404 Testing*).

6.4.2 Section 404 Testing

Materials within the Caño Martín Peña include various types of solid waste, debris, and other materials. Such materials will require further testing prior to and/or during project construction, as appropriate, in accordance with an agreed sampling plan. If the testing determines that any materials contain hazardous substances at levels that are not suitable for unregulated disposal, they will be managed in accordance with the applicable laws and regulations of the relevant regulatory agencies.

Prior to disposal of dredged sediment within the San José Lagoon pits, additional water quality and sediment testing, such as bioassays, would be conducted in accordance with Section 404 of Public Law 92-217 (Clean Water Act of 1977). Coordination with the Puerto Rico Environmental Quality

Board (PREQB) has been initiated, and a Water Quality Certification would be obtained prior to disposal. Specific testing requirements to be conducted during PED would be determined in consultation with the PREQB.

If any (or all) materials were to be found unsuitable for near-shore aquatic disposal in the San José Lagoon pits disposal, they would be collected and disposed of in an upland landfill and/or permanent upland disposal site(s). If the use of the San José Lagoon pits was ruled out entirely, the other feasible disposal option would include the use of permanent upland landfill disposal. The potential use of the permanent upland landfill disposal was eliminated from the final array as those alternatives were considered less complete than the San José Lagoon pits, primarily based on public acceptability. The cost difference between the San José Lagoon pits and permanent upland disposal is estimated to be within approximately $20 million, with San José Lagoon pits being the more cost-effective solution.

6.4.3 Construction Monitoring and Mitigation Measures

Construction monitoring and mitigation measures to be employed are discussed below.

6.4.3.1 Water Quality (Turbidity)

Single and/or double barrier turbidity curtains, as well as a coffer dam(s) would be employed. A coffer dam would be constructed west of the four bridges and potentially at the channel's entrance to San José Lagoon (if access to the lagoon is not required for construction activities). Silt curtains would be employed within the channel corridor and around active dredging and excavations adjacent to the water; and around barges in the staging area of the Western CMP during transfer of dredged materials from pipe to barge and overflow procedures. The curtains would be constructed to the full depth of the water where they are placed; the coffer dam(s) would be sized and constructed in such a way as to prevent flooding impacts to adjacent areas. A double turbidity curtain would be placed around SJ Pit 1 and SJ Pit 2 during disposal operations.

Seeding for temporary plant cover, retention blankets, silt fencing, and/or earthen diversions would be employed.

Morning and afternoon turbidity readings would be taken twice daily with a nephelometer in the San José Lagoon, the Western CMP, and the area for disposal; monitoring would include comparison of turbidity in the water versus the baseline condition of the San José Lagoon and/or CMP.

If turbidity levels exceed the allowed above background regulatory levels, all dredging activity shall cease immediately. Dredging shall not resume until turbidity has returned to acceptable levels as determined by proper testing.

6.4.3.2 Water Quality (Contaminants)

Water columns would be sampled weekly at three locations, at a minimum: 1) within the actively dredged area, 2) a site inside the proposed 1,000-foot mixing zone near the disposal site, and 3) a site outside of the proposed 1,000-foot mixing zone, within the open waters of San José Lagoon. The following constituents, all of which have PREQB standards that results could be tested against, would be measured: antimony, arsenic, cadmium, cyanide (free CN), copper, chromium, fluoride, hydrogen sulfide, lead, mercury, nickel, nitrate plus nitrite, silver, selenium, thallium, and zinc.

If there is a contaminant problem, the response would be to stop work; determine the cause of the problem, and/or review procedures to determine means and methods that are effective.

6.4.3.3 Air Quality

Education and training about the symptoms and dangers of hydrogen sulfide poisoning would be provided for all individuals entering the work area. Personal protective equipment for workers such as respirators and/or SCUBA gear would be employed, as required. Air quality devices (portable on the land and stationary on the barges) would be used every day of construction (dredging) to measure air emissions near the dredging activities to ensure air quality standards are met, and to ensure H_2S levels do not exceed thresholds harmful for human health and safety.

If standards are exceeded, the response would be to stop work; spray water (with additives if necessary) on excavated sediments, trash racks and upland excavations to disperse hydrogen sulfide gas; await improved weather conditions that promote air movement; and/or review procedures to determine means and methods that are effective, such as moving the screening and separation to the more open staging area on the southeast side of San José Lagoon where the distance to receptors is greater.

6.4.3.4 Noise

Temporary noise curtains would be installed to the north and south of the dredging operations. Dredging and construction operations would be limited to 12 hours a day, with no dredging or construction activities to be conducted on Sundays.

Noise levels in areas adjoining construction sites would be monitored with appropriate portable and/or stationary equipment to ensure the levels are under the maximum allowances. If maximum allowances are exceeded, the response would be to stop work; conduct noise producing operations during daylight hours; and/or review procedures to determine means and methods that are more effective.

6.4.3.5 Vibration

Stationary vibration monitoring devices (4) along the border between the work and the adjoining structures, both north and south of the CMP, would be installed. In addition, a photo-survey of the exterior of existing structures facing and adjoining the work would be prepared to document pre-construction condition.

Measurements from the monitoring devices would be monitored for excessive levels of vibration, and visual observation of existing structures in areas adjoining construction sites would be conducted for visible damage. If excessive levels of vibration occurred, the response would be to stop work; avoid using equipment near adjoining structures that produces heavy vibrations; and/or review procedures to determine means and methods that are more effective. Alternative sheet pile installation methods such as "press-in" pile drivers or other drivers that produce less vibration may be used if available and feasible.

6.4.3.6 Environmental (Cultural Resources)

Photo-documentation would be recorded for the historic Martín Peña Bridge. A field archeologist (full-time), aided by a Supervising archeologist (part-time), would be employed to monitor construction activities near the bridge, as well as to monitor dredged materials during the construction (dredging) process. The archeologist would be on the materials barge where screening of dredged material occurs; if multiple dredges are operating simultaneously, at least one archeologist per dredge would be required. Cultural resources monitoring would be conducted as each clamshell bucket of material is laid onto the screen.

In the event that material of interest is observed by the archeologist during dredging and sorting operations, lifting of sediment would halt until the archeologist could determine whether the material is historic. If historic material is encountered, work in the immediate vicinity would halt until the SHPO, USACE, and the Institute for Puerto Rican Culture (IPRC) could be notified, and approval was given to proceed. Dredging could, however, shift to another area provided archeological monitoring occurs to avoid a stop-work situation.

6.4.3.7 Environmental (T&E Species)

A biologist (full-time) would monitor for the presence/absence of Threatened and Endangered species, as well as specifically for West Indian Manatee once the CMP channel is re-opened to San José Lagoon.

If a manatee or other Threatened and Endangered species is located within the project area, the response would be to stop work until the individual(s) leaves the dredging and construction area, or relocation as authorized by appropriate state and/or Federal agency was provided and successfully implemented.

6.4.3.8 Human Health and Safety

Use of protective gear by contractors during dredging and construction operations would be required. In addition, a chain link fence would be constructed along the length of the 2.2 miles, both north and south sides to prohibit animals, such as caimans, from relocating to urban areas when avoiding construction activities in the CMP. Pest control measures would also be employed where rodent traps would be deployed within the Project Area adjacent to the chain link fence. Collection of used traps and replacement traps would occur throughout the duration of the construction activities within the CMP.

If there is a problem, the response would be to stop work, conduct emergency relocations as necessary, and/or review procedures to determine means and methods that are more effective. The chain link fence would be monitored for any disrepair or collapse, and repaired/re-installed.

6.5 LANDS, EASEMENTS, RIGHTS-OF-WAY, RELOCATIONS, AND DISPOSAL AREAS

Prior to construction, access to all lands necessary for construction, easements, and rights-of-way (ROW) will be provided and removal of all structures within the ROW of (a) the eastern segment of the CMP, between the Barbosa bridge and the San José Lagoon, as well as for (b) the protection of the Muñoz Rivera, Tren Urbano, Ponce de León (Martín Peña) and Enrique Martí Coll Lineal Park bridges will be completed. The lands within the MTZ-CMP are public domain lands, and require little, if any, further land acquisition.

6.5.1 Utility Relocations

In addition to the 98 structure acquisitions and 55 relocations already completed as part of the Federal project, the plan would include the acquisition and removal of an additional 336 residential structures, along with relocation of affected families. Those structures would be demolished, their utility services rerouted or terminated, and the debris removed. Existing raw sewage discharges and uncontrolled storm water runoff from the area would be stopped prior to dredging activities. The relocation of the three major utilities that are located within the project area (a 115-kV Power Line, the Borinquen Water Transmission Line, and the Rexach Sewer Line [see Figure 4]) would occur as part of the CMP-ERP. Improvements to the San José Sewer Line, which is adjacent to the CMP-ERP Project Area, would be implemented independent of the Federal CMP-ERP. Any costs associated with its relocation and/or improvement would be 100% non-Federal, and not included as a project cost. Only the costs for the relocation of the Rexach Sewer Line, the Borinquen Water Transmission Line, and the 115-kV Power Line are included as part of the CMP-ERP.

6.5.2 Land Acquisition

Four hundred thirty-four structures and site improvements located within the MTZ-CMP are to be acquired and demolished as part of the dredging of the CMP. The appraised structures are located on land belonging to the Government of Puerto Rico. The 336 structures are mixed reinforced concrete with wood and zinc construction and primarily consist of residential units and a few commercial properties.

6.5.3 Relocation Assistance

The U.S. Army Corps of Engineers, Jacksonville District, has provided oversight and guidance to ENLACE related to the real estate acquisition and relocation process. In accordance with the Uniform Relocation Assistance and Real Property Acquisition Policies Act of 1970 (URA), as amended (42 U.S.C. 9601 et seq.), relocation assistance will be provided to persons displaced as a result of the project. Neither lack of title nor failure to meet any length of occupancy criterion will disqualify a person from being treated as a displaced person eligible for relocation assistance. The nature and amount of assistance provided will be determined in accordance with the URA and the lead agency implementing regulations at 49 C.F.R. Part 24. All displaced persons will receive relocation assistance advisory services and be eligible for reimbursement of moving expenses. No residential owner-occupant or tenant who qualifies as a displaced person will be compelled to relocate unless comparable replacement housing is available. Because there is little comparable replacement housing available to displaced persons within the entire project area, last resort housing assistance will be necessary for the area as a whole. Relocation assistance has already been provided for 55 owner occupants and/or renters as part of the CMP-ERP, and an additional 335 owner occupants and/or renters would receive relocation assistance as part of the Federal CMP-ERP. Currently there is no estimate for the number of businesses within the project footprint.

6.6 OPERATIONS AND MAINTENANCE CONSIDERATIONS

Total operations and maintenance costs are estimated to be $59,422,721 (see Table 28). The Project Channel is considered to be self-operating with flow controlled by the incoming and outgoing tides. There are no mechanical systems in the CMP-ERP.

The Project Channel is considered to be self-operating with flow controlled by the incoming and outgoing tides. Sediment transport from surrounding uplands, the San José Lagoon, and the existing western channel are expected to deposit up to 1.5 inches yearly in the Project Channel. Due to the self-cleaning channel velocities, most of the shoaling is expected to be concentrated at either end of the proposed channel outside of the dredged Project Channel footprint. The high channel velocities at the transition to the western CMP indicate that shoaling in that area would be minimal. Shoaling in San José Lagoon at the outlet of the CMP and within the extended channel is of greater concern, with accumulations of up to 35,000 cy annually expected to be deposited in flood-tide shoals. It is noted that this estimate is based on a conservative 2003 estimate that developed sedimentation rates in the vicinity of the CMP but did not account for mitigating factors such as improved tidal flow through the CMP, which may serve to disperse the sediments into lower energy environments (Moffat and Nichol 2003). This estimate is therefore considered very conservative.

These shoals should be monitored to ensure that the CMP outlets remain unobstructed for tidal flows; if shoaling begins to reduce tidal exchange, maintenance dredging would be required. As the shoaling material is expected to be uncontaminated, disposal of these sediments is not expected to require CAD or upland disposal. The CAD pits have capacity for 1 or 2 years of depositions from the Juan Méndez. After that, the dredged sediments would have to go elsewhere. As these sediments are not expected to be contaminated, disposal should not require confined disposal techniques. The sediments could be loaded into scows and transported to the San Juan ODMDS or to the remaining artificial dredged pits left in the San José Lagoon for unconfined open water disposal. Conveyance of the dredged sediments to the ODMDS would require either pumping over the proposed weir at the western bridges or the use of light loaded, shallow drafting scows. Alternatively, the sediments could be offloaded at the CDRC and trucked to an upland site. All necessary regulatory permits would be secured at that time. A sensible solution for consideration would be determining the necessary stabilization measures needed to prevent the transport of sediments from the Juan Méndez into the eastern CMP in the first place. It is assumed that maintenance dredging activities would occur on a 5-year cycle.

Table 28. Operations and Maintenance Costs

Recreation Features Maintenance Labor			Life Cycle Cost (2015 Constant Dollars)
Supervisory Labor	Removal of litter, fertilization of trees and shrubs; management of disease and/or insects in trees and shrubs either by cultural or chemical methods; sweeping, blowing, and power washing of walkways, and other hardscape surfaces; visual and physical examination of facilities to ensure compliance, safety, and proper operation; maintenance of equipment including drinking fountains, tables, trash receptacles, benches, bike racks, boat docks and gangways	2,080 Hours per Year at $13.96/Hr Plus Fringes and Benefits. Assume $3.00 for Fringes, plus Labor Multiplier of 2.5 for Insurance, Benefits, and Overhead	$4,409,600
Maintenance Labor		4,160 Hours per Year at $ 9.05/Hr plus Fringes and Benefits. Assume $3.00 for Fringes, plus Labor Multiplier of 2.5 for Insurance, Benefits, and Overhead	$6,266,000
Capital Repair and Replacement of Recreation Assets			
Utility Infrastructure	Decorative lighting	5 years repair, Repair Cost is estimated at 10% of the construction cost per year	$525,840
		20 year replacement	$1,029,648
	Yearly operating cost	Assume $350 per park area per month	$4,620,000
Park amenities	Handrails, bollards, tables, benches, trash receptacles, and bike racks	3 years repair, repair cost is estimated at 5% of the construction cost per year	$1,493,941
		10 years replacement	$3,845,885
Paving and hardscapes	Decorative pavement, tree grates, seawalls, and boardwalks	10 years repair, repair cost is estimated at 5% of the construction cost per year	$988,390
		25 years replacement	$6,592,560
Waterfront Equipment	Floating docks and gangways	5 years repair, Repair cost is estimated at 15% of the construction cost per year	$785,870
		25 years replacement	$3,614,986
		TOTAL Recreation O&M	**$34,172,721**
CMP Inspections, Surveys, and Dredging			
Inspection and survey	Perform underwater surveys of channel bottom and inspection of sheet pile structures and bank	Yearly	$2,500,000
Maintenance dredging	Maintenance dredging to remove deposits and sediment accumulations at the confluence of the CMP and the San Juan Lagoon	5-year dredging cycle, estimated at 35,000 cy per year, or 175,000 cy every 5 years	$22,750,000
		TOTAL CMP Inspections, Surveys, and Dredging O&M	**$25,250,000**
		TOTAL O&M	**$59,422,721**

6.7 ENVIRONMENTAL OPERATING PRINCIPLES

The formulation of all of the alternatives considered for implementation was done in accordance with the USACE Environmental Operating Principles:

- Foster sustainability as a way of life throughout the organization.
- Proactively consider environmental consequences of all Corps activities and act accordingly.
- Create mutually supporting economic and environmentally sustainable solutions.
- Continue to meet our corporate responsibility and accountability under the law for activities undertaken by the Corps, which may impact human and natural environments.
- Consider the environment in employing a risk management and systems approach throughout the life cycles of projects and programs.
- Leverage scientific, economic and social knowledge to understand the environmental context and effects of Corps actions in a collaborative manner.
- Employ an open, transparent process that respects views of individuals and groups interested in Corps activities.

Planning for the CMP-ERP was based on over a decade of intense work to engage the public and stakeholders in developing management plans for the San Juan Bay Estuary in general and the CMP in particular. The planning process fully considered the relationship of a restored ecosystem to the socioeconomic wellbeing of the surrounding neighborhoods. The planning process has been open and transparent, and has fully leveraged the scientific, economic, and social knowledge of the project's stakeholders and Federal, Commonwealth, and local agencies. The NER Plan has been designed to be sustainable in its own right, but also to contribute to the sustainability of the ecosystem and communities beyond the Project Area.

As part of its effort to transform the way it does business, the USACE developed its Campaign Plan to identify and establish the agency's priorities. Through implementation of the Campaign Plan, the organization would deliver superior performance, set the standard for the engineering profession, make a positive impact on the Nation, and build to last. Of the four goals of the Campaign Plan, Goal #2, "Transform Civil Works," is focused on delivering enduring and essential water resource solutions, utilizing effective transformation strategies. The conduct of the CMP-ERP is consistent with Goal #2 of the Campaign Plan, and the CMP-ERP is an example where the USACE would meet the objectives of the Campaign Plan to assist ENLACE with the building a sustainable ecosystem restoration project that would have a significant impact to the residents surrounding the CMP, the Commonwealth, and the Nation.

6.8 PROJECT COST AND REAUTHORIZATION

Section 902 of the WRDA of 1986 legislates a maximum total project cost. Projects to which this limitation applies and for which increases in costs exceed the limitations established by Section 902 require further authorization by Congress raising the maximum cost established for the project. No funds may be obligated or expended nor any credit afforded that would result in the maximum cost being exceeded, unless the House and Senate committees on Appropriations have been notified that Section 106 of the Energy and Water Development Appropriations Act of 1997 will be utilized. The maximum project cost allowed by Section 902 includes the authorized cost (adjusted for inflation), the current cost of any studies, modifications, and actions authorized by the WRDA of 1986 or any later law, and 20 percent of the authorized cost (without adjustment for inflation). The Section 902 maximum project cost has further guidance in ER 1105-2-100 (Planning Guidance), Appendix G, Section G-15-1, which states that the maximum project cost limit imposed by Section 902 is a numerical value specified by law which must be computed in a legally supportable manner. It is not an estimate of the current cost of the project. The limit on project cost must be computed including an allowance for inflation through the construction period. This limit will then be compared to the current project estimate including inflation through the construction period.

The authorized cost for the CMP Ecosystem Restoration project in WRDA 2007 is $150,000,000. After Section 902 guidance is applied, the adjusted budget (including inflation and adaptive management costs) of the project is $242,173,000, adjusted to 3Q 2018 dollars. The first cost of construction estimate for the NER Plan is $230,280,000 and the fully funded NER Plan cost estimate is $241,669,000 (mid-point of construction). Table 29 presents Authorized, Adjusted, and Recommended Plan Cost.

Table 29. Caño Martín Peña Ecosystem Restoration Project Authorized, Adjusted, and Recommended Plan Cost Table (FY 2017; 1,000s)

Line 1		
a.	Current Project estimate at current price levels:	$230,280
b.	Current project estimate, inflated through construction:	$241,669
c.	Ratio: Line 1b / line 1a	1.0495
d.	Authorized cost at current price levels:	$202,174
	(Column (h) plus (i) from table G-3)	
e.	Authorized cost, inflated through construction:	$212,173
	(Line c x Line d)	
Line 2	Cost of modifications required by law:	$0
Line 3	20 percent of authorized cost:	$30,000
	.20 x (table G-3, columns (f) + (g)	
Line 4	Maximum cost limited by section 902:	$242,173
	Line 1e + line 2 + line 3	

Notes: The cost index applied to the current estimate through PED is derived from: EM 1110-2-1304, 31 March 2015 (Quarterly Tables), Civil Works Construction Cost Index System.

Real estate costs were not specifically defined in the authorization; therefore, real estate costs have not been escalated separately in the 902 tool.

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7.0 PLAN IMPLEMENTATION

7.1 SCHEDULE

The following schedule outlines the remaining planning, PED, and construction tasks required to implement the Tentatively Selected Plan.

Milestone	Schedule
Request PED Funding	November 2015
Final Report Approval (end of feasibility)	December 2015
Request Construction Funding	January 2016
Execute Cost Sharing Agreement for PED	February 2016
Begin Preconstruction Engineering and Design	April 2016
Execute Project Partnership Agreement (PPA)	October 2016
Start baseline monitoring	April 2017
Complete Design Documentation Report	October 2017
Complete Plans and Specifications	October 2017
Advertise Construction	November 2017
Award the contract	December 2017
Complete Real Estate Acquisition	February 2018
Start construction	October 2018
Complete Construction	December 2020
Turn Over Project to Local Sponsor	2020
Initiate Monitoring and Adaptive Management	January 2021
Complete Monitoring and Adaptive Management	2026

7.2 ITEMS OF LOCAL COOPERATION

ENLACE as the Non-Federal sponsor shall, prior to implementation, agree to perform all of the local cooperation requirements and non-Federal obligations. Local cooperation requirements and ENLACE's obligations include, but are not necessarily limited to:

a. Provide 35 percent of total project costs as further specified below:

   1. Provide 35 percent of design costs in accordance with the terms of a design agreement entered into prior to commencement of design work for the project;

   2. Provide all lands, easements, and rights-of-way, including those required for relocations, the borrowing of material, and the disposal of dredged or excavated material; perform or ensure the performance of all relocations; and construct all improvements required on lands, easements, and rights-of-way to enable the disposal of dredged or excavated

material all as determined by the Government to be required or to be necessary for the construction, operation, and maintenance of the project;

3. Provide, during construction, any additional funds necessary to make its total contribution equal to 35 percent of total project costs;

b. Provide 50 percent of total recreation costs as further specified below:

1. Provide 50 percent of design costs allocated by the Government to recreation in accordance with the terms of a design agreement entered into prior to commencement of design work for the recreation features;

2. Provide, during the first year of construction, any additional funds necessary to pay the full non-Federal share of design costs allocated by the Government to recreation;

3. Provide all lands, easements, and rights-of-way, including those required for relocations, the borrowing of material, and the disposal of dredged or excavated material; perform or ensure the performance of all relocations; and construct all improvements required on lands, easements, and rights-of-way to enable the disposal of dredged or excavated material all as determined by the Government to be required or to be necessary for the construction, operation, and maintenance of the recreation features;

4. Provide, during construction, any additional funds necessary to make its total contribution for recreation equal to 50 percent of total recreation costs;

c. Provide, during construction, 100 percent of the total recreation costs that exceed an amount equal to 10 percent of the Federal share of total ecosystem restoration costs;

d. Shall not use funds from other Federal programs, including any non-Federal contribution required as a matching share therefore, to meet any of the non-Federal obligations for the unless the Federal agency providing the funds verifies in writing that such funds are authorized to carry out the project;

e. Prevent obstructions or encroachments on the project (including prescribing and enforcing regulations to prevent such obstructions or encroachments) such as any new developments on project lands, easements, and rights-of-way or the addition of facilities which might reduce the outputs produced by the project, hinder operation and maintenance of the project, or interfere with the project's proper function;

f. Shall not use the project or lands, easements, and rights-of-way required for the project as a wetlands bank or mitigation credit for any other project;

g. Comply with all applicable provisions of the Uniform Relocation Assistance and Real Property Acquisition Policies Act of 1970, Public Law 91-646, as amended (42 U.S.C. 4601-4655), and the Uniform Regulations contained in 49 CFR Part 24, in acquiring lands, easements, and rights-of-way required for construction, operation, and maintenance of the project, including those necessary for relocations, the borrowing of materials, or the disposal of dredged or excavated material; and inform all affected persons of applicable benefits, policies, and procedures in connection with said Act;

h. For so long as the project remains authorized, operate, maintain, repair, rehabilitate, and replace the project, or functional portions of the project, including any mitigation features, at no cost to the Federal Government, in a manner compatible with the project's authorized purposes and in accordance with applicable Federal and State laws and regulations and any specific directions prescribed by the Federal Government;

i. Give the Federal Government a right to enter, at reasonable times and in a reasonable manner, upon property that the non-Federal sponsor owns or controls for access to the project for the purpose of completing, inspecting, operating, maintaining, repairing, rehabilitating, or replacing the project;

j. Hold and save the United States free from all damages arising from the construction, operation, maintenance, repair, rehabilitation, and replacement of the project and any betterments, except for damages due to the fault or negligence of the United States or its contractors;

k. Keep and maintain books, records, documents, or other evidence pertaining to costs and expenses incurred pursuant to the project, for a minimum of 3 years after completion of the accounting for which such books, records, documents, or other evidence are required, to the extent and in such detail as will properly reflect total project costs, and in accordance with the standards for financial management systems set forth in the Uniform Administrative Requirements for Grants and Cooperative Agreements to State and Local Governments at 32 Code of Federal Regulations (CFR) Section 33.20;

l. Comply with all applicable Federal and State laws and regulations, including, but not limited to: Section 601 of the Civil Rights Act of 1964, Public Law 88-352 (42 U.S.C. 2000d) and Department of Defense Directive 5500.11 issued pursuant thereto; Army Regulation 600-7, entitled "Nondiscrimination on the Basis of Handicap in Programs and Activities Assisted or Conducted by the Department of the Army"; and all applicable Federal labor standards requirements including, but not limited to, 40 U.S.C. 3141–3148 and 40 U.S.C. 3701–3708 (revising, codifying and enacting without substantial change the provisions of the Davis-Bacon Act (formerly 40 U.S.C. 276a et seq.), the Contract Work Hours and Safety Standards Act (formerly 40 U.S.C. 327 et seq.), and the Copeland Anti-Kickback Act (formerly 40 U.S.C. 276c et seq.);

m. Perform, or ensure performance of, any investigations for hazardous substances that are determined necessary to identify the existence and extent of any hazardous substances regulated under the Comprehensive Environmental Response, Compensation, and Liability Act (CERCLA), Public Law 96-510, as amended (42 U.S.C. 9601-9675), that may exist in, on, or under lands, easements, or rights-of-way that the Federal Government determines to be required for construction, operation, and maintenance of the project; however, for lands that the Federal Government determines to be subject to the navigation servitude, only the Federal Government shall perform such investigations unless the Federal Government provides the non-Federal sponsor with prior specific written direction, in which case the non-Federal sponsor shall perform such investigations in accordance with such written direction;

n. Assume, as between the Federal Government and the non-Federal sponsor, complete financial responsibility for all necessary cleanup and response costs of any hazardous substances regulated under CERCLA that are located in, on, or under lands, easements, or rights-of-way that the Federal Government determines to be required for construction, operation, and maintenance of the project;

o. Agree, as between the Federal Government and the non-Federal sponsor, that the non-Federal sponsor shall be considered the operator of the project for the purpose of CERCLA liability, and to the maximum extent practicable, operate, maintain, repair, rehabilitate, and replace the project in a manner that will not cause liability to arise under CERCLA; and

p. Comply with Section 221 of Public Law 91-611, Flood Control Act of 1970, as amended (42 U.S.C. 1962d-5b), and Section 103(j) of the Water Resources Development Act of 1986, Public Law 99-662, as amended (33 U.S.C. 2213(j)), which provides that the Secretary of the Army shall not commence the construction of any water resources project or separable element thereof, until each non-Federal interest has entered into a written agreement to furnish its required cooperation for the project or separable element.

7.2.1 Dredged Material Disposal

7.2.1.1 Applicability of Statutory and Regulatory Exclusions/Exemptions

The extent to which one or more potential exclusions or exceptions apply to the specific materials excavated during the project will depend upon the specific conditions and circumstances existing at the time of excavation.

For example, under the definition of HTRW in USACE Engineering Regulation 1165-2-132, dredged materials and sediments beneath navigable waters, including those that contain CERCLA hazardous substances or RCRA hazardous wastes, qualify as HTRW only if they are within the boundaries of a site undergoing a CERCLA response action or on the National Priorities List. Neither condition is considered applicable to this project. Further, under USEPA's hazardous waste exclusion for dredged material under RCRA, 40 C.F.R § 261.4(g), "dredged material that is subject to the requirements of a permit that has been issued under 404 of the Federal Water Pollution Control Act (33 U.S.C.1344) or section 103 of the Marine Protection, Research, and Sanctuaries Act of 1972 (33 U.S.C. 1413) is not a hazardous waste."

Final determination of the excavated materials' regulatory status will be made by the appropriate Federal and Commonwealth regulatory authorities and would be a matter for discussion between the Commonwealth, as the responsible party, and those regulatory agencies.

7.2.1.2 Actionable Hazardous Substances

The CMP Ecosystem Restoration Federal project will not include costs associated with the management or disposal of any "Actionable Hazardous Substances," as defined herein. The Commonwealth shall be responsible for ensuring that the development and execution of Federal, State, Commonwealth, and/or locally required response actions to address Actionable Hazardous Substances are accomplished at 100 percent non-project cost. The Commonwealth also shall be responsible for and pay all costs associated with the generation, release, management, or disposal of any Actionable Hazardous Substances identified by sampling. The Commonwealth may request the services of the USACE to perform such actions outside of the Federal project.

All dredged or excavated materials will be tested for the presence of hazardous substances in accordance with a sampling plan to be agreed upon by the parties. All Actionable Hazardous Substances shall be segregated.

“Actionable Hazardous Substances” is defined for purposes of this project as any material that:

(1) contains a hazardous waste, as defined in USEPA’s RCRA regulations;

(2) contains a hazardous substance as identified in 40 C.F.R. 302.3 and 302.4 in concentrations that pose a threat to human health or the environment as determined by USEPA; or,

(3) cannot, without additional treatment, be disposed of legally in a Subtitle D municipal solid waste landfill located within the Commonwealth of Puerto Rico, and is not environmentally appropriate, as determined by the Puerto Rico Environmental Quality Board, in consultation with USEPA, for disposal, without additional treatment, in open water or in the San José Lagoon Contained Aquatic Disposal areas.

Materials may constitute Actionable Hazardous Substances under the above definition regardless of whether such materials are subject to disposal pursuant to 33 U.S.C. 1344 or 33 U.S.C. 1413 or of such materials’ jurisdictional status.

Disposal of classes or categories of materials determined not to be an “Actionable Hazardous Substance” as defined above shall be documented with an affirmative determination (by the appropriate regulator entity) supporting the proposed disposal methodology and location.

7.2.1.3 Establishment of Separate Memorandum of Agreement

In addition, prior to or concurrently with the execution of a PPA associated with the Federal project, the parties shall execute a separate MOA between the USACE and the Commonwealth. In accordance with the MOA, the Commonwealth shall be responsible for any Actionable Hazardous Substances encountered during the project. The MOA will explicitly provide that:

- All increased costs associated with the generation, release, management, and disposal of Actionable Hazardous Substances that exceed the cost of normal project design, engineering, and construction activities, and that are necessary to implement the Federal project features shall be excluded from total project costs and shall be paid by the Commonwealth under the terms of the MOA.
- After the discovery of Actionable Hazardous Substances, any further site characterization associated with the Actionable Hazardous Substances; development, planning, selection, and execution of appropriate response and disposal actions; and establishment and future management of disposal areas for all Federal, State, Commonwealth, and locally required actions to address those Actionable Hazardous Substances shall be paid 100 percent by the Commonwealth.

- The Commonwealth shall indemnify the Federal Government for any future liability associated with the generation, release, management, or disposal of any Actionable Hazardous Substances excavated or dredged during the project work.
- The Commonwealth may request USACE assistance in the removal and proper disposal of any Actionable Hazardous Substances necessary for the execution of the Federal project. Such work shall not be considered a Federal project cost and, as such, the only funds ultimately available shall be those funds provided by the Commonwealth under the MOA specifically for those purposes.
- Any future costs associated with such Actionable Hazardous Substances that exceed the scope of the MOA shall be the sole responsibility of the Commonwealth and shall be outside the Federal project.

7.2.1.4 Establishment of Escrow Account

Prior to the initiation of construction, the Commonwealth will establish an escrow account, with interest accruing to the Commonwealth, in an amount to be agreed upon that is sufficient to prevent delays in the execution of project work in the event that Actionable Hazardous Substances are encountered. Such escrow account will be maintained during the course of the project and will be used by the USACE in the execution of work relating to Actionable Hazardous Substances under the MOA, unless other funds are provided by the Commonwealth in time to prevent the suspension of work under the Federal project.

7.2.2 Preconstruction Engineering and Design

Detailed design of the CMP-ERP will be conducted by the USACE Jacksonville District, in coordination with and review by ENLACE.

7.2.3 Lands, Easements, Rights-of-Way, Relocations, and Disposal Areas

Lands, easements, rights of way, relocations, and disposal areas will be the responsibility of ENLACE.

7.2.4 Construction

The CMP-ERP will be constructed by the USACE, in coordination with ENLACE.

7.2.5 Operations, Maintenance, Repair, Rehabilitation, and Replacement

Operations, Maintenance, Repair, Rehabilitation, and Replacement will be the responsibility of the Puerto Rico Department of Natural and Environmental Resources (DNER). The USACE will develop an O&M manual detailing expected OMRR&R requirements and periodically inspect the project to ensure that DNER is implementing the identified procedures.

7.2.6 Floodplain Management and Flood Insurance Program Compliance

ENLACE agrees to participate in and comply with applicable Federal floodplain management and flood insurance programs consistent with its statutory authority. ENLACE shall publicize flood plain information in the area concerned and shall provide this information to zoning and other regulatory agencies for their use in preventing unwise future development in the flood plain and in adopting such regulations as may be necessary to prevent unwise future development and to ensure compatibility with the CMP-ERP.

ENLACE shall prescribe and enforce regulations to prevent obstruction of or encroachment on the authorized CMP-ERP or on the lands, easements, and rights-of-way determined by the Federal Government to be required for the construction, operation, maintenance, repair, replacement, and rehabilitation of the authorized CMP-ERP, that could reduce the benefits the authorized CMP-ERP affords, hinder operation or maintenance of the authorized CMP-ERP, or interfere with the authorized CMP-ERP's proper function.

7.3 COST SHARING

7.3.1 Non-Federal Sponsor and Commonwealth of Puerto Rico Cost Contributions

The Commonwealth, acting through the DNER, jointly with ENLACE as the non-Federal sponsor for the CMP Ecosystem Restoration project, will execute a Project Partnership Agreement with the USACE upon approval and acceptance of the Feasibility Study. The cost share for the planning, design, and construction of the project will be 65 percent Federal and 35 percent non-Federal. Recreational features would be cost shared at 50 percent Federal and 50 percent non-Federal. The non-Federal sponsor must provide all LERRDs required for the project. OMRR&R of the project would be a 100 percent DNER responsibility. Additionally, project monitoring and any Adaptive Management deemed necessary will be cost shared at 65 percent Federal and 35 percent non-Federal for the first 5 years of the project life. Table 30 displays the expected cost sharing requirements for project implementation.

ENLACE would be responsible for providing 35 percent of the First Cost of implementing the NER Plan. The 35 percent share of the project cost includes ENLACE's responsibility for providing all LERRDs. The estimated costs are $75,040,000 in LERRD credit with $1,957,000 in cash. ENLACE is also responsible for OMRR&R of project features.

Table 30. Cost Sharing for Implementation of the Tentatively Selected Plan ($1,000s)
(Based on Project First Cost, effective price level date 1 October 2014)

Item	First Cost	Non-Federal Cost Share %	Non-Federal Cost*	Federal Cost
Ecosystem Restoration				
Construction, Construction Management, PED		35	$1,957	$142,995
LERRDs		100	$75,040	$0
Subtotal - Ecosystem Restoration	**$219,992**		**$76,997**	**$142,995**
Recreation		50		
Subtotal - Recreation	**$10,288**		**$5,144**	**$5,144**
Total First Cost	**$230,280**		**$82,141**	**$148,139**
OMRR&R				
Ecosystem Restoration Maintenance	$25,250	100	$25,250	$0
Recreation OMRR&R	$34,173	100	$34,173	$0
Subtotal - OMRR&R	**$59,423**		**$59,423**	**$0**
Total First Cost with Life Cycle Cost	**$289,703**		**$141,564**	**$148,139**

* Non-Federal requirements for construction, construction management, and PED were adjusted to ensure total non-Federal cost share for ecosystem restoration remains at 35% in light of non-Federal sponsor's 100% responsibility for LERRDs. LERRDs are included in the total cost for ecosystem restoration.

7.3.2 Section 902 Limitations

The Project is currently authorized under Section 5127 of the WRDA 2007 for a total cost of $150,000,000. The basis for the Project 902 maximum cost is the total first cost of $242,173,000 (presented in Table 29), which includes PED, Construction, LERRDs, and construction-funded monitoring. The CMP-ERP project fully-funded cost of $241,669,000 is below the 902 maximum cost limit. During PED, a limited Value Engineering analysis would be conducted to continue efforts to find cost savings measures.

7.3.3 Non-Federal Work-in-Kind

The non-Federal sponsor may be provided in-kind credit for project related work as described in Section 221 of the Flood Control Act of 1970, Public Law 91-611, as amended by Section 2003 of WRDA 2007, Public Law 110-114, and Section 1018 of the Water Resources Reform and Development Act of 2014, Public Law 113-121. The Secretary of the Army, subject to certain limitations and conditions, may afford credit toward the non-Federal share of the cost of the project for the value of in-kind contributions that the Secretary of the Army determines are integral to the CMP-ERP.

Such credit would be applied toward the Non Federal sponsor's share of the costs associated with the implementation of the CMP-ERP, shall not include cash reimbursements, and shall be subject to:

a) the authorization of the CMP-ERP by law;
b) a determination by the Secretary of the Army that the construction work completed under the PPA is integral to the authorized CMP-ERP;
c) a certification by the District Engineer that the costs are reasonable, allowable, necessary, auditable, and allocable; and
d) a certification by the District Engineer that the activities have been implemented in accordance with USACE design and construction standards and applicable Federal and State laws. Also, per Section 601(e)(5)(E) of the Water Resources Development Act of 2000, in-kind credit is subject to audit by the Secretary.

7.4 PROJECT DESIGN

USACE Engineering Regulations typically provide rules and policies that engineers must follow to correlate their design parameters and decisions for approval. USACE Engineering Manuals typically provide general guidance in formulations and procedures that can be followed to complete design efforts for typical projects and will be utilized for design as applicable.

7.5 PROJECT MANAGEMENT PLAN

A Project Management Plan (PMP) draft was prepared in 2009 and reviewed by the USACE. This draft was updated in 2013, and approved by the USACE, Jacksonville District. The PMP will be updated for implementation of the NER Plan. The PMP describes activities, responsibilities, schedules, and costs required for the planning, PED phase, and construction of the project.

7.6 COMPLIANCE WITH ENVIRONMENTAL LAWS, STATUTES, AND EXECUTIVE ORDERS

While the USACE does not issue itself a permit under the Clean Water Act, the USACE is required to apply "the same criteria, procedures, and requirements which apply to the issuance of permits."

7.7 ENVIRONMENTAL COMMITMENTS

Measures to offset temporary project construction losses are proposed to avoid or minimize impacts that would otherwise occur as a result of the implementation of the preferred alternative (see Section 6.43). These environmental and related commitments would be implemented by construction contractors or management authorities. Some commitments, such as monitoring or adaptive management, would continue beyond completion of construction. Throughout the planning process, efforts were made to avoid impacts to the extent practicable. When avoidance could not be achieved, mitigation measures were developed to reduce the magnitude and extent of the impact.

Best management practices would be included in construction specifications and they would be employed during construction activities to minimize environmental effects, such as, but not limited to double barrier turbidity curtain, sound barriers, protective gear and monitoring and emergency relocations.

Many of these BMPs are required by Federal, Commonwealth, or local laws and regulations, regardless of whether they are specifically identified in this document or not. Project implementation would comply with all applicable Federal, Commonwealth, and local laws, ordinances, regulations, and standards during the implementation of the NER Plan. Implementation of the environmental commitments would be documented to track execution and completion of the environmental commitments.

7.8 VIEWS OF THE NON-FEDERAL SPONSOR

ENLACE and community residents through the G-8, Inc., support the 100-foot-wide by 10-foot-deep with sheet-piling square bottom alternative for the CMP-ERP, including the recommended dredged material management plan and basic recreation elements, and will further elaborate recreation elements to be conducted as part of the non-Federal costs.

8.0 SUMMARY OF COORDINATION, PUBLIC VIEWS, AND COMMENTS

8.1 PUBLIC VIEWS AS EXPRESSED IN PREVIOUS STUDIES

Both Puerto Rico and Federal environmental policies require a public participation component. Early engagement with the public and stakeholders is encouraged as a means to identify any issues up front that are subject to controversy and to guide a planning and analysis process that addresses issues of concern to affected parties. This section provides an overview of the public engagement process, including its basis in previous planning and technical analytical efforts, processes used to engage the public, and significant views and comments received. For additional details, please refer to the EIS.

8.1.1 San Juan Bay Estuary Program

In April 1992, the Governor of Puerto Rico nominated the SJBE for inclusion in the United States USEPA National Estuary Program. In October 1992, the USEPA approved the nomination and Federal funds were made available in 1993 to develop a Comprehensive Conservation and Management Plan to identify problems and recommend solutions to guide future management of the SJBE resources. The dredging of the eastern half of CMP is included in the CCMP that was approved by the Governor of Puerto Rico in August 2000.

8.1.2 Project Design Report for the Dredging of Caño Martín Peña

In October 1995, the Puerto Rico DNER (the custodian authority of public domain lands related to the Maritime Terrestrial Zone of the Caño Martín Peña) requested technical assistance from the USACE Jacksonville District for the planning, engineering, design, and environmental assessment for the dredging of the Project Channel under the Support for Others Program. The purpose of the study was to document the plan formulation and design for the dredging of the eastern half of CMP. On July 23, 1996, a general scoping letter requesting views, comments, suggestions, and information about natural, cultural and community resources, study objectives, and environmental features within the Study Area was sent by the Jacksonville District to all resources agencies.

The study considered three alternatives that varied in size and shape of a restored CMP. The alternatives were evaluated on the basis of their construction method and cost, environmental benefits, real estate requirements, impacts to bridges and utilities, disposal of dredged material, project O&M, tidal flow capacity, and the recreation and navigation potential. Based on this evaluation and coordination with resources and infrastructure development agencies, DNER selected one alternative. The detailed design and a Draft EIS were developed for the selected alternative. These information contained within these documents provided sound information on technical considerations and public views, which were incorporated into the current planning effort.

In 2000, the ERDC performed hydrodynamic and water quality modeling of the alternatives with the cooperation of the San Juan Bay Estuary Program. On July 11, 2000, DNER circulated the final Project Design Report to all resources agencies requesting their views and comments on the recommended alternative. Many agencies provided comments and suggestions that must be considered during the feasibility phase. All agencies agreed with the urgent need for the proposed project. Some agencies provided comments and recommendations on disposal of dredged material, compensation from temporary mangrove loss, impacts to historic properties, recreation plans, and impacts to utilities.

A Public Notice inviting scoping comments for the Project Design Report Draft EIS was sent by the USACE Regulatory Division to all resource agencies on August 5, 2003. Preliminary coordination with DNER, the Puerto Rico Planning Board, the USFWS, and the U.S. Department of Agriculture indicate that these agencies generally support an ecosystem restoration project for the Study Area.

8.1.3 Caño Martín Peña Development Plan

With USACE's 2001 Design Report as a baseline reference, the ENLACE Project, within the PHRTA began a parallel and complementary effort to prepare an environmental impact statement in compliance with Puerto Rico's environmental policies. Further in the process, the PRHTA initiated the permitting process with the USACE, which led to the publication of a Notice of Intent and a formal scoping meeting with the participation of local and federal government agencies. This permitting process was interrupted by the ENLACE Project when Congress assigned funds that allowed the USACE Planning Section to prepare a Reconnaissance Report in compliance with Section 905(b) of the WRDA 1998.

The process led by the PRHTA included the preparation of a new technical document titled *Caño Martín Peña Waterway Improvements* (Moffat and Nichol Engineers 2003). In this document, the above-mentioned alternatives of the USACE's 2001 Design Report were reviewed and a new additional alternative was considered. This new alternative, which consisted of a rectangular 10 foot-deep canal with realignment and vertical steel bulkhead system, was developed as the PRHTA was interested in studying the feasibility of a faster route for waterway transportation. The proposed 180-foot-wide channel width was straight with minor bends. The proposed channel alignment followed the existing CMP channel from the Laguna San José to the existing oxbow, crossed the Barrio Obrero Marina peninsula to the north and ended west of the Luis Munoz Rivera Avenue Bridge, a distance of approximately 10,500 feet. The recommended alternative selected in this report was the same as the recommended alternative in the USACE's 2001 Design Report.

As part of the District Plan's participatory planning process, ENLACE held over 700 community meetings between 2002 and 2004, including round table discussions, public assemblies, workshops, presentations, and educational activities at local schools. As part of the discussion of the CMP dredging alternatives, ENLACE developed informational materials that were distributed throughout the District and the Cantera Peninsula. Residents opposed the CMP realignment proposed by PRHTA and favored the alternative recommended by the USACE. The final development plan was completed and approved by law in 2004; it was then adopted by the Puerto Rico Planning Board in 2007.

8.2 PUBLIC ENGAGEMENT FOR THE PROJECT

The process to develop the study has been highly participatory. In addition to public workshops and stakeholder meetings, ENLACE convened two committees to assist with development of the Project and provide inputs to the planning process (Table 31). The Technical Committee was constituted in 2009 to assist ENLACE in preparing a Request for Proposals and selecting consultants to provide technical services in support of conducting the feasibility study and drafting the Environmental Impact Statement. The Technical committee subsequently conducted reviews and provided comments on technical reports supporting the feasibility study, particularly regarding the channel dredging, dredged material disposal planning, and ecosystem restoration opportunities. Lastly, the Community Committee was convened to provide a direct linkage to the eight most affected communities in the vicinity of the CMP and provide an avenue for commenting on the feasibility study's planning and technical analyses. The Community Committee met monthly or bi-monthly, depending on the amount of technical documents produced and the need for community feedback. None of these committees were constituted as advisory committees as defined under the Federal Advisory Committee Act; their purpose was to assist ENLACE in the conduct of the feasibility study and the public engagement process.

A web page (www.dragadomartinpena.org) was created to inform the public and to provide contact information in order to provide additional feedback to the Project. The web page will continue to be used to inform the public, to provide contact information, and to provide feedback on the Project.

Kick-off community assemblies were held during October 2010 at each of the eight CMP communities to inform residents on the status of the project and document their concerns and suggestions. The results of the updated technical documents and hydrologic-hydraulic analysis suggested that the original proposed channel width for the Caño Martín Peña (150–230 feet wide, as established in the District's Plan based on USACE's 2001 Design Report) was not feasible due to channel flow velocities, volume of dredged sediments, wetland impacts, and direct and indirect costs. Therefore, a second round of community assemblies was carried out during October and November 2011 to receive community feedback and input regarding the optimization of the CMP proposed dredging of the canal.

Table 31. Committee Representation for the Public Engagement Process

Member Agencies/ Entities for the Technical Committee	Member Communities on the Community Committee
San Juan Bay Estuary Program	Barrio Obrero – San Ciprian Community
U.S. Environmental Protection Agency	Barrio Obrero – Marina Community
National Marine Fisheries Service	Barrio Obrero – West Community
U.S. Fish and Wildlife Service	Israel – Bitumul Community
State Historic Preservation Office	Las Monjas Community
PR Department of Natural and Environmental Resources	Buena Vista – Hato Rey Community
PR Environmental Quality Board	Buena Vista – Santurce Community
PR Planning Board	Parada 27 Community
Autonomous Municipal Government of Carolina	Tarpon Sports Fishermen
Municipal Government of San Juan	
G-8, Inc. (Community Stakeholder Organization)	
Institute of Puerto Rican Culture	
PR Aqueduct and Sewer Authority	
PR Electric Power Authority	
PR Solid Waste Authority	
Cantera Peninsula Company	
Solid Waste Administration	
University of Puerto Rico	

Prior to each assembly in the second round, ENLACE and community leaders distributed an informational bulletin which included contact information, described in plain language the five most feasible canal width measures once velocity and other considerations were factored in, and compared them to current conditions. The five channel dredging measures considered were:

1. No dredging scenario (a necessary comparison for this draft EIS No-Action scenario);
2. Rectangular section 100-foot-wide x 10-foot-deep canal width with earth bottom and sheet piles;
3. Hybrid section 100-x-10-foot channel width with earth bottom (mixed floor option) and sheet piles in some areas and slopes in others;
4. Rectangular section 75-foot-wide x 10-foot-deep canal with articulated cement bottom; and sheet piles; and
5. Hybrid section 75-foot-wide x 10-foot-deep canal with articulated cement bottom and sheet piles in some areas and slopes in others.

During the community assemblies, residents compared the alternatives, identified their advantages and disadvantages, and finally expressed their preferences related to the alternatives. This ballot was designed to provide residents the option to rank the alternatives based on their preferred order (1 being the favorite and 5 being the least favorite). Gathering ranked community preferences allowed ENLACE to have options validated by the community in case the selected alternative was later deemed unfeasible due to new technical information.

Through their votes, residents clearly expressed that they preferred the 100-foot channel width scenario, with either a rectangular or a hybrid section. Residents considered that the 100-foot channel width alternative was the most natural, the most reminiscent of what the CMP used to be, and the one that better accommodated their expectation for future uses of the CMP. Residents chose the rectangular section over the proposed hybrid section by a slight majority of votes. Although the hybrid channel measures were eliminated from further consideration prior to formulating alternative plans, the preference for a 100-foot-wide channel over a 75-foot-wide channel was noted during these assemblies.

A third round of community assemblies took place on May 2012 to discuss other relevant issues, such as the expected impacts to the communities during construction and the alternatives for the disposal of the dredge material.

In addition, ENLACE held several focused stakeholder meetings with sports fishing business owners, local subsistence fishermen, environmental advocacy organizations, the Autonomous Municipality of Carolina, and the SJBE Program Technical Committee.

Additional public engagement will also be included as part of the public review and comment process regarding this Draft EIS. ENLACE will continue to incorporate public participation throughout evaluation and revision of this Draft EIS. The Draft EIS will be translated into Spanish for public hearings.

8.3 NATIONAL ENVIRONMENTAL POLICY ACT SCOPING COMMENTS AND CONCERNS

A Notice of Intent (NOI) to prepare the Draft EIS was published on November 16, 2012, in the Federal Register. A scoping letter was sent out on February 22, 2013. During the scoping period, seven individuals and/or public agencies provided comment to the USACE, with 36 comments in total. Comments received during scoping are summarized under three categories: the public, Federal agencies, and the Commonwealth.

8.3.1 Public Comments and Concerns

- Flood-prone households should be relocated by the time dredging takes place.
- Community participation should be ensured throughout the project, including reaching a prior agreement as to where the dredged material disposal site should be located.
- Health impacts, especially respiratory illnesses, during dredging should be considered and addressed.
- Excessive noise during construction should be mitigated by relocating vulnerable households and by limiting working hours; there is concern that vibration by such noises could cause structural damage to residents' homes.

- Controls should be provided to reduce pest invasion to adjacent households.
- Precautionary measures should be implemented to avoid exposing children to machinery or dangerous areas.

8.3.2 Federal Agency Comments and Concerns

- The Draft EIS should contain a detailed analysis of alternatives related to the dredging method, including access to the channel and any disposal sites for dredging material; proposed size of the channel (width, depth, and side slopes) under each of the alternatives; and proposed dredged material disposal sites.
- The reasons for the selection of the preferred alternative should include a thorough analysis of the environmental benefits of the preferred alternative versus other proposed alternatives, in particular related to the final channel size and flushing of the channel.
- There are concerns regarding some of the dredging material disposal alternatives, in terms of the potential for transport of contaminated sediments and potential fish kills from dispersal of anoxic waters during the proposed disposal of dredged materials in former dredge pits in the San José Lagoon.
- Provide information regarding the overall master plan for the area and not focus only on the CMP dredging.
- Since the project area contains habitats designated as EFH, any information related to EFH resources and conservation measures should be included in the Draft EIS and project design, as well as EFH consultation requirements for the project.

8.3.3 Commonwealth Agencies

- There would be a need to coordinate with infrastructure-related agencies for infrastructure relocations and excavations would have to take place.
- There is concern as regarding the dredged material disposal route and coordination with the waterway transportation on the western CMP.

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DRAFT
NATIONAL ECOSYSTEM RESTORATION BENEFITS EVALUATION

AN ASSESSMENT OF THE ECOLOGICAL UPLIFT ASSOCIATED WITH THE RESTORATION OF THE CAÑO MARTÍN PEÑA FOCUSING ON BENEFITS TO THE STUDY AREA

Prepared for:

PROYECTO ENLACE DEL CAÑO MARTÍN PEÑA

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September 2015

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Acronyms and Abbreviations

ADCP	Acoustic Doppler Current Profilers
CFU	Fecal coliform bacteria units
CH3D-WES	Curvilinear Hydrodynamics in 3 Dimensions, WES version
CMP-ERP	Caño Martín Peña Ecosystem Restoration Project
ECO-PCX	Ecosystem Restoration Planning Center of Expertise
GIS	Geographic Information System
HU	habitat units
m	meter
mg/L	milligrams per liter
ml	milliliters
NER	National Ecosystem Restoration
NOAA	National Oceanic and Atmospheric Administration
ppt	parts per thousand
SJB	San Juan Bay
SJBE	San Juan Bay Estuary
SJBEP	San Juan Bay Estuary Program
µg	micrograms
USACE	U.S. Army Corps of Engineers
USDA	U.S. Department of Agriculture
USEPA	U.S. Environmental Protection Agency
WRDA	Water Resources Development Act

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Executive Summary

An assessment of the expected ecological uplift associated with the restoration of the Caño Martín Peña was completed, focusing on the benefits to benthic, mangrove, and fish habitat throughout the San Juan Bay Estuary system. General conclusions include the following:

Existing Conditions

- The closure of the historical connection between San Juan Bay and San José Lagoon has resulted in reduced tidal exchange into San José Lagoon via the Caño Martín Peña.
- The current configuration of the San Juan Bay Estuary is one where the fish habitat resources of San Juan Bay and Condado Lagoon are separated from the habitats of San José Lagoon, Suárez Canal, and the La Torrecilla and Piñones Lagoons.
- Reduced tidal exchange has resulted in a condition wherein the waters of San José Lagoon exhibit strong salinity stratification, with a surface layer of brackish, oxygenated waters overlying more saline and hypoxic to anoxic bottom waters.
- Biological surveys of the San José Lagoon have found that the hypoxic to anoxic bottom waters appear to be a regular feature, rather than a temporary condition.
- Implementation of pollution controls since the 1970s have resulted in a trend of improving water quality in the San Juan Bay Estuary.

Restoration Potential and the "Seascape"

- For at least the past 30 years, marine resource managers have documented the importance of the inter-connectedness of habitats such as mangroves, seagrass meadows, open water features, and coral reefs. These habitats function together as a series of linked features referred to as the "seascape."
- Reestablishment of the tidal connection between San Juan Bay and the San José Lagoon would recreate the historical inter-connectedness of the San Juan Bay Estuary, from La Torrecilla and Piñones Lagoons in the east to San Juan Bay in the west, as well as the historical inter-connectedness of the seascape features of the San Juan Bay Estuary system.
- Reestablishment of the tidal connection is anticipated to benefit not only those species that only utilize the estuarine portions of the San Juan Bay Estuary, but also those species that use mangroves, seagrass beds, and estuarine waters for only a portion of their life cycle.
- Species that use estuarine seascape features for a portion of their life cycle, while also using nearshore reef environments for (typically) adult stages, include a number of recreationally and commercially important species of fish in Puerto Rico.
- Reestablishment of the historical tidal connection between San Juan Bay and the San José Lagoon would not only benefit the health of benthic communities, and the open water and mangrove habitats of San José Lagoon, but it would also benefit those systems that would be newly connected through San José Lagoon (e.g. San Juan Bay and Condado Lagoon) as well as

those waterbodies that would be connected through a healthier San José Lagoon (e.g., Suárez Canal, La Torrecilla Lagoon, Piñones Lagoon).

Calculating Ecological Uplift in the San Juan Bay Estuary

- Calculating restoration benefits (ecological uplift) for the benthic community involved the use of a Benthic Index Model, which integrated data from a benthic index for the San Juan Bay Estuary and a hydrodynamic model for the San Juan Bay Estuary.
- An approach was developed to scale benefits to both nearby and more distant habitats when quantifying the amount of seascape features (seagrass meadows, open waters, mangroves, coral reefs) that would benefit from reestablishment of the historical inter-connectedness of the San Juan Bay Estuary.

The Benthic Index Model

- A benthic index was previously developed for the San Juan Bay Estuary. The benthic index is a mathematical technique used to quantify the species diversity and relative pollution tolerance of benthic communities. Benthic index scores were based on two equations: the derivation of a species diversity index, and then the modification of that index score as a function of the relative amount of pollution tolerant or pollution sensitive taxa. There are no confidence intervals or validation steps involved in the calculation of benthic index scores; it is a two-step univariate analysis.
- Use of the benthic index found that scores (which reflect species diversity of benthic communities) were inversely correlated with distance from the Atlantic Ocean, suggesting that tidal exchange has a positive influence on species diversity of benthic communities.
- After reproducing a previously developed hydrodynamic model for San Juan Bay, it was found that residence time was inversely correlated with benthic index scores across San Juan Bay; areas with longer residence times (reduced tidal exchange) were typically characterized by lower benthic index scores.
- Model output from the hydrodynamic model concluded that restoring the historical connection between San Juan Bay and San José Lagoon would significantly reduce residence time estimates for San José Lagoon.
- Based on the previously derived correlation between residence time and benthic index scores, the anticipated increased tidal exchange in San José Lagoon is expected to result in a substantial increase in benthic index scores throughout the lagoon. This relationship was used to develop a Benthic Index Model to estimate current condition and future project benefits from restoring the Caño Martín Peña.
- The Benthic Index Model is properly associated with the residence time within San José Lagoon because the Benthic Index improvement in San José Lagoon depends upon the water with the Lagoon turning over with the reduced residence time and increased dissolved oxygen levels are anticipated in bottom waters of San José Lagoon as a function of decreased salinity stratification, brought about through increasing the exchange of more saline surface waters.

The Fish Habitat and Mangrove Habitat Models

- For the seascape features of open water habitat, seagrass meadows and coral reefs, a scaling technique was applied wherein anticipated benefits were first quantified as acres of habitat (based on Geographic Information System [GIS]) and then habitat quantities were scaled based on how directly connected those areas were to the Caño Martín Peña and San José Lagoon. Seascape features that were less directly connected (e.g., coral reefs) were assigned a lower per acre score than features with a more direct connection (e.g., open waters of Suárez Canal). A Fish Habitat Model was the result of this effort and the model was used to predict current conditions and future project benefits from restoring the Caño Martín Peña.
- For the seascape feature of mangrove forests, a scaling technique was applied wherein anticipated benefits were first quantified as acres of mangrove habitat (based on GIS) and then scaled based on the degree of inter-connectedness based on the current variability in tide phase and the anticipated moderation of that variability through restoration. Mangrove habitats in areas with similar timing of tidal phases were assigned a higher per acre score than areas that had more dissimilar timing of tidal phases. A Mangrove Habitat Model was the result of this effort and the model was used to predict current conditions and future project benefits from restoring the Caño Martín Peña.
- The two approaches to quantifying anticipated benefits of inter-connectedness of seascape features were thus conservative estimates, such that habitats farther away or less directly connected to the Caño Martín Peña and San José Lagoon were given lower per acre scores than habitats that are closer and more directly connected.
- Flux or surface tide level equalization within the estuary system is the appropriate relationship for the Fish Habitat and Mangrove Habitat Models because these models depend upon surface waters moving throughout the system and distributing fish and invertebrate larvae and juveniles to these habitats along with the redistribution of vegetation seeds.

Alternatives

- The four project alternatives — no action, the 75-foot-wide by 10-foot-deep alternative, the 100-foot-wide by 10-foot-deep alternative, and the 125-foot-wide by 10-foot-deep alternative with a weir on the western end of the project — were evaluated using the ecological models.
- The presence of a weir associated with the 100-foot-wide and 125-foot-wide channel would replicate the cross sectional area of the 75-foot-wide channel alternative, thereby restricting water flow of the 100-foot-wide and 125-foot-wide alternatives to equal that of the 75-foot-wide alternative. As a result, the hydrodynamics of the two alternatives would be equal, which, in turn, would result in equal ecological benefits.

NER Benefit Results

- The Benthic Index Model was used to calculate the Benthic Index of each alternative based upon the modeled residence time. The performance of the alternative was developed using an estimated maximum Benthic Index value of 3.0. Based upon project performance the no action, 75-foot-wide alternative, 100-foot-wide alternative with a weir, and 125-foot-wide alternative with a weir have total habitat units of 363.0, 663.8, 663.8, and 663.8, respectively. Using the projected 3-year recovery over the 50-year project period, the three constructed project alternatives would have net average annual habitat units of 294.5.

- The Fish Habitat Model was used to calculate the habitat unit scores for each of the alternatives based upon the scaling factors. Based upon project performance the 75-foot-wide alternative with a weir, and 100-foot-wide alterative with a weir have net habitat units of 5,154.0; 5,159.2; and 5,164.6, respectively. Using the projected 3-year recovery over the 50-year project period, the three constructed project alternatives would have net average annual habitat units of 5,050.9, 5,056.0, and 5,061.3, respectively.
- The Mangrove Habitat Model was used to calculate the net habitat units for each of the alternatives based upon the scaling factors. Based upon project performance the 75-foot-wide alternative, 100-foot-wide alterative with a weir, and 125-foot-wide alternative with weir have net habitat units of 803.8; 798.6; and 793.2, respectively. Using the projected 3-year recovery over the 50-year project period, the three constructed project alternatives would have net average annual habitat units of 787.7, 782.7, and 777.4.
- The total net average annual habitat units for the three constructed project alternatives are estimated to be 6,133.
- Prior research on other estuarine restoration efforts, including those with hydrologic restoration features, suggests measurable improvements in water quality, benthic community health and fish and fish habitat would be expected to occur within 1 to 3 years after project completion. A 3-year linear increase in benefits was used to calculate the average annual habitat unit lift provided by the models.
- Existing water quality (e.g. pollutants) in the San Juan Bay Estuary can sustain restoration benefits achieved by the CMP.

1.0 INTRODUCTION

1.1 BACKGROUND

The Caño Martín Peña is a waterway approximately 4 miles long, connecting San Juan Bay and San José Lagoon, in metropolitan San Juan, Puerto Rico. It is part of the San Juan Bay Estuary (SJBE) system, the only tropical estuary that is included in the U.S. Environmental Protection Agency (USEPA) National Estuary Program. The total drainage area of the Caño Martín Peña is about 4 square miles (2,500 acres). The eastern 2.2-mile-long segment of the Caño Martín Peña and adjacent areas, including the San José Lagoon, are the primary focus of the restoration project; however restoration benefits are envisioned to occur throughout the SJBE system.

Historical problems with the Caño Martín Peña are described in the Reconnaissance Report developed by the U.S. Army Corps of Engineers (U.S. Army Corps of Engineers [USACE] 2004). Originally, the Caño Martín Peña had an average width of approximately 200 feet, with an unknown depth, and it was surrounded by extensive wetlands. The canal was an important ecological resource and acted as a transportation conduit between the cities of San Juan and Carolina. The wetlands surrounding the Caño Martín Peña have been used as a dredged material disposal area for port and channel projects. Urban development has encroached upon the Caño Martín Peña to the point where the canal is blocked as a result of sediment and debris accumulation, and structure encroachment along the eastern portion. At present, there is very little tidal exchange between San José Lagoon and San Juan Bay, resulting in reduced flushing and poor water quality (salinity stratifications and hypoxic conditions) in San José Lagoon. The lack of adequate infrastructure including a combined sewer system (stormwater and wastewater) has exacerbated the degradation of water quality caused by leachate from direct discharges of untreated sewage into the Caño Martín Peña. Encroachment along the eastern half of Caño Martín Peña has increased the intensity and frequency of flooding, affecting nearby communities with a combination of storm and untreated sanitary waters. Wildlife habitat loss has occurred within the system as a result of direct (e.g., construction, dredging, filling) and indirect impacts. Mangrove and other native flora and associated fauna have significantly diminished in the Caño Martín Peña and adjacent areas.

The ENLACE Caño Martín Peña restoration project is the latest of several attempts to bring about an improvement in the quality of life for residents living along the Caño Martín Peña and to restore and/or improve water quality and habitat values in both the Caño Martín Peña and the San Juan Bay Estuary system. The relocation and resettlement of residents from areas adjacent to the eastern segment of the Caño Martín Peña began in 1998. These initial efforts were carried out with the anticipation that such actions would be followed by the initiation of an Ecosystem Restoration Project (the CMP-ERP) that was presented to the U.S. Congress in 2002 (USACE 2004).

The CMP-ERP proposes to dredge the eastern segment of the canal to restore the Caño Martín Peña and adjacent areas and increase tidal flushing within the San Juan Bay Estuary system, in order to achieve environmental restoration. Ancillary benefits would include the reduction of flooding, allowing for the potential for environmentally sound waterway transportation, and the promotion of recreation and tourism. Previous studies (USACE 2004) suggest that the environmental restoration of the Caño Martín Peña can be achieved by dredging the canal and constructing a vertical steel sheet pile and concrete bulkhead system, with a transitional section towards the opening to the San José Lagoon. A major function of the dredging is to provide restoration of tidal exchange between the San José Lagoon and the San Juan Bay, i.e. the east and west sides of the San Juan Bay Estuary system; this increased flushing would provide an ecological lift for both the Caño Martín Peña and the entire estuary system. The proposed construction would be designed to allow tidal inundation and thus, preservation and/or improvement of the mangrove community between the open water and upland areas. Existing water quality in the San Juan Bay Estuary would be able to sustain restoration benefits achieved through implementation of the CMP-ERP.

1.2 PURPOSE OF THIS APPENDIX

The purpose of this Appendix is to describe the methodology used to calculate National Ecosystem Restoration (NER) benefits anticipated to occur from the construction of the CMP-ERP within the San Juan Bay Estuary, including anticipated benefits to fish habitat in the nearshore reefs. The anticipated benefits from the project include:

1) improved benthic habitats of San José and Los Corozos Lagoons,
2) increased health of the fish habitats of the open waters of the San Juan Bay Estuary and the nearshore reefs, associated with increased inter-connectedness of the San Juan Bay Estuary to a restored Caño Martín Peña and San José Lagoon, and
3) improved mangrove habitat through increased inter-connectedness throughout the San Juan Bay Estuary.

1.3 ECOLOGICAL HEALTH OF SAN JOSÉ LAGOON

Several prior studies have focused on the water quality characteristics of the San José Lagoon, including Kennedy et al. (1996), Cerco et al. (2003) and Atkins (2011a, 2011b). The most comprehensive assessments of the ecological health, not just water quality, of San José Lagoon are those compiled within the San Juan Bay Estuary Program's Comprehensive Conservation and Management Plan (2000). In 2007, the U.S. Environmental Protection Agency summarized prior assessments of the environmental conditions within the San Juan Bay Estuary system as being "poor" based on a series of metrics. Within the categories of water quality, sediment quality, and the health of benthic communities, San José Lagoon was consistently found to be the unhealthiest portion of the San Juan Bay Estuary (EPA 2007). Recently completed reports on the water quality (Atkins 2011a, 2011b) and benthic communities of San José Lagoon (PBS&J 2009a) support the conclusions of these earlier assessments that the ecological health of San José Lagoon is severely compromised.

The water quality index compiled by the San Juan Bay Estuary Program (Bauza 2013) gave a score of "D" to San José Lagoon, lower than any other portion of the San Juan Bay Estuary other than the Caño Martín Peña. The Benthic Index report produced for the San Juan Bay Estuary Program showed that in terms of species diversity and the proportion of taxa in pollution-tolerant families, the benthic communities of San José Lagoon were fairly healthy in waters shallower than 4 feet, but the health of the benthic communities was much lower in those areas with water depths greater than 4 feet (PBS&J 2009a). While the mangrove-lined San José Lagoon would not be expected to have water quality similar to that of the better-flushed San Juan Bay or Condado Lagoon, even in an undisturbed condition, it has a lower number of species of fish and much worse water quality than the similarly mangrove-lined waterbody of Piñones Lagoon (Table 1).

Table 1
Comparison of water quality data and fish species richness in San José and Piñones Lagoons.
Water quality data are mean values from 2002 to 2005 (SJBEP 2008).
Fish species data from SJBEP (1996).

Parameter	San José Lagoon	Piñones Lagoon
Salinity (ppt)	11.9	27.5
Dissolved oxygen (mg / liter)	4.55	5.90
Ammonium (mg / liter)	0.38	0.05
Phosphorus (mg / liter)	0.25	0.07
Fecal coliform bacteria (cfu / 100 ml)	1,032	7
Fish species recorded	14	17

1.4 EXPECTATIONS OF ECOSYSTEM RESPONSES WITH PROJECT IMPLEMENTATION – PRIOR DETERMINATIONS OF PROBABLE BENEFITS

The low surface salinities of San José Lagoon, compared to Piñones Lagoon (Table 1), give rise to salinity stratification in those portions of San José Lagoon deeper than 4 feet (Atkins 2011a). This salinity stratification then gives rise to the widespread distribution of hypoxic to anoxic water within the bottom waters of San José Lagoon, which in turn appears to explain the reduced quality of the benthic communities documented in both EPA (2007) and PBS&J (2009a) (Figure 1). It has been shown that reestablishing the historical hydrologic connection between San Juan Bay and San José Lagoon would act to decrease salinity stratification and thus improve the ecological health of San José Lagoon (Atkins 2011a), a conclusion similar to those reached by prior assessments of the likely benefits of hydrologic restoration of the Caño Martín Peña (e.g., Bunch et al. 2000, Cerco et al. 2003).

In consideration of the entirety of reports and data available, the San Juan Bay Estuary Program has committed itself to working with ENLACE to complete the Caño Martín Peña project as part of its efforts to bring about a holistic ecosystem restoration of the San Juan Bay Estuary system (EPA 2007). A "high priority" action within the San Juan Bay Estuary Program's Comprehensive Conservation and Management Plan (2000) is to restore the historical tidal flow regime in the Caño Martín Peña.

1.5 SEASCAPES AND THE INTER-CONNECTEDNESS OF FISH HABITATS IN TROPICAL MARINE ECOSYSTEMS

As noted by many researchers, and summarized by the National Marine Fisheries Service (http://www.habitat.noaa.gov/pdf/fisherieshabitatcriticalhabitatcomparison.pdf), fish habitat can be defined as ". . . habitat necessary for managed fish to complete their life cycle . . ." Important in this definition is the term "life cycle," which denotes that different types of fish habitat may be important for only a portion of an organism's lifespan.

More than thirty years ago, marine biologists referred to the combination of mangrove forests, seagrass meadows, and coral reefs as the "seascape" that supports fisheries in sub-tropical and tropical regions (Ogden and Gladfelter 1983, Birkeland 1985). These early researchers noted the dependence of various species of fish on the combination of these inter-connected seascape components.

More recently, Moberg and Rönnbäck (2003) summarized the state of knowledge related to the inter-connectedness of mangroves, open water, seagrass beds and coral reefs. In their review of numerous studies conducted over the past several decades, the authors concluded that "mangroves, seagrass beds and coral reef ecosystems are not autonomous units, but rather integral parts of a 'seascape' interlinked by ecological and hydrodynamic processes." In South Florida, for example, Porter and Porter (2001) contains numerous examples of the ecological linkages that tie together South Florida ecosystems as far removed from each other as the freshwater marshes of the Everglades, the seagrass meadows and patch reefs of Florida Bay, and the offshore coral reef.

The concept that improvements to the health of the benthos and water column of the Caño Martín Peña and San José Lagoon would benefit the ecological health of the wider San Juan Bay Estuary is one that is supported by prior efforts conducted in San Juan Bay (e.g., Bunch et al. 2000, Cerco et al. 2003). The notion that the offshore reefs would also benefit from the CMP-ERP, via enhanced probabilities that recreationally and commercially important fish species would be able to successfully complete their life cycles, is also supported by decades of research into the concept of the interconnectedness of mangrove, seagrass, and reef habitats in a wider seascape in tropical marine ecosystems.

1.6 ANTICIPATED BENEFITS TO FISH HABITATS OF A RESTORED CAÑO MARTÍN PEÑA

The objective of this Appendix is to summarize the techniques, results, and interpretation of results used to quantify the expected benefits to benthic, fish, and mangrove habitat associated with the restoration of the historical tidal connection between San Juan Bay and the San José Lagoon. Expected benefits are then quantified in terms of three main responses: 1) improved health of the benthic habitat of San José and Los Corozos Lagoons, 2) enhanced value of fish habitat associated with the increased health and inter-connectedness of the open waters, seagrass meadows, and offshore reefs in and adjacent to the San Juan Bay Estuary, and 3) enhanced value of mangrove habitat associated with the increased health and inter-connectedness of that habitat within the San Juan Bay Estuary system.

The results of these benefit quantifications are scaled so that benefits to ecosystem components such as offshore reefs, while anticipated, are given a lower "score" than habitats closer to the project site, such as mangroves in San José Lagoon. The scaling technique allows for the inclusion of anticipated benefits that would extend to the entirety of seascape features, without exaggerating such benefits. Finally, an expected timeline of system responses is proposed, based on prior and similar habitat restoration projects.

Currently, fish within San Juan Bay cannot directly access the mangroves, seagrass meadows, and open water habitats of San José Lagoon, the Suárez Canal, La Torrecilla Lagoon and Piñones Lagoon, just as fish within those waterbodies cannot directly access the habitats afforded by San Juan Bay (located to the west of the western end of the Caño Martín Peña). Due to the current condition of the Caño Martín Peña, there is essentially no tidal exchange between San Juan Bay and the San José Lagoon, i.e., the eastern and western sides of San Juan Bay Estuary system, creating essentially two estuary systems connected independently to the ocean waters by inlets. Because there is low or no exchange of water on a normal tidal cycle, the water quality within the Caño Martín Peña and San José Lagoon has been repeatedly shown to be very poor (i.e., Kennedy et al. 1996, Webb and Gomez-Gomez 1998, San Juan Bay Estuary Program 2000) with multiple exceedances of relevant water quality standards (i.e., Puerto Rico Environmental Quality Board 2010).

The restoration of the Caño Martín Peña is not only expected to benefit water quality and fish habitat within the Caño Martín Peña, San José Lagoon, and Los Corozos Lagoon (i.e., Atkins 2011a); it would benefit fisheries outside of these water bodies by allowing easier access to the variety of fish habitat (i.e., open water, seagrass meadows, hard bottom, mangrove fringes) found throughout the newly inter-connected waters of San Juan Bay, San José Lagoon, the Suárez Canal, La Torrecilla Lagoon and Piñones Lagoon (i.e., the entire San Juan Bay Estuary system).

The Sport Fisheries Study (Atkins 2011b) includes an assessment of the red mangrove prop root community within the Caño Martín Peña and within zones in designated distances away from the

Caño Martín Peña. It was found that the numbers and diversity of the attached (e.g., mussels and oysters) and mobile (e.g., crabs) organisms found on the roots increased from the Caño Martín Peña and western San José Lagoon out to La Torrecilla Lagoon, thus providing an indicator of water quality improvement that would likely respond to the improvements provided by the opening of the Caño Martín Peña. Through this preliminary study, a significant relationship was found between the number of crabs found on mangrove prop roots and distance from the Caño Martín Peña (Section 2.1.3.2).

2.0 PERFORMANCE METRIC DEVELOPMENT

A key component of environmental benefits analyses is the development of metrics to evaluate achievement of restoration objectives (McKay et al. 2010). USACE policy requires restoration projects use metrics that are “expressed quantitatively” [Engineering Report 1105-2-100A (USACE 2000)]. A conceptual ecological model was developed for the Caño Martín Peña and included as Appendix A1 of this document. This model was used to develop hypotheses about relationships within the system and to assist in understanding changes brought about by planned project elements. The planning objectives for the Caño Martín Peña Feasibility Study include:

1. Improve fish habitat in the San Juan Bay Estuary (SJBE) system by increasing connectivity and tidal access to estuarine areas;
2. Restore benthic habitat in San José Lagoon by increasing dissolved oxygen in bottom waters and improving the salinity regime to levels that support native estuarine benthic species; and
3. Increase the distribution and population density and diversity of native fish and aquatic invertebrates in the mangrove community by improving hydrologic conditions in the SJBE system.

The opening of the Caño Martín Peña will result in changes in the stressors affecting the San Juan Bay Estuary, thereby, resulting in changes in the attributes of the estuary system. These attributes include sediment and water quality, organisms, and habitats within the system. The performance metrics or measures are used to evaluate those changes. Several hypotheses are evident in the planning objectives described above. Improved water flow and circulation will:

- improve water quality within the system;
- improve mangrove habitat and functionality within the system;
- enhance the ability of fish species and life history stages of fish species to move throughout the estuary system; and
- improve conditions for benthic communities within the system.

All of these relationships and hypotheses were considered for performance metric development. The previous discussion has described where benefits are expected to occur within the system; the following discussion will develop the quantification of those benefits which will become performance metrics in the CMP-ERP Monitoring Plan.

2.1 OVERVIEW OF MODELS AND EXISTING DATA SETS

An existing hydrodynamic model originally produced for San Juan Bay by Bunch et al. (2000; Appendix A2) was used as the basis for the development of all of the ecological models developed for the National Ecosystem Restoration (NER) benefits evaluation. A previously developed benthic index

(PBS&J 2009a) was used in the development of the Benthic Index Model. These two "base" models and equations are initially described below and the documents further describing these models are attached as Appendix A2 (hydrodynamic model) and C (benthic index). The three ecological models used in the NER benefits evaluation — Benthic Index Model, Fish Habitat Model, and Mangrove Habitat Model — are described after the descriptions of the hydrodynamic model and benthic index. The hydrodynamic model is an approved model by USACE Headquarters, and the habitat models have been evaluated by the USACE Ecosystem Restoration Planning Center of Expertise (ECO-PCX) and approved for single-use by the Model Certification Team, USACE HQ.

2.1.1 Hydrodynamic Model

The quantification of anticipated benefits summarized here is mostly based on assessments developed from existing efforts. These prior efforts include a hydrodynamic model originally produced for San Juan Bay by Bunch et al. (2000; Appendix A2), which was recreated with various potential tidal reestablishment scenarios by Atkins (2011a). The hydrodynamic model used was the Curvilinear-grid Hydrodynamics model in 3-Dimensions, developed by USACE researchers from the Waterways Experimental Station model (i.e., **C**urvilinear **H**ydrodynamics in **3 D**imensions, WES version = CH3D-WES). The physical boundaries of the hydrodynamic model (Bunch et al. 2000) are consistent with the physical boundaries of the estuary and nearshore waters used by the San Juan Bay Estuary Program in developing its various resource management programs. The data sources used for model calibration and verification, as well as details of model output from various project scenario runs, are summarized in Section 2.1.1.1. Additional detail can be found in Atkins (2011a).

2.1.1.1 Model Features and Calibration

The hydrodynamic model originally developed by USACE researchers (Bunch et al. 2000) was calibrated based on data that was collected to characterize both boundary conditions and conditions within the San Juan Bay Estuary. Model output was compared to actual field data collected over a 3-month period as summarized by Fagerburg (1998). The model variables used for the hydrodynamic modeling efforts are water level elevations, water velocities, and salinity. The data sets used for model calibration are described below. The model outputs of greatest interest was residence time and tidal exchange, which was a derived based on inflow from the landscape and inter-basin flows.

Field data used for calibration purposes included water-surface elevations, salinity and water velocities. Data were collected at several locations throughout the San Juan Bay Estuary during June to August 1995. Acoustic Doppler Current Profilers (ADCP) were used to quantify velocities at canal locations that connected the various waterbodies of the San Juan Bay Estuary, as shown in Bunch et al. (2000). Due to issues associated with fouling of sensors, flow data were mostly restricted to short-term measurements (Fagerburg 1998). Salinity data were collected and summarized by Kennedy et al. (1996).

At six locations, model output on tidal elevations were compared to measured data, with results originally shown in Bunch et al. (2000). Re-created model output was then compared to the original calibration efforts in Atkins (2011a). Both the original model and the recreated model results for the three month modeling period (June through August 1995) were very close for tidal stage throughout the estuary and flux (water exchange) in the Caño Martín Peña.

At those same six locations, model output was compared to measured salinity data collected from both surface and bottom waters, with results originally shown in Bunch et al. (2000). Re-created model output was then compared to the original calibration efforts in Atkins (2011a). Salinity results, for the three month modeling period, agreed in pattern but were not precisely the same.

For reasons stated above, the model was most useful for tide stage and tidal exchange (flux) in understanding the changes in the estuary from the restoration project alternatives. These attributes of the hydrodynamic model were used in the further development of the ecological models. Model output on flow rates were compared to measured flows at the following locations: 1) Caño Martín Peña (between San Juan Bay and San José Lagoon), 2) Suárez Canal (between San José Lagoon and La Torrecilla Lagoon), and 3) La Torrecilla-Piñones Canal (between La Torrecilla and Piñones Lagoons). Model results were compared to measured flow data over the modeling period in Bunch et al. (2000) and then recreated model output was compared to the original calibration efforts in Atkins (2011a).

2.1.2 Benthic Index

The benthic index is a mathematical technique with a purpose to be used to quantify the species diversity and relative pollution tolerance of benthic communities. The objective was to refine the diversity index typically used for evaluating benthic communities to be more useful in interpreting benthic community data in the San Juan Bay estuary. Benthic index scores are based on two equations: the derivation of a species diversity index, and then the modification of that index score as a function of the relative amount of pollution tolerant or pollution sensitive taxa. There are no confidence intervals or validation steps involved in the calculation of benthic index scores; it is a two-step univariate analysis.

A prior report for the San Juan Bay Estuary Program was conducted to meet U.S. EPA guidance for the development of an index of health of benthic communities throughout the San Juan Bay Estuary. That report (PBS&J 2009a; Appendix A3) used an extensive data base on the species composition prepared by Rivera (2005) (example station locations from San José Lagoon, Figure 1). The benthic index was produced in an iterative manner. The first step involved the calculation of the Shannon Diversity Index:

Figure 1. Locations and Benthic Index Scores for Stations located in San José Lagoon Values are color-coded as to their Benthic Index Scores (PBS&J 2009a).

$_{I=1}^{S}H = -\Sigma\ (P_i * Ln\ P_i)$Where:

H= Shannon Diversity Index score,

P_i= Proportion of sample comprised of family i,

Ln = natural log, and

S = Number of families in the sample

The Shannon Diversity Index score was then further modified, as per guidance from existing literature, so that scores would increase due to the presence of members of the families Aoridae and Ampeliscidae, which represent pollution-sensitive organisms (Lee et al 2005, Weston 1996, Traunspurger and Drews 1996). Scores would also decrease due to the presence of members of the families Capitellidae and Tubificidae, which are regarded as pollution-tolerant and/or tolerant of disturbed benthic habitats (Paul et al. 2001, Pinto et al. 2009).

Combined, the final benthic index score is calculated as:

$$B = H - P_{Cap}^{2} - P_{Tub}^{2} + P_{Aor}^{0.5} + P_{Amp}^{0.5}$$

Where:

B = Benthic Index Score,

H = Shannon Diversity Score,

P_{Cap} = Proportion of the sample in the family Capitellidae,

P_{Tub} = Proportion of the sample in the family Tubificidae,

P_{Aor} = Proportion of the sample in the family Aoridae, and

P_{Amp} = Proportion of the sample in the family Ampeliscidae.

In the original report prepared for the San Juan Bay Estuary Program (Appendix A3), the authors determined that benthic index scores were lowest in the Caño Martín Peña, followed by the San José Lagoon. It was also determined that distance from the Atlantic Ocean, used as a surrogate for tidal influence, was a better predictor of benthic index scores than water depth.

2.1.2.1 Benthic Index Model Features and Quantification of Anticipated Benefits

The Benthic Index Model refers to the statistically significant bivariate model derived between residence time (as an independent model variable) and benthic index scores (as potentially statistically significant dependent model variables). Because residence time is a variable that the hydrodynamic model predicts well, the purpose of the Benthic Index Model is to develop this relationship between residence time and benthic index scores for the objective of using the model to evaluate the differences between the modeled project alternatives. The mathematical relationship between these two model variables does allow for the quantification of confidence intervals for the derived relationship, and a comparison between measured and modeled values allows for some measure of model validation, at least for existing conditions.

The scientific basis of the Benthic Index Model is developed in the report produced by Atkins (2011a) and summarized here. Output from the hydrodynamic model was used to determine whether the previously derived correlation between benthic index scores and distance from the Atlantic Ocean, as a surrogate for tidal influence (PBS&J 2009a), could be replicated with residence time. If a statistically significant relationship could be found, then the hydrodynamic model could be used to predict changes in residence time with different scenarios for restoring the tidal connection between San Juan Bay and San José Lagoon, and anticipated changes in benthic index scores could be calculated. The model variables used for the linked hydrodynamic-Benthic Index Model are the hydrodynamic model output of residence time (as an independent variable) and benthic index scores (as a potentially statistically significant independent response variable). The model assumptions are that residence time affects benthic index scores, and the derived mathematical equation reveals the direction of the relationship, the variability associated with the derived relationship, and the statistical significance of the relationship. The Benthic Index Model is properly associated with the residence time within San José Lagoon because the benthic index improvement in San José Lagoon depends upon the water within the Lagoon turning over with the reduced residence time and increased dissolved oxygen levels are anticipated in bottom waters of San José Lagoon as a function of decreased salinity stratification, brought about through increasing the exchange of more saline surface waters (further discussion in 2.2.1). Larger, deeper waterbodies like San Juan Bay proper will not experience a significant reduction in residence time with the opening of the Caño Martín Peña; whereas, smaller, fairly shallow waterbodies like San José Lagoon will experience significant reductions in residence time.

Figure 2 (reproduced from Figure 19 in Atkins 2011a) illustrates the statistically significant relationship between benthic index scores and residence time in the San Juan Bay Estuary.

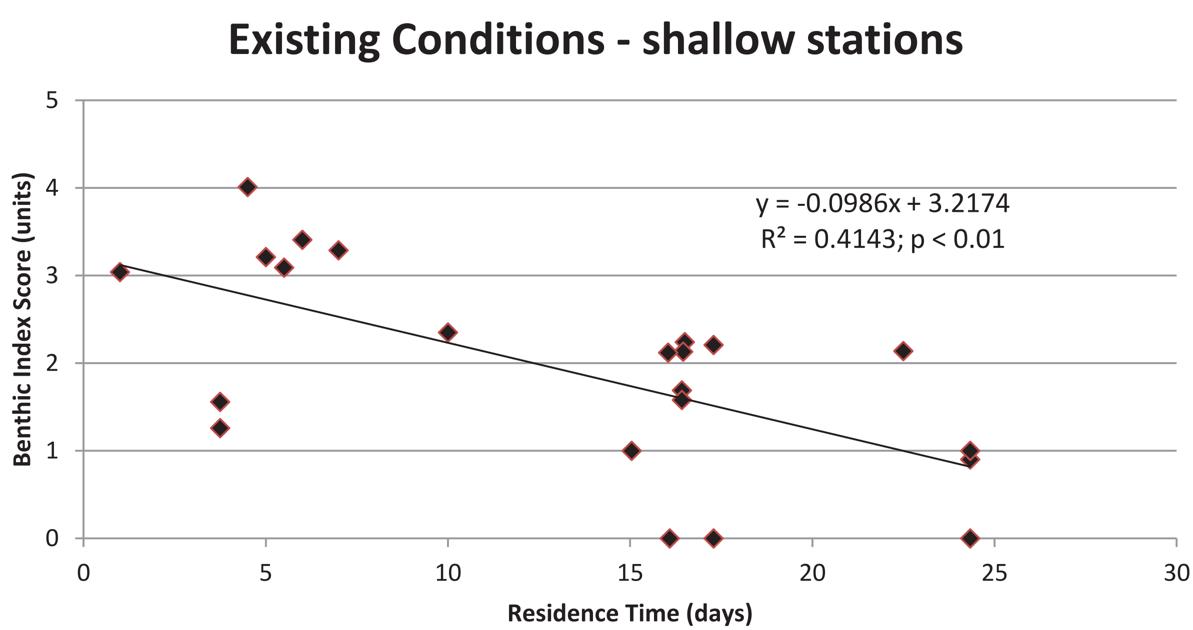


Figure 2. Relationship between residence time (days) and benthic index scores for shallow (<2 m) locations throughout the San Juan Bay Estuary.

The derived and statistically significant relationship (=Benthic Index Model) between residence time and benthic index scores is:

$$BI = -0.0986\,(RT) + 3.2174\ (r^2 = 0.4143;\ p < 0.01)$$

Where:

BI = benthic index score

RT = residence time, and

-0.0986 and 3.2174 are constants

The relationship between benthic index scores and residence time is empirically-based. A limitation of the model is that the exact mechanism through which residence time influences benthic index scores is not determined. The thought is that tidal mixing will decrease salinity stratification and increase oxygen level, thereby increasing benthic index scores (Section 2.2.1 for further discussion). Since the relationship between residence time and benthic index scores is mathematically derived, there are no assumed or literature-derived variables other than those in the calibrated hydrodynamic model. The r-squared value of 0.4143 indicates that approximately 41 percent of the variability in benthic index scores can be attributed to variability in residence time.

The hydrodynamic model was then used to calculate changes in residence time for San José Lagoon with various project channel width configurations (Atkins 2011a). Based on a number of different constraints related to costs of debris removal, issues with bank stabilization and scouring from tidal currents, etc., a channel configuration with a weir-restricted cross-section width of 75 feet became the preferred alternative project scenario. The remainder of the project length would have a 100-foot width; however, the hydrodynamics of the system are determined by the 75-foot constriction.

The residence time in San José Lagoon was also determined by the standard definition of the volume of water divided by the average inflow rate. The volume was computed to be the area of the lagoon (the area of the cells within the hydrodynamic model within the lagoon) times an assumed depth of 6 feet. This depth was assumed to be 6 feet because field data indicated stratification at around 6 feet of water depth in the San José Lagoon (see Section 2.2.1 for further discussion) (Atkins 2011b). Above this depth the salinity is relatively low and the water has relatively high dissolved oxygen levels. Below 6 feet of depth, the water has a relatively high salinity and little to no dissolved oxygen. This indicates that the water below 6 feet of depth is not involved in typical tidal circulation.

The inflow rates in both the Caño Martín Peña and the Suárez Canal were determined by analyzing the hourly flow rates over the three month modeling period (June through August 1995, see Section 2.1.1.1 and Bunch et al. 2000). The absolute values of the hourly flows were averaged and then divided by two; the assumption being that the flow in equals the flow out. The residence time computed for the existing condition for the San José Lagoon using this method is 16.9 days.

The above method was considered the best method using the model. The following describes a second method used to verify the volume exchange method. There were eleven data output locations (grids) selected in San José Lagoon. The residence time as determined by the time required for the salinity at a location to increase from zero to 90 percent of the boundary inflow salinity. The average residence time at the data output locations was 16.57 days with a standard deviation of 0.41 days. The residence time values ranged from 16.04 to 17.29 days, within the range computed by volume exchange.

Upon restoration of the historical tidal connection between San Juan Bay and San José Lagoon, with a controlling channel width of 75 feet and with a modeled channel depth of 9 feet (model depths are in 3-foot increments; project construction depth is 10 feet), the average modeled residence time for San José Lagoon decreases to approximately 3.9 days (Atkins 2011a).

Based on the empirically-derived relationship between residence time and benthic index scores, average benthic index scores are estimated at 1.55 and 2.84 for existing conditions and with a 75-foot controlling channel width, respectively, based on the equation shown above. The average benthic index score for shallow stations in San José Lagoon is 1.33, vs. the predicted value of 1.55 based on the derived equation, a difference of 17 percent. The 17 percent difference between model output and measured data found here is much less than the average difference between modeled vs. measured phytoplankton abundance (quantified as μg chlorophyll-*a* / liter) found by Cerco and Noel (2004) in their report on water quality modeling efforts in the Chesapeake Bay, illustrating the value of this metric as a measure of project success.

2.1.3 Scientific Basis for Habitat Models

The following outlines the scientific basis for the two habitat models — the Fish Habitat Model and the Mangrove Habitat Model.

The availability of mangrove nursery habitat has a striking impact on the community structure and biomass of fish inhabiting reef habitats as adults, as the biomass of several species more than doubled when mangrove habitats were available to reef-dwelling species (Mumby 2006). In the Gulf of California, Aburto-Oropeza et al. (2008) showed that fisheries landings in offshore waters were positively correlated with the local abundance of mangroves. In addition, the presence of mangroves significantly increases species richness and the abundance of shrimp in seagrass beds, relative to seagrass beds without adjacent mangroves (Skilleter et al. 2005). In research focused on the Caribbean, including Puerto Rico, Nagelkerken, et al. (2001, 2002) concluded that for some of the fish species they investigated, adult densities on coral reefs appear to be a function of the presence of nearby mangroves and seagrass beds, which function as nurseries for the juveniles.

These conclusions imply that documented declines in fishery landings in Puerto Rico (Matos-Caraballo 2008) can be attributed at least in part to the decline in the quantity and quality of accessible nearshore habitats. These conclusions also imply that restoring the historical inter-connectedness between the seascape features of San Juan Bay and the nearshore reefs will benefit the long-term health of both inshore and nearshore marine ecosystems, which should improve both fisheries and fishing-related tourism. The San Juan Bay Estuary system is unique in that is one of the only combined reef and estuary systems on the north coast of Puerto Rico making it significant in the relationships described above.

Within the San Juan Bay Estuary, there are at least seven species of fish that occupy a combination of mangroves, seagrass meadows and coral reefs at various life-history stages (SJBEP 1996, Nagelkerken et al. 2001, 2002). Those species include doctor fish (*Acanthurs chirugus*), yellowfin mojarra (*Gerres cinereus*), schoolmaster (*Lutjanus apodus*), gray snapper (*L. griseus*), yellowtail snapper (*Ocyurus chrysurus*), blue parrotfish (*Scarus coerulus*), and great barracuda (*Sphyraena barracuda*). In addition, the spiny lobster (*Panulirus argus*) is presently found in Condado Lagoon (Jorge Bauza, personal communication) and this species has been documented to use mangrove habitats as well as seagrass meadows and coral ledges during portions of their life history (Acosta and Butler 1997).

Of particular local interest, mutton snapper (*L. analis*) is an important commercial fishery in Puerto Rico, but one that is in decline (Cummings 2007, Sais et al. 2008). Although the commercial fishery for this species targets adults in both open waters and reef environments, this species uses mangrove habitat during post-larval, juvenile and adult phases (Sais et al. 2008). While fishing pressure undoubtedly plays an important role in the health of the fishery, direct and indirect impacts to nearshore fish habitats are thought to be an additional reason for the decline in the health of this fishery (Sais et al. 2008).

The inter-dependence of the fish habitats of mangroves, seagrass meadows, open water, and nearby coral reefs as inter-connected "seascape" features that support fish and fisheries is discussed in Sections 1.4 through 1.6. More locally, Sais et al. (2008) warned that impacts to nearshore mangrove and seagrass habitats would have repercussions beyond these estuarine locations alone. As related to mangrove, seagrass meadows and the open water features of Puerto Rico's various estuarine environments, Sais et al. (2008) concluded that, "impacts to these important habitats also lead to effects in coral reefs due to the loss of juvenile habitat for reef species such as spiny lobster, snappers, and groupers." The reverse is equally true, habitat restoration focused on Puerto Rico's estuarine waters, seagrass meadows and mangroves should benefit reef fish populations, and thus the reefs themselves.

Prior researchers have also concluded that restoration of the historical tidal connection between San Juan Bay and the San José Lagoon would benefit the ecological health of the wider San Juan Bay Estuary (e.g. Bunch et al. 2000, Cerco et al. 2003). The concept that the offshore reefs would also benefit from the restoration of the Caño Martín Peña is based on enhanced probabilities that recreationally and commercially important fish species would be able to successfully complete their life cycles if San José Lagoon became a healthier waterbody, and if more fish habitats in the San Juan

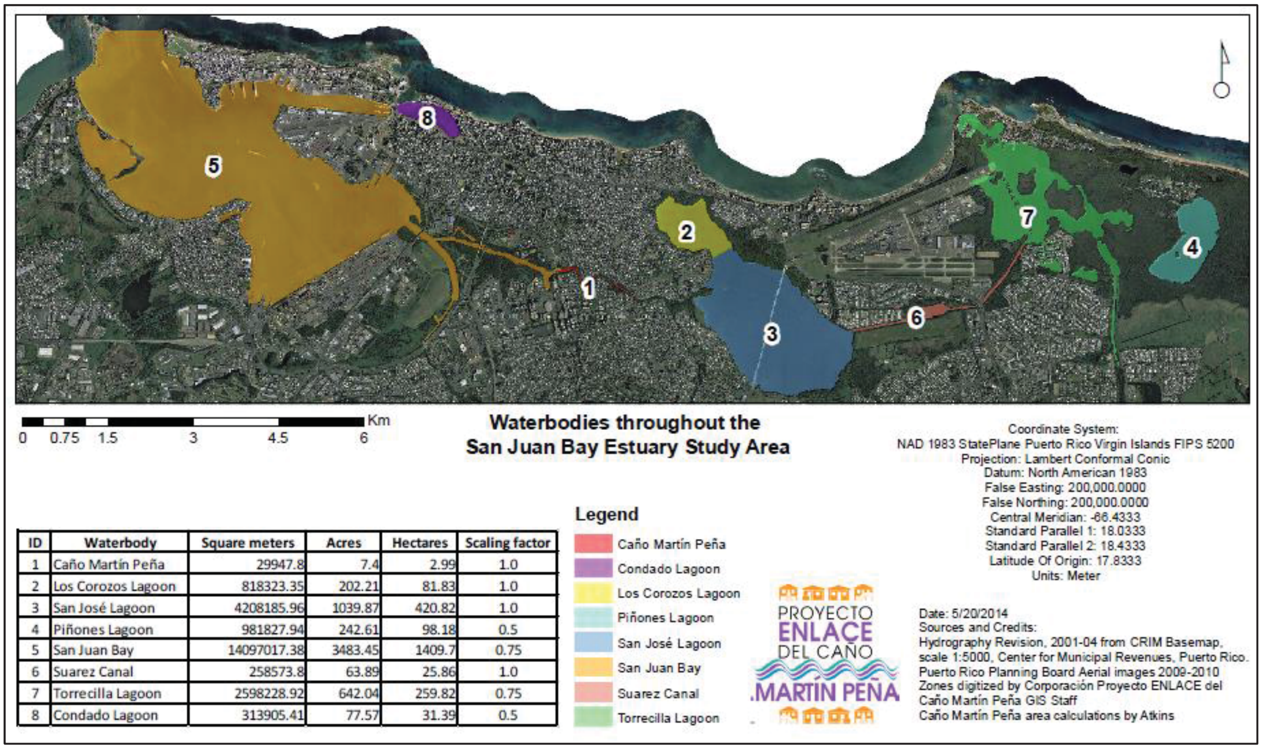
Bay Estuary complex would be more fully inter-connected. This concept is fully consistent with a determination that increased inter-connectedness of the seascape features of mangroves, open water, seagrass meadows and reefs would benefit all of these seascape features, not simply the one(s) being actively restored (Moberg and Rönnbäck 2003).

Flux or surface tide level equalization within the estuary system is the appropriate relationship for the Fish Habitat and Mangrove Habitat Models because these models depend upon surface waters moving efficiently throughout the estuary system and distributing fish and invertebrate larvae and juveniles to these habitats along with the redistribution of mangrove seeds to appropriate locations. Surface tide level will become more equal throughout the San Juan Bay Estuary system with the opening of the Caño Martín Peña.

2.1.3.1 Fish Habitat Model Features and Quantification of Anticipated Benefits

The purpose of the Fish Habitat Model is to develop a GIS-based assessment of the anticipated benefits to the seascape features of open water, seagrass meadows, and coral reefs associated with the restoration of the historical tidal connection between San Juan Bay and San José Lagoon for use in evaluating the differences between the project alternatives. The variables used for the Fish Habitat Model are GIS-derived acreage estimates of the fish habitats of open water/seagrass meadows and reefs, as modified by scaling factors that were used to decrease habitat benefit calculations with greater distance from the restored tidal connection between San Juan Bay and San José Lagoon. The model assumptions are that increasing the inter-connectedness of the various fish habitats of the San Juan Bay Estuary system and adjacent coastal waters will increase the habitat value of these newly inter-connected habitats, but that that degree of benefit will be most strongly expressed in areas closest to the restored tidal connection. A limitation of the fish habitat model is that the exact mechanism through which the inter-connectedness influences fish habitat has not been determined; therefore, the level of influence has associated uncertainty.

The quantification of benefits to the fish habitats that constitute the seascape features of the San Juan Bay Estuary is based on a two-step process. The first step involves the use of existing GIS maps to quantify acreage associated with the habitats of open water, seagrass meadows, and nearby coral reefs. Model boundaries were those previously delimited by the San Juan Bay Estuary Program. For the habitats of open waters, seagrass meadows and adjacent coral reefs the GIS layers summarized in the report “Methods Used to Map the Benthic Habitats of Puerto Rico and the U.S. Virgin Islands” (NOAA 2011) were accessed and clipped to meet bay segment boundaries that were reviewed and approved by local researchers in February 2013. For the Caño Martín Peña, the actual mapped habitats and channel configurations (Appendix A4) were used to quantify the acres for the proposed channel alternatives.



ID	Waterbody	Square meters	Acres	Hectares	Scaling factor
1	Caño Martín Peña	29947.8	7.4	2.99	1.0
2	Los Corozos Lagoon	818323.35	202.21	81.83	1.0
3	San José Lagoon	4208185.96	1039.87	420.82	1.0
4	Piñones Lagoon	981827.94	242.61	98.18	0.5
5	San Juan Bay	14097017.38	3483.45	1409.7	0.75
6	Suarez Canal	258573.8	63.89	25.86	1.0
7	Torrecilla Lagoon	2598228.92	642.04	259.82	0.75
8	Condado Lagoon	313905.41	77.57	31.39	0.5

Figure 3. Open water habitat within the San Juan Bay Estuary System.

The GIS layers of both open water within the San Juan Bay Estuary system and seagrass were combined, as seagrass coverage in San Juan Bay is sparse, and mostly restricted to Condado and La Torrecilla Lagoons. Seagrass coverage estimates for the San Juan Bay Estuary vary substantially, but little coverage has been recorded in San Juan Bay, San José Lagoon and Piñones Lagoon. Consequently, seagrass cover estimates are contained within the acreage estimates for the category of "open water" for the various segments of San Juan Bay (Figure 3). The eastern and western boundaries shown for the reef tract are based on well-defined geographic borders in the GIS data set from the National Oceanic and Atmospheric Administration, NOAA (2011). The delineation of the area termed the "Central Reef Tract" is also based on natural borders in the NOAA (2011) data set. The "open water" over the reef tract is included in the reef category.

The acreage estimates for the combined areas of open water and seagrass habitat were quantified using GIS for each of the following waterbodies: 1) Caño Martín Peña (from the existing condition and project alternatives), 2) Los Corozos Lagoon, 3) San José Lagoon, 4) Piñones Lagoon, 5) San Juan Bay, 6) Suárez Canal, 7) La Torrecilla Lagoon, and 8) Condado Lagoon (Figure 3). For the reef tract, GIS coverage was divided between West Near Inlet, East Near Inlet, and Central Reef Tract portions (Figure 4).

ID	TRACT	Area	Acres	Hectares	Scaling factor
2	Central Reef Tract	10043820	2481.9	1004.4	0.25
3	East Near Inlet Reef	1252094	309.4	125.2	0.125
1	West Near Inlet Reef	3128130	773	312.8	0.25

Date: 5/21/2014

Sources and Credits:
Kendall, M.S.1, M.E. Monaco1, K.R. Buja1, J.D. Christensen1, C.R. Kruer2, and M. Finkbeiner3, R.A. Warner1. 2001. (On-line). Methods Used to Map the Benthic Habitats of Puerto Rico and the U.S. Virgin Islands Puerto Rico Planning Board Aerial images 2009-2010
Atkins

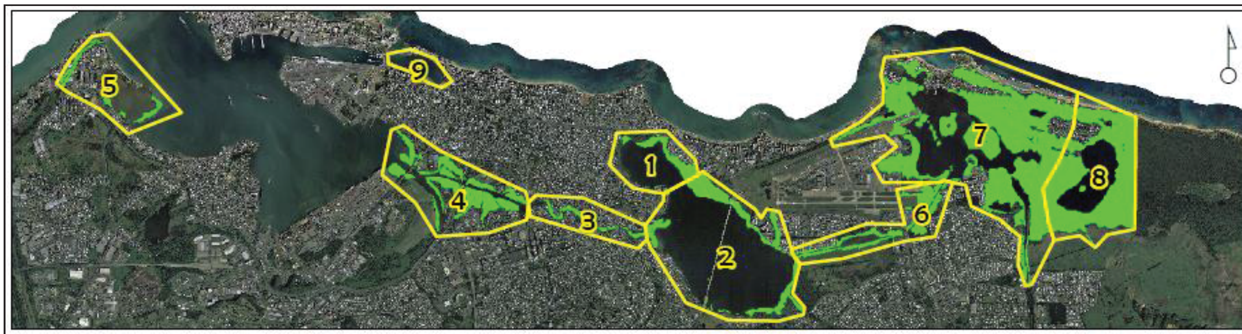
Figure 4. GIS-based estimates of reef habitat in waters adjacent to the San Juan Bay Estuary.

The fish habitats associated with open waters and seagrass meadows (if present) in Caño Martín Peña, San José Lagoon, the Suárez Canal, and Los Corozos Lagoon would directly benefit from the restoration of the historical tidal connection between San Juan Bay and San José Lagoon, and therefore the anticipated ecological uplift with project implementation is calculated by multiplying acres of open water habitat by a scaling factor of 1.0. For areas other than San José Lagoon, an approach was used whereby the relative degree of connectivity between a given location and San José Lagoon would be the basis for scaling habitat uplift estimates. The scaling factor decreased in increments of 0.25 for every intervening waterbody between a location and San José Lagoon, until reaching the farthest locations for any reasonable expectations of environmental benefit. Thus, the fish habitat benefits associated with open waters and seagrass meadows (if present) in San Juan Bay and La Torrecilla Lagoon are less direct than in San José Lagoon, and the anticipated ecological uplift is calculated by multiplying their acres of habitat by the scaling factor of 0.75. For Condado and Piñones Lagoons, the fish habitat uplift associated with open waters and seagrass meadows (if present) are less direct still, and the anticipated ecological uplift with project implementation is calculated by multiplying habitat acres by a scaling factor of 0.50.

Although it is anticipated that reef habitats will benefit from the restored water quality that would occur in San José Lagoon and the Caño Martín Peña, and that both local research (Sais et al. 2008) and a more global understanding of marine ecosystem management (e.g., Moberg and Rönnbäck 2003) support such a contention, a conservative approach to quantifying anticipated ecological uplift is appropriate. Consequently, the fish habitat uplift associated with the reef tract upon project implementation is calculated by multiplying reef acreage estimates in the eastern near inlet and western near inlet regions by a scaling factor of 0.25. For the Central Reef Tract, a scaling factor of 0.125 is used.

2.1.3.2 Mangrove Habitat Model Features and Quantification of Anticipated Benefits

For mangroves, the GIS data layers summarized in the report "The Puerto Rico Gap Analysis Project" (USDA 2008) were accessed and clipped to meet model boundaries that were reviewed and approved by local researchers in February 2013. The boundaries for mangrove habitat shown in Figure 5 are based on the geographic boundaries for the San Juan Bay Estuary program. The mangrove habitat data layer does not overlap with the data layers described above for the Fish Habitat Model avoiding "double counting" of acreage between the two habitat models. Note that the mangroves associated with Piñones Lagoon stops at a boundary considered to be the eastern edge of that lagoon and does not extend further to include the mangrove system that continues to the east. For the Caño Martín Peña, the actual mapped proposed mangrove habitat and channel configurations (Appendix A4) were used to quantify the acres for the proposed channel alternatives.



Id	UNIT	Square meters	Acres	Hectares	Scaling factor
1	Los Corozos	217525.11	53.75	21.75	1.0
2	San José	637264.17	157.47	63.73	1.0
3	Caño Martín Peña	135412.62	33.46	13.54	1.0
4	Laguna de San Juan	838878.03	207.29	83.89	0.75
5	Laguna de San Juan	138592.82	34.25	13.86	0.125
6	Canal Suarez	479644.31	118.52	47.96	0.75
7	Laguna Torrecillas	4315798.25	1066.46	431.58	0.125
8	Laguna Piñones	2300658.86	568.51	230.07	0.125
9	Condado Lagoon*	N/A	N/A	N/A	0.125

*The PRGAP data did not show any mangrove cover for the Condado Lagoon

Figure 5. GIS-based estimates of mangrove cover throughout the San Juan Bay Estuary.

The purpose of the Mangrove Habitat Model is to develop a GIS-based assessment of the anticipated benefits to the seascape feature of mangroves that are anticipated to occur with the restoration of the historical tidal connection between San Juan Bay and San José Lagoon for use in evaluating the differences between the project alternatives. For mangroves, no habitats exist along the exposed shoreline where the reef habitat is found. The variables used for the mangrove model are GIS-derived acreage estimates of mangrove habitat, as modified by scaling factors that were used to decrease habitat benefit calculations with greater distance from the restored tidal connection between San Juan Bay and San José Lagoon. The model assumptions are that restoring the historical tidal connection between San Juan Bay and San José Lagoon will increase the mangrove habitat value, based on a mathematically derived relationship that was developed between distance from the Caño Martín Peña and the abundance of fish life history stages within the mangroves and invertebrates found on and around the mangrove prop roots, but that that degree of benefit will be most strongly expressed in areas closest to the restored tidal connection.

In the Sports Fishery Study (Appendix A4; Atkins 2011b), a relationship was found between distance from the Caño Martín Peña and the abundance of invertebrates associated with the mangrove community, as illustrated in Figure 6.

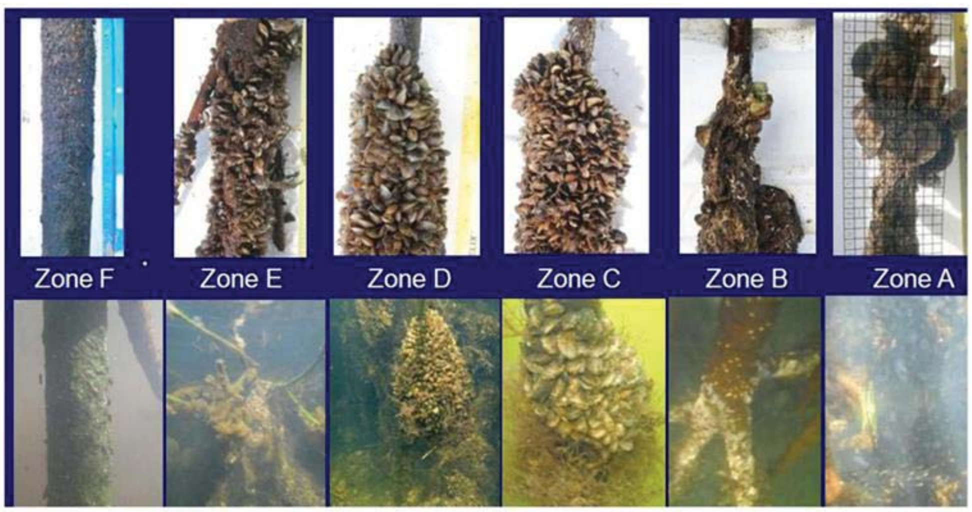


Figure 6. Example photographs of mangrove prop roots in various portions of the San Juan Bay Estuary. Zone A = northern La Torrecilla Lagoon close to the inlet, Zone B = southern La Torrecilla Lagoon, Zone C – Suárez Canal, Zone D = eastern San José Lagoon, Zone E – western San José Lagoon, and Zone F = Caño Martín Peña (Atkins 2011b).

In that study (Atkins 2011b), the number of aquatic invertebrates found on submerged portions of red mangrove prop roots increased with increasing distance from the poorly flushed waters of the Caño Martín Peña and western San José Lagoon, indicating that the fish habitat value of mangroves would be expected to increase with the restoration of the historical tidal connection between San Juan Bay and San José Lagoon (Figure 7).

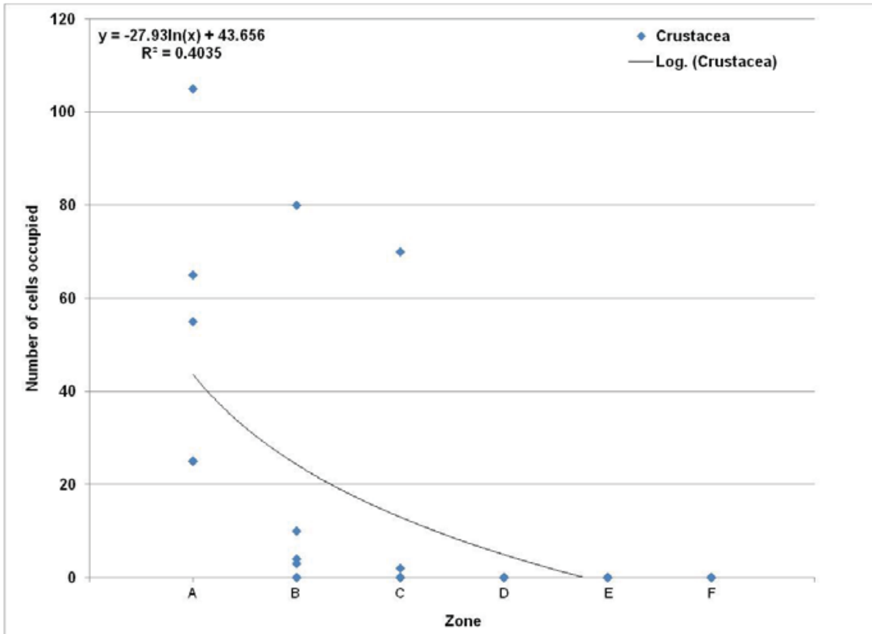


Figure 7. Relationship of the number of crabs and the distance from the Caño Martín Peña (Atkins 2011b).

The mangrove habitat (e.g., vegetation health and seed distribution) and the organisms (e.g., fish and invertebrate life stages) associated with that habitat in Caño Martín Peña and San José Lagoon would directly benefit from the restoration of the historical tidal connection between San Juan Bay and San José Lagoon. The mangrove habitat in eastern San Juan Bay and Suárez Lagoon is somewhat more distant, and the anticipated ecological uplift is less direct; benefits are calculated by multiplying acres of mangrove habitat by the scaling factor of 0.75. Mangrove uplift for La Torrecilla Lagoon is quantified as acreage multiplied by 0.25. For the more distant areas of western San Juan Bay, Condado Lagoon and Piñones Lagoon, anticipated ecological uplift of mangrove habitat is quantified by multiplying acres of mangroves by 0.125.

This scaling method for the Mangrove Habitat Model uses the differential in tide phase within San Juan Bay Estuary system reported by Fagerburg (1998) in the field data study for the hydrodynamic model calibration. In that study, Fagerburg (1998) reported finding a large tide differential (in hours) in the waterbodies immediately east of the Caño Martín Peña and a smaller differential tide phasing in waterbodies further east and west. This is because San José Lagoon is dependent on tidal waters entering through Suárez Canal and Boca de Cangrejos on the east side of the San Juan Bay Estuary system. The tide differential roughly correlates with residence time, i.e. the larger the differential in the tide phase the longer residence time of the water within the waterbody; however, as stated previously, the tide phase differential relates more to changes in surface waters, whereas, the residence time is related to the exchange of the volume of water within a waterbody. Opening the Caño Martín Peña will nearly equilibrate the tidal phase within the central portion of the San Juan Bay Estuary system as tidal waters are able to enter the central portion of the estuary system from both the East and the West. The greatest benefits will occur within the Caño Martín Peña, San José Lagoon, and Los Corozos Lagoon. Suárez Canal and the western portion of the Caño Martín Peña will also benefit greatly, but less so, as evidenced by tidal phasing. The scaling factor decreased in increments of 0.125 based on the relative degree of similarity of tidal phases. This increase in flow and equalization will also increase the movement of fish and invertebrate eggs, larvae, and juvenile and plant seeds throughout the system. A level of uncertainty does exist with this scaling approach and further calibration or validation of the Mangrove Habitat Model cannot be done at this time. Validation will occur through the adaptive management and monitoring program.

2.2 RESULTS

2.2.1 Quantification of Benefits Based on the Benthic Index Model

The objective of the Benthic Index Model was to use the relationship of residence time and benthic index scores to evaluate the environmental benefits produced by the project alternatives within the San Juan Bay Estuary system. Based on the restoration of the historical tidal connection between San Juan Bay and San José Lagoon, the average modeled residence time (based on volume replacement) in San José Lagoon is anticipated to decrease from an average of 16.6 days down to 3.9 days (Section 2.1.2.1). Using the empirically-derived relationship between residence time and benthic index scores, benthic index scores would increase from a current value of 1.33 to an anticipated value of 2.84 with such a change in tidal exchange; however, not all of the waters of San José Lagoon would be expected to benefit from the change in tidal flushing. Some portions of the lagoon are shallow enough that salinity stratification and hypoxia do not occur, which is the most likely basis for the reduced benthic index scores in San José Lagoon (Atkins 2011a). Also, there are deep dredge pits in San José Lagoon; those areas are likely to continue to be problematic for water quality regardless of any potential changes in tidal mixing.

To estimate the spatial extent of benthic communities expected to benefit, with regard to the benthic index model, the water quality surveys conducted in the Hydrodynamic and Water Quality Modeling Effort (Atkins 2011a) were examined in greater detail. A close examination of the water column profiles contained in that report shows that salinity stratification and bottom water hypoxia/anoxia occurs at depths greater than about 4 feet. Waters shallower than 4 feet do not show evidence of salinity stratification. There are a number of deep dredge pits in the San José Lagoon, mostly in the southeastern portion of the lagoon. The deep waters of these dredge pits grade down to depths in excess of 20 feet from a more typical depth within the lagoon of approximately 6 feet. It was thus concluded that waters shallower than 4 feet would not likely benefit from enhanced tidal circulation, as they are too shallow to exhibit hypoxia/anoxia brought about by salinity stratification. Those bottom areas associated with deep dredge pits which will likely continue to be problematic in terms of hypoxia and anoxia.

Figure 8 displays those portions of San José Lagoon that are between 4 and 6 feet in depth. These areas represent the portions of San José Lagoon that are anticipated to have improved benthic index scores upon restoration of the historical tidal connection between San Juan Bay and San José Lagoon.

The amount of bay bottom anticipated to benefit from tidal restoration is quantified as those portions of San José Lagoon between 4 and 6 feet in depth (Figure 8). The benefit would be expected to arise due to reduced frequencies and/or duration of hypoxia/anoxia due to reduced salinity stratification. The benefit is expected to be expressed in terms of areas with increased diversity of benthic communities, which can be tracked over time as benthic index scores calculated as in PBS&J (2009a). The spatial extent of the bay bottom to benefit in this manner (Figure 8) is quantified at 702 acres.

2.2.2 Quantification of Benefits Based on the Fish Habitat Model

The objective of the Fish Habitat Model was to use the relationship of the level of inter-connectedness created by the project alternatives to evaluate the environmental benefits of that alternative within the San Juan Bay Estuary system. The GIS layers for the fish habitat features of open water/seagrass, and reefs were mapped and quantified as described in Section 2.1.3.1. The acres of fish habitats were then multiplied by the scaling factors described in Section 2.1.3.1, so that the ecological uplift associated with an acre of habitat would be greater for those waterbodies closest to the restored Caño Martín Peña and San José Lagoon, compared to areas that would also benefit, but indirectly. Indirect benefits are anticipated to occur as well, but the approach of scaling responses based on geographic proximity to the restored tidal connection is a conservative approach to the quantification of anticipated benefits.

Table 2 displays the location/habitat feature, acreage, scaling factor, and resulting habitat units for the fish habitat model features of open water/seagrass meadows and reef environments. Table 3 provides the open water habitat units for the existing condition and proposed channel alternatives within the Caño Martín Peña.

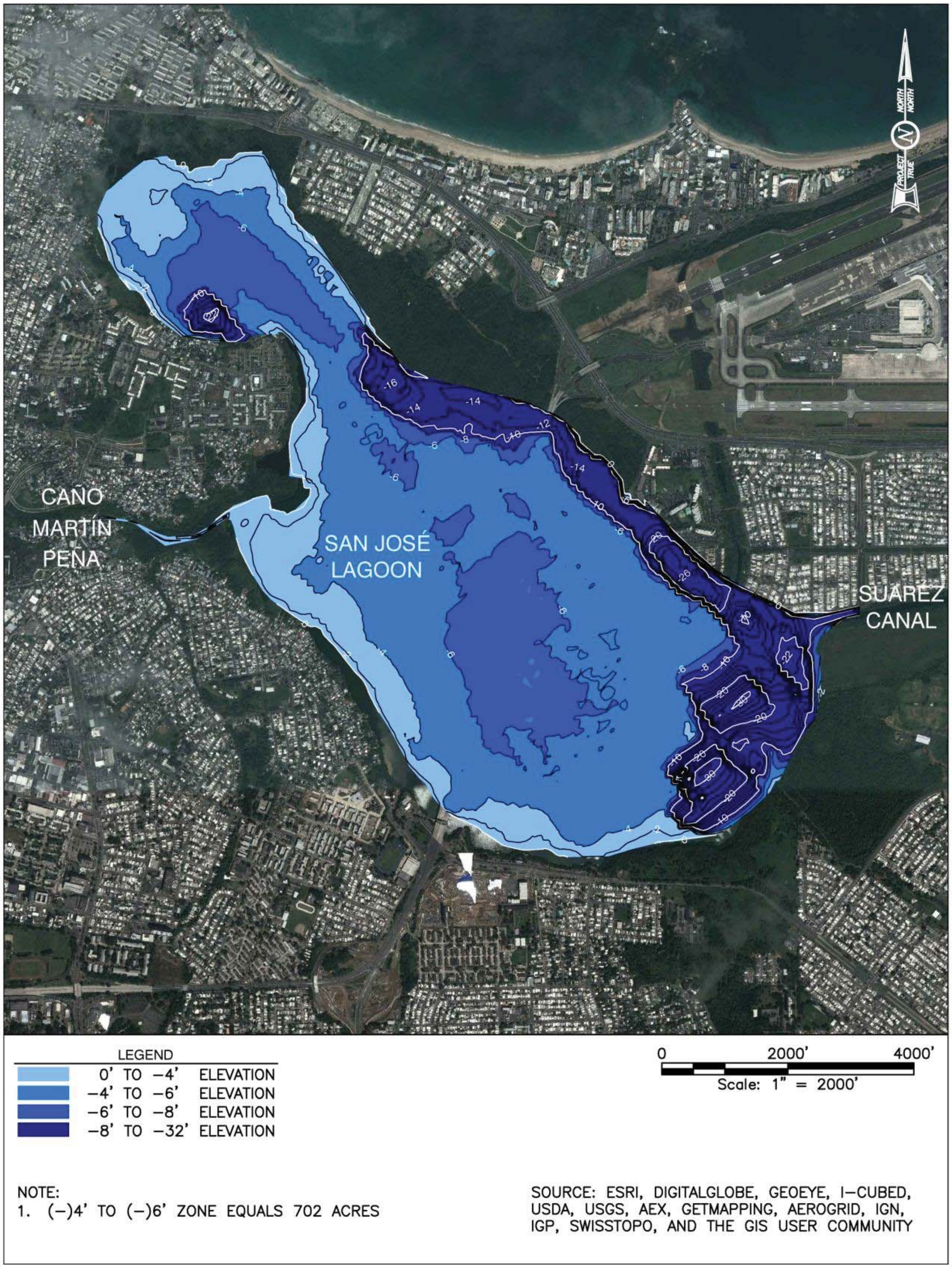


Figure 8. Spatial extent of water depth areas within San José Lagoon. Those depths with expectation of improvement in hypoxia/anoxia are the 702 acres located within the 4- to 6-foot elevation.

Table 2
Quantification of Open Water/Seagrass and Reef Habitat
Unit Benefits with Project Implementation.

Location / Habitat Feature	Acres of Habitat	Scaling Factor	Net Habitat Units
San Juan Bay	3,483.4	0.75	2,612.6
Condado Lagoon	77.6	0.50	38.8
San José Lagoon	1,039.9	1.00	1,039.9
La Torrecilla Lagoon	642.0	0.75	481.5
Piñones Lagoon	242.6	0.50	121.3
Suárez Canal	63.9	1.00	63.9
Caño Martín Peña	see Table 3	1.00	see Table 3
Los Corozos Lagoon	202.2	1.00	202.2
Western near Inlet Reef	773.0	0.25	193.3
Eastern near Inlet Reef	309.4	0.25	77.4
Central Reef Tract	2,481.9	0.125	310.2
SUBTOTAL			5,141.0
TOTALS	**All totals include the added values above and the values in table 3 for the project alternatives. See table 3.**		

Table 3
Quantification of Open Water Habitat Unit Benefits for the
No Action and Project Alternatives within the Caño Martín Peña.

Project Alternative	Acres Open Water Habitat in CMP	Net Habitat Units in CMP	Subtotal Net Habitat Units[1]	Total Net Habitat Units
No action	7.4	0	0	0
75-foot-wide	20.4	13.0	5,141.0	5,154.0
100-foot-wide with weir	25.6	18.2	5,141.0	5,159.2
125-foot-wide with weir	31.0	23.6	5,141.0	5,164.6

[1]Sub-total Habitat Units from Table 2.

2.2.3 Quantification of Benefits Based on the Mangrove Habitat Model

The objective of the Mangrove Habitat Model was to use the relationship of the level of tidal equalization (a measure of inter-connectedness) created by the project alternatives to evaluate the environmental benefits of that alternative within the San Juan Bay Estuary system. The GIS layers for the fish habitat feature of mangroves was mapped and quantified as described in Section 2.1.3.2. The acres of mangrove habitats were then multiplied by the scaling factors described in Section 2.1.3.2, so that the ecological uplift associated with an acre of mangroves would be greater for those waterbodies closest to the restored Caño Martín Peña and San José Lagoon, compared to areas that would also benefit, but indirectly. Indirect benefits are anticipated to occur as well, but the approach of scaling responses based on geographic proximity to the restored tidal connection is a conservative approach to the quantification of anticipated benefits.

Table 4 displays the location, acreage, scaling factor, and resulting habitat units for the fish habitat model feature of mangroves. Table 5 provides the mangrove habitat units for the existing condition and proposed channel alternatives within the Caño Martín Peña. The 125-foot alternative with a weir does indicate a net loss of 4.4 Habitat Units within the Caño Martín Peña.

Table 4
Quantification of Mangrove Habitat Unit Benefits with Project Implementation.
(NM = none mapped / not shown in GIS data files)

Location	Acres of Habitat	Scaling Factor	Net Habitat Units
Western San Juan Bay	34.2	0.125	4.3
Eastern San Juan Bay	207.3	0.75	155.5
Condado Lagoon	NM	0.125	NM
San José Lagoon	157.5	1.00	157.5
La Torrecilla Lagoon	1,066.5	0.25	266.6
Piñones Lagoon	568.5	0.125	71.1
Suárez Canal	118.5	0.75	88.9
Caño Martín Peña	see Table 5	1.00	see Table 5
Los Corozos Lagoon	53.8	1.00	53.8
SUB-TOTAL			797.6
TOTAL	**All totals include the added values above and the values in Table 5 for the project alternatives. See table 5.**		

Table 5
Quantification of Mangrove Habitat Unit Benefits for the
No Action and Project Alternatives within the Caño Martín Peña.

Project Alternative	Acres of Mangrove Habitat in CMP	Net Habitat Units in CMP	Subtotal Net Habitat Units[1]	Total Net Habitat Units
No action	33.5	0	0	0
75-foot-wide	39.6	6.2	797.6	803.8
100-foot-wide with weir	34.5	1.0	797.6	798.6
125-foot-wide with weir	29.1	-4.4	797.6	793.2

[1]Sub-total Habitat Units from Table 4.

2.3 TIMELINE OF EXPECTED ECOSYSTEM RECOVERY

A literature search was completed to determine the probable timelines required for ecological restoration such as that envisioned for the Caño Martín Peña project. Restoration projects, where the focus of activities was the reestablishment of historical hydrologic connections, were included, as well as restoration that occurred via the reduction in external pollutant loads. These projects typically experience hydrologic changes (e.g., tide, water velocity, residence time) quickly after restoration. Water quality changes are experienced with greater water movement and flushing. Finally, overtime, the organism response will follow with the improved water quality. This same timeline for change is anticipated for the Caño Martín Peña project; however, there is uncertainty in the amount of time that it will take the habitats and organisms in the habitats to respond to the hydrologic and water quality changes. The results of this literature review are summarized in Table 6.

Based on restoration projects completed in both temperate and sub-tropical estuarine environments, positive responses of water quality and benthic communities would be expected to occur within the first 3 years of implementing a project such as the restoration of the tidal connection between San Juan Bay and the San José Lagoon. For those projects that included a fish habitat component, there is no discernible difference between the timeline of recovery of fisheries resources and the timeline for recovery of either benthic communities or water quality. Quantification of fisheries responses seems to be less often pursued than is the case for water quality monitoring and/or benthic community responses, yet the existing information suggests a similar timeline is expected. For ecosystem restoration projects as a whole, ecosystem recovery would be expected to be substantial and documentable within a few years. For those projects where activities focused on the restoration of historical tidal connections, all seven examples shown in Table 4 had initial recovery within a 1-year period. Of these seven studies, three of them showed evidence of substantial recovery of benthic communities within the first year after restoration of tidal connections, three had documentation of substantial recovery within a 2-year period, and the remaining study documented substantial recovery within a 3-year period. All seven examples used words such as “substantial” or “significant” or “noticeable” to portray the level of ecosystem response to the restoration of historical tidal connections. As such, a trajectory of fish habitat responses over time would indicate relatively rapid recovery is expected in a restored San Juan Bay Estuary.

Table 6
Summary of Ecosystem Response Timelines for Completed Restoration Projects.

Study	Location	Type of Restoration	Highlights of System Response	Timeline for Initial Response	Timeline for Substantial Recovery
Dean and Haskin 1964	Raritan Bay, New Jersey	Removal of point source pollution	Benthic community recovery	Within 1 year	Within 3 years
Rosenberg 1973	Sweden	Removal of point source pollution	Benthic community recovery	Within 1 year	Within 6 years
Rosenberg 1976	Sweden	Removal of point source pollution	Benthic community recovery	Within 1 year	Within 8 years
Wu 1982	Hong Kong	Removal of point source pollution	Water quality and benthic community recovery	Within 1 year	Within 1 year
Karakassis et al. 1999	Greece	Removal of fish farm influences	Benthic community recovery	Within 1 year	Within 2 years
Vose and Bell 1994	Tampa Bay, Florida	Restoration of historical tidal exchange	Water and sediment quality, benthic community and fish abundance recovery	Within 1 year	Within 2 years
Zajac and Whitlatch 2001	Alewife Cove, Connecticut	Restoration of historical tidal exchange	Sediment quality, benthic community recovery	Within 1 year	Within 3 years
Raposa 2002	Narragansett Bay, Rhode Island	Restoration of historical tidal exchange	Water quality and benthic community recovery	Within 1 year	Within 2 years
Roman et al. 2002	Narragansett Bay, Rhode Island	Restoration of historical tidal exchange	Water quality, benthic community and fish abundance recovery	Within 1 year	Within 1 year
Thelen and Thiet 2008	East Bay, Rhode Island	Restoration of historical tidal exchange	Water quality, benthic community and fish abundance recovery	Within 1 year	Within 1 year
PBS&J 2009b	Key Largo, Florida	Restoration of historical tidal exchange	Water quality	Within 1 year	Within 1 year
Marcus 2010	Key Largo, Florida	Restoration of historical tidal exchange	Benthic community recovery	Within 1 year	Within 2 years

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3.0 BENEFITS EVALUATION

The commercial and recreational benefits derived from the ecological uplift anticipated to occur with the proposed Caño Martín Peña Ecosystem Restoration Project could be substantial. Matos-Caraballo (2008) estimates that between 1.2 to 1.8 million pounds of fish and shellfish are landed in Puerto Rico annually by commercial fisheries, valued at between $2.8 and $4.2 million. This represents economic benefits for the 809 part- or full-time commercial fishermen in the Island, and for the countless businesses that rely upon this harvest. The "north" region, which includes the San Juan Bay Estuary area, is responsible for approximately 5 percent of this amount (Matos-Caraballo, 2007). In contrast, the marine recreational fishery in Puerto Rico is over 15 times more valuable than the commercial fishery (Lilyestrom, personal communication, 2013). While there were 809 commercial fishermen in 2008, there were approximately 30,000 non-resident and 192,128 resident recreational anglers in Puerto Rico (LeGore 2007). The additional habitat, habitat-connectivity, and habitat-suitability that the Caño Martín Peña Ecosystem Restoration Project will provide are sure to add stability to this important component of Puerto Rico's tourism-related economy.

The large-scale and inter-twined ecosystem recovery envisioned as a project outcome is consistent with the Conceptual Ecosystem Model developed for the Caño Martín Peña restoration project (Appendix A1). The techniques used to develop the estimated ecosystem response quantified here involved logic, techniques, and peer-review processes that were carried out in a manner consistent with guidance outlined in Fischenich (2008 and 2010).

The purpose of the benefits evaluation is to use the information developed further in the previous sections of the Appendix with the objective to determine the anticipated Habitat Units obtained from each project alternative and the anticipated average annual Habitat Units achieved over the project period (50 years). Four project alternatives - the existing condition, the 75-foot-wide by 10-foot-deep alternative, the 100-foot-wide by 10-foot-deep alternative with a weir on the western end of the project, and the 125-foot-wide by 10-foot-deep alternative with a weir on the western end of the project - were evaluated using the ecological models. The weir is included in the larger project widths to prevent potential scouring from tidal current on the western end of the project. Although the western and eastern segments of the Project Channel have different cross-sectional areas and bottom elevations for the 100- and 125-foot alternatives with the weir, water flow through a tidal system such as the CMP is, and would continue to be, restricted by the smallest cross-sectional area. Accordingly, once the weir is included in the larger channel configurations, there is no further benefit to residence time in San José Lagoon with channel widths wider than 75 feet, and thus no additional national ecosystem restoration benefits. Therefore, the NER benefits related to ecological uplift for all alternatives would be the same as the 75-foot channel alternative. Open water and mangrove habitat restoration within the Project Channel are included in the calculation of NER benefits for the alternatives; however, there would be a minor variation in habitat scores as it related to open water and mangrove habitat within the Project Channel between the alternatives, and as such, the benefits are assumed to be equal among the alternatives. The results of the benefits evaluation are presented in Table 7.

The following is an explanation of the inputs to the benefits evaluation, for each of the project alternatives, proceeding across the headings presented in Table 7.

- **Residence time** – the average residence time in San José Lagoon calculated from the hydrodynamic model.
- **Benthic Index** – the benthic index score calculated from the residence time using the Benthic Index Model.
- **Benthic Index Project Performance** – the performance of the project alternative based upon the maximum benthic index score of 3.0 estimated using the model and a 200-foot-wide by 10-foot-deep alternative. This would approximately match the maximum predicted value for the Benthic Index in San José Lagoon after restoring the Caño Martín Peña to its original width and depth.
- **Benthic Index Habitat Units** – the Habitat Units based upon the project performance with the maximum area of benefit of 702 acres.
- **Benthic Index Net Habitat Units** – the Habitat Units provided by the project above no action.
- **Net Benthic Habitat Net Average Annual Habitat Units** – net average annual Habitat Units considering the Benthic Index Model is based upon the recovery of the area in San José Lagoon to the predicted Benthic Index value with the expected linear time of recovery of 3 years to full benefit from the existing condition and the project period of 50 years.
- **Fish Habitat Model Net Habitat Units** – the Habitat Unit score based upon the percentage lift from the existing condition depending on the location of the habitat.
- **Fish Habitat Model Net Average Annual Habitat Units** - The average annual Habitat Units for the Fish Habitat Model is based upon the linear recovery time of 3 years to full benefit from the existing condition and a project period of 50 years.
- **Mangrove Habitat Model Net Habitat Units** – the Habitat Unit score based upon the percentage lift from the existing condition depending on the location of the habitat.
- **Mangrove Habitat Model Net Average Annual Habitat Units** - The average annual Habitat Units for the Mangrove Habitat Model is based upon the linear recovery time of 3 years to full benefit from the existing condition and a project period of 50 years.
- **Total Net Average Annual Habitat Units** - The total average annual Habitat Units is the combination of the average annual Habitat Units for the Benthic Index Model, the Fish Habitat Model, and the Mangrove Habitat Model.

The calculation of the Benthic Index and the development of the Benthic Index Model are explained Sections 2.1.2 and 2.1.2.1, respectively. The performance of the Benthic Index Model is based on achieving a Benthic Index value of 3.0, which would be approximately the maximum predicted value for the Benthic Index in San José Lagoon after restoring the Caño Martín Peña to its original width and depth of an estimated 200 feet by 10 feet (Section 1.1). The Habitat Units, as explained in Section 2.2.1, are based upon the project performance and the maximum spatial extent of the area of San José Lagoon that would benefit from the opening of the Caño Martín Peña (702 acres). The net average annual Habitat Units (294.54 Habitat Units) for the Benthic Index Model is based upon the recovery of the area in San José Lagoon to the predicted, modeled Benthic Index Habitat Units (663.81 Habitat Units) starting from no action (362.95 Habitat Units) with the expected time of recovery of 3 years (linearly from the existing condition to the predicted, modeled score) and the project period of 50 years (Section 2.3).

The quantification of the Fish Habitat Model is explained in Section 2.1.3.1. The total acreage of open water and reef habitat were calculated from available GIS data. The construction of the CMP-ERP would result in the eventual benefit to open water and reef habitat of additional net habitat units based upon the scaling factors and the proposed Caño Martín Peña channel alternatives (5,154.01 Habitat Units for the 75-foot Alternative; 5.159.16 Habitat Units for the 100-foot Alternative with weir; and 5,164.56 Habitat Units for the 125-foot Alternative with weir), as explained in Sections 2.2.2 and 3.2. The net average annual Habitat Units for the Fish Habitat Model varies between the proposed Caño Martín Peña channel alternatives (5,050.93 Habitat Units for the 75-foot Alternative; 5,055.98 Habitat Units for the 100-foot Alternative with weir; and 5,061.27 Habitat Units for the 125-foot Alternative with weir) and is based upon the recovery time of 3 years (linearly from the existing condition to the predicted, modeled score) and a project period of 50 years (Section 2.3).

The Mangrove Habitat Model is also quantified based on a scaling factor and the total mangrove habitat acres within the San Juan Bay Estuary system from available GIS data (Section 2.1.3.2 and 2.2.3). The net Habitat Units would be those Habitat Units (803.77 Habitat Units for the 75-foot Alternative; 798.63 Habitat Units for the 100-foot Alternative with weir; and 793.23 Habitat Units for the 125-foot Alternative with weir) gained with each project alternative above the no action alternative (Section 3.2). The net average annual Habitat Units for the Mangrove Habitat Model (787.69 Habitat Units for the 75-foot Alternative; 782.66 Habitat Units for the 100-foot Alternative with weir; and 777.37 Habitat Units for the 125-foot Alternative with weir) is based upon the recovery time of 3 years (linearly from the existing condition to the predicted, modeled score) and a project period of 50 years (Section 2.3).

Table 7
Average Annual Habitat Unit lift for the project alternatives

Project Condition	Residence Time (days)	Benthic Index[1]	Benthic Index Project Perfor-mance	Benthic Index Habitat Units (HU)[2]	Benthic Index Net HU	Net Benthic Index Net Average Annual HU[3]	Fish Habitat Model Net HU[4]	Fish Habitat Model Net Average Annual HU[3]	Mangrove Habitat Model Net HU[4]	Mangrove Habitat Model Net Average Annual HU[3]	Total Net Habitat Units	Total Net Average Annual HU[5]
No action	16.9	1.55	51.70%	362.95	0	0	0	0	0	0	0	0
75-ft-wide Alternative	3.9	2.84	94.56%	663.81	300.86	294.54	5,154.01	5,050.93	803.77	787.69	6,258.64	6,133.16
100-ft-wide Alternative with weir	3.9	2.84	94.56%	663.81	300.86	294.54	5,159.16	5,055.98	798.63	782.66	6,258.65	6,133.17
125-ft-wide Alternative with weir	3.9	2.84	94.56%	663.81	300.86	294.54	5,164.56	5,061.27	793.23	777.37	6,258.65	6,133.17

[1] Based upon a maximum Benthic Index Score of 3.0 (see text for further explanation).

[2] Based upon an expected area to benefit = those regions between -4 and -6 feet in water depth within San José Lagoon (= 702 acres maximum).

[3] Average annual habitat unit lift from existing condition based upon a 3-year recovery time after project construction.

[4] See text for explanation.

[5] Combined Benthic Index Average Annual HU lift, Fish Habitat Model Average Annual HU lift and Mangrove Habitat Model HU lift based upon a 3-year recovery time after project construction [Columns F + H + J = K].

Table 8
Summary of Net Average Annual Habitat Units for the Models

Project Condition	Benthic Index	Fish Habitat	Mangrove Habitat	Total
No Action	0	0	0	0
75-foot-wide Alternative	294.54	5,050.93	787.69	6,133.16
100-foot-wide Alternative with weir	294.54	5,055.98	782.66	6,133.17
125-foot-wide Alternative with weir	294.54	5,061.27	777.37	6,133.17

The net total average annual Habitat Units (6,133.2 Habitat Units) is the combination of the net average annual Habitat Units for the Benthic Index Model, the Fish Habitat Model, and the Mangrove Habitat Model. The net average annual habitat units do not vary significantly between alternatives because, as the proposed channel configuration becomes wider, the open water habitat increases and the proposed mangrove habitat decreases. Tables 3 and 5 show this shift with the proposed project alternatives. Figure 9 shows the anticipated Habitat Units over the project period timeline accumulating linearly over the first 3 years of recovery and maintain the full habitat units over the 50-year project period. Because of the 75-foot constriction caused by the proposed weir, all of the proposed construction alternatives for the project have essentially the same estimated performance (i.e., Habitat Unit lift) over the 50-year project period.

Uncertainties and limitations exist with any model that attempts to predict an environmental parameter. As has been expressed in this Appendix and the supporting literature, changes in benthic, fish, and mangrove habitat are anticipated to occur with the restoration of the Caño Martín Peña. There are uncertainties and limitations that have been expressed as to the exact mechanisms behind the correlations with hydrologic and water quality changes and the anticipated organism and habitat changes. A limitation of the fish habitat model is that the exact mechanism through which the inter-connectedness influences fish habitat has not been determined; therefore, the level of influence has an associated uncertainty. While the timeline for ecosystem response is anticipated to be approximately 3 years for the Caño Martín Peña project, there is uncertainty in the amount of time that it will take the habitats and organisms in the habitats to respond to the hydrologic and water quality changes. Lastly, there is uncertainty associated with the scaling approach as it relates to the scaling factors identified for the various waterbodies and habitats associated with both the Fish Habitat and the Mangrove Habitat Models. The calculation of the fish and mangrove habitat scores is directly influenced by the assigned scaling factors, and the actual ecological benefit could be greater than, or lesser than, the projected benefits assigned for both habitat models. Much of the validation of the models and the performance of the models/metrics will be dependent upon the data collected using the Adaptive Management and Monitoring Program.

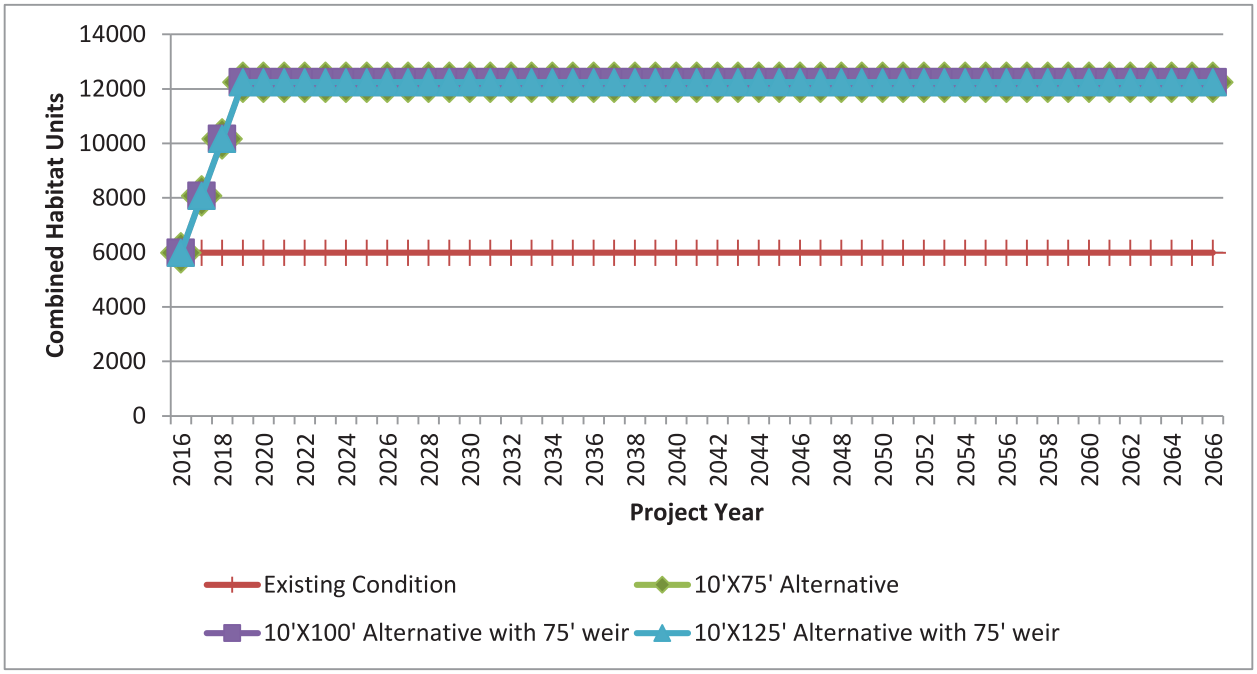

Figure 9. Average Annual Habitat Unit lift for the combined models for each project alternative based upon an estimated recovery time for the habitats of 3 years and a 50-year project period.

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Appendix A1

San Juan Bay Estuary Conceptual Ecological Model

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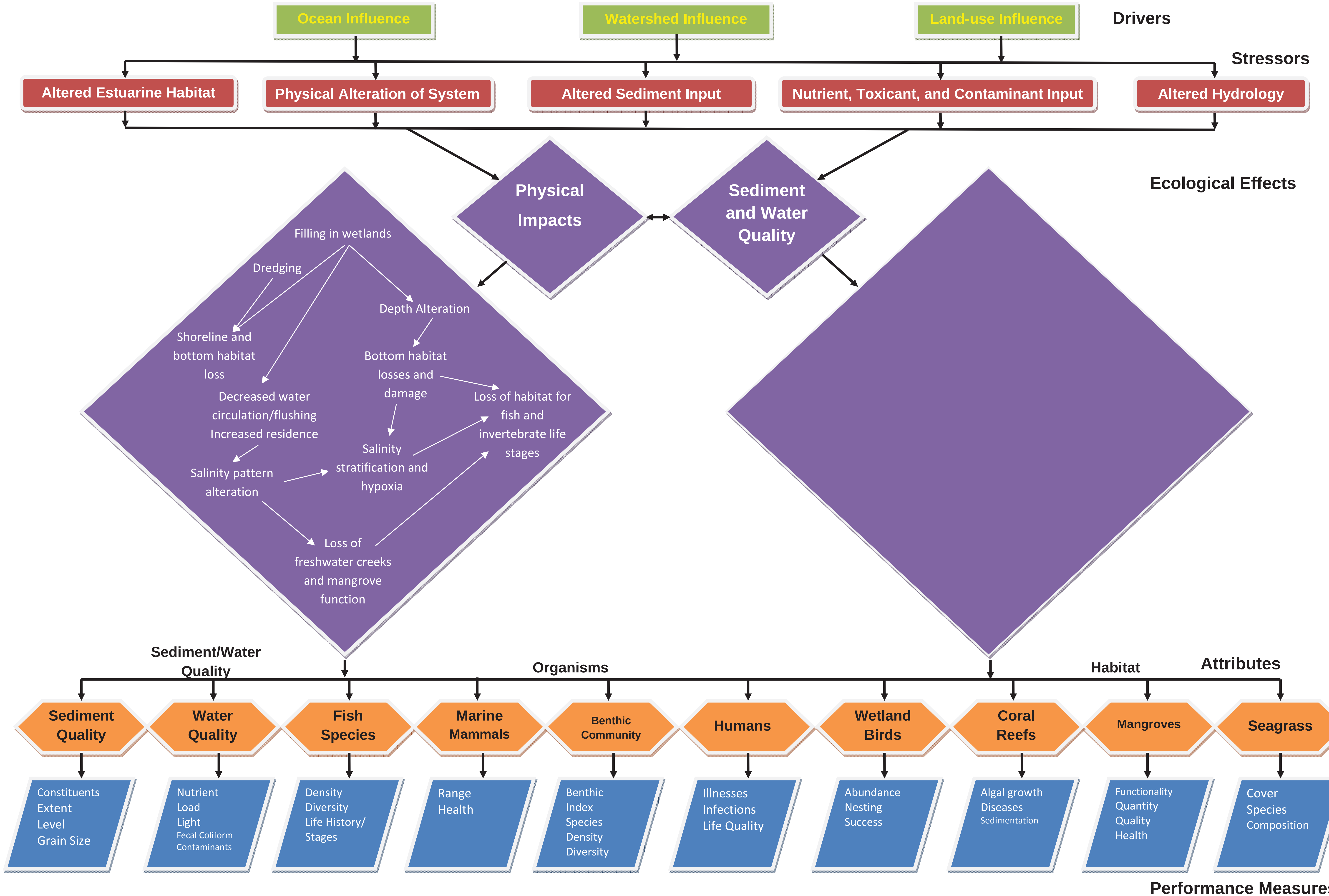

Ocean Influence
Watershed Influence
Land-use Influence
Drivers
Stressors
Altered Estuarine Habitat
Physical Alteration of System
Altered Sediment Input
Nutrient, Toxicant, and Contaminant Input
Altered Hydrology
Physical Impacts
Sediment and Water Quality
Ecological Effects
Filling in wetlands
Dredging
Depth Alteration
Shoreline and bottom habitat loss
Bottom habitat losses and damage
Loss of habitat for fish and invertebrate life stages
Decreased water circulation/flushing Increased residence
Salinity stratification and hypoxia
Salinity pattern alteration
Loss of freshwater creeks and mangrove function
Sediment/Water Quality
Organisms
Habitat
Attributes
Sediment Quality
Water Quality
Fish Species
Marine Mammals
Benthic Community
Humans
Wetland Birds
Coral Reefs
Mangroves
Seagrass
Constituents
Extent
Level
Grain Size
Nutrient
Load
Light
Fecal Coliform
Contaminants
Density
Diversity
Life History/
Stages
Range
Health
Benthic
Index
Species
Density
Diversity
Illnesses
Infections
Life Quality
Abundance
Nesting
Success
Algal growth
Diseases
Sedimentation
Functionality
Quantity
Quality
Health
Cover
Species
Composition
Performance Measures

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Appendix A2

Hydrodynamic and Water Quality Model Study of San Juan Bay Estuary (Bunch et al. 2000)

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ERDC TR-00-1

US Army Corps of Engineers®

Hydrodynamic and Water Quality Model Study of San Juan Bay Estuary

Barry W. Bunch, Carl F. Cerco, Mark S. Dortch,
Billy H. Johnson, Keu W. Kim

April 2000

Engineer Research and Development Center

ERDC TR-00-1
April 2000

Hydrodynamic and Water Quality Model Study of San Juan Bay Estuary

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TA7 E8 no.ERDC TR-00-1

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Preface

A hydrodynamic and water quality model study of San Juan Bay Estuary, Puerto Rico, was conducted from January 1996 through May 1999. This study was part of the United States Environmental Protection Agency's (USEPA) National Estuary Program. It was managed by the U.S. Army Engineer District, Jacksonville (CESAJ), and was sponsored by the USEPA Region II through the San Juan Bay Estuary Program (SJBEP), San Juan, Puerto Rico, and by the Carribean Environment and Development Institute of San Juan, Puerto Rico, through a Cooperative Research and Development Agreement with the U.S. Army Engineer Research and Development Center (ERDC). Messrs. A. J. Salem, G. M. Strain, and James Duck were Chief, Acting Chief, and Chief, respectively, Planning Division, CESAJ, and Ms. Teré Rodríguez and Ms. Edna Villanueva were Directors, SJBEP. Mr. Mitch Granat of Planning Division, CESAJ, Mr. Jorge Tous of the Jacksonville District's Antilles Office, and Messrs. Héctor Abreu-Cintrón and Luis Jorge Rivera-Herrera of the SJBEP were the technical points of contact for this study.

Dr. Mark S. Dortch, Chief, Water Quality and Contaminant Modeling Branch (WQCMB), Environmental Processes and Effects Division (EPED), Environmental Laboratory (EL), ERDC, was the study manager and ERDC technical point of contact. The hydrodynamic modeling portion of this study was conducted by Drs. Billy H. Johnson and Keu W. Kim of the Waterways and Estuaries Division (WED), of the ERDC Coastal and Hydraulics Laboratory (CHL), under the general supervision of Dr. William H. McAnally, Chief, WED. The water quality modeling portion of this study was conducted by Drs. Carl F. Cerco and Barry W. Bunch of the WQCMB, EL, under the direct supervision of Dr. Dortch and the general supervision of Dr. Richard E. Price, Chief, EPED. Drs. Bunch and Kim conducted most of the day-to-day modeling tasks.

Dr. Jorge Capella, Mr. Aurelio Mercado, and Dr. Jorge Corredor from the University of Puerto Rico Marine Sciences Department, and Dr. Richard Signell from the U.S. Geological Survey in Woods Hole, MA, were members of the SJBEP Modeling Evaluation Group, which provided very valuable assistance for the study's model adjustment and skill assessment tasks. The SJBEP Management Committee and the Scientific and Technical Advisory Committee selected the management scenarios modeled and evaluated in the study.

This report was prepared by Drs. Bunch, Cerco, Dortch, Johnson, and Kim. The order of the authors is alphabetical and does not represent the amount of contribution provided by each to this study. Each author provided significant contributions to this study. However, Drs. Bunch and Johnson did provide the greatest amount of written contributions to the report.

At the time of publication of this report, Director of CHL was Dr. James R. Houston, Acting Director of EL was Dr. John W Keeley, and Acting Director of ERDC was Dr. Lewis E. Link. Commander of ERDC was COL Robin R. Cababa, EN.

This report should be cited as follows:

> Bunch, B. W., Cerco, C. F., Dortch, M. S., Johnson, B. H., and Kim, K. W. (2000). "Hydrodynamic and Water Quality Model Study of San Juan Bay Estuary," ERDC TR-00-1, U.S. Army Engineer Research and Development Center, Vicksburg, MS.

1 Introduction

Background and Site Description

Urbanization and anthropogenic influences from metropolitan areas of San Juan, Puerto Rico, have significantly impacted the water quality of the San Juan Bay Estuary (SJBE) system. Water quality impacts consist of eutrophication (i.e., nutrient enrichment), depressed dissolved oxygen (DO) concentrations, high concentrations of fecal coliform bacteria (FCB), an indicator of pathogens, and the presence of toxic substances. Portions of the SJBE system may have less than adequate flushing characteristics to assimilate pollutant loadings.

The San Juan Metropolitan area includes thirteen municipalities located on the north coast of Puerto Rico. Within this region, the municipalities of Toa Baja, Cataño, Guaynabo, Bayamón, San Juan, Trujillo Alto, Carolina, and Loiza share part of their territories with the SJBE or its watershed. Over 700,000 people live in the 240-km^2 SJBE drainage basin, of which 215 km^2 is land and 25 km^2 is covered with water.

The SJBE consists of five embayments (see Figure 1-1). From west to east these include: Bahia de San Juan, Laguna del Condado, Laguna San José (including Laguna Los Corozos), Laguna La Torrecilla, and Laguna de Piñones. San Juan Bay (ca. 7 km^2) contains navigation channels, and the shoreline is highly developed. Laguna del Condado is a relatively small lagoon adjacent to an ocean inlet which keeps it well flushed. Laguna San José (4.6 km^2) is the innermost lagoon which is shallow (mean depth of 1.5 m) and has the least tidal fluctuation of 5-10 cm with the tidal range in San Juan Bay and Laguna La Torrecilla being about 60 cm. As a result Laguna San José experiences little tidal flushing. Laguna La Torrecilla (2.5 km^2) is connected to the ocean by Boca De Cangrejos and is bordered mostly by mangrove trees. Laguna de Piñones is connected to Laguna La Torrecilla through a small tidal creek with a width and depth of less than 5 m and 1 m, respectively. As a result, as in Laguna San José, tidal flushing in Laguna de Piñones is also small. Laguna de Piñones is surrounded by a large mangrove forest which can influence water quality in that lagoon.

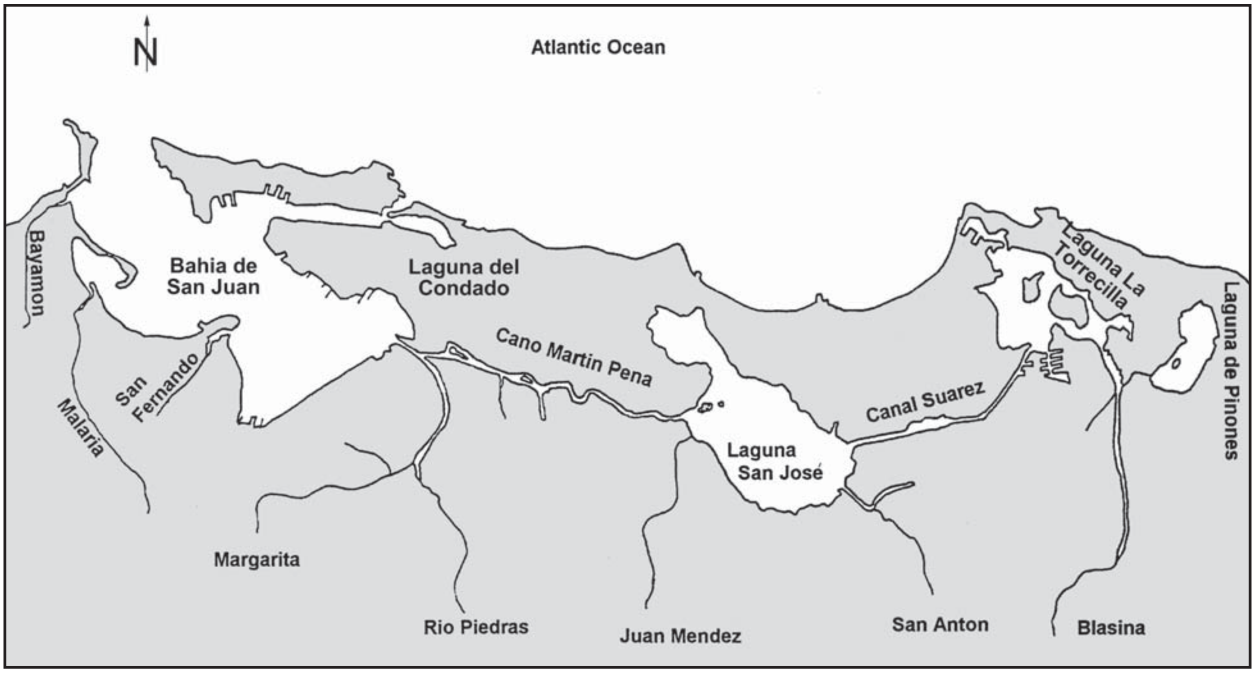


Figure 1-1. The San Juan Bay and Estuary system, San Juan, PR

The bay and lagoons are connected by narrow channels as shown in Figure 1-1. The two most distinct channels are Caño Martín Peña and Canal Suàrez. Caño Martín Peña, which connects Laguna San José and San Juan Bay, is about 6 km long with a width that varies from a few meters at its eastern end to about 100 m at its western end with a dredged depth of 3.6 m. The average depth of the canal is about 1.2 m. The narrow, shallow constriction along the eastern end of Caño Martín Peña is due to sedimentation and debris and greatly impedes flushing of Laguna San José. As a result, the eastern portion of Caño Martín Peña and Laguna San José have the poorest water quality. Canal Suàrez, which connects Laguna San José and Laguna La Torrecilla, is approximately 4 km long with widths ranging from greater than 30 m to less than 5 m where a major road crosses the canal. Depths of Canal Suàrez range from as great as 10 m where dredging has taken place to less than 1 m at the narrow constriction. This constriction contributes to the reduced tidal range in Laguna San José. The SJBE system opens to the ocean at three locations, San Juan Bay, Laguna del Condado, and Laguna La Torrecilla.

Portions of the system have been altered due to dredging. An 11.9-m- (39-ft-) deep navigation channel traverses the interior and the perimeter of San Juan Bay. Borrow pits exist within Laguna del Condado, Laguna San José, and Laguna La Torrecilla where sand and fill mining occurred for the development of residential and service facilities, such as the Luis Muñoz Marín International Airport. The borrow pits are as deep as 10-18 m and are chemically stratified. Thus, the waters in the pits are low in DO and high in dissolved substances, including nutrients and chemical oxygen demand.

Treated municipal wastewater has been discharged off the coast since 1986. However, pollutants still enter the SJBE system from combined sewer overflows; runoff from residential, agricultural, and industrialized areas; faulty sewage lines; and un-sewered residential areas. Caño Martín Peña receives considerable untreated domestic wastes from adjacent residential areas. Storm water is collected and pumped directly into the SJBE or indirectly through its tributaries by a total of 12 pump stations that have a combined maximum capacity of over 900,000 gpm (56.8 m^3/s). Pumped storm water is untreated and can contain pollutants. Additionally, pollutant loads can enter via freshwater inflow tributaries which enter the system through the Puerto Nuevo River, Malaria Channel, and three creeks, Juan Mèndez, San Antòn, and Blasina (see Figure 1-1). Freshwater flows are quite flashy as they are driven by local rainfall, and their water quality is dominated by local wash-off. There are no significant waste-water dischargers in the system, although there are two cooling water discharges from power plants.

Habitat loss has occurred within the system as a result of direct (e.g., construction, dredging, filling) and indirect impacts. Increased sediment runoff and eutrophication have increased water turbidity to the extent that benthic primary production is no longer possible in many locations. Water quality is poor in some areas of the system due to eutrophication and FCB contamination. Solid waste disposal is a problem within Caño Martín Peña as a result of inadequate waste collection from low income areas lining the canal.

Objective and Scope

San Juan Bay Estuary is one of the estuarine systems included in the U.S. Environmental Protection Agency's National Bay and Estuary Program (NEP; U.S. Environmental Protection Agency 1993). The NEP was started in 1987 as part of the Clean Water Act to protect and restore estuaries while supporting economic and recreational activities.

One of the goals of the San Juan Bay Estuary Program (SJBEP) and the Environmental Quality Board of Puerto Rico included the development of a hydrodynamic and a water quality model of the SJBE system for use in determining effective alternatives for water quality improvement and predicting the impacts of future development. The study reported herein was conducted to satisfy this goal. The objective of this study included development of such models and application of the models to evaluate the effectiveness of management alternatives on water quality improvement. Management alternatives considered included methods to increase system flushing and reduce pollutant loadings.

This study included four components: (1) bathymetric surveys; (2) hydrodynamic field data collection; (3) water quality data collection; and (4) hydrodynamic and water quality modeling. The first three components were necessary to conduct the fourth. Recent bathymetric surveys were necessary for model input since considerable dredging, filling, and sedimentation had occurred since the last survey. Bathymetric data collection was conducted through contract by CESAJ. Recent data collection efforts did not contain the information required for hydrodynamic and water quality model calibration, thus, it was necessary to conduct components (2) and (3). These two efforts and the resulting data are documented by Kennedy et al. (1996) and Fagerburg (1998). Much of the data collected from components (2) and (3) are shown within this report where model results are compared against field observations to assess model accuracy.

There are many potential future uses for these models for evaluating the effects of changes in system hydrology, structural features, and/or pollutant loadings on circulation and water quality. These models can serve as valuable tools to help guide management and monitoring of the SJBE.

This report presents the approach, descriptions of the hydrodynamic and water quality models, including their input data, adjustment/calibration and skill assessment, methods used for and results of management scenario simulations, and conclusions and recommendations.

2 Approach

Depths within SJBES range from about 1 m to 20 m. Since the water column density and related water quality variables experience significant variation over the water depth in the deeper channels and borrow areas, a three-dimensional (3D) model was recommended. However, shallow areas were represented as vertically mixed (i.e., one layer), and the connecting channels were represented as laterally mixed (i.e., one segment wide) in some areas.

Numerical, 3D hydrodynamic and water quality models were used to simulate the effects of strategies to increase flushing and reduce pollutant loadings. The hydrodynamic model (HM) and the water quality model (WQM) were indirectly coupled without feedback. This means that the HM was executed and results were saved for subsequent use by the WQM to drive its transport terms. Hydrodynamic results were saved as hourly averages and used to provide hourly hydrodynamic updates to the WQM. Feedback from the WQM to the HM was not necessary since temperature and salinity, which affect water density and thus the hydrodynamics, were included in the HM simulations. Other water quality variables simulated by the WQM have an insignificant effect on water density. The models used the same computational grid but different time steps. The HM time step was one minute, whereas the WQM time step was variable and on the order of tens of minutes.

The 3D numerical hydrodynamic model, CH3D-WES (**C**urvilinear **H**ydrodynamics in **3 D**imensions, WES version), was used for this study. The WES version of a former model (CH3D) was developed by Johnson et al. (1991 and 1993). Physical processes in the model include tides, wind, density effects, freshwater inflows, turbulence, and the effect of the earth's rotation. As its name implies, CH3D-WES makes hydrodynamic computations on a curvilinear or boundary-fitted planform grid. However, the vertical dimension is Cartesian which allows for modeling density stratification on relatively coarse grids. Shallow areas can be modeled with one layer which effectively treats such areas in a vertically averaged sense.

The CE-QUAL-ICM (referred to as ICM) multi-dimensional, water quality model (Cerco and Cole 1995) was used for this study. ICM uses the integrated compartment method (thus ICM) for numerical treatment, which is the same as a finite volume approach. This model was originally developed during a study of Chesapeake Bay (Cerco and Cole 1993 and 1994, Cerco 1995a and 1995b) and has subsequently been applied to other systems, including lower Green Bay (Mark et al. 1993), Newark Bay (Cerco and Bunch 1997 and Cerco, Bunch, and Letter 1999), New York Bight (Hall and Dortch 1994), Indian River and Rehoboth Bay, Delaware (Cerco et al. 1994 and Cerco and Seitzinger 1997). This model can and has been linked to a variety of hydrodynamic models for transport. However, the most common linkage is to CH3D-WES. The WQM has multiple water quality state variables, including temperature, salinity, DO, various forms of nitrogen, phosphorus, silica, and carbon, suspended solids, and phytoplankton. The model also includes a benthic sediment diagenesis submodel (DiToro and Fitzpatrick 1993) that simulates the decay and mineralization of bottom organic matter (e.g., settled algae) and the resulting nutrient and DO fluxes between the sediments and water column. The sediment diagenesis submodel dynamically couples sediment-water column interactions. For example, pollutant loading changes eventually affect sediment oxygen demand, which affects water column DO. Thus, this approach extends the credibility of the model for predicting future water quality. For this study, the WQM included the following 16 state variables:

- temperature
- salinity
- dissolved oxygen
- phytoplankton (one group)
- dissolved organic carbon
- particulate organic carbon
- particulate organic nitrogen
- dissolved organic nitrogen
- nitrate+nitrite nitrogen
- ammonium nitrogen
- particulate organic phosphorus
- dissolved organic phosphorus
- total inorganic phosphorus (with partitioning to dissolved and particulate phases)
- chemical oxygen demand (released from sediments)
- total suspended solids
- fecal coliform bacteria

In previous applications, models would be calibrated with one data set, then run with another independent data set, without changing any model parameters to verify model accuracy and adequacy for making predictions. In practice, if the verification was considered insufficiently accurate by the modelers, the parameters would be adjusted, and both the calibration and verification data sets would be re-run to assess accuracy of each. This process would be repeated until the model demonstrated acceptable accuracy for both the calibration and verification periods using the same coefficients. If the modelers were furnished a third data set, then all three periods would be used. In fact, modelers are data hungry and will use data whenever available to adjust/calibrate their models, with the hope of finding *universal* coefficients that are satisfactory for all periods. This procedure is basically the same as using all available data sets for model adjustment/calibration and assessing the accuracy, or *skill*, of the calibration. Therefore, the term "verification" has been recently dropped from the process and replaced with "skill assessment." As an example, the Chesapeake Bay model (Cerco and Cole 1994) was calibrated and the skill assessed for a continuous three-year period, rather than calibrating for one or two years and verifying for another. This was a truly tough test of the model since it was run continuously for the three years where errors from one year were passed to the next. The model evaluation group for the Chesapeake Bay study knew that essentially the modelers would use all three years anyway to calibrate the model, so why not just calibrate all three years together? Thus, calibration/adjustment and skill assessment were conducted in the Chesapeake Bay study rather than calibration and verification, and this was the approach used in the present study.

The terms model adjustment and model calibration are used for the HM and WQM, respectively. The primary difference in these terms is that HM adjustment is limited to a few parameters, whereas WQM calibration can involve varying a host of parameters that affect water quality kinetic rates and transfers. Due to study funding constraints, it was possible to collect data from only one time period for use in model adjustment/calibration and skill assessment. Ideally, it is desirable to have data from multiple time periods, or to have data from a long period of time so that the model can be evaluated for a large range of conditions.

HM and WQM adjustment/calibration were accomplished with data collected over approximately two months during the summer of 1995. Summer conditions generally result in the most severe water quality conditions due to increased stratification and warmer water. The hydrodynamic data collection period extended from 22 June 1995 through 19 August 1995. The water quality data collection period extended from 26 June 1995 through 2 September 1995. Locations where surface water quality was sampled during this period are shown in Figure 2-1. Both models were applied for this approximately two-month period during model adjustment/calibration and skill assessment.

Each management scenario simulation was conducted using conditions from the summer of 1995 for boundary conditions for freshwater flows, tides, winds, meteorological, and water quality. However, it was necessary to run the WQM longer than the summer season in order to bring the system to a new state caused by altered circulation and/or loadings. Thus, for each simulation scenario, numerous runs of the WQM were made where each successive run used results from the previous run as initial conditions. This process was continued until water quality variables reached a new equilibrium condition, which required approximately eight months of

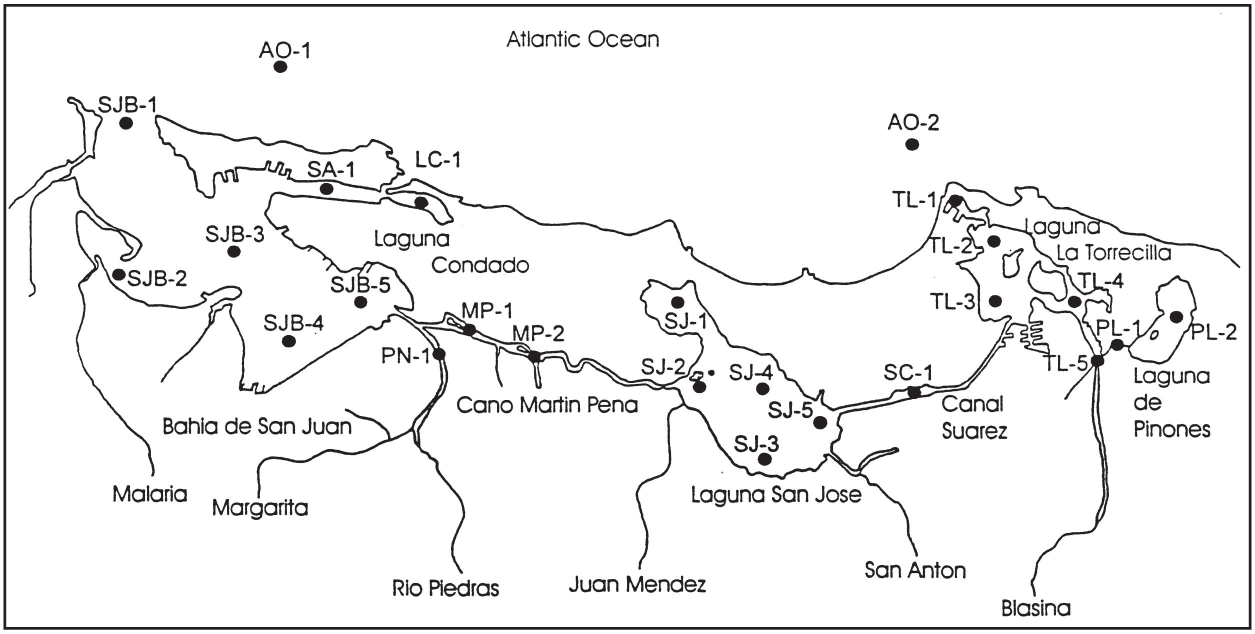


Figure 2-1. Water quality stations, San Juan Bay Estuary, summer 1995

water quality model simulation time. This procedure required using the HM output record repeatedly, or looping the hydrodynamics, to drive the WQM for longer periods. This approach approximated the long-term, steady-state response of the system to various management alternatives. The WQM required a relatively short time to reach equilibrium compared to other systems, which required on the order of several years. The part of the reason for this is believed to be due to the fact that relatively small changes in nutrient loadings to the system and/or system flushing characteristics were evaluated which required less time to reach equilibrium. Additionally, the model was repeatedly applied to warm-water conditions which accelerate reaction rates thus decreasing the time to reach equilibrium.

The results of each management scenario were then compared with results for a baseline scenario (Scenario 1a) which represented present conditions for circulation and loadings. The methods used in conducting scenario simulations are explained in more detail in Chapter 4. Looping the hydrodynamics to drive the water quality model to a long-term, steady-state, summer condition for scenario evaluations is considered a conservative approach, i.e., providing results that favor degraded rather than improved water quality, since summer conditions, which favor degraded water quality, do not persist repeatedly for long time frames. Management Scenarios 1b and 1c involved channel expansions in Caño Martín Peña. Scenario 2 involved filling dredged material borrow pits primarily in Laguna San José. Scenarios 3 and 4 evaluated channel expansion and a one-way tide gate in Canal Suárez, respectively. Scenarios 5a and 5b consisted of reductions of un-sewered loads to Caño Martín Peña and removal of pump station loads at the Baldorioty de Castro outfall in northern Laguna San José, respectively. Scenarios 6a and 6b were limited combinations of the above scenarios. The location of each management alternative is shown on the map of Figure 2-2.

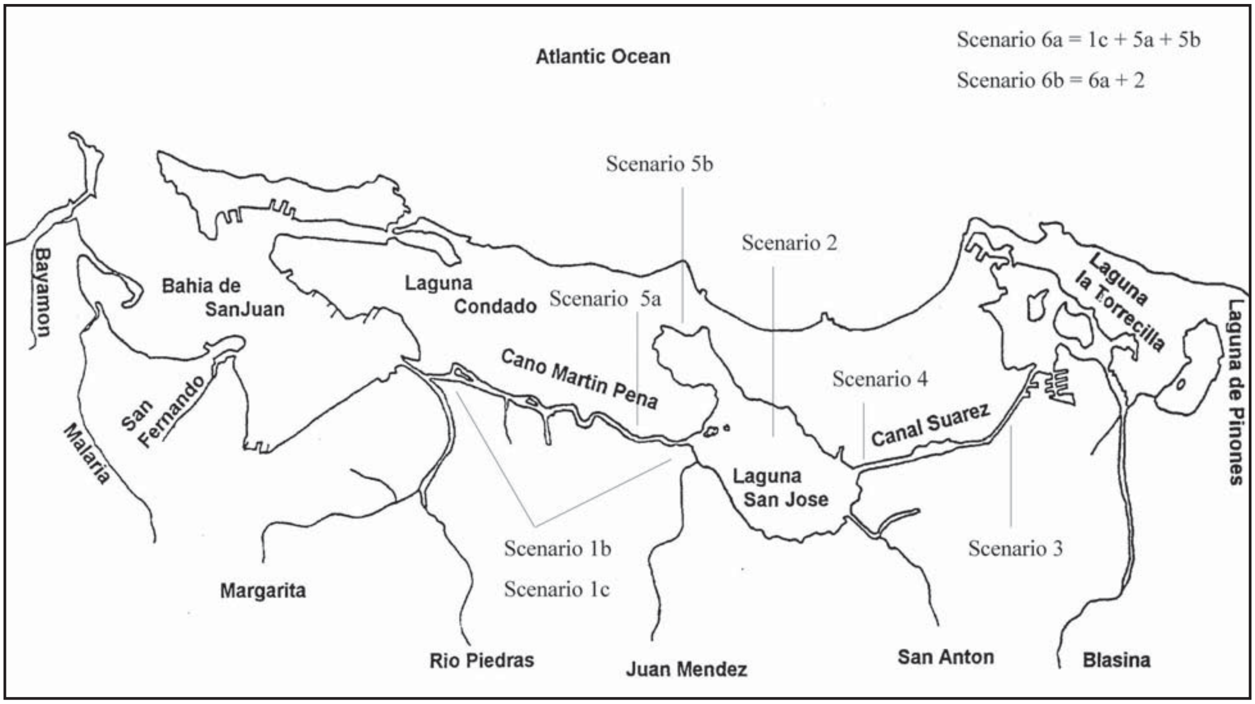


Figure 2-2. Locations of management alternatives (scenarios) in the San Juan Bay Estuary system

3 The Hydrodynamic Model

General

As noted, a 3D numerical hydrodynamic model of the San Juan Bay Estuary System has been developed to provide flow fields to the 3D water quality model of the system. As discussed in Chapter 2, to aid in model adjustment and skill assessment and to provide boundary conditions for production runs, a field data-collection effort was conducted during June-August 1995 (Fagerburg 1998). Water-surface elevations, salinity, and water-velocity data were collected at several locations. The short-term data were collected over 17-19 August 1995 when the crew went back to remove the long-term instruments. These data included Acoustic Doppler Current Profiler (ADCP) data collected over several ranges in an attempt to define the water flux through the connecting canals of the system. Model adjustment has primarily revolved around reproducing the observed tides throughout the system, reproducing the extreme stratification in salinity that often exists in the canals, and reproducing the net flux through the Martín Peña and Suàrez Canals.

The verified numerical hydrodynamic model has been used to generate flow fields for various scenarios expected to improve the water quality of San José Lagoon. These include widening and deepening the Martín Peña Canal, removing a bridge from Suàrez Canal that severely restricts the tidal flow, filling dredged holes throughout the system, and installing a tide gate in the Suàrez Canal.

Discussions of the model adjustment and skill assessment effort and results from the scenario runs are presented in Chapters 6 and 8, respectively. In this chapter, theoretical details of the 3D numerical model are provided along with discussions of the computational grid and boundary forcings employed in its application to the San Juan Bay Estuary System.

CH3D-WES Description

The basic model (CH3D) was originally developed by Sheng (1986) for the U.S. Army Engineer Waterways Experiment Station (WES) but was extensively modified in its application to Chesapeake Bay. These modifications have consisted of different basic formulations as well as substantial recoding for more efficient computing. As its name implies, CH3D-WES makes hydrodynamic computations on a curvilinear or boundary-fitted planform grid. Physical processes impacting bay-wide circulation and vertical mixing that are modeled include tides, wind, density effects (salinity and temperature), freshwater inflows, turbulence, and the effect of the earth's rotation.

Adequately representing the vertical turbulence is crucial to a successful simulation of stratification/destratification. What is referred to as a k-ϵ turbulence model is employed. The boundary-fitted coordinates feature of the model provides enhancement to fit the irregular shoreline configuration of the San Juan Estuary system and permits adoption of an accurate and economical grid schematization. The solution algorithm employs an external mode consisting of vertically averaged equations to provide the solution for the free surface to the internal mode consisting of the full 3-D equations. Model details are discussed below.

Basic Equations

The basic equations for an incompressible fluid in a right-handed Cartesian coordinate system (x, y, z) are:

$$\frac{\partial u}{\partial x}+\frac{\partial v}{\partial y}+\frac{\partial w}{\partial z}=0 \tag{3.1}$$

$$\frac{\partial u}{\partial t}+\frac{\partial u^2}{\partial x}+\frac{\partial uv}{\partial y}+\frac{\partial uw}{\partial z}=fv-\frac{1}{\rho}\frac{\partial p}{\partial x}+\frac{\partial}{\partial x}\left(A_H\frac{\partial u}{\partial x}\right)$$

$$+\frac{\partial}{\partial y}\left(A_H\frac{\partial u}{\partial y}\right)+\frac{\partial}{\partial z}\left(A_v\frac{\partial u}{\partial z}\right) \tag{3.2}$$

$$\frac{\partial v}{\partial t}+\frac{\partial uv}{\partial x}+\frac{\partial v^2}{\partial y}+\frac{\partial vw}{\partial z}=-fu-\frac{1}{\rho}\frac{\partial p}{\partial y}+\frac{\partial}{\partial x}\left(A_H\frac{\partial v}{\partial x}\right)$$

$$+\frac{\partial}{\partial y}\left(A_H\frac{\partial v}{\partial y}\right)+\frac{\partial}{\partial z}\left(A_v\frac{\partial v}{\partial z}\right) \tag{3.3}$$

$$\frac{\partial p}{\partial z} = -\rho g \tag{3.4}$$

$$\frac{\partial T}{\partial t} + \frac{\partial uT}{\partial x} + \frac{\partial vT}{\partial y} + \frac{\partial wT}{\partial z}$$

$$= \frac{\partial}{\partial x}\left(K_H \frac{\partial T}{\partial x}\right) + \frac{\partial}{\partial y}\left(K_H \frac{\partial T}{\partial y}\right) + \frac{\partial}{\partial z}\left(K_v \frac{\partial T}{\partial z}\right) \tag{3.5}$$

$$\frac{\partial S}{\partial t} + \frac{\partial uS}{\partial x} + \frac{\partial vS}{\partial y} + \frac{\partial wS}{\partial z}$$

$$= \frac{\partial}{\partial x}\left(K_H \frac{\partial S}{\partial x}\right) + \frac{\partial}{\partial y}\left(K_H \frac{\partial S}{\partial y}\right) + \frac{\partial}{\partial z}\left(K_v \frac{\partial S}{\partial z}\right) \tag{3.6}$$

$$\rho = \rho(T, S) \tag{3.7}$$

where

(u, v, w) = velocities in x-, y-, z-directions

t = time

f = Coriolis parameter defined as $2\Omega \sin \phi$ where Ω is the rotational speed of the earth and ϕ = latitude

ρ = density

p = pressure

A_H, K_H = horizontal turbulent eddy coefficients

A_v, K_v = vertical turbulent eddy coefficients

g = gravitational acceleration

T = temperature

S = salinity

Equation 3.4 implies that vertical accelerations are negligible. Thus, the pressure is hydrostatic.

Various forms of the equation of state can be used for Equation 3.7. In the present model, Equation 3.8 is used:

$$\rho = P / (\alpha + 0.698 P) \tag{3.8}$$

where

$$P = 5890 + 38T - 0.375T^2 + 3S$$

$$\alpha = 1779.5 + 11.25T - 0.0745T^2$$

and T is in degrees Celsius (°C), S is in parts per thousand (ppt), and ρ is in g/cm^3.

Working with the dimensionless form of the governing equations makes it easier to compare the relative magnitude of various terms in the equations. Therefore, the following dimensionless variables are used:

$$(u^*, v^*, w^*) = (u, v, wX_r / Z_r) / U_r$$

$$(x^*, y^*, z^*) = (x, y, zX_r / Z_r) / X_r$$

$$(\tau_x^*, \tau_y^*) = (\tau_x^w, \tau_y^w) / \rho_o f Z_r U_r$$

$$t^* = tf$$

$$\zeta^* = g\zeta / fU_r X_r = \zeta / S_r$$

$$\rho^* = (\rho - \rho_o) / (\rho_r - \rho_o)$$

$$T^* = (T - T_o) / (T_r - T_o)$$

$$A_H^* = A_H / A_{Hr}$$

$$A_v^* = A_v / A_{vr}$$

$$K_H^* = K_H / K_{Hr}$$

$$K_v^* = K_v / K_{vr}$$

where

(τ_x^w, τ_y^w) = wind stress in x-, y-directions

ζ = water-surface elevation

ρ_0, T_0 = typical values for the water density and temperature and S_r, T_r, U_r, ρ_r, X_r, Z_r, A_{Hr}, A_{vr}, K_{Hr}, and K_{vr} are arbitrary reference values of the salinity, temperature, velocity, density, horizontal dimension, vertical dimension, horizontal viscosity, vertical viscosity, horizontal diffusion, and vertical diffusion, respectively. This then yields the following dimensionless parameters in the governing equations:

a. Vertical Ekman number:
$E_v = A_{vr} / fZ_r^2$

b. Lateral Ekman number:
$E_H = A_{Hr} / fX_r^2$

c. Vertical Prandtl (Schmidt) number:
$Pr_v = A_{vr} / K_{vr}$

d. Lateral Prandtl (Scmidt) number:
$Pr_H = A_{Hr} / K_{Hr}$

e. Froude number:
$F_r = U_r / \left(gZ_r\right)^{1/2} \left(6.26\right)$

f. Rossby number:
$R_o = U_r / fX_r$

g. Densimetric Froude number:
$Fr_D = F_r / \sqrt{\epsilon}$

where

$$\epsilon = (\rho_r - \rho_o) / \rho_o$$

External-Internal Modes

The basic equations (Equations 3.1 through 3.8) can be integrated over the depth to yield a set of vertically integrated equations for the water surface, ζ, and unit flow rates U and V in the x- and y-directions. Using the dimensionless variables (asterisks have been dropped) and the parameters previously defined, the vertically integrated equations constituting the external mode are:

$$\frac{\partial \zeta}{\partial t} + \beta\left(\frac{\partial U}{\partial x} + \frac{\partial V}{\partial y}\right) = 0 \tag{3.9}$$

$$\frac{\partial U}{\partial t} = -H\frac{\partial \zeta}{\partial x} + \tau_{sx} - \tau_{bx} + V$$

$$- R_o\left[\frac{\partial}{\partial x}\left(\frac{UU}{H}\right)+\frac{\partial}{\partial y}\left(\frac{UV}{H}\right)\right]$$

$$+ E_H\left[\frac{\partial}{\partial X}\left(A_H\frac{\partial U}{\partial x}\right)+\frac{\partial}{\partial y}\left(A_H\frac{\partial U}{\partial y}\right)\right]$$

$$-\frac{R_o}{Fr_D^2}\frac{H^2}{2}\frac{\partial \rho}{\partial x} \tag{3.10}$$

$$\frac{\partial V}{\partial t} = -H\frac{\partial \zeta}{\partial y}+\tau_{sy}-\tau_{by}-U$$

$$- R_o\left[\frac{\partial}{\partial x}\left(\frac{UV}{H}\right)+\frac{\partial}{\partial y}\left(\frac{VV}{H}\right)\right]$$

$$+ E_H\left[\frac{\partial}{\partial x}\left(A_H\frac{\partial V}{\partial x}\right)+\frac{\partial}{\partial y}\left(A_H\frac{\partial V}{\partial y}\right)\right]$$

$$-\frac{R_o}{Fr_D^2}\frac{H^2}{2}\frac{\partial \rho}{\partial y} \tag{3.11}$$

where

β = $gZ_r / f^2X_r^2 = (R_o / F_r)^2$

H = total depth

τ_s, τ_b = surface and bottom shear stresses

As will be discussed later, the major purpose of the external mode is to provide the updated water-surface field.

The dimensionless form of the internal mode equations from which the 3-D velocity, salinity, and temperature fields are computed are:

$$\frac{\partial hu}{\partial t} = -h\frac{\partial \zeta}{\partial x}+E_v\frac{\partial}{\partial z}\left(A_v\frac{\partial hu}{\partial z}\right)+hv$$

$$- R_o\left(\frac{\partial huu}{\partial x}+\frac{\partial huv}{\partial y}+\frac{\partial huw}{\partial z}\right)$$

$$+E_H\left[\frac{\partial}{\partial x}\left(A_H\frac{\partial hu}{\partial x}\right)+\frac{\partial}{\partial y}\left(A_H\frac{\partial hu}{\partial y}\right)\right]$$

$$-\frac{R_o}{Fr_D^2}\left(\int_z^\zeta\frac{\partial\rho}{\partial x}dz\right) \tag{3.12}$$

$$\frac{\partial hv}{\partial t}=-h\frac{\partial\zeta}{\partial y}+E_v\frac{\partial}{\partial z}\left(A_v\frac{\partial hv}{\partial z}\right)-hu$$

$$-R_o\left(\frac{\partial hvu}{\partial x}+\frac{\partial hvv}{\partial y}+\frac{\partial hvw}{\partial z}\right)$$

$$+E_H\left[\frac{\partial}{\partial x}\left(A_H\frac{\partial hv}{\partial x}\right)+\frac{\partial}{\partial y}\left(A_H\frac{\partial hv}{\partial y}\right)\right]$$

$$-\frac{R_o}{Fr_D^2}\left(\int_z^\zeta\frac{\partial\rho}{\partial y}dz\right) \tag{3.13}$$

$$w_{k+1/2}=w_{k-1/2}-\left(\frac{\partial uh}{\partial x}+\frac{\partial vh}{\partial y}\right) \tag{3.14}$$

$$\frac{\partial hT}{\partial t}=\frac{E_v}{Pr_v}\frac{\partial}{\partial z}\left(K_v\frac{\partial T}{\partial z}\right)-R_o\left(\frac{\partial huT}{\partial x}+\frac{\partial hvT}{\partial y}+\frac{\partial hwT}{\partial z}\right)$$

$$+\frac{E_H}{Pr_H}\left[\frac{\partial}{\partial x}\left(K_H\frac{\partial hT}{\partial x}\right)+\frac{\partial}{\partial y}\left(K_H\frac{\partial hT}{\partial y}\right)\right] \tag{3.15}$$

$$\frac{\partial hS}{\partial t}=\frac{E_v}{Pr_v}\frac{\partial}{\partial z}\left(K_v\frac{\partial S}{\partial z}\right)-R_o\left(\frac{\partial huS}{\partial x}+\frac{\partial hvS}{\partial y}+\frac{\partial hwS}{\partial z}\right)$$

$$+\frac{E_H}{Pr_H}\left[\frac{\partial}{\partial x}\left(K_H\frac{\partial hS}{\partial X}\right)+\frac{\partial}{\partial y}\left(K_H\frac{\partial hS}{\partial y}\right)\right] \tag{3.16}$$

In these equations h is the thickness of an internal layer, w is the vertical component of the velocity, and k+1/2 and k-1/2 represent the top and bottom, respectively, of the k^{th} vertical layer.

Boundary-Fitted Equations

To better resolve complex geometries in the horizontal directions, the CH3D-WES makes computations on the boundary-fitted or generalized curvilinear planform grid shown in Figure 3-1. This necessitates the transformation of the governing equations into boundary-fitted coordinates (ξ,η). If only the x- and y-coordinates are transformed, a system of equations similar to those solved by Johnson (1980) for vertically averaged flow fields is obtained. However, in CH3D-WES not only are the x- and y-coordinates transformed into the (ξ,η) curvilinear system, but also the velocity is transformed such that its components are perpendicular to the (ξ,η) coordinate lines; i.e., contravariant components of the velocity are computed. This is accomplished by employing the following definitions for the components of the Cartesian velocity (u, v) in terms of contravariant components $\bar{u}$ and $\bar{v}$

$$u = x_\xi \bar{u} + x_\eta \bar{v}$$

$$v = y_\xi \bar{u} + y_\eta \bar{v}$$

along with the following expressions for replacing Cartesian derivatives

$$f_x = \frac{1}{J}\left[\left(f y_\eta\right)_\xi - \left(f y_\xi\right)_\eta\right]$$

$$f_y = \frac{1}{J}\left[-\left(f x_\eta\right)_\xi + \left(f x_\xi\right)_\eta\right]$$

where J is the Jacobian of the transformation defined as

$$J = x_\xi y_\eta - x_\eta y_\xi$$

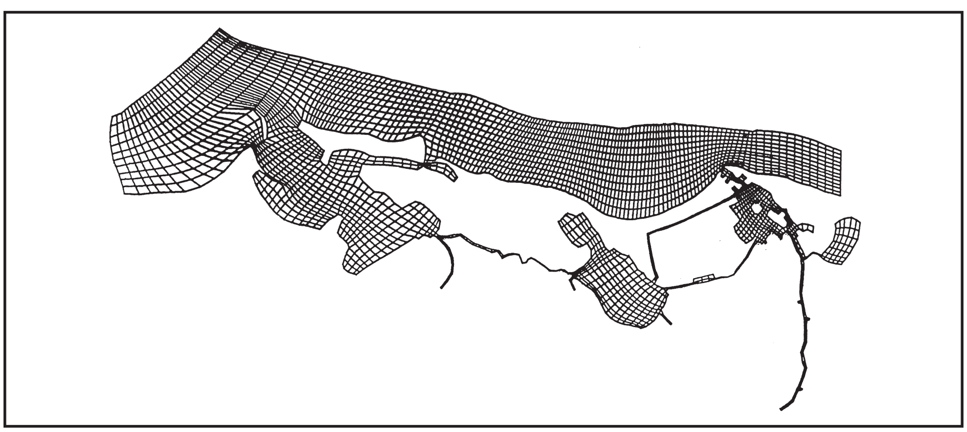


Figure 3-1. Numerical grid of San Juan estuarine system

With the governing equations written in terms of the contravariant components of the velocity, boundary conditions can be prescribed on a boundary-fitted grid in the same manner as on a Cartesian grid since $\bar{u}$ and $\bar{v}$ are perpendicular to the curvilinear cell faces (e.g., at a land boundary, either $\bar{u}$ or $\bar{v}$ is set to zero).

Initially the vertical dimension was handled through the use of what is commonly called a sigma-stretched grid. However, with a sigma-stretched grid, the bottom layer in one column communicates with the bottom layer in an adjacent column. Thus, if depth changes are rather coarsely resolved, channel stratification cannot be maintained. As a result, the governing equations, Equations 3.17-3.21, presented for solution on the Cartesian or z-plane in the vertical direction are the ones constituting the internal mode.

With both the Cartesian coordinates and the Cartesian velocity transformed, the following boundary-fitted equations for $\bar{u}$, $\bar{v}$, w, S, and T to be solved in each vertical layer are obtained.

$$\frac{\partial h\bar{u}}{\partial t} = -h\left(\frac{G_{22}}{J^2}\frac{\partial\zeta}{\partial\xi} - \frac{G_{12}}{J^2}\frac{\partial\zeta}{\partial\eta}\right) + \frac{h}{J}\left(G_{12}\bar{u} + G_{22}\bar{v}\right) + \frac{R_o x_\eta}{J^2}\left[\frac{\partial}{\partial\xi}\left(Jy_\xi h\bar{u}\bar{u}\right.\right.$$

$$\left.\left. + Jy_n h\bar{u}\bar{v}\right) + \frac{\partial}{\partial\eta}\left(Jy_\xi h\bar{u}\bar{v} + Jy_\eta h\bar{v}\bar{v}\right)\right] - \frac{R_o y_\eta}{J^2}\left[\frac{\partial}{\partial\xi}\left(Jx_\xi h\bar{u}\bar{u} + Jx_\eta h\bar{u}\bar{v}\right)\right.$$

$$\left. + \frac{\partial}{\partial\eta}\left(Jx_\xi h\bar{u}\bar{v} + Jx_\eta h\bar{v}\bar{v}\right)\right] - R_o\left[\left(w\bar{u}\right)_{top} - \left(w\bar{u}\right)_{bot}\right]$$

$$+ E_v\left[\left(A_v\frac{\partial\bar{u}}{\partial z}\right)_{top} - \left(A_v\frac{\partial\bar{u}}{\partial z}\right)_{bot}\right] - \frac{R_o h}{Fr_D^2}\left[\int_z^\zeta\left(\frac{G_{22}}{J^2}\frac{\partial\rho}{\partial\xi}\right.\right.$$

$$\left.\left. - \frac{G_{12}}{J^2}\frac{\partial\rho}{\partial\eta}\right)dz\right] + Horizontal\ Diffusion \tag{3.17}$$

$$\frac{\partial h\bar{v}}{\partial t} = -h\left(-\frac{G_{21}}{J^2}\frac{\partial\zeta}{\partial\xi} + \frac{G_{11}}{J^2}\frac{\partial\zeta}{\partial\eta}\right) - \frac{h}{J}\left(G_{11}\bar{u} + G_{21}\bar{v}\right) - \frac{R_o x_\xi}{J^2}\left[\frac{\partial}{\partial\xi}\left(Jy_\xi h\bar{u}\bar{u}\right.\right.$$

$$\left.\left. + Jy_n h\bar{u}\bar{v}\right) + \frac{\partial}{\partial\eta}\left(Jy_\xi h\bar{u}\bar{v} + Jy_\eta h\bar{v}\bar{v}\right)\right] + \frac{R_o y_\xi}{J^2}\left[\frac{\partial}{\partial\xi}\left(Jx_\xi h\bar{u}\bar{u} + Jx_\eta h\bar{u}\bar{v}\right)\right.$$

$$\left. + \frac{\partial}{\partial\eta}\left(Jx_\xi h\bar{u}\bar{v} + Jx_\eta h\bar{v}\bar{v}\right)\right] - R_o\left[\left(w\bar{v}\right)_{top} - \left(w\bar{v}\right)_{bot}\right]$$

$$+E_v\left[\left(A_v\frac{\partial \bar{v}}{\partial z}\right)_{top}-\left(A_v\frac{\partial \bar{v}}{\partial z}\right)_{bot}\right]-\frac{R_o h}{Fr_D^2}\left[\int_z^{\zeta}\left(-\frac{G_{21}}{J^2}\frac{\partial\rho}{\partial\xi}+\frac{G_{11}}{J^2}\frac{\partial\rho}{\partial\eta}\right)dz\right]$$

$$+\ Horizontal\ Diffusion \tag{3.18}$$

$$w_{top}=w_{bot}-\frac{1}{J}\left(\frac{\partial J\bar{u}h}{\partial\xi}+\frac{\partial J\bar{v}h}{\partial\eta}\right) \tag{3.19}$$

$$\frac{\partial hS}{\partial t}=\frac{E_v}{\mathrm{Pr}_v}\left[\left(K_v\frac{\partial S}{\partial z}\right)_{top}-\left(K_v\frac{\partial S}{\partial z}\right)_{bot}\right]-\frac{R_o}{J}\left(\frac{\partial hJ\bar{u}S}{\partial\xi}+\frac{\partial hJ\bar{v}S}{\partial\eta}\right)$$

$$-R_o\left[(wS)_{top}-(wS)_{bot}\right]+Horizontal\ Diffusion \tag{3.20}$$

$$\frac{\partial hT}{\partial t}=\frac{E_v}{Pr_v}\left[\left(K_v\frac{\partial T}{\partial z}\right)_{top}-\left(K_v\frac{\partial T}{\partial z}\right)_{bot}\right]-\frac{R_o}{J}\left(\frac{\partial hJ\bar{u}T}{\partial\xi}+\frac{\partial hJ\bar{v}T}{\partial\eta}\right)$$

$$-R_o\left[(wT)_{top}-(wT)_{bot}\right]+Horizontal\ Diffusion \tag{3.21}$$

where

$$G_{11}=x_\xi^2+y_\xi^2$$
$$G_{22}=x_\eta^2+y_\eta^2$$
$$G_{12}=G_{21}=x_\xi x_\eta+y_\xi y_\eta$$

Similarly, the transformed external mode equations become:

$$\frac{\partial\zeta}{\partial t}+\beta\left(\frac{\partial\bar{U}}{\partial\xi}+\frac{\partial\bar{V}}{\partial\eta}\right)=0 \tag{3.22}$$

$$\frac{\partial\bar{U}}{\partial t}=-\frac{H}{J^2}\left(G_{22}\frac{\partial\zeta}{\partial\xi}-G_{12}\frac{\partial\zeta}{\partial\eta}\right)$$

$$+\frac{1}{J}\left(G_{12}\bar{U}+G_{22}\bar{V}\right)+\frac{R_o x_n}{J^2H}\left[\frac{\partial}{\partial\xi}\left(Jy_\xi\overline{U}\overline{U}+Jy_\eta\overline{U}\overline{V}\right)+\frac{\partial}{\partial\eta}\left(Jy_\xi\overline{U}\overline{V}+Jy_\eta\overline{V}\overline{V}\right)\right]$$

$$- \frac{R_o y_\eta}{J^2} \left[\frac{\partial}{\partial \xi} \left(J x_\xi \overline{U}\,\overline{U} + J x_\eta \overline{U}\,\overline{V} \right) + \frac{\partial}{\partial \eta} \left(J x_\xi \overline{U}\,\overline{V} + J x_\eta \overline{V}\,\overline{V} \right) \right]$$

$$+ \tau_{s\xi} - \tau_{b\xi} - \frac{R_o}{Fr_D^2} \frac{H^2}{2} \left(G_{22} \frac{\partial \rho}{\partial \xi} - G_{12} \frac{\partial \rho}{\partial \eta} \right)$$

$$+ \textit{Horizontal Diffusion} \tag{3.23}$$

$$\frac{\partial \overline{V}}{\partial t} = - \frac{H}{J^2} \left(-G_{21} \frac{\partial \zeta}{\partial \xi} + G_{11} \frac{\partial \zeta}{\partial \eta} \right) - \frac{1}{J} \left(G_{11} \overline{U} + G_{21} \overline{V} \right)$$

$$- \frac{R_o x_\xi}{J^2 H} \left[\frac{\partial}{\partial \xi} \left(J y_\xi \overline{U}\,\overline{U} + J y_\eta \overline{U}\,\overline{V} \right) + \frac{\partial}{\partial \eta} \left(J y_\xi \overline{U}\,\overline{V} + J y_\eta \overline{V}\,\overline{V} \right) \right]$$

$$+ \frac{R_o y_\xi}{J^2 H} \left[\frac{\partial}{\partial \xi} \left(J x_\xi \overline{U}\,\overline{U} + J x_\eta \overline{U}\,\overline{V} \right) + \frac{\partial}{\partial \eta} \left(J x_\xi \overline{U}\,\overline{V} + J x_\eta \overline{V}\,\overline{V} \right) \right]$$

$$+ \tau_{s\eta} - \tau_{b\eta} - \frac{R_o}{Fr_D^2} \frac{H^2}{2} \left(-G_{21} \frac{\partial \rho}{\partial \xi} + G_{11} \frac{\partial \rho}{\partial \eta} \right)$$

$$+ \textit{Horizontal Diffusion} \tag{3.24}$$

where $\overline{U}$ and $\overline{V}$ are contravariant components of the vertically averaged velocity.

Equations 3.22-3.24 are solved first to yield the water-surface elevations, which are then used to evaluate the water-surface slope terms in the internal mode equations. The horizontal diffusion terms are given in Appendix A.

Numerical Solution Algorithm

Finite differences are used to replace derivatives in the governing equations, resulting in a system of linear algebraic equations to be solved in both the external and internal modes. A staggered grid is used in both the horizontal and vertical directions of the computational domain. In the horizontal directions, a unit cell consists of a ζ-point in the center ($\zeta_{i,j}$), a U-point on its left face ($U_{i,j}$), and a V-point on its bottom face ($V_{i,j}$). In the vertical direction, the vertical velocities are computed at the “full” grid points. Horizontal velocities, temperature, salinity, and density are computed at the “half” grid points (half grid spacing below the full points).

The external mode solution consists of the surface displacement and vertically integrated contravariant unit flows $\overline{U}$ and $\overline{V}$. All of the terms in the transformed vertically averaged continuity equation are treated implicitly whereas only the water-surface slope terms in the transformed vertically averaged momentum equations are treated implicitly. If the external mode is used purely as a vertically averaged model, the bottom friction is also treated implicitly. Those terms treated implicitly are weighted between the new and old time-steps. The resulting finite difference equations are then factored such that a ξ-sweep followed by an η-sweep of the horizontal grid yields the solution at the new time-step.

Writing Equations 3.11 as

$$\frac{\partial \zeta}{\partial t} + \beta\left(\frac{\partial \overline{U}}{\partial \xi} + \frac{\partial \overline{V}}{\partial \eta}\right) = 0 \tag{3.25}$$

$$\frac{\partial \overline{U}}{\partial t} + \frac{H}{J^2} G_{22} \frac{\partial \zeta}{\partial \eta} = M \tag{3.26}$$

$$\frac{\partial \overline{V}}{\partial t} + \frac{H}{J^2} G_{11} \frac{\partial \zeta}{\partial \eta} = N \tag{3.27}$$

where M and N are the remaining terms in Equations 3.10 and 3.11, the ξ-sweep is

$$\xi - sweep \rightarrow \zeta_{ij}^{*} + \frac{\beta\theta\Delta t}{\Delta\xi}\left(\overline{U}_{i+1,j}^{*} - \overline{U}_{ij}^{*}\right)$$

$$= \zeta_{ij}^{n}(1-\theta)\frac{\Delta t}{\Delta\xi}\left(\overline{U}_{i+1,j}^{n} - \overline{U}_{ij}^{n}\right)\frac{\Delta t}{\Delta\eta}\left(\overline{V}_{ij+1}^{n} - \overline{V}_{ij}^{n}\right) \tag{3.28}$$

where θ is a parameter determining the degree of implicitness and

$$\overline{U}_{ij}^{n+1} + \frac{\theta\Delta t H G_{22}}{\Delta\xi J^2}\left(\zeta_{ij}^{*} - \zeta_{i-1,j}^{*}\right) = \overline{U}_{ij}^{n} - (1-\theta)\frac{\Delta t H G_{22}}{\Delta\xi J^2}\left(\zeta_{ij}^{n} - \zeta_{i-1,j}^{n}\right) + \Delta t M^{n} \tag{3.29}$$

The η-sweep then provides the updated ζ and $\overline{V}$ at the n + 1 time level.

$$\eta - sweep \rightarrow \zeta_{ij}^{n+1} + \frac{\beta\theta\Delta t}{\Delta\eta}\left(\overline{V}_{i,j+1}^{n+1} - \overline{V}_{ij}^{n+1}\right) = \zeta_{i,j}^{*}$$

$$-\left(1-\theta\right)\frac{\Delta t}{\Delta\eta}\left(\overline{V}^{n}_{i,j+1}-\overline{V}^{n}_{i,j}\right)+\frac{\Delta t}{\Delta\eta}\left(\overline{V}^{n}_{i,j+1}-\overline{V}^{n}_{i,j}\right) \tag{3.30}$$

and

$$\overline{V}^{n+1}_{i,j}+\frac{\theta\Delta tHG_{11}}{\Delta\eta J^2}\left(\zeta^{n+1}_{i,j+1}-\zeta^{n+1}_{i,j}\right)$$

$$=V^{n}_{i,j}-\left(1-\theta\right)\frac{\Delta tHG_{11}}{\Delta\eta J^2}\left(\zeta^{n}_{i,j+1}-\zeta^{n}_{i,j}\right)+\Delta tN^{n} \tag{3.31}$$

A typical value of θ of 0.55 yields stable and accurate solutions.

The internal mode consists of computations from Equations 3.17-3.21 for the three velocity components $\overline{u}$, $\overline{v}$, and w, salinity, and temperature. The same time-step size is used for both internal and external modes. The only terms treated implicitly are the vertical diffusion terms in all equations and the bottom friction and surface slope terms in the momentum equations. Values of the water-surface elevations from the external mode are used to evaluate the surface slope terms in Equations 3.17 and 3.18. As a result, the extremely restrictive speed of a free-surface gravity wave is removed from the stability criteria. Roache's second upwind differencing is used to represent the convective terms in the momentum equations, whereas a spatially third-order scheme developed by Leonard (1979) called QUICKEST is used to represent the advective terms in Equations 3.20 and 3.21 for salinity and temperature, respectively. For example, if the velocity on the right face of a computational cell is positive, then with QUICKEST the value of the salinity used to compute the flux through the face is

$$S_R=\frac{1}{2}\left(S_{i,j,k}+S_{i+1,j,k}\right)-\frac{1}{6}\left[1-\left(\frac{\overline{U}_{i+1,j,k}\Delta t}{\Delta\xi}\right)^2\right]\left(S_{i+1,j,k}-2S_{i,j,k}+S_{i-1,j,k}\right)$$

$$-\frac{1}{2}\frac{U_{i+1,j,k}\Delta t}{\Delta\xi}\left(S_{i+1,j,k}-S_{i,j,k}\right) \tag{3.32}$$

Turbulence Parameterization

The effect of vertical turbulence is modeled using the concept of eddy viscosity and diffusivity to parameterize the velocity and density correlation terms that arise from a time averaging of the governing equations. The eddy coefficients are computed through the implementation of what is referred to as a k-∈ turbulence model. This model is a two-equation model for the computation of the kinetic energy of the turbulence (k) and the dissipation of the turbulence ($\in$). Both time evolution and vertical diffusion are retained, and the efffects of surface wind shear, bottom shear, velocity gradient turbulence production, dissipation, and stratification are included. The basic idea behind the k-$\in$ turbulence model (Rodi 1980) is that the vertical eddy viscosity coefficient can be related to the turbulent kinetic energy per unit mass, k, and its rate of dissipation, $\in$, and an empirical coefficient (c_v = 0.09) by:

$$A_z = c_v \frac{k^2}{\in} \tag{3.33}$$

The transport equation for the turbulence quantities are:

$$\frac{\partial(k)}{\partial t} - \frac{\partial}{\partial z}\left(A_z \frac{\partial k}{\partial z} \right) = \left(P_z - \in + G \right) \tag{3.34}$$

$$\frac{\partial(\in)}{\partial t} - \frac{\partial}{\partial z}\left(\frac{A_z}{\sigma_\in} \frac{\partial \in}{\partial z} \right) = \left(c_1 \frac{\in}{k} P_z - c_2 \frac{\in^2}{k} \right) \tag{3.35}$$

in which σ_ε = 1.3, c_1 = 1.44, and c_2 = 1.92 (Rodi 1980). The source and sink terms on the right-hand side of Equations 3.34 and 3.35 represent mechanical production of turbulence due to velocity gradients, P_z, and buoyancy production or destruction in the stable stratified condition, G. Surface (s) and bottom (b) boundary conditions for the turbulence quantities are specified as:

$$k_{s,b} = \frac{U_*^2}{\sqrt{c_v}} \tag{3.36}$$

$$\in_{s,b} = \frac{U_*^3}{\kappa \frac{\Delta z}{2}} \tag{3.37}$$

where κ is the von Karman constant (= 0.4). The friction velocity used for the surface boundary condition is defined as the square root of the resultant wind shear stress divided by the water density. The bottom friction velocity is computed in an identical way with the wind shear stress being replaced by the bottom shear stress. The suppression of the vertical diffusivity by stratification is given by:

$$K_z = A_z \left(1 + 3R_i\right)^{-2} \tag{3.38}$$

where R_i is the Richardson Number (Bloss et al. 1988).

Therefore, the number becomes::

$$P_r = (1 + 3R_i)^2 \tag{3.39}$$

Boundary Conditions

The boundary conditions at the free surface are

$$A_v\left(\frac{\partial \bar{u}}{\partial z}, \frac{\partial \bar{v}}{\partial z}\right) = \left(\tau_{s_\xi}, \tau_{s_\eta}\right)/\rho = \left(CW_\xi^2, CW_\eta^2\right) \tag{3.40}$$

$$\frac{\partial T}{\partial z} = \frac{\Pr}{E_v} K(T - T_e) \tag{3.41}$$

$$\frac{\partial S}{\partial z} = 0 \tag{3.42}$$

whereas the boundary conditions at the bottom are

$$A_v\left(\frac{\partial \bar{u}}{\partial z}, \frac{\partial \bar{v}}{\partial v}\right) = \left(\tau_{b_\xi}, \tau_{b_\eta}\right)/\rho = \frac{U_r}{A_{vr}} Z_r C_d \left(\bar{u}_1^2 + \bar{v}_1^2\right)^{½} \left(\bar{u}_1, \bar{v}_1\right) \tag{3.43}$$

$$\frac{\partial T}{\partial z} = 0 \tag{3.44}$$

$$\frac{\partial S}{\partial z} = 0 \tag{3.45}$$

where

C = surface drag coefficient

W = wind speed

K = surface heat exchange coefficient

T_e = equilibrium temperature

C_d = bottom friction coefficient

$\bar{u}_1, \bar{v}_1$ = values of the horizontal velocity components next to the bottom

With z_1 equal to one-half the bottom layer thickness, C_d is given by

$$C_d = k^2 \left[\ln\left(z_1 / z_0 \right) \right]^{-2} \tag{3.46}$$

where

k = von Karman constant

z_o = bottom roughness height

As can be seen from Equation 3.40, the surface shear stress is computed from wind data. Figure 3-2 shows the hourly wind data recorded for each study month at the San Juan International Airport. These data were assumed to be constant over the numerical grid (Figure 3-1).

Manning's formulation is employed for the bottom friction in the external mode equations if the model is used purely to compute vertically averaged flow fields. As presented by Garratt (1977), the surface drag coefficient is computed from

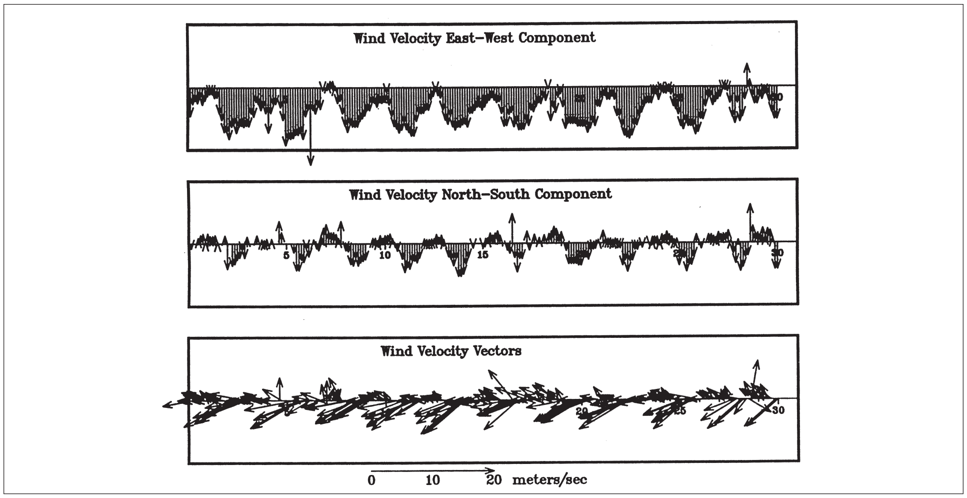
$$C = \left(0.75 + 0.067W\right) \times 10^{-3} \tag{3.47}$$

with the maximum allowable value being 0.003.

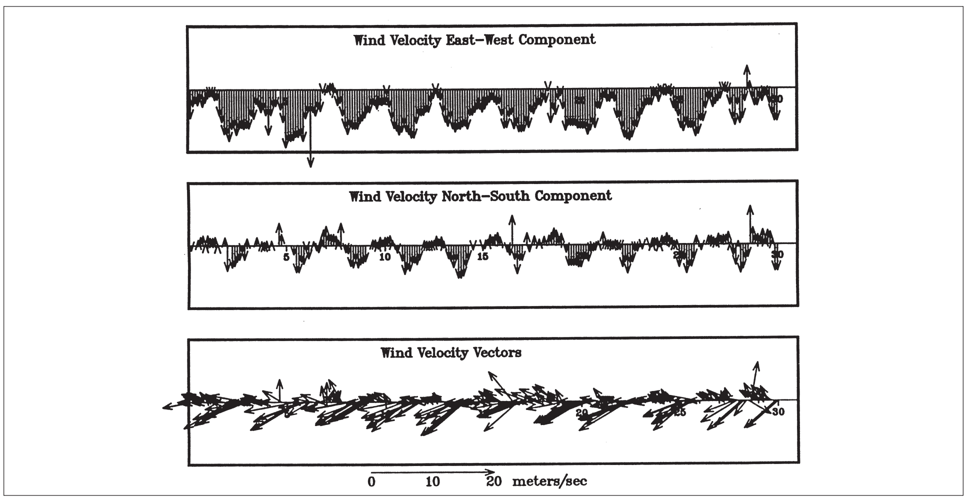
As discussed by Edinger, Brady, and Geyer (1974), the surface heat exchange coefficient, K, and the equilibrium temperature, T_e , are computed from the meteorological data (wind speed, cloud cover, dry bulb air temperatures, and either wet bulb air temperature or relative humidity). However, it should be noted that temperature was not computed in this study. Since there was virtually no change in the temperature during the simulation period, a constant temperature was input and used in the computation of the water density.

At river boundaries, the freshwater inflow and its temperature are prescribed and the salinity is normally assumed to be zero. Freshwater inflows into the San Juan Estuary system occur primarily through the Puerto Nuevo River, Juan Mendez Creek, San Anton Creek, Blasima Creek, and the Malaria Channel (Figure 1-1). As can be seen from an inspection of Figure 3-3, these inflows are quite flashy and, as will be seen in Chapter 6, can result in high salinity stratification in parts of the system. A discussion of the inflow of these data is presented in Chapter 5. The locations of these inflows are shown in Figure 5-4.

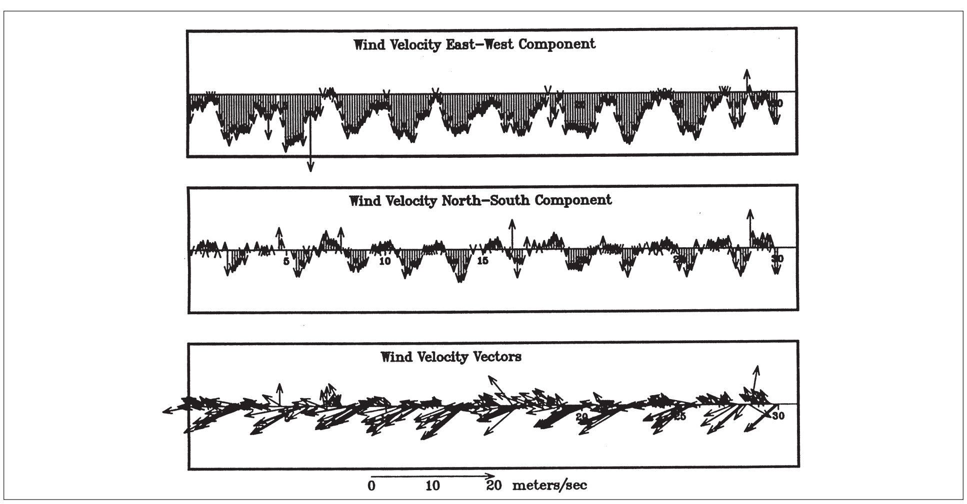
At an ocean boundary, the water-surface elevation is prescribed along with time-varying vertical distributions of salinity and temperature. To prescribe water surface elevations along the open ocean portion of the numerical grid shown in Figure 3-1, a global vertically averaged model called ADCIRC (Westerink et al. 1992) was applied. Figure 3-4 shows the ADCIRC grid which covers the Gulf of Mexico, the Carribean, and a portion of the Atlantic Ocean. A blowup of the grid surrounding Puerto Rico is shown in Figure 3-5. Time-varying water-surface elevations were saved from the ADCIRC model at several locations along the open ocean grid in



a. June

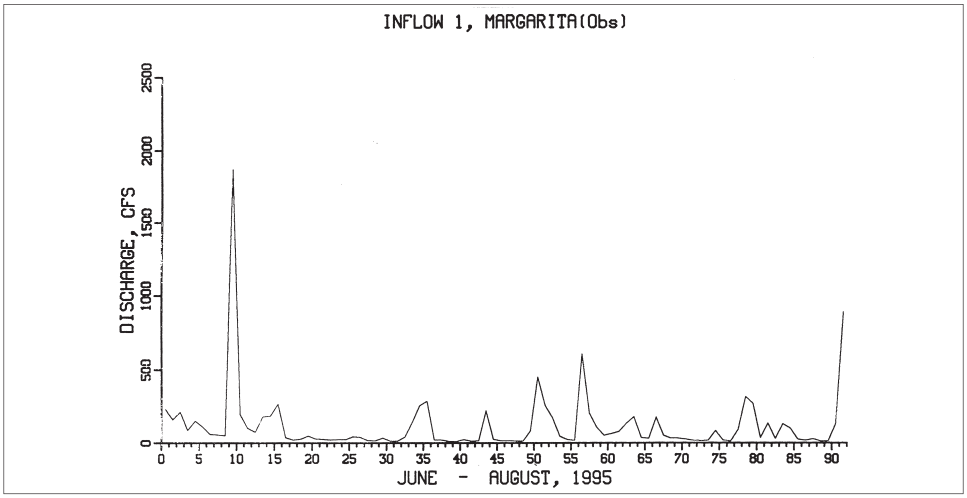


b. July

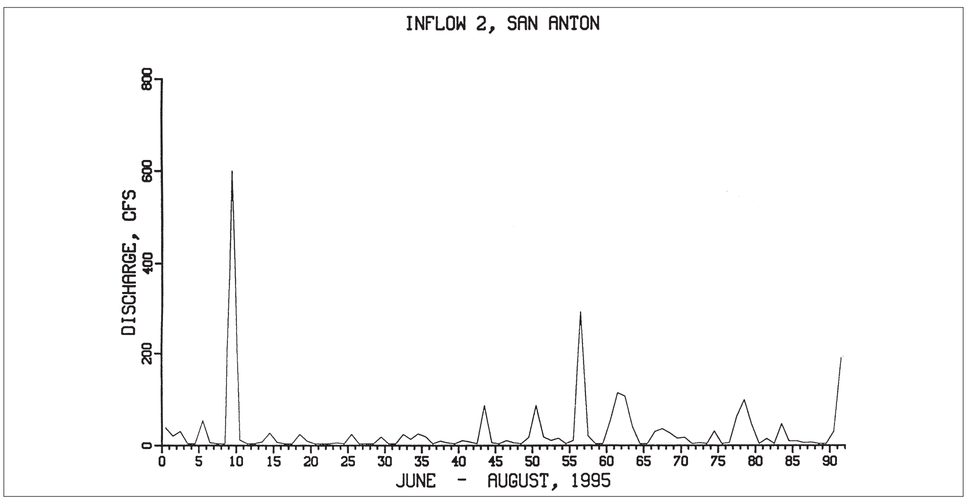


c. August

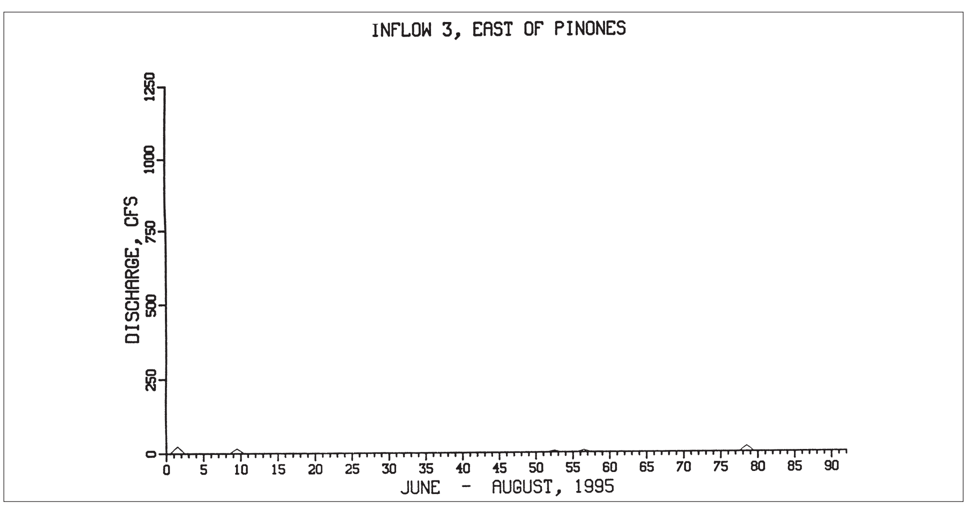
Figure 3-2. San Juan Airport wind data



a. Inflow 1

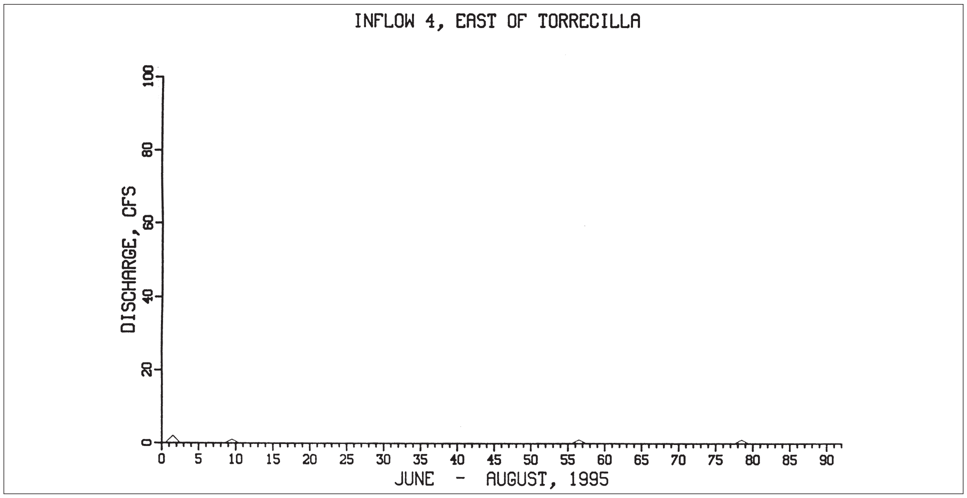


b. Inflow 2

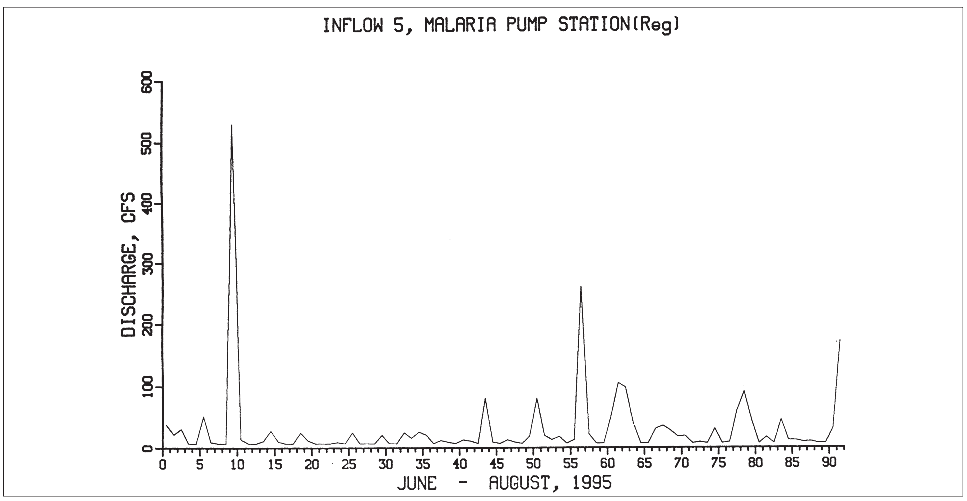


c. Inflow 3

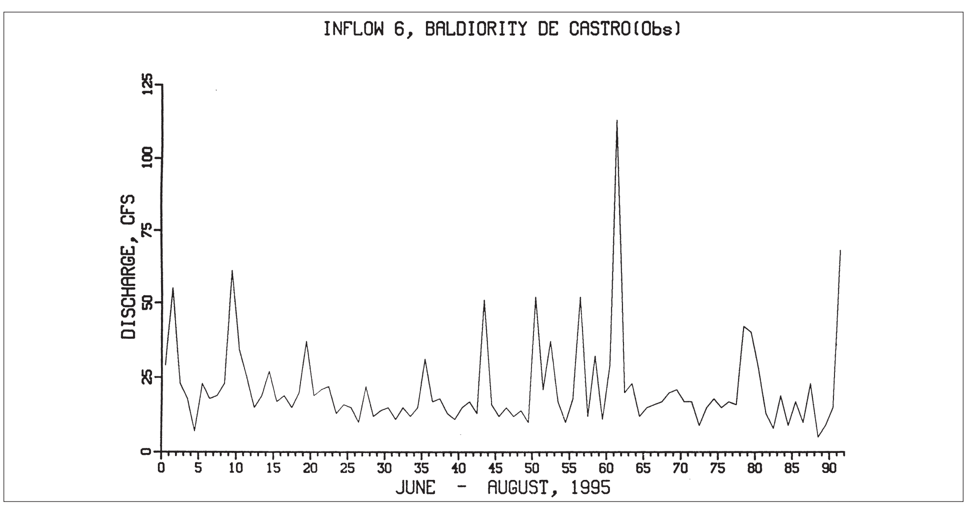
Figure 3-3. Freshwater inflows (continued)



d. Inflow 4

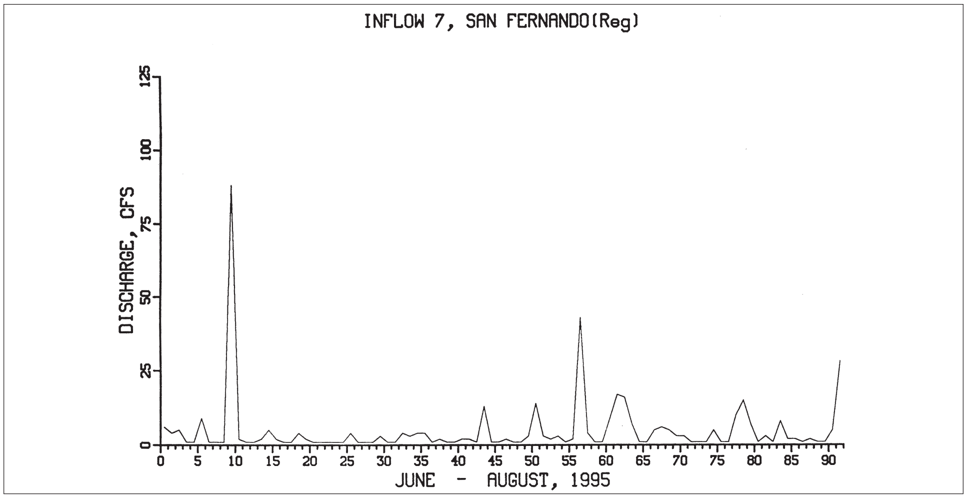


e. Inflow 5

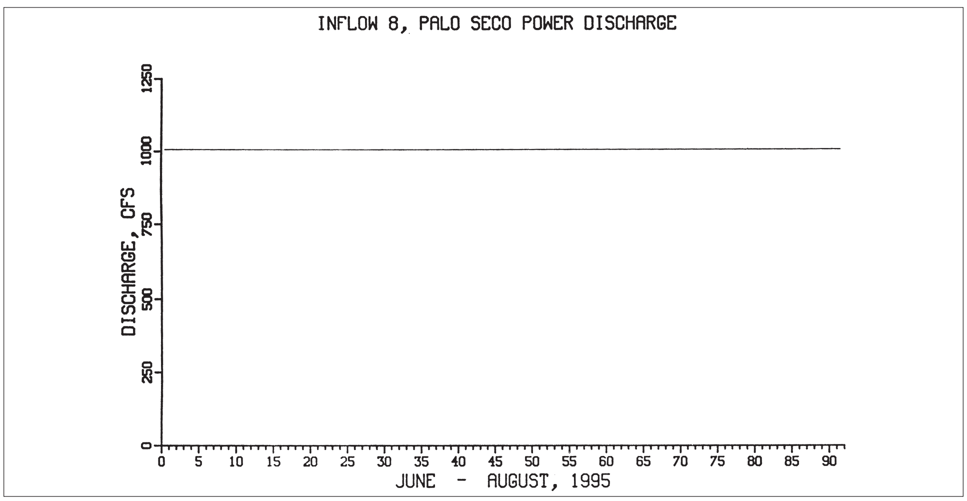


f. Inflow 6

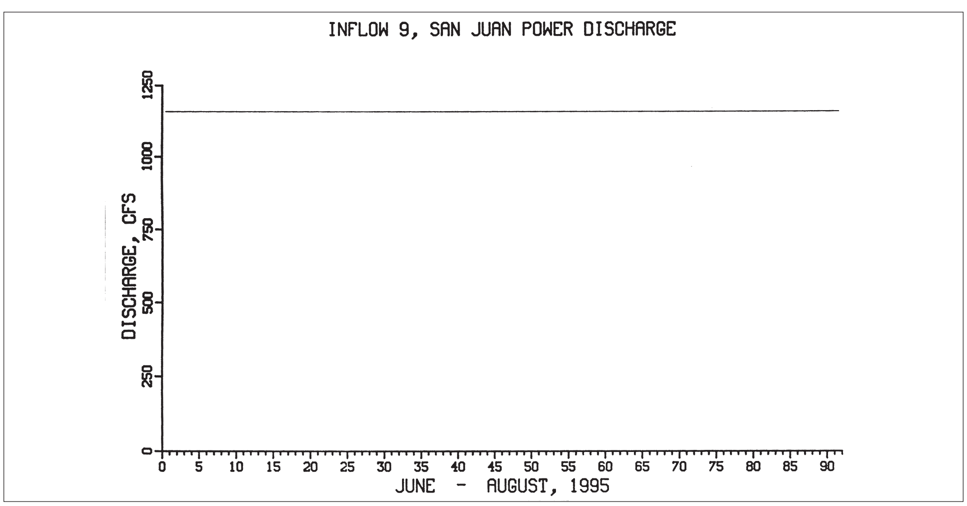
Figure 3-3. Continued



g. Inflow 7

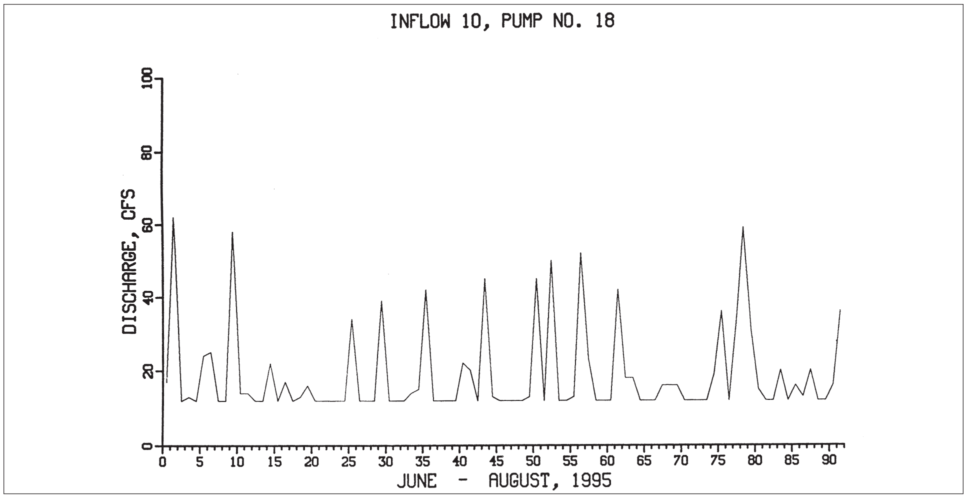


h. Inflow 8

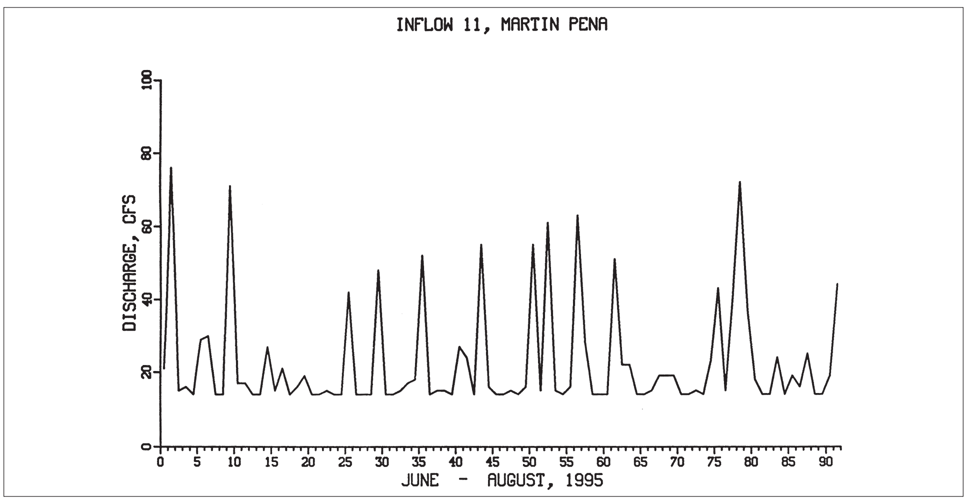


i. Inflow 9

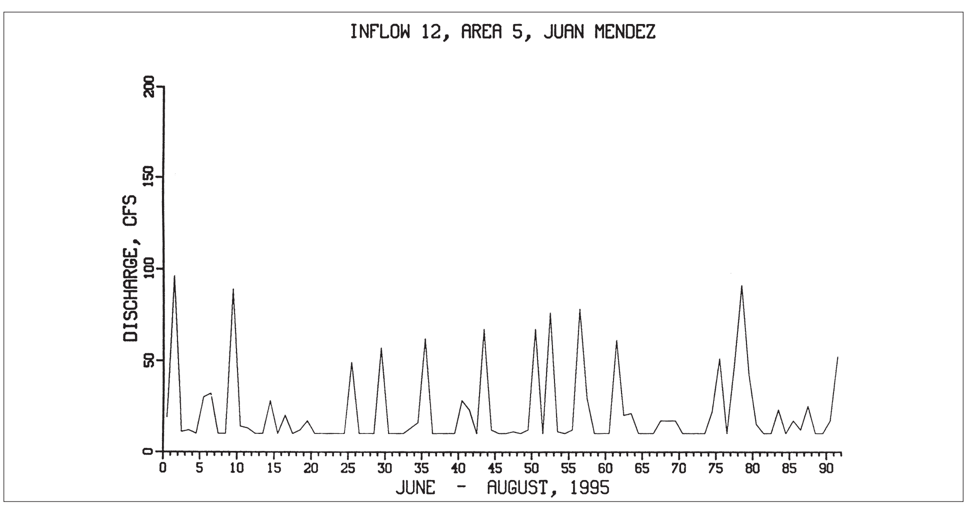
Figure 3-3. Continued



j. Inflow 10

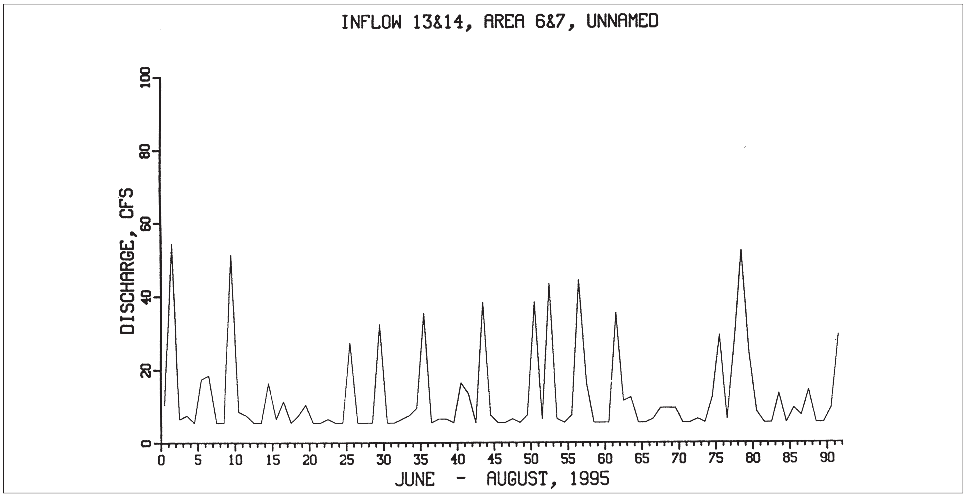


k. Inflow 11

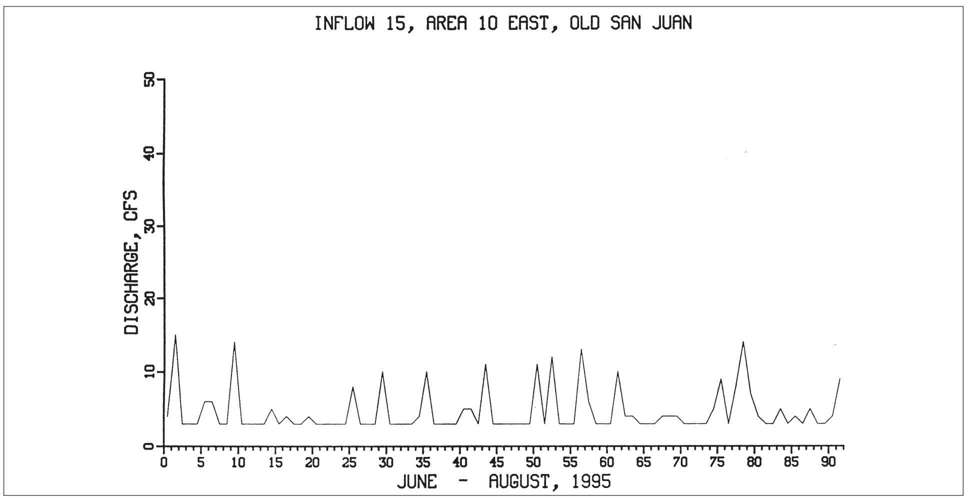


l. Inflow 12

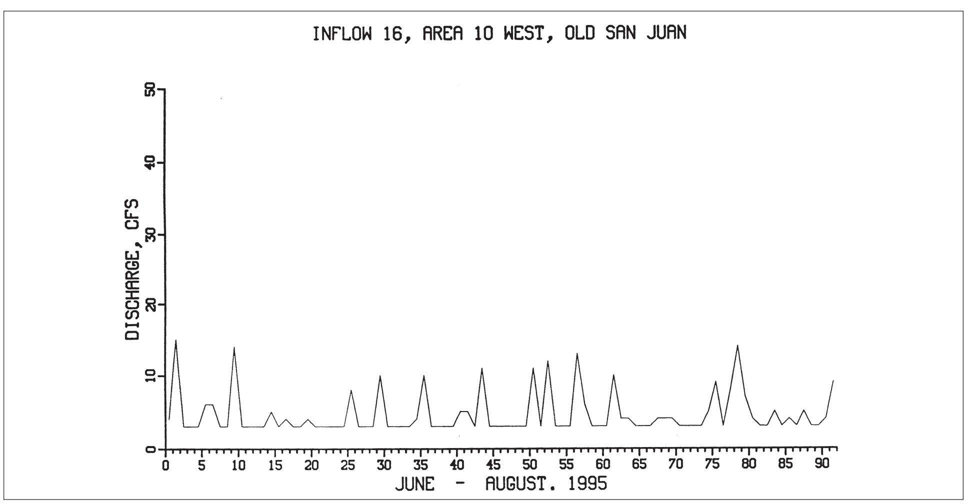
Figure 3-3. Continued



m. Inflow 13 & 14

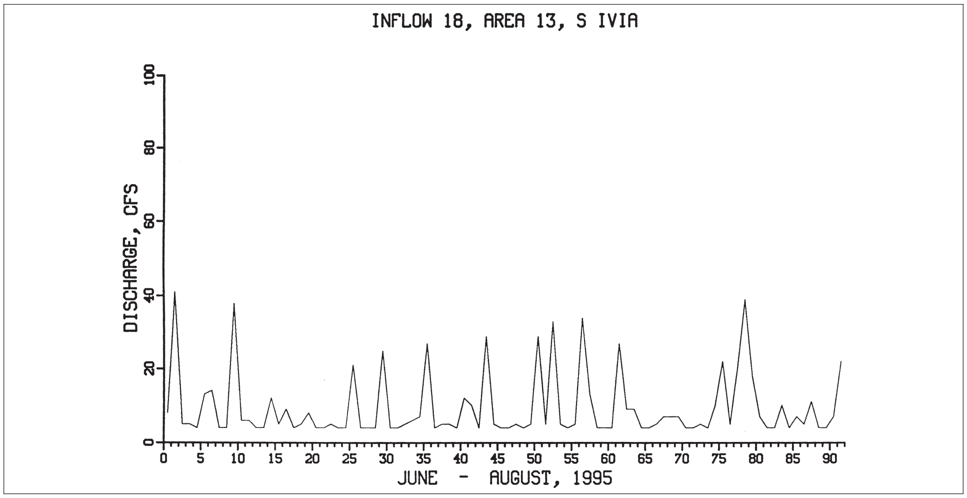


n. Inflow 15

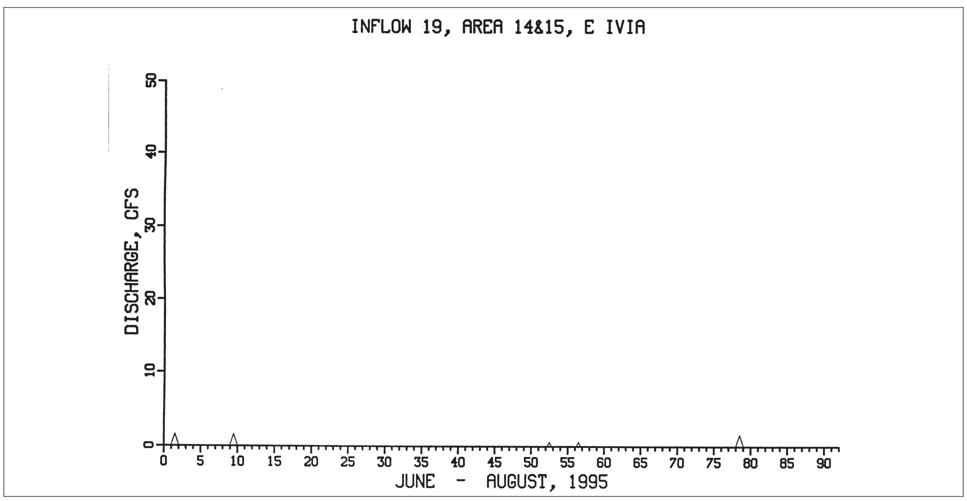


o. Inflow 16

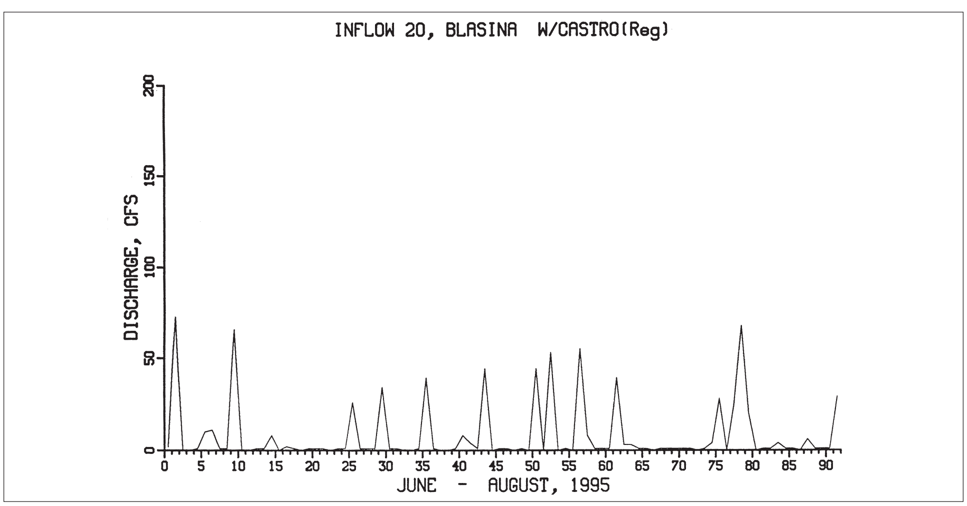
Figure 3-3. Continued



p. Inflow 18

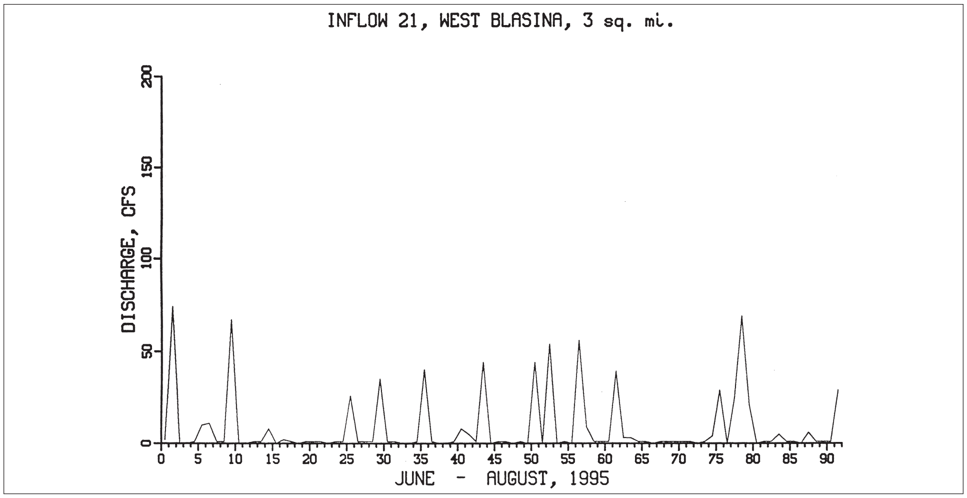


q. Inflow 19



r. Inflow 20

Figure 3-3. Continued



s. Inflow 21

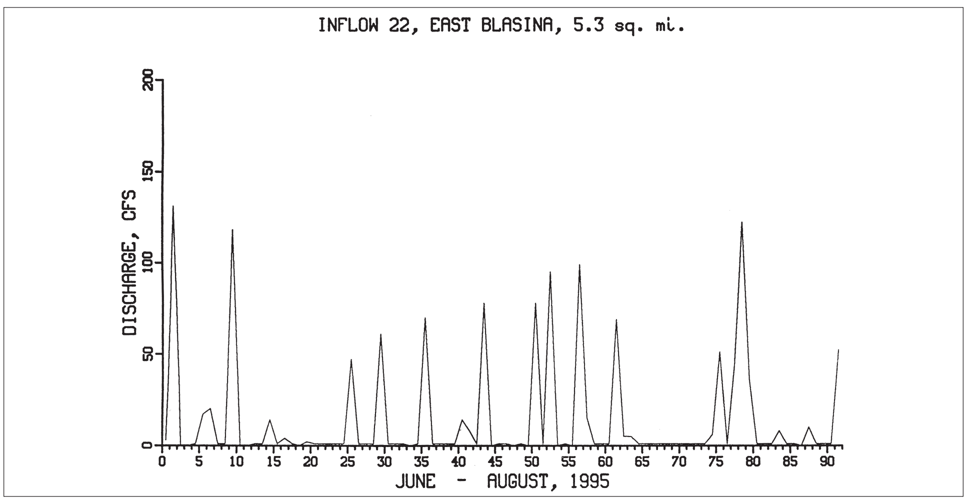


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Figure 3-3. Concluded

Figure 3-1. These elevations reflect both the astronomical tide as well as wind effects. An example of the water-surface elevations computed by ADCIRC and used in the CH3D-WES simulation is given in Figure 3-6.

The vertical distribution of salinity along the open ocean grid was specified from data collected by Fagerburg (1998). Since the temperature was specified as a constant, temperatures were not required to be specified along the ocean boundary of the grid. During flood, the specified values of salinity are employed, whereas during ebb, interior values are advected out of the grid. Along a solid boundary, the normal component of the velocity and the viscosity and diffusivity are set to zero.

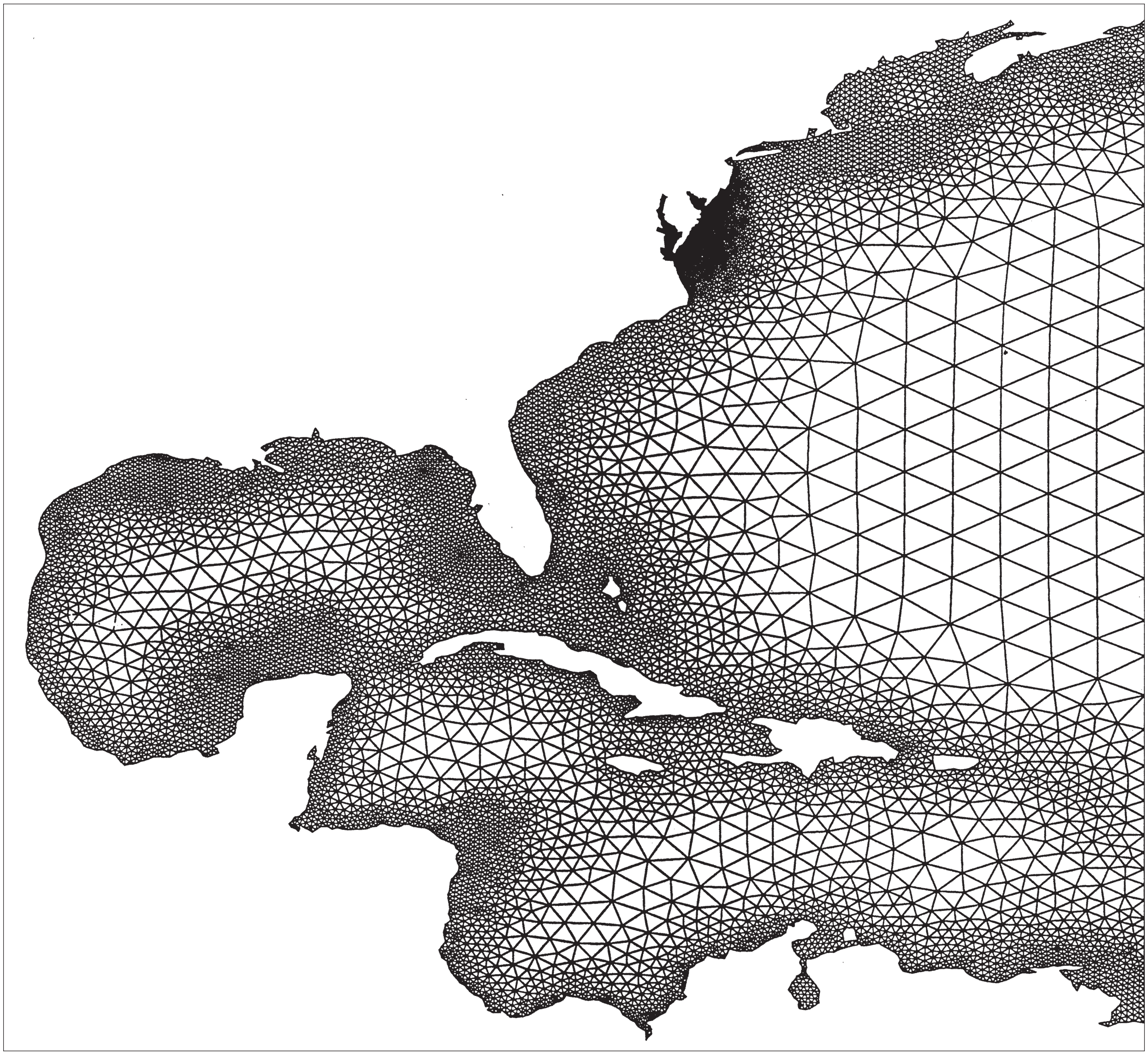


Figure 3-4. ADCIRC numerical grid

Initial Conditions

At the start of a model run, the values of ζ, $\overline{u}$, $\overline{v}$, w, $\overline{U}$, and $\overline{V}$ are all set to zero. Values of the salinity and temperature are read from input files. These initial fields are generated from known data at a limited number of locations. Once the values in individual cells are determined by interpolating from the field data, the resulting 3-D field is smoothed several times. Generally, the salinity and temperature fields are frozen for the first few days of a simulation.

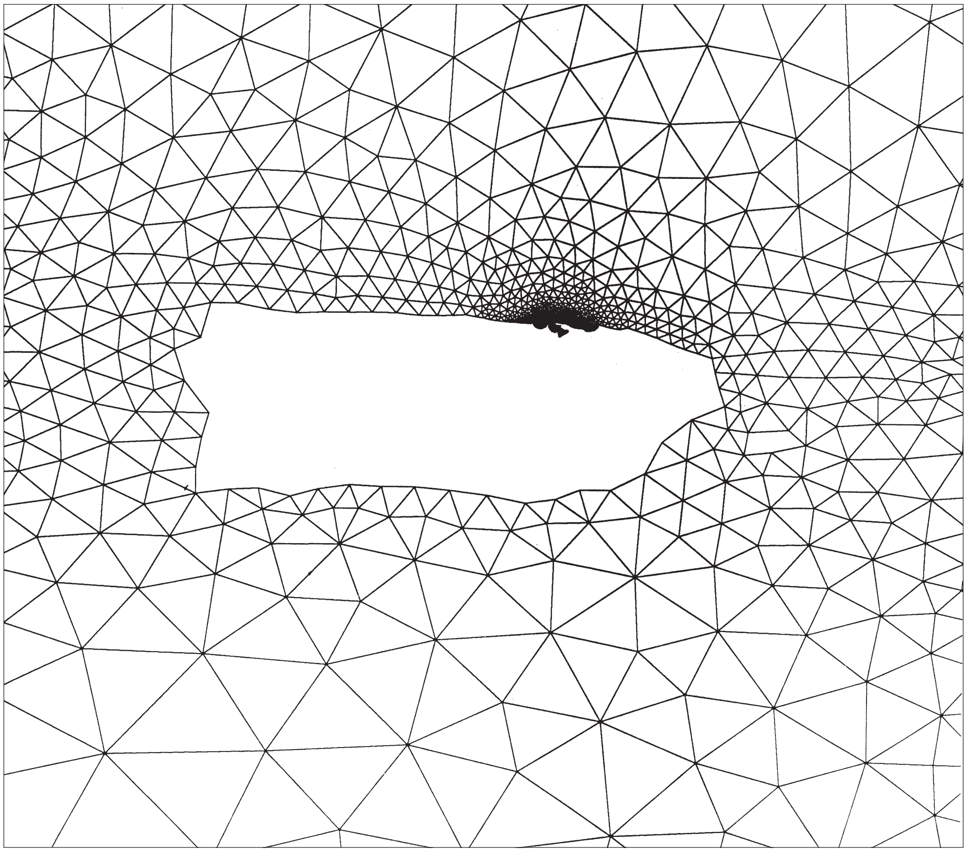


Figure 3-5. ADCIRC grid near Puerto Rico

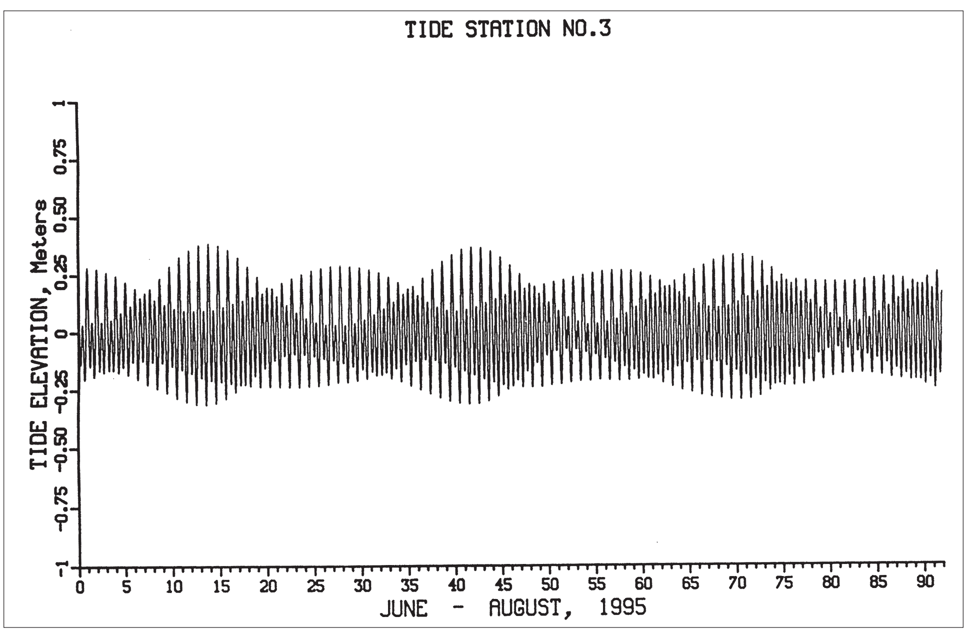


Figure 3-6. Tide computed by ADCIRC and applied on ocean boundary

Numerical Grid

The first step in any numerical modeling study is the generation of a suitable grid that captures the geometry of the modeled system. A map of the San Juan Bay Estuary system is shown in Figure 1-1 with the planform numerical boundary-fitted grid of the system illustrated in Figure 3-1. The numerical grid contains 2690 planform cells with a maximum of 30 vertical layers. Each layer is 3 ft (0.91 m) thick except for the top layer which varies with the tide. With much of the system being very shallow, many of the planform cells are represented by one layer. Thus, the computations involve a mixture of 3D as well as vertically averaged computations. With a total of 28,200 computational cells and a computational time step of 60 seconds, a 3-month simulation requires about 12 CPU hours on a 400 Mhz DEC Alpha work station.

4 Water Quality Model Formulation

Introduction

Kinetics for CE-QUAL-ICM were developed for application of the model to Chesapeake Bay (Cerco and Cole 1994). Model formulations are robust, however, and widely applicable. The model can be configured for specific applications by enabling various user-specified options. The description of the kinetics provided here is for the model as applied to the SJBE system. Descriptions of the complete kinetics are provided by Cerco and Cole (1994, 1995).

The central issues in eutrophication modeling are primary production of carbon by algae and concentration of dissolved oxygen. Primary production provides the energy required by the ecosystem to function. Excessive primary production is detrimental, however, since its decomposition, in the water and sediments, consumes oxygen. Dissolved oxygen is necessary to support the life functions of higher organisms and is considered an indicator of the "health" of estuarine systems. In order to predict primary production and dissolved oxygen, a large suite of model state variables is necessary (Table 4-1).

Table 4-1.
Water Quality Model State Variables

Temperature	Salinity
Fecal Coliform Bacteria	Algae
Dissolved Organic Carbon	Labile Particulate Organic Carbon
Refractory Particulate Organic Carbon	Ammonium
Nitrate	Dissolved Organic Nitrogen
Labile Particulate Organic Nitrogen	Refractory Particulate Organic Nitrogen
Total Phosphorus	Dissolved Organic Phosphorus
Labile Particulate Organic Phosphorus	Refractory Particulate Organic Phosphorus
Chemical Oxygen Demand	Dissolved Oxygen

Eutrophication, however, is not the only problem in the San Juan Estuary. Contamination with human and animal waste is also an issue. Consequently, fecal coliform bacteria were added to the suite of eutrophication variables.

Temperature

In some systems, temperature can be a primary determinant of the rate of biochemical reactions. Reaction rates increase as a function of temperature although extreme temperatures result in the mortality of organisms.

Salinity

Salinity is a conservative tracer that provides verification of the transport component of the model and facilitates examination of conservation of mass. Salinity also influences the dissolved oxygen saturation concentration and is used in the determination of kinetics constants that differ in saline and fresh water.

Fecal Coliform Bacteria

Fecal coliform bacteria are commonly found in human and animal waste. Although these organisms are harmless, they indicate waters are contaminated by waste matter.

Algae

Algae are represented in San Juan Estuary as a single group and quantified as carbonaceous biomass. Chlorophyll concentrations, for comparison with observations, are obtained through division of computed biomass by the carbon-to-chlorophyll ratio.

Organic Carbon

Three organic carbon state variables are considered: dissolved, labile particulate, and refractory particulate. Labile and refractory distinctions are based upon the time scale of decomposition. Labile organic carbon decomposes on a time scale of days to weeks while refractory organic carbon requires more time. Labile organic carbon decomposes rapidly in the water column or the sediments. Refractory organic carbon decomposes slowly, primarily in the sediments, and may contribute to sediment oxygen demand years after deposition.

Phosphorus

As with carbon and nitrogen, organic phosphorus is considered in three states: dissolved, labile particulate, and refractory particulate. Only a single mineral form, total phosphate, is considered. Total phosphate exists as two states within the model ecosystem: dissolved phosphate and phosphate incorporated in algal cells. Equilibrium partition coefficients are used to distribute the total among the states.

Nitrogen

Nitrogen is first divided into organic and mineral fractions. Organic nitrogen state variables are: dissolved organic nitrogen, labile particulate organic nitrogen, and refractory particulate organic nitrogen. Two mineral nitrogen forms are considered: ammonium and nitrate. Both are utilized to fulfill algal nutrient requirements although ammonium is preferred from thermodynamic considerations. The primary reason for distinguishing the two is that ammonium is oxidized by nitrifying bacteria into nitrate. This oxidation can be a significant sink of oxygen in the water column and sediments. An intermediate in the complete oxidation of ammonium, nitrite, also exists. Nitrite concentrations are usually much less than nitrate and for modeling purposes nitrite is combined with nitrate. Hence the nitrate state variable actually represents the sum of nitrate plus nitrite.

Chemical Oxygen Demand

Chemical oxygen demand is the concentration of reduced substances that are oxidizable by inorganic means. The primary component of chemical oxygen demand is sulfide released from sediments. Oxidation of sulfide to sulfate may remove substantial quantities of dissolved oxygen from the water column.

Dissolved Oxygen

Dissolved oxygen is required for the existence of higher life forms. Oxygen availability determines the distribution of organisms and the flows of energy and nutrients in an ecosystem. Dissolved oxygen is a central component of the water-quality model.

Conservation of Mass Equation

The foundation of CE-QUAL-ICM is the solution to the three-dimensional mass-conservation equation for a control volume. The control-volume structure was selected to allow maximum flexibility in linkage of CE-QUAL-ICM to alternate hydrodynamic models. Control volumes in CE-QUAL-ICM correspond to cells in x-y-z space on the CH3D grid. CE-QUAL-ICM solves, for each volume and for each state variable, the conservation of mass equation:

$$\frac{\delta V_i C_i}{\delta t} = \sum_{j=1}^{n} Q_j C_j^* + \sum_{j=1}^{n} A_j D_j \frac{\delta C}{\delta x_j} + \sum S_i \tag{4.1}$$

where

V_i = volume of ith control volume (m^3)

C_i = concentration in ith control volume (gm m^{-3})

Q_j = volumetric flow across flow face j of ith control volume (m^3 sec^{-1})

C^*_j = concentration in flow across flow face j (gm m^{-3})

A_j = area of flow face j (m^2)

D_j = diffusion coefficient at flow face j (m^2 sec^{-1})

n = number of flow faces attached to ith control volume

S_i = external loads and kinetic sources and sinks in ith control volume (gm sec^{-1})

t, x = temporal and spatial coordinates

Solution to the mass-conservation equation is via the finite-difference method using the QUICKEST algorithm (Leonard 1979) in the horizontal directions and a Crank-Nicolson scheme in the vertical direction.

The majority of this chapter details with the kinetics portion of the mass-conservation equation for each state variable. Parameters are defined where they first appear. All parameters are listed, in alphabetical order, in a glossary (see Table 4-2). For consistency with reported rate coefficients, kinetics are detailed using a temporal dimension of days. Within the CE-QUAL-ICM code, kinetics sources and sinks are converted to a dimension of seconds before employment in the mass-conservation equation.

Algae

Algae play a central role in the carbon and nutrient cycles that comprise the model ecosystem. Sources and sinks of algae are:

Growth (production)
Basal metabolism
Predation
Settling

The governing equation for algal biomass is:

$$\frac{\delta}{\delta t}B = \left(P - BM - PR - WSa\frac{\delta}{\delta z}\right)B \tag{4.2}$$

where

B = algal biomass, expressed as carbon (gm C m^{-3})

P = production (day^{-1})

BM = basal metabolism (day^{-1})

PR = predation (day^{-1})

WSa = settling velocity (m day^{-1})

z = vertical coordinate (m)

Production

Production by phytoplankton is determined by the availability of nutrients, by the intensity of light, and by the ambient temperature. The effects of each are considered to be multiplicative:

$$P = PM\ f(N) f(I) f(T) \tag{4.3}$$

where

PM = production under optimal conditions (day^{-1})

f(N) = effect of suboptimal nutrient concentration ($0 \leq f \leq 1$)

f(I) = effect of suboptimal illumination ($0 \leq f \leq 1$)

f(T) = effect of suboptimal temperature ($0 \leq f \leq 1$)

Nutrients

Carbon, nitrogen, and phosphorus are the primary nutrients required for algal growth. Inorganic carbon is usually available in excess and is not considered in the model. The effects of the remaining nutrients on growth are described by the formulation commonly referred to as “Monod kinetics” (Monod 1949). In the Monod formulation (Figure 4-1) growth is dependent upon nutrient availability at low nutrient concentrations but is independent of nutrients at high concentrations. A key parameter in the formulation is the “half-saturation concentration.” Growth rate is half the maximum when available nutrient concentration equals the half-saturation concentration. Liebig’s “law of the minimum” (Odum 1971) indicates growth is determined by the nutrient in least supply:

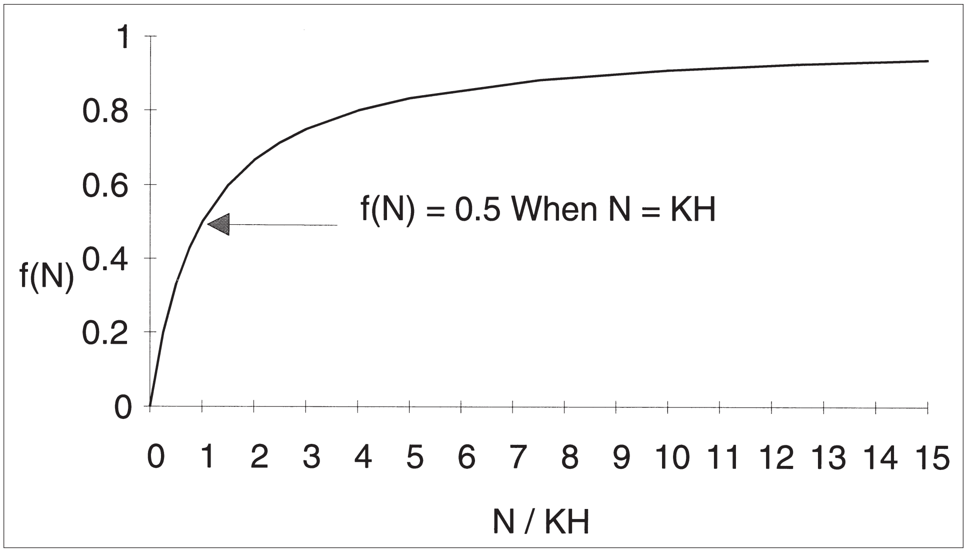


Figure 4-1. The Monod formulation for nutrient-limited growth

$$f(N) = minimum\left(\frac{NH_4 + NO_3}{KHn + NH_4 + NO_3}, \frac{PO_4d}{KHp + PO_4d}\right) \tag{4.4}$$

where

NH_4 = ammonium concentration (gm N m^{-3})

NO_3 = nitrate concentration (gm N m^{-3})

KHn = half-saturation constant for nitrogen uptake (gm N m^{-3})

PO_4d = dissolved phosphate concentration (gm P m^{-3})

KHp = half-saturation constant for phosphorus uptake (gm P m^{-3})

Light

Algal production increases as a function of light intensity until an optimal intensity is reached. Numerous options are available for a function which represents the increase of production as a function of light intensity. The function employed here is analogous to the Monod function used to compute nutrient limitations:

$$f(I) = \frac{I}{Ih + I} \tag{4.5}$$

where

I = illumination rate (Langleys day^{-1})

Ih = half-saturation illumination (Langleys day^{-1})

Equation 4.5 describes the instantaneous light limitation at a point in space. The model, however, computes processes integrated over discrete time intervals and aggregated spatially into model segments. Therefore, the equation must be integrated over an appropriate time interval and averaged over the thickness of each model segment. The integration interval selected is one day. This interval does not preclude computation steps less than a day but frees the model from accounting for illumination in "real time." Daily averaging does preclude computation of diurnal fluctuations in algal production. This restriction is not severe, however, since the classic equations for algal growth are not appropriate for short time scales.

Assuming light intensity declines exponentially with depth, the integrated, averaged form of Equation 4.5 is:

$$f(I) = \frac{FD}{Kess \Delta z} \ln\left(\frac{Ih + Io\, e^{-Kess\ z_1}}{Ih + Io\, e^{-Kess\ z_2}} \right) \tag{4.6}$$

where

Io = daily illumination at water surface (Langleys day^{-1})

FD = fractional daylength ($0 \leq FD \leq 1$)

Kess = total light attenuation coefficient (m^{-1})

Δz = model segment thickness (m)

z_1 = distance from water surface to top of model segment (m)

z_2 = distance from water surface to bottom of model segment (m)

Light attenuation in the water column is composed of two fractions: a background value dependent on water color and concentration of suspended particles, and extinction due to light absorption by ambient chlorophyll:

$$Kess = Keb + Kechl \frac{B}{CChl} \tag{4.7}$$

where

Keb = background light attenuation (m^{-1})

Kechl = light attenuation coefficient for chlorophyll 'a' (m^{2} mg^{-1})

CChl = algal carbon-to-chlorophyll ratio (gm C mg^{-1} chl)

Temperature

Algal production increases as a function of temperature until an optimum temperature or temperature range is reached. Above the optimum, production declines until a temperature lethal to the organisms is attained. Numerous functional representations of temperature effects are available. Inspection of growth versus temperature curves indicates a function similar to a Gaussian probability curve. (Figure 4-2 provides a good fit to observations.)

$$f(T) = e^{-KTg1(T-Tm)^2} \; when \; T \le Tm \qquad (4.8)$$

$$= e^{-KTg2(Tm-T)^2} \; when \; T > Tm$$

where

T = temperature (C°)

Tm = optimal temperature for algal growth (C°)

KTg1 = effect of temperature below Tm on growth ($C^{\circ -2}$)

KTg2 = effect of temperature above Tm on growth ($C^{\circ -2}$)

Basal Metabolism

As employed here, basal metabolism is the sum of all internal processes that decrease algal biomass. A portion of metabolism is respiration which may be viewed as a reversal of production. In respiration, carbon and nutrients are returned to the environment accompanied by the consumption of dissolved oxygen. A second internal sink of biomass is the excretion of dissolved organic carbon.

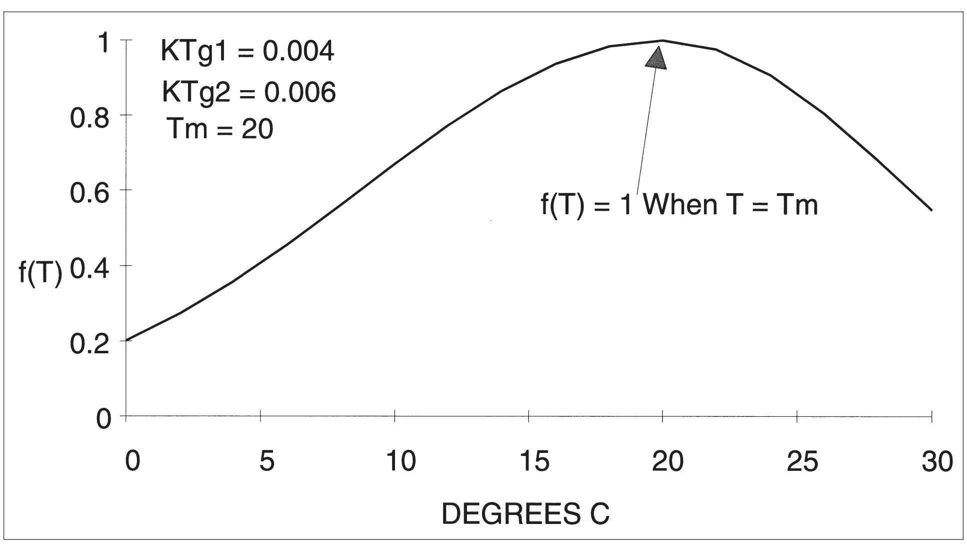


Figure 4-2. Effect of temperature on algal production

Respiration cannot proceed in the absence of oxygen. Basal metabolism cannot decrease in proportion to oxygen availability, however, or algae would approach immortality under anoxic conditions. To solve this dilemma, basal metabolism is considered to be independent of dissolved oxygen concentration but the distribution of metabolism between respiration and excretion is oxygen-dependent. When oxygen is freely available, respiration is a large fraction of the total. When oxygen is restricted, excretion becomes dominant. Formulation of this process is detailed in the following text that describes algal effects on carbon and dissolved oxygen.

Basal metabolism is commonly considered to be an exponentially increasing (Figure 4-3) function of temperature:

$$BM = BMr\ e^{KTb(T - Tr)} \tag{4.9}$$

where

BMr = metabolic rate at Tr (day^{-1})

KTb = effect of temperature on metabolism ($C^{\circ -1}$)

Tr = reference temperature for metabolism (C°)

Predation

Detailed specification of predation within the water column requires predictive modeling of zooplankton biomass and activity. Absence of data prohibited the modeling of zooplankton in the San Juan Estuary. Consequently, a constant predation rate was specified. This specification implicitly assumed zooplankton biomass is a constant fraction of algal biomass. Zooplankton activity was assumed to be influenced by temperature. The temperature effect was represented by an exponential relationship

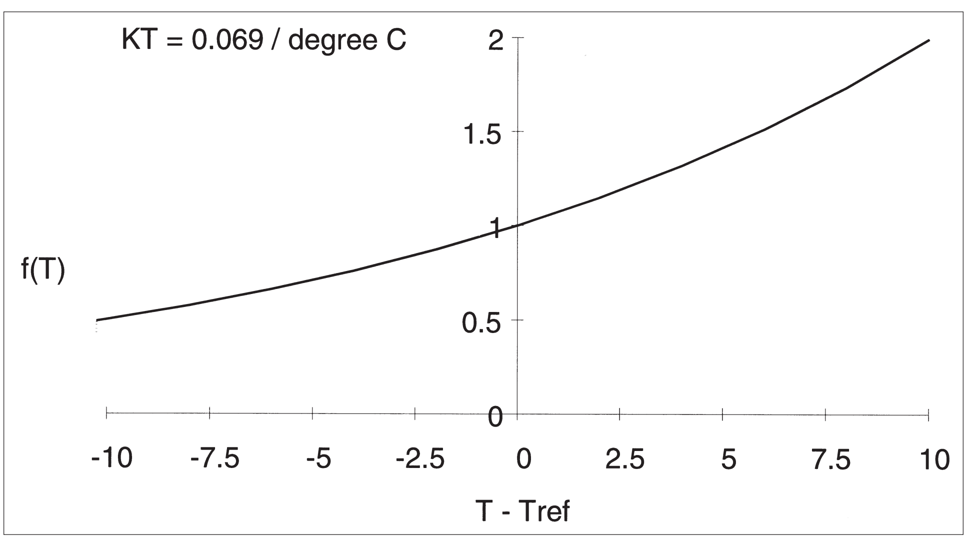


Figure 4-3. Exponential temperature function

(Figure 4-3). The predation formulation is identical to basal metabolism. The difference in predation and basal metabolism lies in the distribution of the end products of these processes.

$$PR = BPR\ e^{KTb(T - Tr)} \tag{4.10}$$

where

BPR = predation rate at Tr (day^{-1})

Macrobenthic Grazing

A second form of predation on algae is grazing by filter-feeding organisms which inhabit the sediment-water interface. As with zooplankton, detailed specification of predation by macrobenthos requires predictive modeling of macrobenthic activity and biomass. In the absence of a benthos model, a formulation was specified which converted macrobenthic grazing into an equivalent settling rate:

$$WSmb = MBGM\ FR \frac{DO}{KHomb + DO} \tag{4.11}$$

where

WSmb = equivalent settling rate ($m\ day^{-1}$)

MBGM = macrobenthic biomass ($gm\ C\ m^{-2}$)

FR = filtering rate ($m^{-3}\ gm^{-1}\ C\ day^{-1}$)

DO = dissolved oxygen concentration ($gm\ DO\ m^{-3}$)

KHomb = dissolved oxygen concentration at which macrobenthic grazing is halved ($gm\ DO\ m^{-3}$)

Macrobenthic grazing is implemented only in the model cells which interface with the bottom. Biomass is specified based on the observed distribution of benthos in the system. Incorporation of dissolved oxygen into the relationship accounts for the cessation of filtering and eventual demise of benthos under anoxic conditions. Algal biomass filtered from the water column is routed into the sediment diagenesis portion of the model package.

Effect of Algae on Organic Carbon

During production and respiration, algae primarily take up and produce carbon dioxide, an inorganic form not considered in the model. A small fraction of basal metabolism is exuded as dissolved organic carbon, however, and in the model this fraction increases as dissolved oxygen becomes scarce. Algae also produce organic carbon through the effects of predation. Zooplankton take up and redistribute algal carbon through grazing, assimilation, respiration, and excretion. Since zooplankton are not included in the model, routing of algal carbon through zooplankton is simulated by empirical distribution coefficients. The effects of algae on organic carbon are expressed:

$$\frac{\delta}{\delta t} DOC = \left[FCD + (1 - FCD)\left(\frac{KHr}{KHr + DO}\right) BM + FCDP\ PR \right] \tag{4.12}$$

$$\frac{\delta}{\delta t} LPOC = FCLP\ PR\ B \tag{4.13}$$

$$\frac{\delta}{\delta t} RPOC = FCRP\ PR\ B \tag{4.14}$$

where

DOC = dissolved organic carbon concentration (gm C m^{-3})

DO = dissolved oxygen concentration (gm O_2 m^{-3})

LPOC = labile particulate organic carbon concentration (gm C m^{-3})

RPOC = refractory particulate organic carbon concentration (gm C m^{-3})

FCD = fraction of basal metabolism exuded as dissolved organic carbon

KHr = half-saturation concentration for algal dissolved organic carbon excretion (gm O_2 m^{-3})

FCDP = fraction of dissolved organic carbon produced by predation

FCLP = fraction of labile particulate carbon produced by predation

FCRP = fraction of refractory particulate carbon produced by predation

The sum of the three predation fractions must equal unity.

Effect of Algae on Phosphorus

Algae take up dissolved phosphate during production and release dissolved phosphate and organic phosphorus through mortality. As with carbon, the fate of algal phosphorus released by metabolism and predation is represented by distribution coefficients. Since the total phosphate state variable includes both intra- and extracellular phosphate, no explicit representation of the effect of algae on phosphate is necessary. Distribution of total phosphate is determined by partition coefficients as detailed in the Phosphorus section of this chapter. The equations that express the effects of algae on organic phosphorus are:

$$\frac{\delta}{\delta t} DOP = \left(BM\ FPD + PR\ FPDP\right) APC\ B \tag{4.15}$$

$$\frac{\delta}{\delta t} LPOP = \left(BM\ FPL + PR\ FPLP\right) APC\ B \tag{4.16}$$

$$\frac{\delta}{\delta t} RPOP = \left(BM\ FPR + PRx\ FPRP\right) APC\ B \tag{4.17}$$

where

DOP = dissolved organic phosphorus concentration (gm P m^{-3})

LPOP = labile particulate organic phosphorus concentration (gm P m^{-3})

RPOP = refractory particulate organic phosphorus concentration (gm P m^{-3})

APC = phosphorus-to-carbon ratio of all algal groups (gm P gm^{-1} C)

FPD = fraction of dissolved organic phosphorus produced by metabolism

FPL = fraction of labile particulate phosphorus produced by metabolism

FPR = fraction of refractory particulate phosphorus produced by metabolism

FPDP = fraction of dissolved organic phosphorus produced by predation

FPLP = fraction of labile particulate phosphorus produced by predation

FPRP = fraction of refractory particulate phosphorus produced by predation

The sums of the metabolism and respiration fractions must each be less than or equal to unity.

Effect of Algae on Nitrogen

Algae take up ammonium and nitrate during production and release ammonium and organic nitrogen through mortality. Nitrate is internally reduced to ammonium before synthesis into biomass occurs (Parsons et al. 1984). Trace concentrations of ammonium inhibit nitrate reduction so that, in the presence of ammonium and nitrate, ammonium is utilized first. The "preference" of algae for ammonium can be expressed empirically (Thomann and Fitzpatrick 1982):

$$PN = NH_4 \frac{NO_3}{(KHn + NH_4)(KHn + NO_3)} \tag{4.18}$$

$$+ NH_4 \frac{KHn}{(NH_4 + NO_3)(KHn + NO_3)}$$

where

PN = algal preference for ammonium uptake ($0 \leq PN \leq 1$)

The ammonium preference function (Figure 4-4) has two limiting values. When nitrate is absent, the preference for ammonium is unity. When ammonium is absent, the preference is zero. In the presence of ammonium and nitrate, the preference depends on the abundance of both forms relative to the half-saturation constant for nitrogen uptake. When both ammonium and nitrate are abundant, the preference for ammonium approaches unity. When ammonium is scarce but nitrate is abundant, the preference decreases in magnitude and a significant fraction of algal nitrogen requirement comes from nitrate.

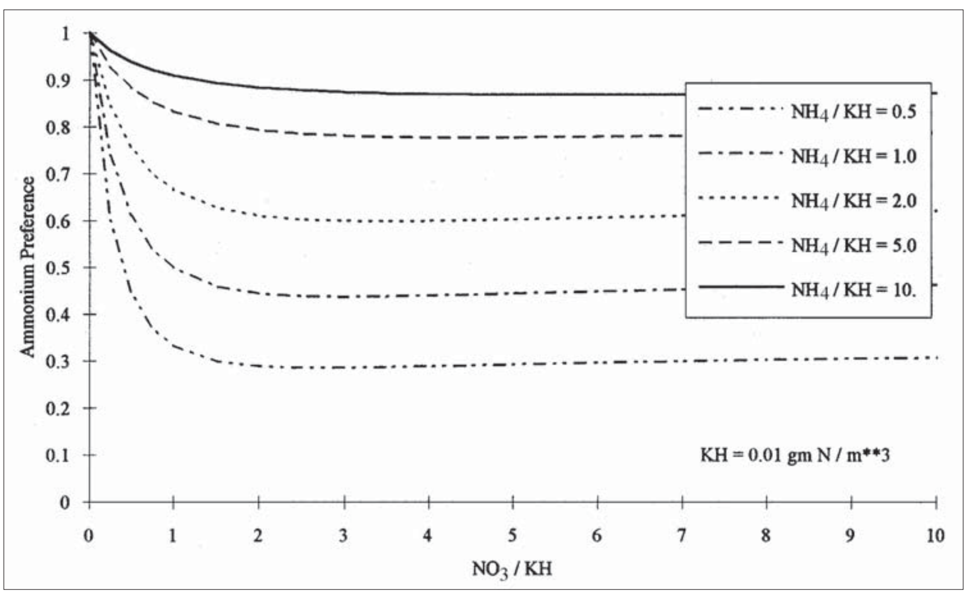


Figure 4-4. The ammonium preference function

The fate of algal nitrogen released by metabolism and predation is represented by distribution coefficients. The effects of algae on the nitrogen state variables are expressed:

$$\frac{\delta}{\delta t} NH_4 = \left(BM\ FNI + PR\ FNIP - PN\ P\right) ANC\ B \tag{4.19}$$

$$\frac{\delta}{\delta t} NO_3 = (PN - 1) P\ ANC\ B \tag{4.20}$$

$$\frac{\delta}{\delta t} DON = \left(BM\ FND + PR\ FNDP\right) ANC\ B \tag{4.21}$$

$$\frac{\delta}{\delta t} LPON = \left(BM\ FNL + PR\ FNLP\right) ANC\ B \tag{4.22}$$

$$\frac{\delta}{\delta t} RPON = \left(BM\ FNR + PR\ FNRP\right) ANC\ B \tag{4.23}$$

where

DON = dissolved organic nitrogen concentration (gm N m^{-3})

LPON = labile particulate organic nitrogen concentration (gm N m^{-3})

RPON = refractory particulate organic nitrogen concentration (gm N m^{-3})

ANC = nitrogen-to-carbon ratio of algae (gm N gm^{-1} C)

FNI = fraction of inorganic nitrogen produced by metabolism

FND = fraction of dissolved organic nitrogen produced by metabolism

FNL = fraction of labile particulate nitrogen produced by metabolism

FNR = fraction of refractory particulate nitrogen produced by metabolism

FNIP = fraction of inorganic nitrogen produced by predation

FNDP = fraction of dissolved organic nitrogen produced by predation

FNLP = fraction of labile particulate nitrogen produced by predation

FNRP = fraction of refractory particulate nitrogen produced by predation

The sums of the metabolism fractions and the predation fractions must each equal unity.

Algal Stoichiometry

Algal biomass is quantified in units of carbon. In order to express the effects of algae on nitrogen and phosphorus, the ratios of nitrogen-to-carbon and phosphorus-to-carbon in algal biomass must be specified. Global mean values of these ratios are well known (Redfield et al. 1966). Algal composition varies, however, especially as a function of nutrient availability. As nitrogen and phosphorus become scarce, algae adjust their composition so that smaller quantities of these vital nutrients are required to produce carbonaceous biomass (Droop 1973; DiToro 1980; Parsons et al. 1984).

Observations from upper Chesapeake Bay were examined to assess the potential variability of algal stoichiometry. Data employed were collected by the Maryland Department of the Environment from June 1985 to December 1987. This subset of the monitoring database was selected since it contained direct laboratory analysis of particulate nutrients. Examination was restricted to surface (≤2 m) data to maximize the fraction of algae in the particulate analyses. The ratio of particulate carbon-to-nitrogen was plotted as a function of ammonium plus nitrate concentration (Figure 4-5). The ratio of particulate carbon-to-phosphorus was plotted as a function of dissolved phosphate concentration (Figure 4-6). (These ratios were plotted to correspond to conventional reporting of algal composition. Their inverses are used in the model.) The variation of carbon-to-nitrogen stoichiometry in the upper Bay was small. No altered composition as a function of diminished nutrient availability was evident. As a consequence of these observations, the model formulation specified constant algal nitrogen-to-carbon ratio, ANC. Large variations in carbon-to-phosphorus ratio occurred, however. The carbon-to-phosphorus ratio in seston more than doubled as dissolved phosphate concentration diminished. To account for this effect, a variable algal phosphorus-to-carbon ratio, APC, was specified in the model.

Calculation of APC requires specification of three parameters:

- APCmin = minimum phosphorus-to-carbon ratio (gm P gm^{-1} C);
- APCmax = maximum phosphorus-to-carbon ratio (gm P gm^{-1} C); and
- PO_4dmax = dissolved phosphate concentration at which algal phosphorus-to-carbon ratio achieves its maximum value (gm P m^{-3}).

The minimum phosphorus-to-carbon ratio is assumed to occur when dissolved phosphate is zero. The ratio increases linearly from the minimum to the maximum which occurs when dissolved phosphate equals PO_4dmax:

$$APC = APC\,\min + \frac{APC\,\max - APC\,\min}{PO_4d\,\max} PO_4 d \tag{4.24}$$

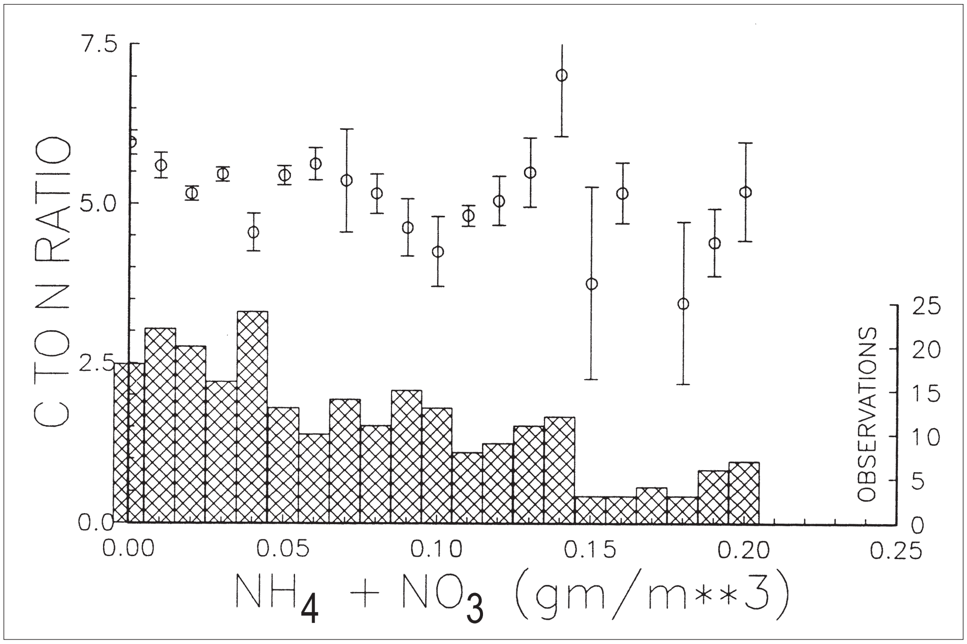


Figure 4-5. Carbon-to-nitrogen ratio (mean and standard error) of seston in upper Chesapeake Bay. Bars show number of observations

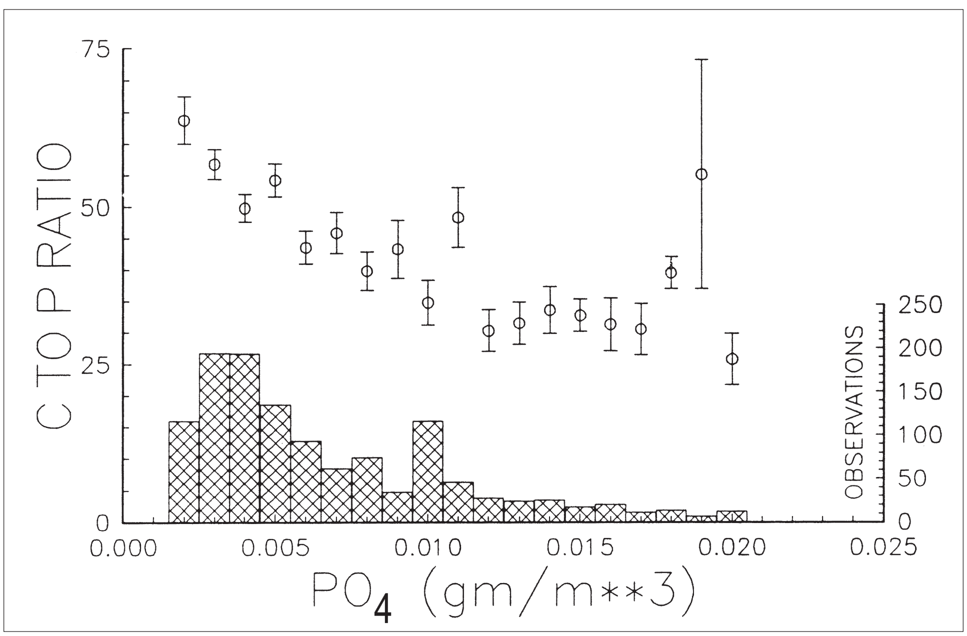


Figure 4-6. Carbon-to-phosphorus ratio (mean and standard error) of seston in upper Chesapeake Bay. Bars show number of observations

where

APC = algal phosphorus-to-carbon ratio (gm P gm^{-1} C)

When dissolved phosphate exceeds PO_4dmax, APC is held at its maximum value (Figure 4-7).

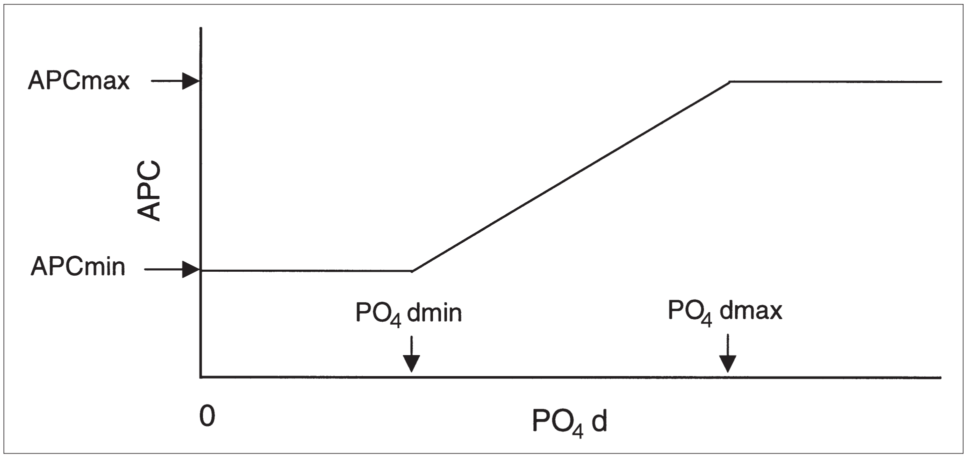


Figure 4-7. Model algal phosphorus-to-carbon ratio

Effect of Algae on Dissolved Oxygen

Algae produce oxygen during photosynthesis and consume oxygen through respiration. The quantity produced depends on the form of nitrogen utilized for growth. More oxygen is produced, per unit of carbon fixed, when nitrate is the algal nitrogen source than when ammonium is the source. Equations describing algal uptake of carbon and nitrogen and production of dissolved oxygen (Morel 1983) are:

$$06\,CO_2 + 16\,NH_4^+ + H_2PO_4^- + 106\,H_2O - \rightarrow \\ protoplasm + 106\,O_2 + 15\,H \tag{4.25}$$

$$106\,CO_2 + 16\,NO_3^- + H_2PO_4^- + 122\,H_2O + 17\,H^+ - - \rightarrow \\ protoplasm + 138\,O_2 \tag{4.26}$$

When ammonium is the nitrogen source, one mole oxygen is produced per mole carbon dioxide fixed. When nitrate is the nitrogen source, 1.3 moles oxygen are produced per mole carbon dioxide fixed.

The equation that describes the effect of algae on dissolved oxygen in the model is:

$$\frac{\delta}{\delta t} DO = \left[\left(1.3 - 0.3\, PN\right) P - \left(1 - FCD\right) \frac{DO}{KHr + DO} BM \right] AOCR\, B \tag{4.27}$$

where

AOCR = dissolved oxygen-to-carbon ratio in respiration ($2.67\ gm\ O_2\ gm^{-1}\ C$)

The magnitude of AOCR is derived from a simple representation of the respiration process:

$$CH_2O + O_2 = CO_2 + H_2O \tag{4.28}$$

The quantity (1.3 - 0.3 PN) is the photosynthesis ratio and expresses the molar quantity of oxygen produced per mole carbon fixed. The photosynthesis ratio approaches unity as the algal preference for ammonium approaches unity.

Organic Carbon

Organic carbon undergoes innumerable transformations in the water column. The model carbon cycle (Figure 4-8) consists of the following elements:

- Phytoplankton production
- Phytoplankton exudation
- Predation on phytoplankton
- Dissolution of particulate carbon
- Heterotrophic respiration
- Denitrification
- Settling

Algal production is the primary carbon source although carbon also enters the system through external loading. Predation on algae releases particulate and dissolved organic carbon to the water column. A fraction of the particulate organic carbon undergoes first-order dissolution to dissolved organic carbon. The remainder settles to the sediments. Dissolved organic carbon produced by phytoplankton exudation, by predation, and by dissolution is respired or denitrified at a first-order rate to inorganic carbon. No carbon is recycled from the sediments to the water column although oxygen demand created by carbon diagenesis is included in the model.

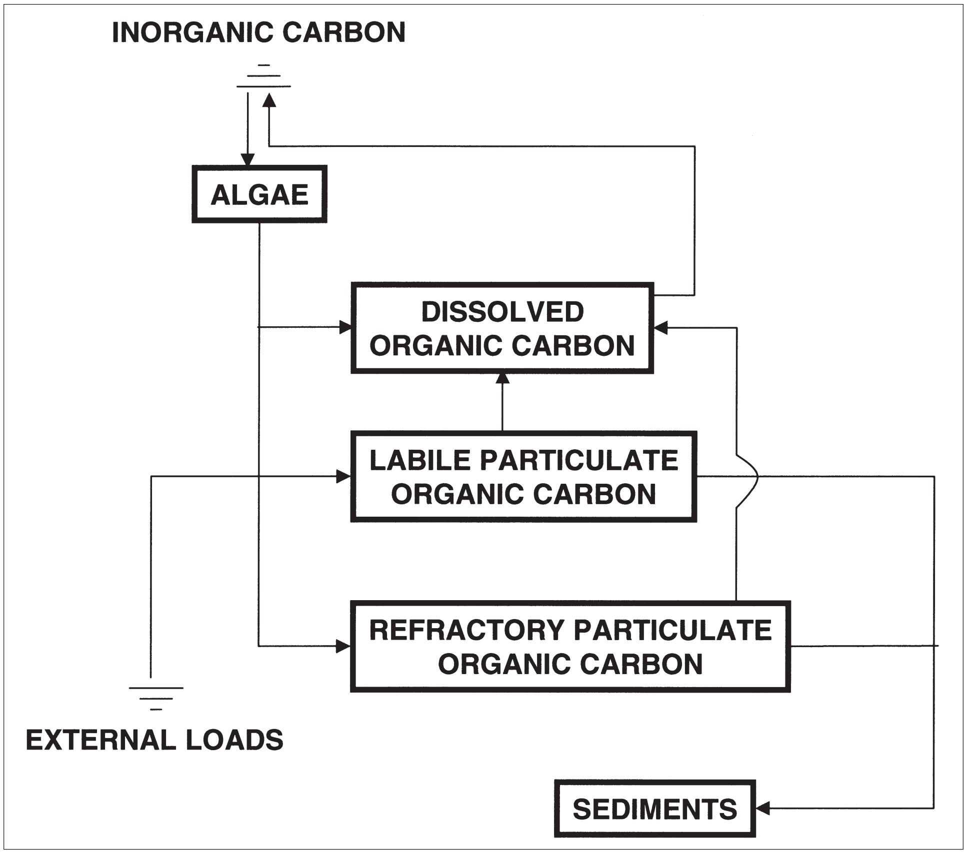


Figure 4-8. Model carbon cycle

Dissolution and Respiration Rates

Dissolution and respiration rates depend on the availability of carbonaceous substrate and on heterotrophic activity. Heterotrophic activity and biomass have been correlated with algal activity and biomass across a wide range of natural systems (Bird and Kalff 1984; Cole et al. 1988). Consequently, algal biomass can be incorporated into dissolution and respiration rate formulations as a surrogate for heterotrophic activity. The correlation between algae and heterotrophs occurs because algae produce labile carbon that fuels heterotrophic activity. Dissolution and respiration processes do not require the presence of algae, however, and may be fueled entirely by external carbon inputs. Representation of dissolution and respiration in the model allows specification of algal-dependent and algal-independent rates:

$$Kdoc = Kdc + Kdcalg\ B \tag{4.29}$$

where

Kdoc = respiration rate of dissolved organic carbon (day^{-1})

Kdc = minimum respiration rate (day^{-1})

Kdcalg = constant that relates respiration to algal biomass ($m^3\ gm^{-1}\ C\ day^{-1}$)

$$Klpoc = Klc + Klcalg\ B \tag{4.30}$$

where

Klpoc = dissolution rate of labile particulate organic carbon (day^{-1})

Klc = minimum dissolution rate (day^{-1})

Klcalg = constant that relates dissolution to algal biomass ($m^3\ gm^{-1}\ C\ day^{-1}$)

$$Krpoc = Krc + Krcalg\ B \tag{4.31}$$

where

Krpoc = dissolution rate of refractory particulate organic carbon (day^{-1})

Krc = minimum dissolution rate (day^{-1})

Krcalg = constant that relates dissolution to algal biomass ($m^3\ gm^{-1}\ C\ day^{-1}$)

An exponential function (Figure 4-3) relates dissolution and respiration to temperature.

Denitrification

As oxygen is depleted from natural systems, oxidation of organic matter is affected by the reduction of alternate oxidants (referred to as "alternate electron acceptors"). The sequence in which alternate acceptors are employed is determined by the thermodynamics of oxidation-reduction reactions. The first substance reduced in the absence of oxygen is nitrate. A representation of the denitrification reaction can be obtained by balancing standard half-cell redox reactions (Stumm and Morgan 1981):

$$4\,NO_3^- + 4\,H^+ + 5\,CH_2O -\!\!\rightarrow 2\,N_2 + 7\,H_2O + 5\,CO_2 \tag{4.32}$$

Equation 4-32 describes the stoichiometry of the denitrification reaction. The kinetics of the reaction, represented in the model, are first-order. The dissolved organic carbon respiration rate, Kdoc, is modified so that significant decay via denitrification occurs only when nitrate is freely available and dissolved oxygen is depleted (Figure 4-9). A parameter is included so that the anoxic respiration rate is slower than oxic respiration:

$$Denit = \frac{KHodoc}{KHodoc + DO}\,\frac{NO_3}{KHndn + NO_3}\,AANOX\ Kdoc \tag{4.33}$$

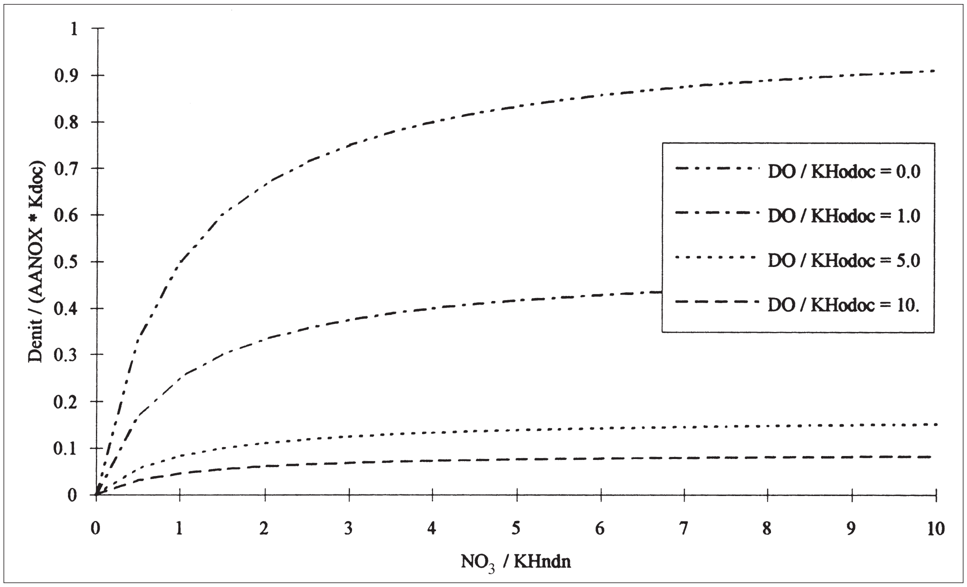


Figure 4-9. Effect of nitrate and dissolved oxygen on denitrification rate

where

Denit = denitrification rate of dissolved organic carbon (day^{-1})

AANOX = ratio of denitrification to oxic carbon respiration rate ($0 \le AANOX \le 1$)

KHodoc = half-saturation concentration of dissolved oxygen required for oxic respiration ($gm\ O_2\ m^{-3}$)

KHndn = half-saturation concentration of nitrate required for denitrification ($gm\ N\ m^{-3}$)

An exponential function (Figure 4-3) relates denitrification to temperature. Parameter values in the function are the same as those for dissolved organic carbon respiration.

Dissolved Organic Carbon

The complete representation of all dissolved organic carbon sources and sinks in the model ecosystem is:

$$\frac{\delta}{\delta t} DOC =$$
$$\left(FCD + (1 - FCD) \frac{KHr}{KHr + DO} BM + FCDP\ PR \right) B$$
$$+ Klpoc\ LPOC + Krpoc\ RPOC - \frac{DO}{KHodoc + DO} Kdoc\ DOC$$
$$- Denit\ DOC \tag{4.34}$$

Labile Particulate Organic Carbon

The complete representation of all labile particulate organic carbon sources and sinks in the model ecosystem is:

$$\frac{\delta}{\delta t} LPOC = FCLP\ PR\ B - Klpoc\ LPOC - WSl \frac{\delta}{\delta z} LPOC \tag{4.35}$$

where

WSl = settling velocity of labile particles (m day^{-1})

Refractory Particulate Organic Carbon

The complete representation of all refractory particulate organic carbon sources and sinks in the model ecosystem is:

$$\frac{\delta}{\delta t} RPOC = FCRP\ PR\ B - Krpoc\ RPOC - WSr \frac{\delta}{\delta z} RPOC \tag{4.36}$$

where

WSr = settling velocity of refractory particles (m day^{-1})

Phosphorus

The model phosphorus cycle (Figure 4-10) includes the following processes:

- Algal production and metabolism
- Predation
- Hydrolysis of particulate organic phosphorus
- Mineralization of dissolved organic phosphorus
- Settling

External loads provide the ultimate source of phosphorus to the system. Dissolved phosphate is incorporated by algae during growth and released as phosphate and organic phosphorus through respiration and predation. A portion of the particulate organic phosphorus hydrolyzes to dissolved organic phosphorus. The balance settles to the sediments. Dissolved organic phosphorus is mineralized to phosphate. Within the sediments, particulate phosphorus is mineralized and recycled to the water column as dissolved phosphate.

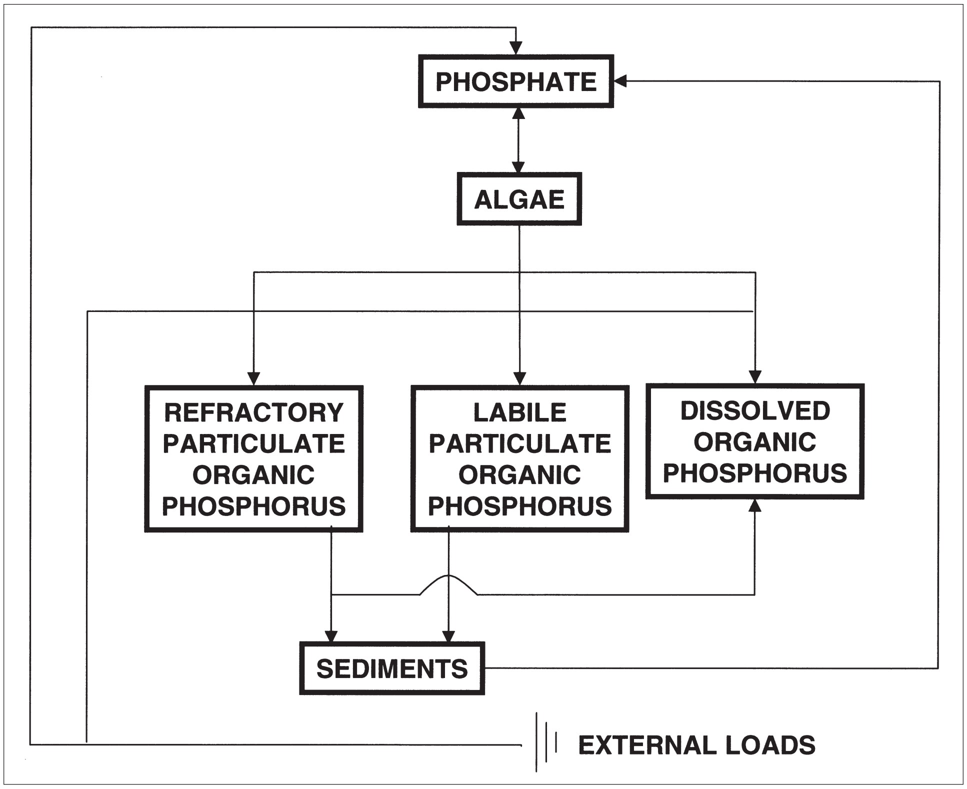


Figure 4-10. Model phosphorus cycle

Effects on phosphorus of algal production, metabolism, and predation have already been detailed. Descriptions of hydrolysis and mineralization and of the total phosphate system follow.

Hydrolysis and Mineralization

Within the model, hydrolysis is defined as the process by which particulate organic substances are converted to dissolved organic form. Mineralization is defined as the process by which dissolved organic substances are converted to dissolved inorganic form. Conversion of particulate organic phosphorus to phosphate proceeds through the sequence of hydrolysis and mineralization. Direct mineralization of particulate organic phosphorus does not occur.

Mineralization of organic phosphorus is mediated by the release of nucleotidase and phosphatase enzymes by bacteria (Ammerman and Azam 1985; Chrost and Overbeck 1987) and algae (Matavulj and Flint 1987; Chrost and Overbeck 1987; Boni et al. 1989). Since the algae themselves release the enzyme and since bacterial abundance is related to algal biomass, the rate of organic phosphorus mineralization is related, in the model, to algal biomass. A most remarkable property of the enzyme process is that alkaline phosphatase activity is inversely proportional to ambient phosphate concentration (Chrost and Overbeck 1987; Boni et al. 1989).

Put in different terms, when phosphate is scarce, algae stimulate production of an enzyme that mineralizes organic phosphorus to phosphate. This phenomenon is simulated by relating mineralization to the algal phosphorus nutrient limitation. Mineralization is highest when algae are strongly phosphorus limited and is least when no limitation occurs.

Expressions for mineralization and hydrolysis rates are:

$$Kdop = Kdp + \frac{KHp}{KHp + PO_4d} Kdpalg\ B \tag{4.37}$$

where

Kdop = mineralization rate of dissolved organic phosphorus (day^{-1})

Kdp = minimum mineralization rate (day^{-1})

Kdpalg = constant that relates mineralization to algal biomass ($m^3\ gm^{-1}\ C\ day^{-1}$)

$$Klpop = Klp + \frac{KHp}{KHp + PO_4d} Klpalg\ B \tag{4.38}$$

where

Klpop = hydrolysis rate of labile particulate phosphorus (day^{-1})

Klp = minimum hydrolysis rate (day^{-1})

Klpalg = constant that relates hydrolysis to algal biomass ($m^3\ gm^{-1}\ C\ day^{-1}$)

$$Krpop = Krp + \frac{KHp}{KHp + PO_4d} Krpalg\ B \tag{4.39}$$

where

Krpop = hydrolysis rate of refractory particulate phosphorus (day^{-1})

Krp = minimum hydrolysis rate (day^{-1})

Krpalg = constant that relates hydrolysis to algal biomass ($m^3\ gm^{-1}\ C\ day^{-1}$)

An exponential function (Figure 4-3) relates mineralization and hydrolysis rates to temperature.

Potential effects of algal biomass and nutrient limitation on mineralization and hydrolysis rates are shown in Figure 4-11. When nutrient concentration greatly exceeds the half-saturation concentration for algal uptake, the rate roughly equals the minimum. Algal biomass has little influence. As nutrient becomes scarce relative to the half-saturation concentration,

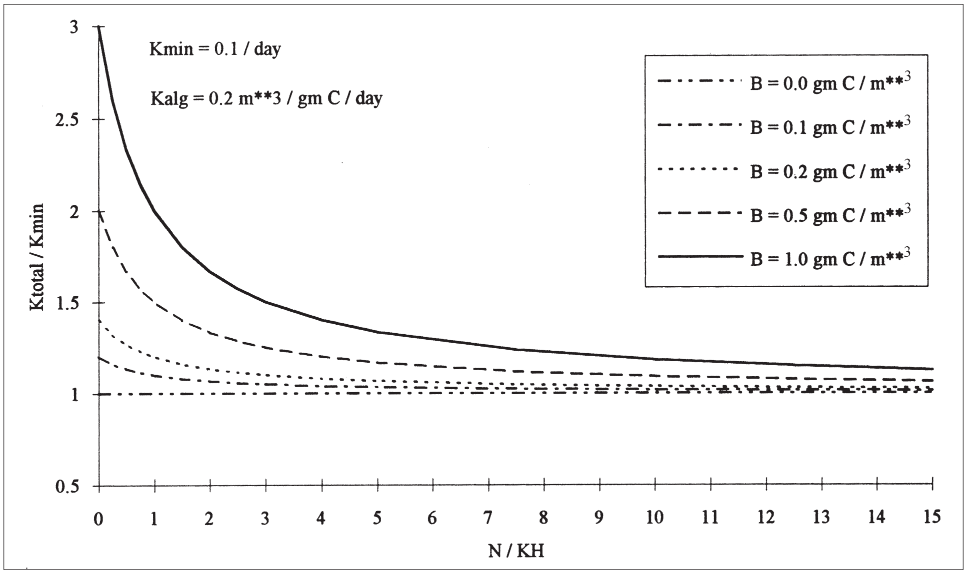


Figure 4-11. Effect of algal biomass and nutrient concentration on hydrolysis and mineralization

the rate increases. The magnitude of increase depends on algal biomass. Factor of two to three increases are feasible.

The Total Phosphate System

One fraction of total phosphorus in the water column is phosphorus incorporated in algal biomass. This fraction is computed in the model as the product of algal biomass and APC, the phosphorus-to-carbon ratio. In the environment, algae adjust their phosphorus content in response to external conditions. Algal phosphorus content is high when external phosphorus is abundant, and phosphorus content is low when phosphorus is scarce. The adaptation of algae to their environment indicates phosphorus-to-carbon ratio should be a variable in the model. Treatment of the ratio as a variable, however, greatly complicates computation of phosphorus transport due to the mixture of algal masses of different composition. The complication is avoided if intracellular and extracellular phosphorus are treated and transported as a single state variable. Intracellular and extracellular concentrations are determined by equilibrium partitioning of their sum.

The model phosphate state variable is defined as the sum of dissolved phosphate and algal phosphorus content:

$$PO_4t = PO_4d + PO_4a \tag{4.40}$$

where

PO_4t = total phosphate (gm P m^{-3})

PO_4d = dissolved phosphate (gm P m^{-3})

PO_4a = algal phosphorus (gm P m^{-3})

Computation of Algal Phosphorus

Algal phosphorus is defined:

$$PO_4a = APC\ B \tag{4.41}$$

The phosphorus-to-carbon ratio is calculated by the empirical function expressed in Equation 4.24.

The expressions 4.24 and 4.40 form a set of simultaneous equations in which APC depends on PO_4d and PO_4d depends on APC. The equations can be solved directly for APC:

$$APC = \frac{APCMIN + APCRAT\ PO_4t}{1 + APCRAT\ B} \tag{4.42}$$

in which:

$$APCRAT = \frac{APCMAX - APCMIN}{PO_4d\ \max} \tag{4.43}$$

The computation of APC takes place only when $PO_4d < PO_4dmax$. Otherwise, APC takes the value APCMAX.

Effect of Variable Phosphorus Stoichiometry

The effect of the variable phosphorus-to-carbon ratio and the operation of the total phosphate system is best seen by an example. The model was applied to a chemostat supplied with unlimited inorganic nitrogen. Phosphorus recycling was eliminated in the water and sediments so that only the initial phosphate was available to the algae. The chemostat was simulated for thirty days. Midway through the simulation, a phosphate load, equivalent to the initial mass in the chemostat, was injected. Simulations were conducted with and without variable stoichiometry.

Algal production was initially identical with and without variable stoichiometry (Figure 4-12). As dissolved phosphate became scarce in the constant-stoichiometry chemostat, algal production diminished so that respiration exceeded growth prior to day five. Biomass decreased until the phosphate injection at day fifteen. In the variable-stoichiometry chemostat, algae responded to diminished phosphate availability by reducing their phosphorus-to-carbon ratio. Because less phosphorus was required per unit carbonaceous biomass formed, growth exceeded respiration beyond day five and maximum biomass exceeded biomass formed under constant stoichiometry. Upon injection of new phosphate, algal production increased with and without variable stoichiometry. Algae with variable stoichiometry responded with increased phosphorus-to-carbon ratio as well as increased production. As a result of the altered ratio,

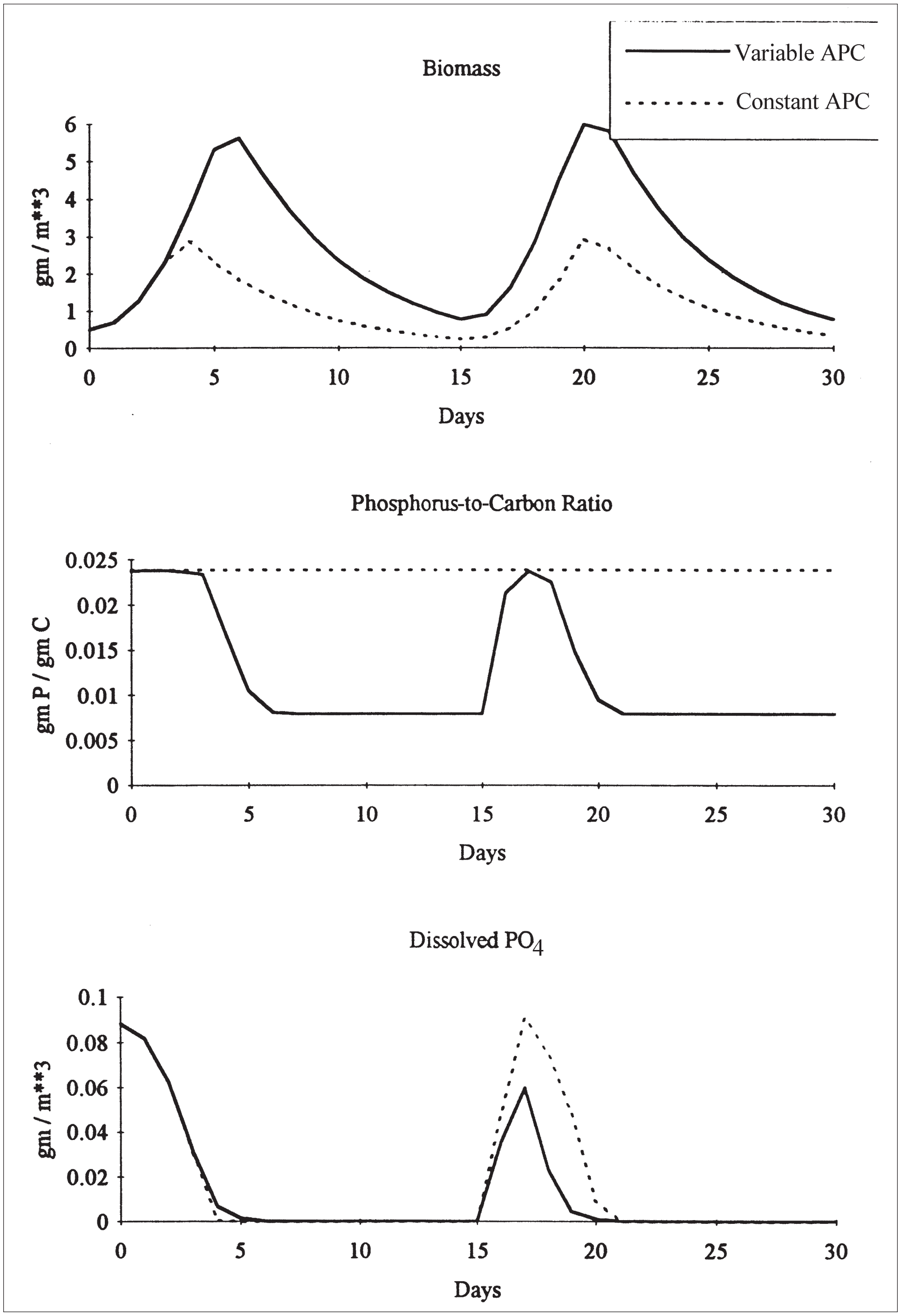


Figure 4-12. Chemostat simulation with and without variable phosphorus stoichiometry

dissolved phosphate peaked at a lower concentration in the presence of variable stoichiometry. The ability of algae to diminish phosphorus-to-carbon ratio still allowed algae in the variable-stoichiometry chemostat to exceed biomass formed in the constant-stoichiometry chemostat, however.

Phosphate

Once the interactions of dissolved and algal phosphate are made explicit, the balance of the equations describing phosphorus are straightforward summations of previously described sources and sinks:

$$\frac{\delta}{\delta t} PO_4 t = -WSa \frac{\delta}{\delta z} APC\ B + Kdop\ DOP \tag{4.44}$$

Algal uptake and release of phosphate represents an exchange of phosphate fractions rather than a phosphate source or sink. Consequently, no algal source or sink terms are included in the phosphate mass-conservation equation. The settling term is required to represent the settling of particulate phosphate incorporated in algal biomass.

Dissolved Organic Phosphorus

$$\frac{\delta}{\delta t} DOP = (BM\ FPD + PR\ FPDO) APC\ B$$
$$+ Klpop\ LPOP + Krpop\ RPOP - Kdop\ DOP \tag{4.45}$$

Labile Particulate Organic Phosphorus

$$\frac{\delta}{\delta t} LPOP = (BM\ FPL + PR\ FPLP) APC\ B$$
$$- Klpop\ LPOP - WSl \frac{\delta}{\delta z} LPOP \tag{4.46}$$

Refractory Particulate Organic Phosphorus

$$\frac{\delta}{\delta t} RPOP = (BM\ FPR + PR\ FPRP) APC\ B$$
$$- Krpop\ RPOP - WSr \frac{\delta}{\delta z} RPOP \tag{4.47}$$

Nitrogen

The model nitrogen cycle (Figure 4-13) includes the following processes:

- Algal production and metabolism
- Predation
- Hydrolysis of particulate organic nitrogen
- Mineralization of dissolved organic nitrogen
- Settling

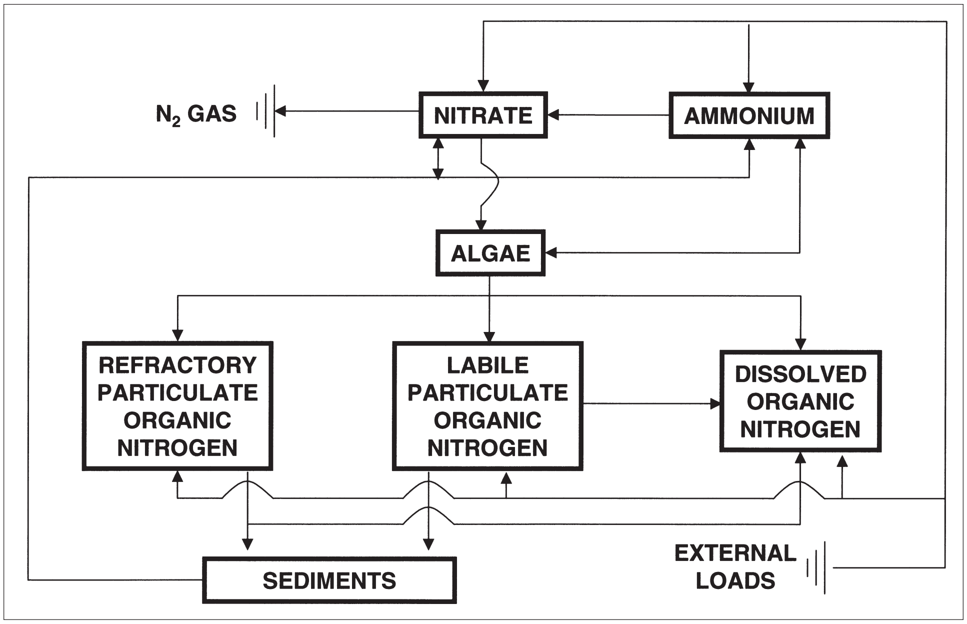


Figure 4-13. Model nitrogen cycle

- Nitrification
- Denitrification

External loads provide the ultimate source of nitrogen to the system. Inorganic nitrogen is incorporated by algae during growth and released as ammonium and organic nitrogen through respiration and predation. A portion of the particulate organic nitrogen hydrolyzes to dissolved organic nitrogen. The balance settles to the sediments. Dissolved organic nitrogen is mineralized to ammonium. In an oxygenated water column, a fraction of the ammonium is subsequently oxidized to nitrate through the nitrification process. In anoxic water, nitrate is lost to nitrogen gas through denitrification. Particulate nitrogen that settles to the sediments is mineralized and recycled to the water column, primarily as ammonium. Nitrate moves in both directions across the sediment-water interface, depending on relative concentrations in the water column and sediment interstices.

Effects on nitrogen of algal production, metabolism, and predation have already been detailed. Descriptions of hydrolysis, mineralization, nitrification, and denitrification follow.

Hydrolysis and Mineralization

In the model, particulate organic nitrogen is converted to the dissolved organic form via hydrolysis. Dissolved organic nitrogen is converted to ammonium through mineralization. Conversion of particulate nitrogen to ammonium proceeds through the sequence of hydrolysis and mineralization. Direct mineralization of particulate nitrogen does not occur. The argument for accelerated hydrolysis and mineralization during nutrient-limited conditions is not as clear for nitrogen as for phosphorus. The same formulations are made available for nitrogen as for phosphorus, however. Accelerated processes can be activated or deactivated through parameter selection. The nitrogen hydrolysis and mineralization formulations are:

$$Kdon = Kdn + \frac{KHn}{KHn + NH_4 + NO_3} Kdnalg\ B \tag{4.48}$$

where

Kdon = mineralization rate of dissolved organic nitrogen (day^{-1})

Kdn = minimum mineralization rate (day^{-1})

Kdnalg = constant that relates mineralization to algal biomass ($m^3\ gm^{-1}\ C\ day^{-1}$)

$$Klpon = Kln + \frac{KHn}{KHn + NH_4 + NO_3} Klnalg\ B \tag{4.49}$$

where

Klpon = hydrolysis rate of labile particulate nitrogen (day^{-1})

Kln = minimum hydrolysis rate (day^{-1})

Klnalg = constant that relates hydrolysis to algal biomass ($m^3\ gm^{-1}\ C\ day^{-1}$)

$$Krpon = Krn + \frac{KHn}{KHn + NH_4 + NO_3} Krnalg\ B \tag{4.50}$$

where

Krpon = hydrolysis rate of refractory particulate nitrogen (day^{-1})

Krn = minimum hydrolysis rate (day^{-1})

Krnalg = constant that relates hydrolysis to algal biomass ($m^3\ gm^{-1}\ C\ day^{-1}$)

An exponential function (Figure 4-3) relates mineralization and hydrolysis rates to temperature.

Nitrification

Nitrification is a process mediated by specialized groups of autotrophic bacteria that obtain energy through the oxidation of ammonium to nitrite and oxidation of nitrite to nitrate. A simplified expression for complete nitrification (Tchobanoglous and Schroeder 1987) is:

$$NH_4^* + 2\,O_2 - \rightarrow NO_3^- + H_2O + 2\,H^+ \tag{4.51}$$

The equation indicates that two moles of oxygen are required to nitrify one mole of ammonium into nitrate. The simplified equation is not strictly true, however. Cell synthesis by nitrifying bacteria is accomplished by the fixation of carbon dioxide so that less than two moles of oxygen are consumed per mole ammonium utilized (Wezernak and Gannon 1968).

The kinetics of complete nitrification are modeled as a function of available ammonium, dissolved oxygen, and temperature:

$$NT = \frac{DO}{KHont + DO}\,\frac{NH_4}{KHnnt + NH_4}\,f(T)\,NTm \tag{4.52}$$

where

NT = nitrification rate (gm N m^{-3} day^{-1})

KHont = half-saturation constant of dissolved oxygen required for nitrification (gm O_2 m^{-3})

KHnnt = half-saturation constant of NH_4 required for nitrification (gm N m^{-3})

NTm = maximum nitrification rate at optimal temperature (gm N m^{-3} day^{-1})

The kinetics formulation (Figure 4-14) incorporates the products of two "Monod" functions. The first function diminishes nitrification at low dissolved oxygen concentration. The second function expresses the influence of ammonium concentration on nitrification. When ammonium concentration is low, relative to KHnnt, nitrification is proportional to ammonium concentration. For NH_4 << KHnnt, the reaction is approximately first-order. (The first-order decay constant ≈ NTm/KHnnt.) When ammonium concentration is large, relative to KHnnt, nitrification approaches a maximum rate. This formulation is based on a concept proposed by Tuffey et al. (1974). Nitrifying bacteria adhere to benthic or suspended sediments. When ammonium is scarce, vacant surfaces suitable for nitrifying bacteria exist. As ammonium concentration increases, bacterial biomass increases, vacant surfaces are occupied, and the rate of nitrification increases. The bacterial population attains maximum density when all surfaces suitable for bacteria are occupied. At this point, nitrification proceeds at a maximum rate independent of additional increase in ammonium concentration.

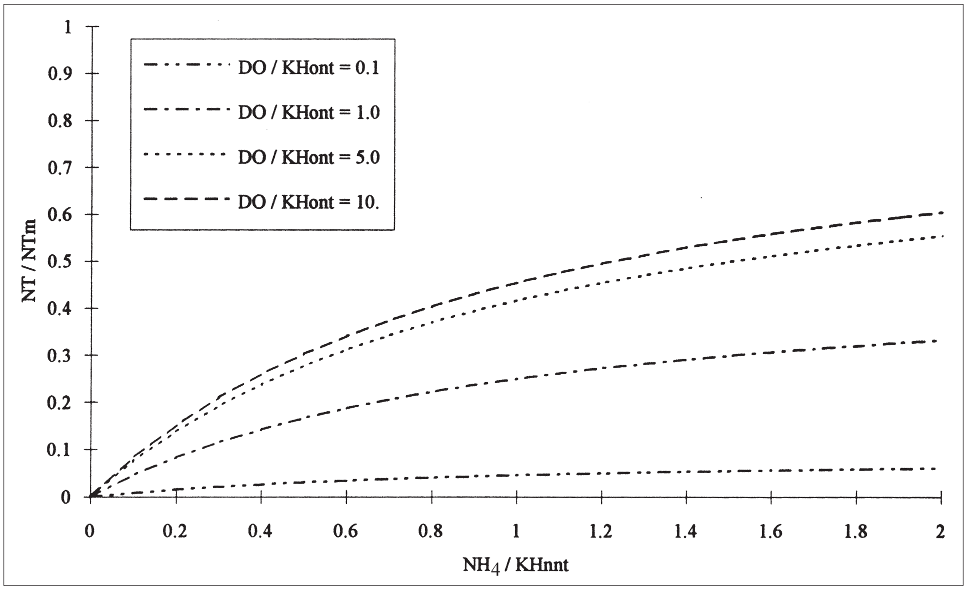


Figure 4-14. Effect of dissolved oxygen and ammonium concentration on nitrification rate

The optimal temperature for nitrification may be less than peak temperatures that occur in coastal waters. To allow for a decrease in nitrification at superoptimal temperature, the effect of temperature on nitrification is modeled in the Gaussian form of Equation 4.8.

Effect of Nitrification on Ammonium

$$\frac{\delta}{\delta t} NH_4 = -NT \qquad (4.53)$$

Effect of Nitrification on Nitrate

$$\frac{\delta}{\delta t} NO_3 = NT \qquad (4.54)$$

Effect of Nitrification on Dissolved Oxygen

$$\frac{\delta}{\delta t} DO = -AONT\ NT \qquad (4.55)$$

where

AONT = mass dissolved oxygen consumed per mass ammonium-nitrogen nitrified (4.33 gm O_2 gm^{-1} N)

Effect of Denitrification on Nitrate

The effect of denitrification on dissolved organic carbon has been described. Denitrification removes nitrate from the system in stoichiometric proportion to carbon removal:

$$\frac{\delta}{\delta t} NO_3 = -ANDC\ Denit\ DOC \tag{4.56}$$

where

ANDC = mass nitrate-nitrogen reduced per mass dissolved organic carbon oxidized (0.933 gm N gm^{-1} C)

Nitrogen Mass Balance Equations

The mass-balance equations for nitrogen state variables are written by summing all previously described sources and sinks:

Ammonium

$$\frac{\delta}{\delta t} NH_4 = \left(BM\ FNI + PR\ FNIP - PN\ P\right) ANC\ B + Kdon\ DON - NT \tag{4.57}$$

Dissolved Organic Nitrogen

$$\frac{\delta}{\delta t} DON = \left(BM\ FND + PR\ FNDP\right) ANC\ B + Klpon\ LPON + Krpon\ RPON - Kdon\ DON \tag{4.58}$$

Labile Particulate Organic Nitrogen

$$\frac{\delta}{\delta t} LPON = \left(BM\ FNL + PR\ FNLP\right) ANC\ B - Klpon\ LPON - WSl \frac{\delta}{\delta z} LPON \tag{4.59}$$

Refractory Particulate Organic Nitrogen

$$\frac{\delta}{\delta t} RPON = \left(BM\ FNR + PR\ FNRP\right) ANC\ B - Krpon\ RPON - WSr \frac{\delta}{\delta z} RPON \tag{4.60}$$

Nitrate

$$\frac{\delta}{\delta t} NO_3 = (PN - 1) P \; ANC \; B$$
$$+ \; NT - ANDC \; Denit \; DOC \qquad (4.61)$$

Chemical Oxygen Demand

Chemical oxygen demand is the concentration of reduced substances that are oxidizable through inorganic means. The source of chemical oxygen demand in saline water is sulfide released from sediments. A cycle occurs in which sulfate is reduced to sulfide in the sediments and reoxidized to sulfate in the water column. In freshwater, methane is released to the water column by the sediment model. Both sulfide and methane are quantified in units of oxygen demand and are treated with the same kinetics formulation:

$$\frac{\delta}{\delta t} COD = - \frac{DO}{KHocod + DO} Kcod \; COD \qquad (4.62)$$

where

COD = chemical oxygen demand concentration (gm O_2-equivalents m^{-3})

KHocod = half-saturation concentration of dissolved oxygen required for exertion of chemical oxygen demand (gm O_2 m^{-3})

Kcod = oxidation rate of chemical oxygen demand (day^{-1})

An exponential function (Figure 4-3) describes the effect of temperature on exertion of chemical oxygen demand.

Dissolved Oxygen

Sources and sinks of dissolved oxygen in the water column (Figure 4-15) include:

- Algal photosynthesis
- Atmospheric reaeration
- Algal respiration
- Heterotrophic respiration
- Nitrification
- Chemical oxygen demand

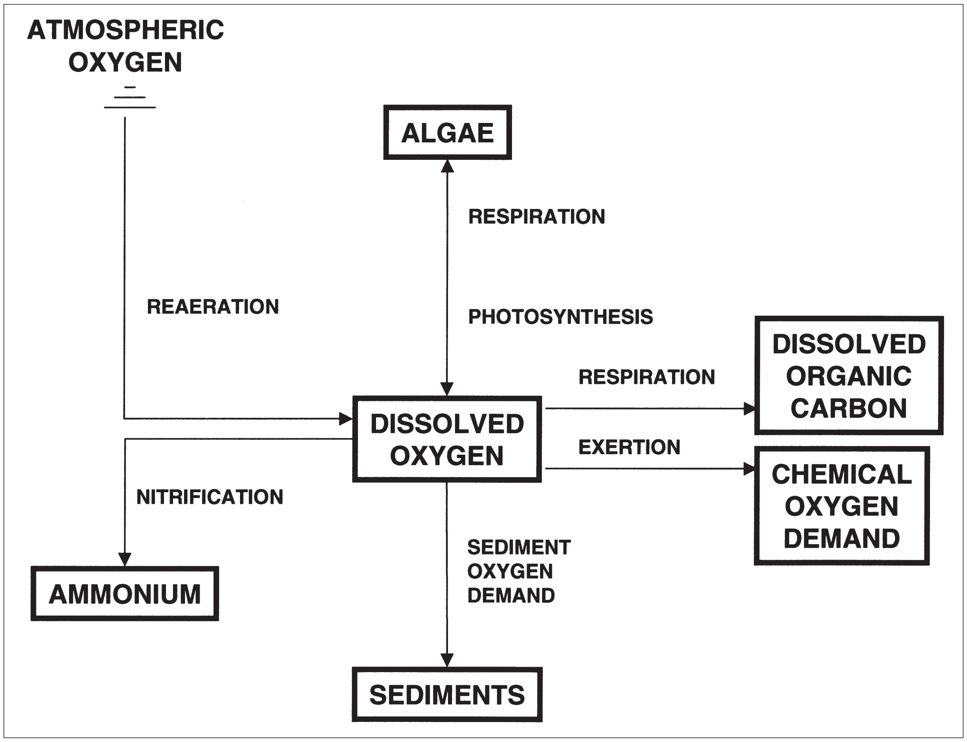


Figure 4-15. Model dissolved oxygen cycle

Reaeration

The rate of reaeration is proportional to the dissolved oxygen deficit in model segments that form the air-water interface:

$$\frac{\delta}{\delta t} DO = \frac{Kr}{\Delta z}\left(DOs - DO\right) \tag{4.63}$$

where

Kr = reaeration coefficient (m day^{-1})

DOs = dissolved oxygen saturation concentration (gm O_2 m^{-3})

In shallow water (e.g. free-flowing streams), the reaeration coefficient depends largely on turbulence generated by bottom shear stress (O'Connor and Dobbins 1958). In deeper systems (e.g. estuaries), however, wind effects may dominate the reaeration process (O'Connor 1983). The reaeration coefficient is also influenced by temperature (ASCE 1961) and salinity (Wen et al. 1984). No universal formula for evaluation of the reaeration coefficient exists. In the model, the reaeration coefficient is treated as a user-supplied parameter.

Saturation dissolved oxygen concentration diminishes as temperature and salinity increase. An empirical formula that describes these effects (Genet et al. 1974) is:

$$DOs = 14.5532 - 0.38217\,T + 0.0054258\,T^2 - CL\left(1.665\times10^{-4} - 5.866\times10^{-6}\,T + 9.796\times10^{-8}\,T^2\right) \tag{4.64}$$

where

CL = chloride concentration (= salinity/1.80655)

Summary of Dissolved Oxygen Sources and Sinks

The complete kinetics for dissolved oxygen are:

$$\frac{\delta}{\delta t} DO = \left((1.3 - 0.3PN)P - \frac{DO}{KHr + DO} BM\right) AOCR\ B - AONT\ NT - \frac{DO}{KHodoc + DO} AOCR\ Kdoc\ DOC - \frac{DO}{KHocod + DO} Kcod\ COD + \frac{Kr}{\Delta z}(DOs - DO) \tag{4.65}$$

Salinity

No internal sources or sinks of salinity exist. Salinity is included to verify proper transport and linkage to the HM.

Temperature

A conservation of internal energy equation can be written analogous to the conservation of mass equation. The only source or sink of internal energy considered is exchange with the atmosphere. Although solar radiation can penetrate several meters into the water column, radiation-induced increases in internal energy are here assigned entirely to the surface model layer.

For practical purposes, the internal-energy equation can be written as a conservation of temperature equation. Change of temperature due to atmospheric exchange is considered proportional to the temperature difference between the water surface and a theoretical equilibrium temperature (Edinger et al. 1974):

$$\frac{\delta}{\delta t} T = \frac{KT}{\rho \, Cp \, \Delta z} \left(Te - T \right) \qquad (4.66)$$

where

Te = equilibrium temperature (C°)

KT = heat exchange coefficient (watt m^{-2} $C^{\circ -1}$)

Cp = specific heat of water (4200 watt sec kg^{-1} $C^{\circ -1}$)

ρ = density of water (1000 kg m^{-3})

Fecal Coliform

Mortality of fecal coliform bacteria in the environment is represented as a first-order loss process:

$$\frac{\delta}{\delta t} FC = -Kfc \, FC \qquad (4.67)$$

where

Kfc = decay rate of fecal coliform (day^{-1})

Glossary

Table 4-2 presents a glossary of terms employed in water-column kinetics described in this chapter.

Table 4-2.
Terms in Kinetics Equations

Symbol	Definition	Units
A_j	Area of flow face j	m^2
AANOX	Ratio of denitrification to oxic carbon respiration rate	
ANC	Nitrogen-to-carbon ratio of algae	gm N gm^{-1} C
AOCR	Dissolved oxygen-to-carbon ratio in respiration	gm O_2 gm^{-1} C
AONT	Mass dissolved oxygen consumed per mass ammonium nitrified	gm O_2 gm^{-1} N
ANDC	Mass nitrate-nitrogen consumed per mass carbon oxidized	gm N gm^{-1} C
APC	Algal phosphorus-to-carbon ratio	gm P gm^{-1} C
APCmin	Minimum phosphorus-to-carbon ratio	gm P gm^{-1} C
APCmax	Maximum phosphorus-to-carbon ratio	gm P gm^{-1} C
APCRAT	Change in phosphorus-to-carbon ratio per unit change in dissolved phosphate	C^{-1}
BMr	Basal metabolic rate of algae at reference temperature Tr	day^{-1}
BPR	Predation rate on algae at reference temperature Tr	day^{-1}
B	Biomass of algae	gm C m^{-3}
C_i	Concentration in ith control volume	gm m^{-3}
C_j^*	Concentration in flow across face j	gm m^{-3}
CChl	Carbon-to-chlorophyll ratio of algae	gm C mg^{-1} chl
CL	Chloride concentration	ppt
COD	concentration of chemical oxygen demand	gm m^{-3}
Cp	specific heat of water	watt sec kg^{-1} °C^{-1}
Dj	Diffusion coefficient at flow face j	m^2 sec^{-1}
Denit	Denitrification rate of dissolved organic carbon	day^{-1}
DO	Dissolved oxygen	gm O_2 m^{-3}
DOC	Dissolved organic carbon	gm C m^{-3}
DON	Dissolved organic nitrogen	gm N m^{-3}
DOP	Dissolved organic phosphorus	gm P m^{-3}
DOs	Saturation dissolved oxygen concentration	gm O_2 m^{-3}
FCD	Fraction of basal metabolism exuded as dissolved organic carbon by algae	$0 \le FCDx \le 1$
FCDP	Fraction of dissolved organic carbon produced by predation	$0 \le FCDP \le 1$
FCLP	Fraction of labile particulate carbon produced by predation	$0 \le FCLP \le 1$
FCRP	Fraction of refractory particulate carbon produced by predation	$0 \le FCRP \le 1$
FD	Daylight fraction of total daylength	$0 \le FD \le 1$
f(I)	Effect of suboptimal illumination on algal production	$0 \le f(I) \le 1$

(Sheet 1 of 5)

Table 4-2. Continued

Symbol	Definition	Units
f(N)	Effect of suboptimal nutrient concentration on algal production	$0 \le f(N) \le 1$
FNI	Fraction of inorganic nitrogen produced by metabolism of algae	$0 \le FNIx \le 1$
FNIP	Fraction of inorganic nitrogen produced by predation	$0 \le FNIP \le 1$
FND	Fraction of dissolved organic nitrogen produced by metabolism of algae	$0 \le FNDx \le 1$
FNDP	Fraction of dissolved organic nitrogen produced by predation	$0 \le FNDP \le 1$
FNL	Fraction of labile particulate nitrogen produced by metabolism of algae	$0 \le FNLx \le 1$
FNLP	Fraction of labile particulate nitrogen produced by predation	$0 \le FNLP \le 1$
FNR	Fraction of refractory particulate nitrogen produced by metabolism of algae	$0 \le FNRx \le 1$
FNRP	Fraction of refractory particulate nitrogen produced by predation	$0 \le FNRP \le 1$
FPD	Fraction of dissolved organic phosphorus produced by metabolism by algae	$0 \le FPDx \le 1$
FPDP	Fraction of dissolved organic phosphorus produced by predation	$0 \le FPDP \le 1$
FPI	Fraction of inorganic phosphorus produced by metabolism of algae	$0 \le FPI \le 1$
FPIP	Fraction of inorganic phosphorus produced by predation	$0 \le FPIP \le 1$
FPL	Fraction of labile particulate phosphorus produced by metabolism of algae	$0 \le FPLx \le 1$
FPLP	Fraction of labile particulate phosphorus produced by predation	$0 \le FPLP \le 1$
FPR	Fraction of refractory particulate phosphorus produced by metabolism of algae	$0 \le FPRx \le 1$
FPRP	Fraction of refractory particulate phosphorus produced by predation	$0 \le FPRP \le 1$
FR	Macrobenthic filtration rate	$m^3\ gm^{-1}C\ day^{-1}$
f(T)	Effect of suboptimal temperature on algal production	$0 \le f(T) \le 1$
I	Illumination rate	Langleys day^{-1}
Ih	Illumination rate at which algal production is halved	Langleys day^{-1}
Io	Daily illumination at water surface	Langleys day^{-1}
Kcod	Oxidation rate of chemical oxygen demand	day^{-1}
Kdc	Minimum respiration rate of dissolved organic carbon	day^{-1}
Kdcalg	Constant that relates respiration rate to algal biomass	$m^3\ gm^{-1}\ C\ day^{-1}$
Kdn	Minimum mineralization rate of dissolved organic nitrogen	day^{-1}
Kdnalg	Constant that relates mineralization rate to algal biomass	$m^3\ gm^{-1}\ C\ day^{-1}$
Kdoc	Dissolved organic carbon respiration rate	day^{-1}

(Sheet 2 of 5)

Table 4-2. Continued

Symbol	Definition	Units
Kdon	Dissolved organic nitrogen mineralization rate	day^{-1}
Kdop	Dissolved organic phosphorus mineralization rate	day^{-1}
Kdp	Minimum mineralization rate of dissolved organic phosphorus	day^{-1}
Kdpalg	Constant that relates mineralization rate to algal biomass	$m^3\ gm^{-1}\ C\ day^{-1}$
Keb	Background light attenuation	m^{-1}
Kechl	Light attenuation coefficient for chlorophyll ‘a’	$m^2\ mg^{-1}$
Kess	Total light attenuation	m^{-1}
Kfc	Decay rate of fecal coliform	day^{-1}
KHn	Half-saturation concentration for nitrogen uptake by algae	$gm\ N\ m^{-3}$
KHndn	Half-saturation concentration of nitrate required for denitrification	$gm\ N\ m^{-3}$
KHnnt	Half-saturation concentration of NH_4 required for nitrification	$gm\ N\ m^{-3}$
KHocod	Half-saturation concentration of dissolved oxygen required for exertion of COD	$gm\ O_2\ m^{-3}$
KHodoc	Half-saturation concentration of dissolved oxygen required for oxic respiration	$gm\ O_2\ m^{-3}$
KHomb	Dissolved oxygen concentration at which macrobenthic grazing is halved	$gm\ O_2\ m^{-3}$
KHont	Half-saturation concentration of dissolved oxygen required for nitrification	$gm\ O_2\ m^{-3}$
KHp	Half-saturation concentration for phosphorus uptake by algae	$gm\ P\ m^{-3}$
KHr	Half-saturation concentration for dissolved organic carbon excretion by algae	$gm\ O_2\ m^{-3}$
Klc	Minimum dissolution rate of labile particulate carbon	day^{-1}
Klcalg	Constant that relates dissolution rate to algal biomass	$m^3\ gm^{-1}\ C\ day^{-1}$
Kln	Minimum dissolution rate of labile particulate nitrogen	day^{-1}
Klnalg	Constant that relates dissolution rate to algal biomass	$m^3\ gm^{-1}\ C\ day^{-1}$
Klp	Minimum dissolution rate of labile particulate phosphorus	day^{-1}
Klpalg	Constant that relates dissolution rate to algal biomass	$m^3\ gm^{-1}\ C\ day^{-1}$
Klpoc	Labile particulate organic carbon dissolution rate	day^{-1}
Klpon	Labile particulate organic nitrogen hydrolysis rate	day^{-1}
Klpop	Labile particulate organic phosphorus hydrolysis rate	day^{-1}
Kr	Reaeration coefficient	$m\ day^{-1}$
Krc	Minimum dissolution rate of refractory particulate carbon	day^{-1}
Krcalg	Constant that relates dissolution rate to algal biomass	$m^3\ gm^{-1}\ C\ day^{-1}$
Krn	Minimum dissolution rate of refractory particulate nitrogen	day^{-1}
Krnalg	Constant that relates dissolution rate to algal biomass	$m^3\ gm^{-1}\ C\ day^{-1}$

(Sheet 3 of 5)

Table 4-2. Continued		
Symbol	**Definition**	**Units**
Krp	Minimum dissolution rate of refractory particulate phosphorus	day^{-1}
Krpalg	Constant that relates dissolution rate to algal biomass	m^3 gm^{-1} C day^{-1}
Krpoc	Refractory particulate organic carbon dissolution rate	day^{-1}
Krpon	Refractory particulate organic nitrogen hydrolysis rate	day^{-1}
Krpop	Refractory particulate organic phosphorus hydrolysis rate	day^{-1}
KT	Surface heat exchange coefficient	watt m^{-2} $°C^{-1}$
KTb	Effect of temperature on basal metabolism of algae	$°C^{-1}$
KTcod	Effect of temperature on oxidation of chemical oxygen demand	$°C^{-1}$
KTg1	Effect of temperature below Tm on growth of algae	$°C^{-2}$
KTg2	Effect of temperature above Tm on growth of algae	$°C^{-2}$
KThdr	Constant that relates hydrolysis rates to temperature	$°C^{-1}$
KTmnl	Constant that relates mineralization rates to temperature	$°C^{-1}$
KTnt1	Effect of temperature below Tmnt on nitrification	$°C^{-2}$
KTnt2	Effect of temperature above Tmnt on nitrification	$°C^{-2}$
LPOC	Labile particulate organic carbon	gm C m^{-3}
LPON	Labile particulate organic nitrogen	gm N m^{-3}
LPOP	Labile particulate organic phosphorus	gm P m^{-3}
MBGM	Macrobenthic biomass	gm C m^{-2}
NH_4	Ammonium concentration	gm N m^{-3}
NO_3	Nitrate+nitrite concentration	gm N m^{-3}
NT	Nitrification rate	gm N m^{-3} day^{-1}
NTm	Maximum nitrification rate at optimal temperature	gm N m^{-3} day^{-1}
PM	Production rate of algae under optimal conditions	day^{-1}
PN	Preference for ammonium uptake by algae	$0 \le PN \le 1$
PO_4a	Phosphate in algal biomass	gm P m^{-3}
PO_4d	Dissolved phosphate concentration	gm P m^{-3}
PO_4dmax	Dissolved phosphate concentration at which algal phosphorus-to-carbon ratio achieves its maximum value	gm P m^{-3}
PO_4t	Total phosphate concentration	gm P m^{-3}
PR	Rate of predation on algae	day^{-1}
P	Production rate of algae	day^{-1}
Q_j	Volumetric flow across flow face j	m^3 sec^{-1}
RPOC	Refractory particulate organic carbon	gm C m^{-3}
RPON	Refractory particulate organic nitrogen	gm N m^{-3}
		(Sheet 4 of 5)

Table 4-2. Concluded		
Symbol	**Definition**	**Units**
RPOP	Refractory particulate organic phosphorus	gm P m^{-3}
S	Salinity	ppt
S_i	External loads and kinetics sources and sinks in ith control volume	gm sec^{-1}
t	Temporal coordinate	sec
T	temperature	°C
Te	Equilibrium temperature	°C
Tm	Optimal temperature for growth of algae	°C
Tmnt	Optimal temperature for nitrification	°C
Tr	Reference temperature for metabolism	°C
Trcod	Reference temperature for COD oxidation	°C
Trhdr	Reference temperature for hydrolysis	°C
Trmnl	Reference temperature for mineralization	°C
V_i	Volume of ith control volume	m^3
WSl	Settling velocity of labile particles	m day^{-1}
WSr	Settling velocity of refractory particles	m day^{-1}
WSa	Settling velocity of algae	m day^{-1}
WSmb	Equivalent settling rate induced by macrobenthic grazing	m day^{-1}
x	Spatial coordinate	m
z	Vertical coordinate	m
z_1	Distance from water surface to top of model segment	m
z_2	Distance from water surface to bottom of model segment	m
Δz	Model segment thickness	m
ρ	Density of water	kg m^{-3}
		(Sheet 5 of 5)

Predictive Sediment Submodel

The predictive sediment submodel was developed as one component of the Chesapeake Bay eutrophication model study (Cerco and Cole 1994). The need for a predictive benthic sediment model was made apparent by the results of a preceding steady-state model study of the bay (HydroQual 1987). The study indicated sediments were the dominant source of phosphorus and ammonium during the summer period of minimum dissolved oxygen. Increased sediment oxygen demand and nutrient releases were implicated in a perceived dissolved oxygen decline from 1965 to 1985. No means existed to predict how these sediment processes would respond to nutrient load reductions, however. Neither was the time scale for completion of the responses predictable.

For management purposes, a sediment model was required with two fundamental capabilities: (1) predict effects of management actions on sediment-water exchange processes, and (2) predict time scale for alterations in sediment-water exchange processes.

The model (Figure 4-16) was driven by net settling of organic matter from the water column to the sediments. In the sediments, the model simulated the diagenesis (decay) of the organic matter. Diagenesis produced oxygen demand and inorganic nutrients. Oxygen demand, as sulfide (in salt water) or methane (in fresh water), took three paths out of the sediments: export to the water column as chemical oxygen demand, oxidation at the sediment-water interface as sediment oxygen demand, or burial to deep, inactive sediments. Inorganic nutrients produced by diagenesis took two paths out of the sediments: release to the water column, or burial to deep, inactive sediments.

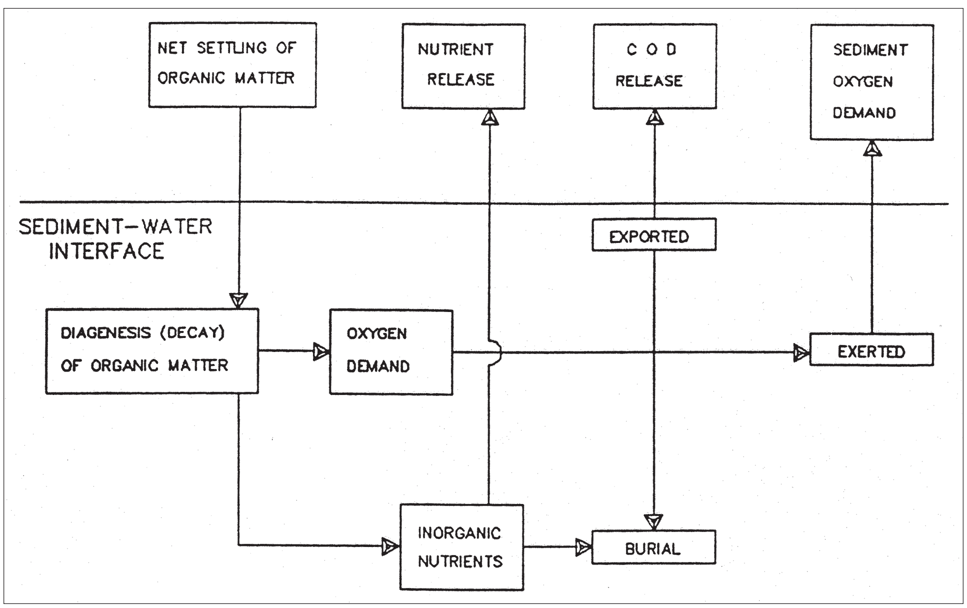


Figure 4-16. Sediment model schematic

Additional details of the model, required to understand the coupling of the sediment submodel to the model of the water column, are provided below. Complete model documentation is provided by DiToro and Fitzpatrick (1993). A listing of sediment model state variables and predicted sediment-water fluxes is provided in Table 4-3.

Table 4-3.
Sediment Model State Variables and Fluxes

State Variable	Sediment-Water Flux
Temperature	
Particulate Organic Carbon	Sediment Oxygen Demand
Sulfide/Methane	Release of Chemical Oxygen Demand
Particulate Organic Nitrogen	
Ammonium	Ammonium Flux
Nitrate	Nitrate Flux
Particulate Organic Phosphorus	
Phosphate	Phosphate Flux

Description of Sediment Model

Benthic sediments are represented as two layers with a total depth of 10 cm (Figure 4-17). The upper layer, in contact with the water column, may be oxic or anoxic depending on dissolved oxygen concentration in the water. The lower layer is permanently anoxic. The thickness of the upper layer is determined by the penetration of oxygen into the sediments. At its maximum thickness, the oxic layer depth is only a small fraction of the total.

The sediment model consists of three basic processes. The first is deposition of particulate organic matter from the water column to the sediments. Due to the negligible thickness of the upper layer, deposition proceeds from the water column directly to the lower, anoxic layer. Within the lower layer, organic matter is subject to the second basic process, diagenesis (or decay). The third basic process is flux of substances produced by diagenesis to the upper sediment layer, to the water column, and to deep, inactive sediments. The flux portion of the model is the most complex. Computation of flux requires consideration of reactions in both sediment layers, of partitioning between particulate and dissolved fractions in both layers, of sedimentation from the upper to lower layer and from the lower layer to deep inactive sediments, of particle mixing between layers, of diffusion between layers, and of mass transfer between the upper layer and the water column.

Deposition

Deposition is one process which couples the model of the water column with the model of the sediments. Consequently, deposition is represented in both the sediment and water-column models. In the water column, deposition is represented with a modification of the mass-balance equation applied only to cells that interface the sediments:

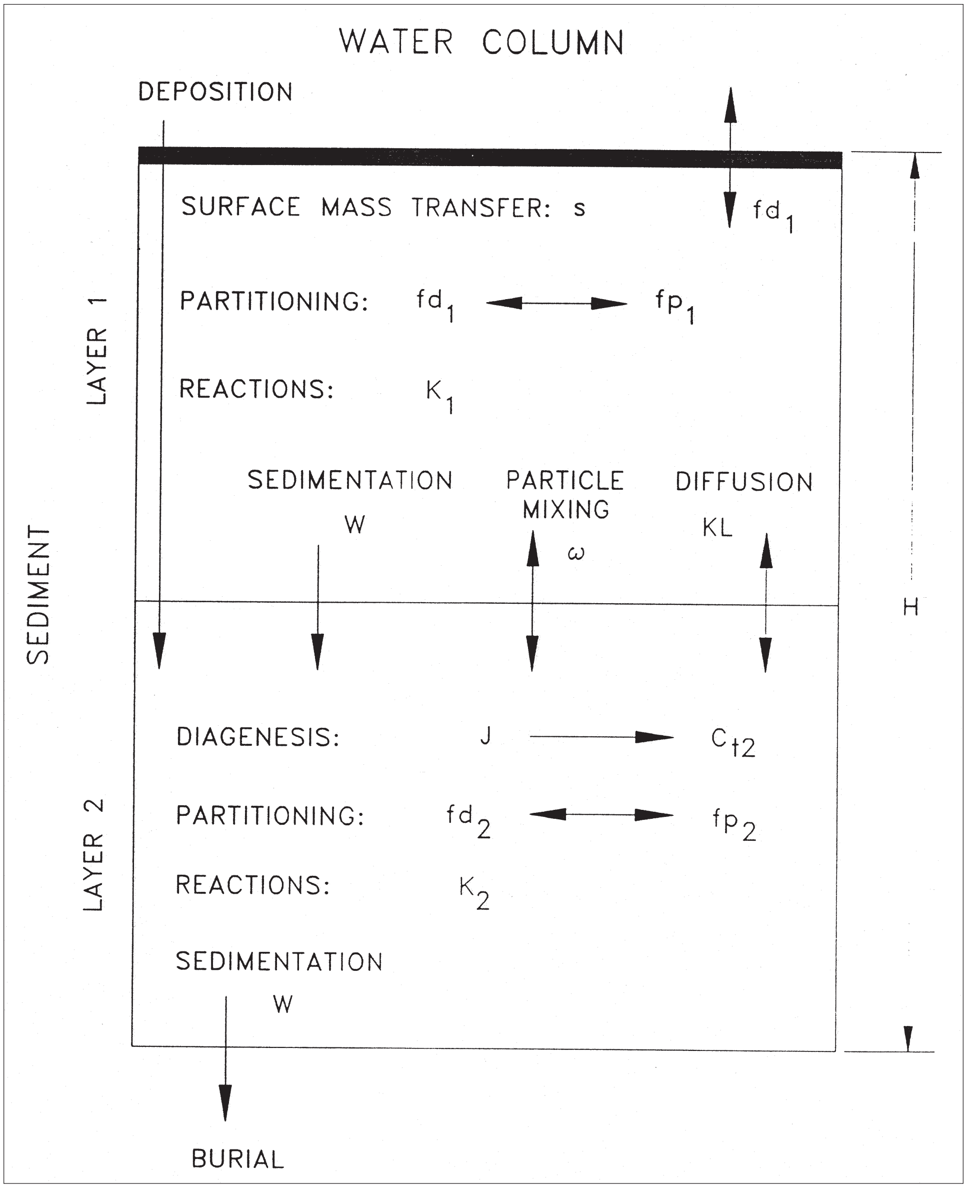


Figure 4-17. Sediment model layers and definitions

$$\frac{\delta C}{\delta t} = [transport] + [kinetics] + \frac{WS}{\Delta z} C_{up} - \frac{W_{net}}{\Delta z} C \tag{4.68}$$

where

C = concentration of particulate constituent (gm m^{-3})

WS = settling velocity in water column (m day^{-1})

C_{up} = constituent concentration two cells above sediments (gm m^{-3})

W_{net} = net settling to sediments (m day^{-1})

Δz = cell thickness (m)

Net settling to the sediments may be greater or lesser than settling in the water column. Sediment resuspension is implied when settling to the sediments is less than settling through the water column. Net settling that exceeds particle settling velocity implies active incorporation of particles into sediment by biota or other processes.

Diagenesis

Organic matter in the sediments is divided into three G classes or fractions, in accordance with principles established by Westrich and Berner (1984). Division into G classes accounts for differential decay rates of organic matter fractions. The G1, labile, fraction has a half life of 20 days. The G2, refractory, fraction has a half life of one year. The G3, inert, fraction undergoes no significant decay before burial into deep, inactive sediments. Each G class has its own mass-conservation equation:

$$H\frac{\delta Gi}{\delta t} = W_{net} f_i C - W\,Gi - H\,K_i Gi \theta_\iota^{(T-20)} \tag{4.69}$$

where

H = total thickness of sediment layer (m)

Gi = concentration organic matter in G class i (gm m^{-3})

f_i = fraction of deposited organic matter assigned to G class I

W = burial rate (m day^{-1})

K_i = decay rate of G class i (day^{-1})

θ_i = constant that expresses effect of temperature on decay of G class i

Since the G3 class is inert, $K_3 = 0$.

Total diagenesis is the rate at which oxygen demand and nutrients are produced by diagenesis of the G1 and G2 fractions:

$$J = H\left[K_1 G1 \theta_1^{(T-20)} + K_2 G2 \theta_2^{(T-20)}\right] \tag{4.70}$$

where

J = total diagenesis (gm m^{-2} day^{-1})

Flux

Total diagenesis provides the driving force for the flux portion of the model. Computation of flux requires mass-balance equations for oxygen demand and nutrients in both sediment layers. The upper layer is thin such that a steady-state approximation is appropriate:

$$s\, fd_1\, Ct_1 = \omega\left(fp_2 Ct_2 - fp_1 Ct_1\right) + KL\left(fd_2 Ct_2 - fd_1 Ct_1\right) - W\, Ct_1 \pm \sum K_1 \qquad (4.71)$$

where

Ct_1 = total concentration in upper layer (gm m^{-3})

Ct_2 = total concentration in lower layer (gm m^{-3})

fd_1 = dissolved fraction of total substance in upper layer ($0 \leq fd \leq 1$)

fd_2 = dissolved fraction of total substance in lower layer

fp_1 = particulate fraction of total substance in upper layer = 1 - fd_1

fp_2 = particulate fraction of total substance in lower layer

s = sediment-water mass-transfer coefficient (m day^{-1})

ω = particle mixing velocity (m day^{-1})

KL = diffusion velocity for dissolved fraction (m day^{-1})

ΣK_1 = sum of all sources and sinks due to reactions in upper layer (gm m^{-2} day^{-1})

The left-hand side of Equation 4-71 represents flux to the water column under the assumption that dissolved concentration in the water column is negligibly small compared to the sediments. The assumption is made here for notational simplicity. Effects of concentration in the overlying water are computed in the sediment model code. The terms on the right-hand side are mass transport due to particle mixing, diffusion of dissolved substance, deposition to the lower layer, and reactive sources and sinks. The reactions include, for example, the oxidation of sulfide that results in sediment oxygen demand. The equation states that flux to the water column, deposition from surficial sediments, and reactive sources and sinks are balanced by mixing and diffusion from deeper sediments.

The mass balance equation for the lower layer accounts for temporal concentration variations:

$$\frac{\delta Ct_2}{\delta t} = \frac{J}{H} - \frac{\omega}{H}\left(fp_2 Ct_2 - fp_1 Ct_1\right) - \frac{KL}{H}\left(fd_2 Ct_2 - fd_1 Ct_1\right) + \frac{W}{H}\left(Ct_1 - Ct_2\right) \pm \sum K_2 \qquad (4.72)$$

where

ΣK_2 = sum of all sources and sinks due to reactions in lower layer (gm m^{-2} day^{-1})

The first term on the right of Equation 4.72 represents the diagenetic source of oxygen demand or nutrient. The second term represents exchange of the particulate fraction with the upper layer. The third term represents exchange of the dissolved fraction with the upper layer. The fourth term represents deposition of total substance from the upper layer to the lower layer and burial from the lower layer to deep, inactive sediments. The last term is the sum of all internal sources and sinks due to reactions.

The mass balance equations, with appropriate sources and sinks, are solved within the sediment model for sulfide, methane, ammonium, nitrate, phosphate, and silica. Details of the reactions and solution scheme may be found in the model documentation (DiToro and Fitzpatrick 1993).

The water-quality and sediment models interact on a time scale equal to the integration time step of the water-quality model. After each integration, predicted particle deposition, temperature, nutrient and dissolved oxygen concentrations are passed from the water-quality model to the sediment model. The sediment model computes sediment-water fluxes of dissolved nutrients and oxygen based on predicted diagenesis and concentrations in the sediments and water. The computed sediment-water fluxes are incorporated by the water-quality model into appropriate mass balances and kinetic reactions.

5 Water Quality Model Input

The CE-QUAL-ICM (ICM) requires various forms of information in order to accurately predict water quality. Types of input data required include hydrodynamic, meteorological, initial conditions, boundary conditions and external loadings, and also parameters. Descriptions of these inputs for this study are presented below. Parameters include kinetic rate coefficients, half saturation constants, stoichiometry, and other coefficients used in water quality reactions. Parameters used in this study are presented in Chapter 7.

Hydrodynamics

CH3D-WES (see Chapter 3) was the source for all hydrodynamic information for ICM during this study. The hydrodynamic information generated by CH3D can be described as time-invariant and time-varying. Time-invariant data are the information obtained from CH3D which do not change, or are constant, during the ICM simulation. Time-varying data are information which change during the simulation and which must be updated in ICM at each hydrodynamic update interval.

Time-invariant hydrodynamic data consist of: cell areas (m^2) in planform, i.e., in the horizontal plane; initial cell volumes (m^3) for all computational cells; distances (m) between neighboring cell centroids; and initial subsurface horizontal flow-face areas (m^2) between all cells. With the z-plane version of CH3D-WES, which was used for this study, the horizontal flow-face areas and volumes of cells below the surface layer do not change over time. However, since the surface layer thicknesses increase and decrease with the tides, horizontal flow-face areas and cell volumes in the surface layer do change over time.

Time-varying data consist of three-dimensional flows (m^3/sec) between computational cells, horizontal flow-face areas (m^2) for surface layer cells, cell volumes (m^3) for the surface layer, and vertical diffusivities (m^2/sec) between layers. The flows, facial areas, and diffusivities are updated within ICM at each hydrodynamic update interval, but they are held constant in ICM between hydrodynamic updates. Volumes are used for comparison purposes during each hydrodynamic update to ensure that the internally computed volume of ICM is consistent with CH3D-WES volumes, i.e., to check for preservation of volume conservation.

A calibrated version of CH3D-WES must be applied for the same period over which the WQM is to be applied. A processor is appended as subroutines to the CH3D-WES source code. The processor computes time-averaged flows, surface layer flow-face areas, and vertical diffusivities throughout the ICM grid for each hydrodynamic update interval and then writes these values to an output file that is subsequently used by ICM. For the SJBE study, the averaging interval, or hydrodynamic update interval was fifteen minutes. Processing the hydrodynamic information separately and storing it in a file allows a set of hydrodynamic information to be generated once and used repeatedly for WQM application. Details of the hydrodynamic model and its application are covered in Chapter 3.

For this study, a one-to-one correspondence of the HM and WQM grids was used, i.e., the same grid was used for both models. Since water levels are used to drive the ocean boundaries of the HM, the outermost row of cells is not used within the WQM grid. It is possible for the WQM to use either a coarser overlay of the HM grid or an entirely different grid and project mass conserving flow fields from the HM grid to the WQM. The latter approach has been developed recently and is still undergoing testing.

For this study, a modification was made to the grid. The areas of concern in this study were in the interior bays and canals of the system and not the offshore regions. There are large differences in depth (and the number of layers) between the areas of concern and the offshore waters. Numerous areas in the interior of the system had depths of approximately 3 ft and were modeled as one layer. Offshore regions were over 90 ft deep or 30 layers. The large numbers of cells required offshore resulted in un-necessarily long computational requirements. To alleviate this problem, an additional four rows of cells were removed along the ocean boundary. The final grid shown in Figure 5-1 contained 1,923 surface cells and 10,600 total cells. The deepest portion of the reduced grid was directly offshore of the mouth of San Juan Bay which was 30 layers or approximately 90 ft deep.

Meteorological Data

ICM utilizes meteorological information in the computation of temperature and algal growth. Daily meteorological observations were obtained for the National Weather Service Station at the San Juan International Airport for the period May through September 1995. Data obtained consisted of daily average values for dry bulb temperature, wet bulb temperature, cloud cover, and wind speed. With this information values for equilibrium temperature, heat exchange coefficient, daily solar illumination, and

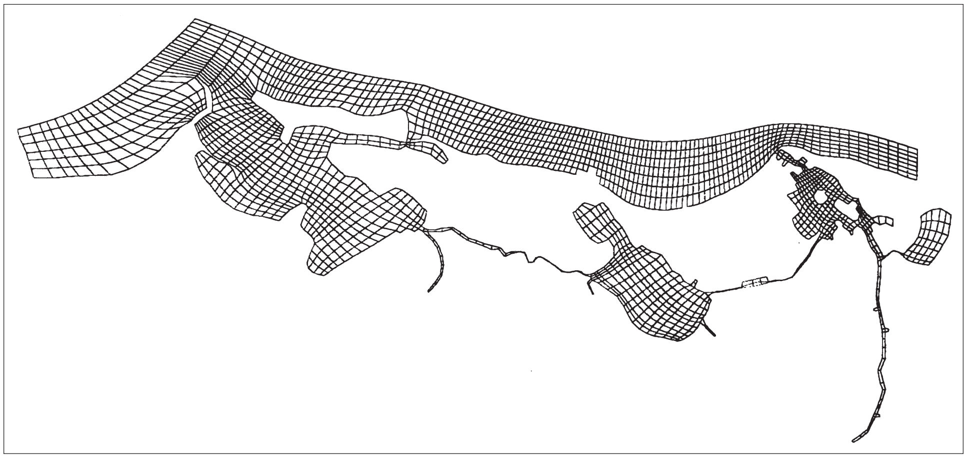


Figure 5-1. Water quality model grid, reduced from hydrodynamic model grid

fractional day length were computed. Details of the computational procedures used are found in Edinger et al. (1974).

Initial Conditions

ICM requires initial concentrations for all modeled constituents in all water column and sediment cells. These values must be realistic, otherwise model results can be biased by the initial conditions and may not fully reflect the loading and hydrodynamic processes occurring during simulation. Appropriate initial conditions for the sediment model are especially crucial since sediment model cells respond more slowly to changes in the loads and processes than does the water column.

Initial conditions were generated by spinning up the model. Spinning up was accomplished by initiating model calibration with a set of uniform initial conditions for water column cells based upon sampling data. Initial conditions in the sediments were specified in a similar manner. ICM was run using the calibration period hydrodynamics, loads, and boundary conditions. At the end of the first calibration run, the concentrations of all constituents in all water column and sediment cells were stored in a binary file. This file was then used as the initial conditions for a second calibration run. At the completion of the second calibration run, concentrations for all cells were again written to a binary file which was used as the initial conditions for the third calibration run. This process was repeated in subsequent calibration runs until a quasi steady-state condition (in terms of initial conditions) was reached in both the water column and sediment cells. This process required approximately 12 runs. Once a quasi steady-state set of initial conditions existed, all subsequent runs were made using the same set of initial conditions. The same iterative procedure was used to establish initial conditions for scenario runs. The scenario simulation period was run multiple times using results from the previous run to establish a new set of initial conditions. The process was repeated until a quasi steady-state set of initial conditions existed between runs.

Boundary Concentrations and Loading Estimates

Water quality boundary conditions for this study can be divided into two forms, ocean and terrestrial. Atmospheric loadings were not included. Ocean boundary conditions are concentrations set along the open ocean boundary. These concentrations are used for all flow conditions during which flow is coming into the water quality model grid at the edge of the grid along the ocean boundary. Terrestrial boundary concentrations or loads are specified for inflows entering the water quality model grid from tributary headwaters, local, nonpoint source runoff directly from land into the bays, and point source loads. Point source loads are usually used to account for discharges from treatment plants, wastewater, combined sewer overflows, pumping plants, and other sources of pollutants at specified locations. Point and nonpoint source loadings are usually treated as loads, which means they are input as mass/time (the product of flow times concentration) at the appropriate grid locations and are not tied to a HM tributary inflow. Boundary concentrations are usually specified to the WQM for tributaries since flows are passed from the HM to the WQM for all tributaries. However, for this study, the tributary loads were computed and input for all constituents, except temperature and DO for which concentration boundary conditions were input.

Ocean Boundary Concentrations

The values used for the ocean boundary were obtained from the data collected at stations AO-1 and AO-2 (Kennedy et al., 1996). Analysis of data at these stations indicates that there is little variation in the data between the stations, and there was no vertical stratification. Nutrient levels were low relative to levels inside the SJBE system. Consequentially, these data were averaged and a single value was determined which was used for all ocean boundary faces (Table 5-1). Ocean boundary concentrations varied over time and were updated periodically as shown in Table 5-1.

Table 5-1.
Ocean Boundary Concentrations

Parameter	Day 0	Day 38	Day 52	Day 66	Day 81
Temperature, °C	28.0	28.0	28.3	28.2	28.9
Salinity, ppt	37.9	36.6	36.2	37.9	37.1
Total Suspended Solids, mg/l	0.0	0.0	0.0	0.0	0.0
Chlorophyll-a, μg/l	0.48	0.37	0.48	0.23	0.50
DOC, mg/l	3.12	0.94	3.15	8.47	1.98
POC, mg/l	0.38	0.43	0.38	1.50	0.32
NH_4, mg/l	0.0	0.09	0.0	0.03	0.16
NO_3, mg/l	0.01	0.01	0.0	0.0	0.0
TON, mg/l	0.0	0.0	0.0	0.0	0.0
TIP, mg/l	0.002	0.002	0.001	0.001	0.003
DOP, mg/l	0.003	0.017	0.0	0.007	0.007
POP, mg/l	0.001	0.006	0.003	0.0	0.004
DO, mg/l	6.2	6.1	5.9	5.3	4.8

Loading Estimates

External loads of constituents are separated into two categories, point source and nonpoint source. Point source loads are traditionally defined as those which are attributable to a single location or "point." Examples include effluent pipes from municipal or industrial wastewater treatment facilities. Nonpoint source loads are defined as those whose origin is distributed over a widely spaced area. A traditional example is runoff from a local subwatershed along the model shoreline. Nonpoint source loads can also include loads which are truly point source in nature but which occur in the watershed and not at the model boundary.

When commencing this study, an extensive effort was made to identify significant point source and nonpoint source loads for the SJBE system. Many possible sources of pollution were identified as reasons for poor water quality in various regions of the system. Unfortunately, little documentation was discovered which substantiated these theories. Part of the problem is that in some cases it is hard to quantify the loads due to their distributed nature. Other cases, such as sewer pump station overflows, are intermittent and the quantity of water and load cannot be easily determined. In other instances, data on concentration or flow were lacking.

A review of EPA permit records indicated that there were no major municipal wastewater treatment plants or industrial point source dischargers for nutrients or oxygen-depleting substances that were releasing effluents directly into the SJBE system. Treatment plant effluents are removed via a Puerto Rico Aqueduct and Sewer Authority (PRASA) pipeline for ocean disposal beyond the boundary of the water quality model grid. Two Puerto Rico Electric Power Association (PREPA) power plants discharge cooling water to San Juan Bay. The net effect of these two power plants is that they increase the temperature of the cooling water. Therefore, all of the external loads can be considered as nonpoint source loads.

Estimation of Flows. While there are officially no major point source dischargers to the system, the system receives significant loads in the form of runoff loads from the adjacent watershed and storm water pump stations. Prior to estimation of these loads, two pieces of information are required, flow and concentration. Two forms of flow data were available, Rio Piedras (see Figure 1-1) flow records and storm water pump station records.

Rio Piedras at Hato Rey flow records for the period being modeled were obtained from the USGS. The frequency of these data were 15 minutes. A review of the records for the calibration period indicated that observed flows varied from 0.11 to 236.6 m^3/s (4 to 8355 ft^3/s), see Figures 5-2a through 5-2d for June through September 1995. Daily averages of flow were used in the hydrodynamic model for the Rio Piedras inflow.

Records for storm water pump stations operated by the Puerto Rico Department of Natural Resources were obtained. The only pump station whose records overlapped the calibration period was the Baldorioty de Castro Pump Station on San José Lagoon. (Records for the calibration period for the other pump stations were unavailable.) Information on these records consisted of hours of operation for pumps from which the daily pumping duration could be obtained. The daily total water volume pumped was determined by multiplying the pump capacity by the daily pumping duration. This volume was then converted into an equivalent daily flow rate as shown in Figure 5-3.

The SJBE watershed was divided into 21 sub-basins as shown in Figure 5-4 based upon information extracted from USGS topographic maps. Areas for each sub-basin were determined and are listed in Table 5-2. Freshwater flows were introduced in the HM at each location where there is an arrow shown in Figure 5-4. There are more arrows than sub-basins since flows were put in and taken out at two power plants and in several cases more than one flow location was used for a sub-basin. For all cases, except Caño Martín Peña, the HM inflow was treated as a tributary (i.e., quantity with momentum). For Caño Martín Peña, inflow was distributed along the canal as a lateral flow, i.e., no momentum.

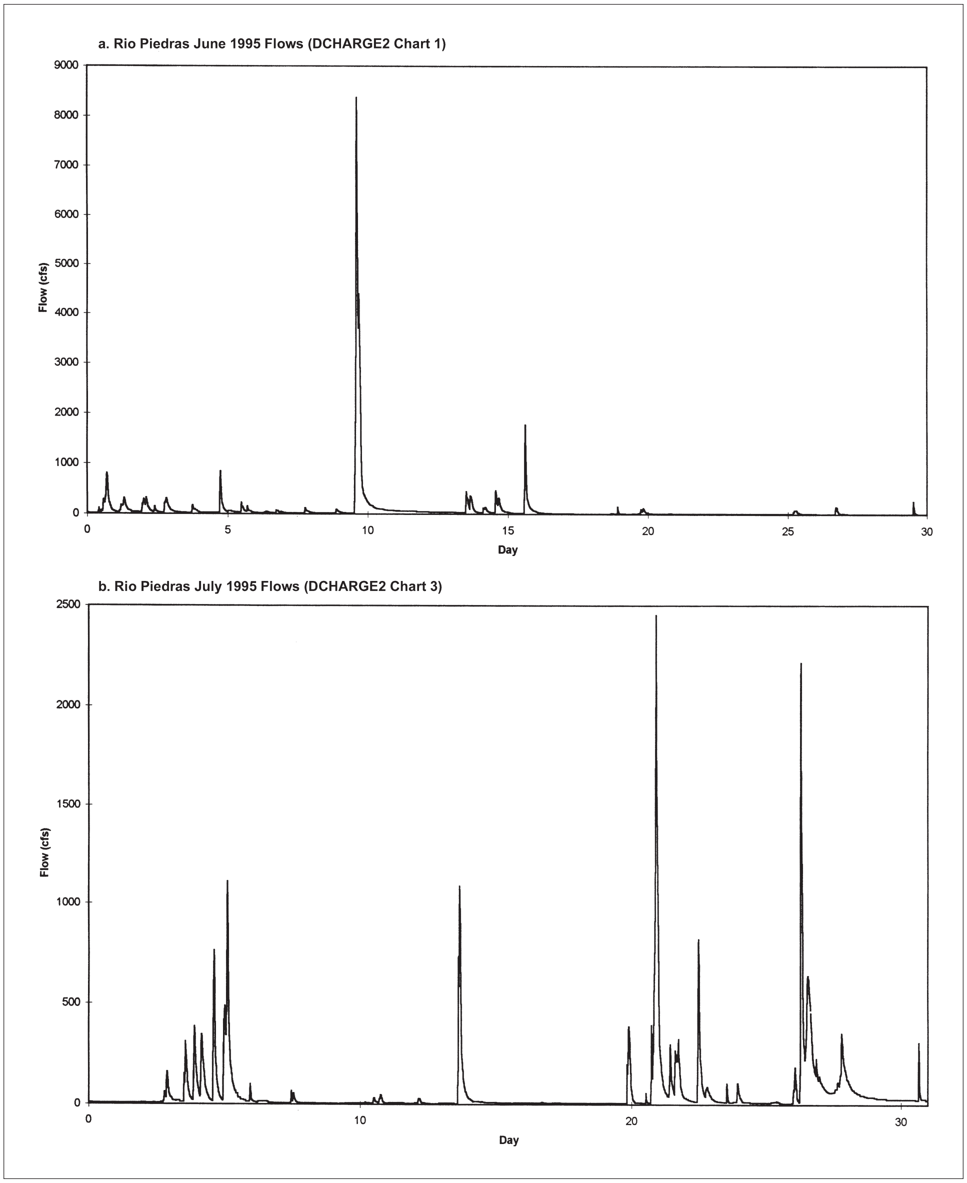


Figure 5-2. Flows observed at Hato Rey, Rio Piedras, June-September 1995 (continued)

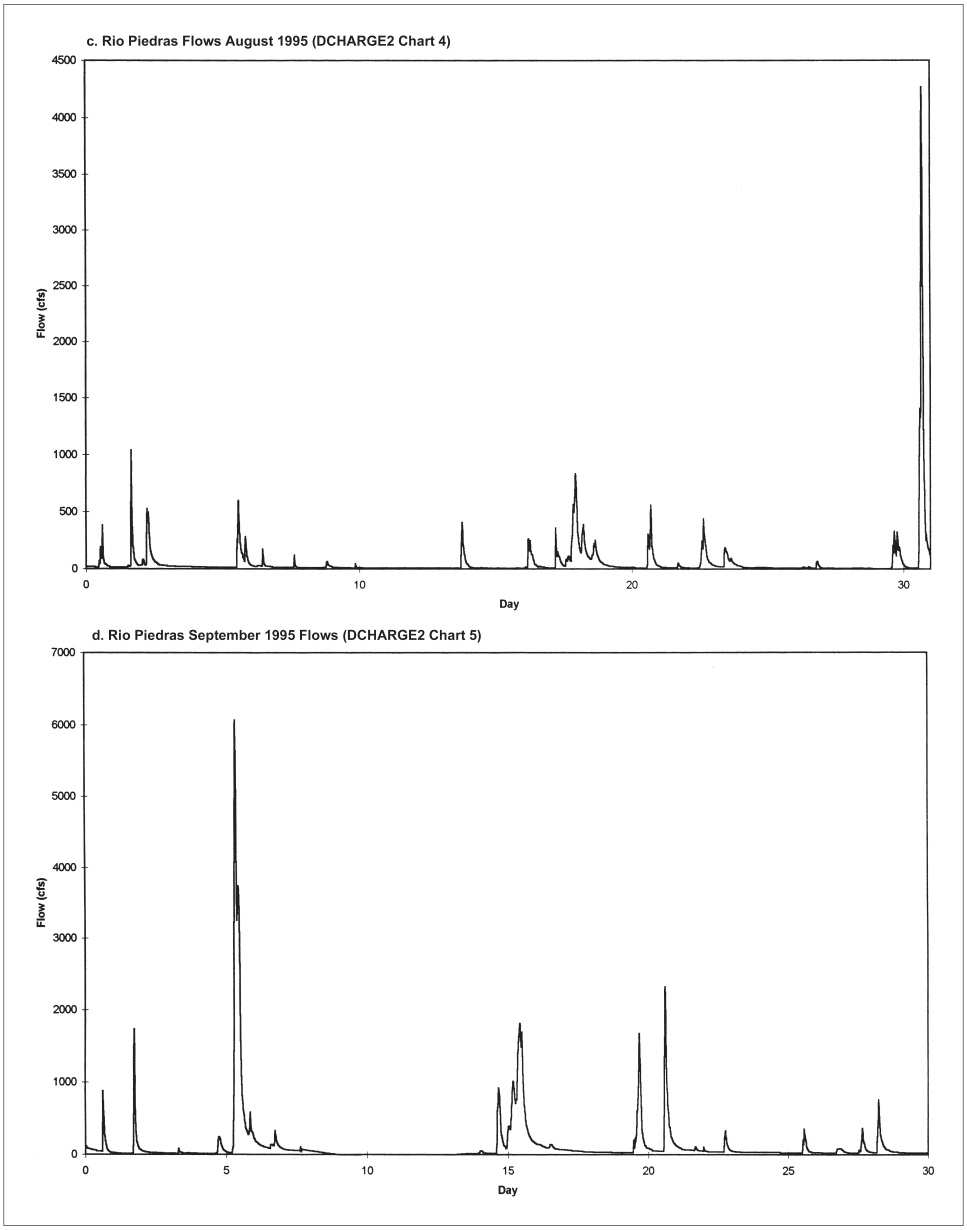


Figure 5-2. (concluded)

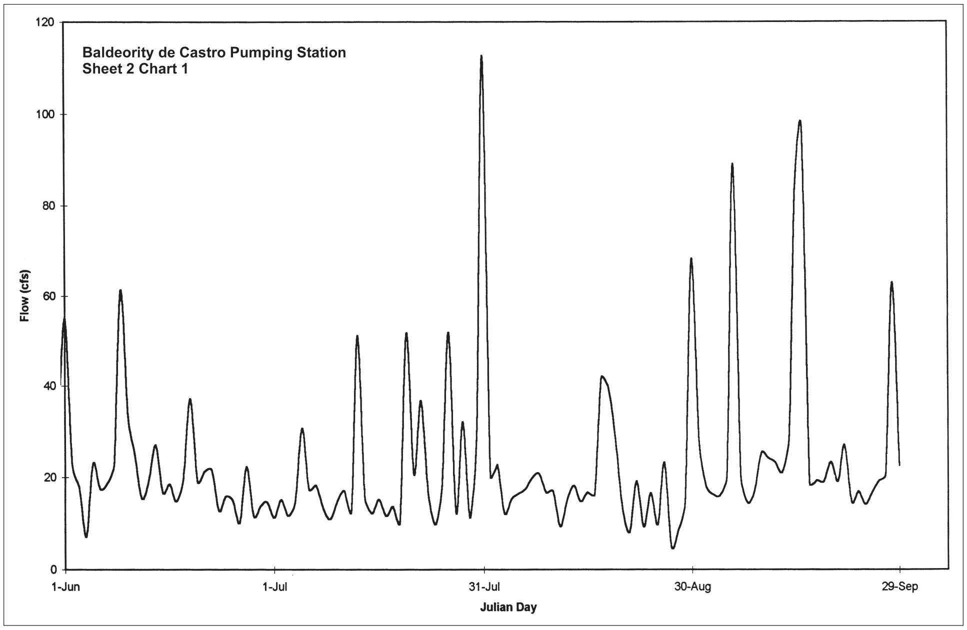


Figure 5-3. Flows for Baldeority de Castro Pump Station computed from pumping records for June-September 1995

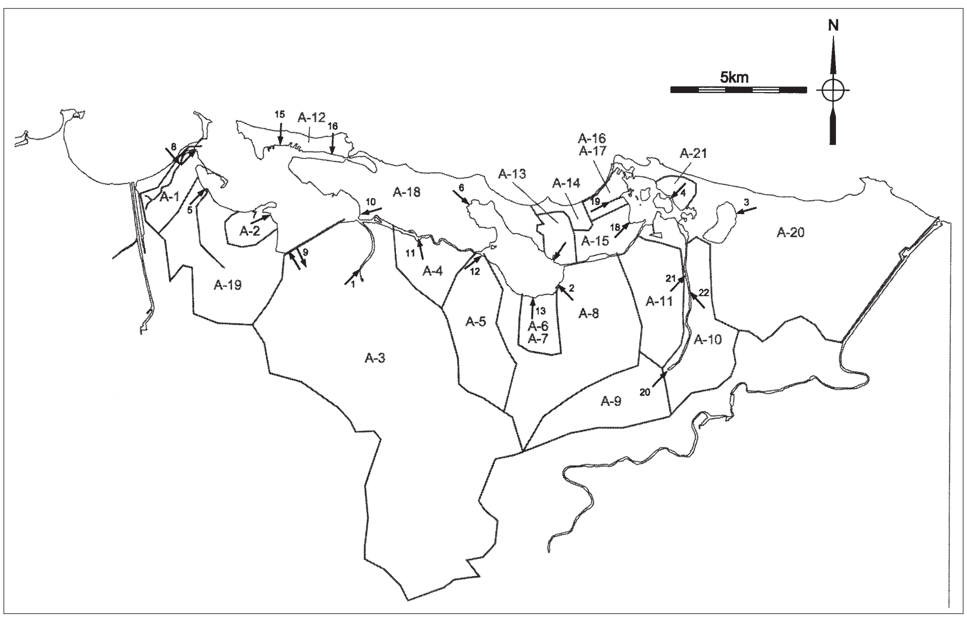


Figure 5-4. Model sub-basins of the San Juan Bay Estuary System with model locations of freshwater inflows indicated by the arrows

Table 5-2. SJBE Sub-Basins and Areas		
Sub-basin	**Name**	**Size (mi^2)**
A1	Bayamon	1.35
A2	San Fernando	1.0
A3	Rio Piedras	27.1
A4	Martin Peña	2.3
A5	Juan Mèndez	3.2
A6	Unnamed creek sw Laguna San José	0.9
A7	Unnamed creeks Laguna San José	0.9
A8	Quebrada San Antòn	6.8
A9	Quebrada Blasina	2.96
A10	Eastern Blasina	5.3
A11	Western Blasina	3.0
A12	Old San Juan	0.9
A13	Western End of Airport	0.9
A14	Northern End of Airport	0.45
A15	Southern End of Airport	1.35
A16	Eastern End of Airport 1	0.22
A17	Eastern End of Airport 2	0.23
A18	Santurce	5.86
A19	Malaria	6.0
A20	Piñones	13.0
A21	East of Torrecilla	1.0

Using the USGS gaged flow records from Hato Rey and the Baldorioty de Castro Pump Station pumping records, flow relationships were derived for each sub-basin of the watershed. However, prior to the derivation of any flow relationships, the observed flows for the two locations had to be converted to inches per day of runoff. This was accomplished by dividing the equivalent daily volume of flow by the area of the respective sub-basin expressed in square feet. The resulting height of runoff was then converted from ft/day to in./day. Sub-basin area used for the Rio Piedras regression was the area upstream of the USGS flow gage at Hato Rey (15.2 mi^2). A contributing area of 1.94 mi^2 was used for the Baldorioty de Castro sub-basin.

Rainfall records for the calibration period were available from the National Weather Service station at the San Juan International Airport and for a number of USGS rainfall collection stations in the basin. Using rainfall records from the USGS rain gage at Rio Piedras and flow records from the USGS flow gage at Hato Rey, a type II regression was performed to determine a relationship between rainfall and runoff. A similar procedure was followed using pumping records from Baldorioty de Castro Pump Station and National Weather Service rainfall records. The rainfall-runoff relationships developed for Rio Piedras at Hato Rey and Baldorioty de Castro Pump Station, respectively, are

$$q_P = 0.046 + 0.7468 * rain \tag{5.1}$$

where

q_P = Rio Piedras flow at Hato Rey, inches/day

rain = daily rainfall observed at the Rio Piedras rain gage, inches/day

and

$$q_B = 0.232 + 0.9 * rain \tag{5.2}$$

where

q_B = Baldorioty de Castro Pump Station flow, inches/day

rain = daily rainfall observed at the San Juan International Airport, inches/day

Figures 5-5 and 5-6 show the relationship between Equations 5.1 and 5.2 and the observed rainfall and flow. The first term in Equations 5.1 and 5.2 represents a base flow and the second a runoff flow. The base flow occurs whether there is any rainfall or not. Runoff flow only occurs when there has been rainfall. The values computed in the above equations are in inches per day of flow which were converted to ft^3/s for each sub-basin by the following relationship

$$Q = 5.093 \times 10^{-3}\, q\, A_{Basin} \tag{5.3}$$

where

A_{Basin} = measured area of sub-basin in mi^2

Initially, Equations 5.1 - 5.3 were used to compute runoff flows for all sub-basins for which there were no observed flows, which included all the sub-basins except for Rio Piedras and the Baldorioty de Castro Pump Station. For Rio Piedras, flows observed at Hato Rey were multiplied by 1.78 to account for contributions from the portion of the watershed below the stream gage.

Refinements were made to several of the other sub-basins after tests with the hydrodynamic model indicated that the predicted inflows were too high to maintain proper salinity. Because water levels and flows through transects compared favorably with measured data, it was assumed that estimated flows were probably too high rather than ocean exchange too low. Inflows for the several sub-basins around Quebrada Blasina and Laguna de Piñones were computed using the SCS Curve Number Method (Mississippi

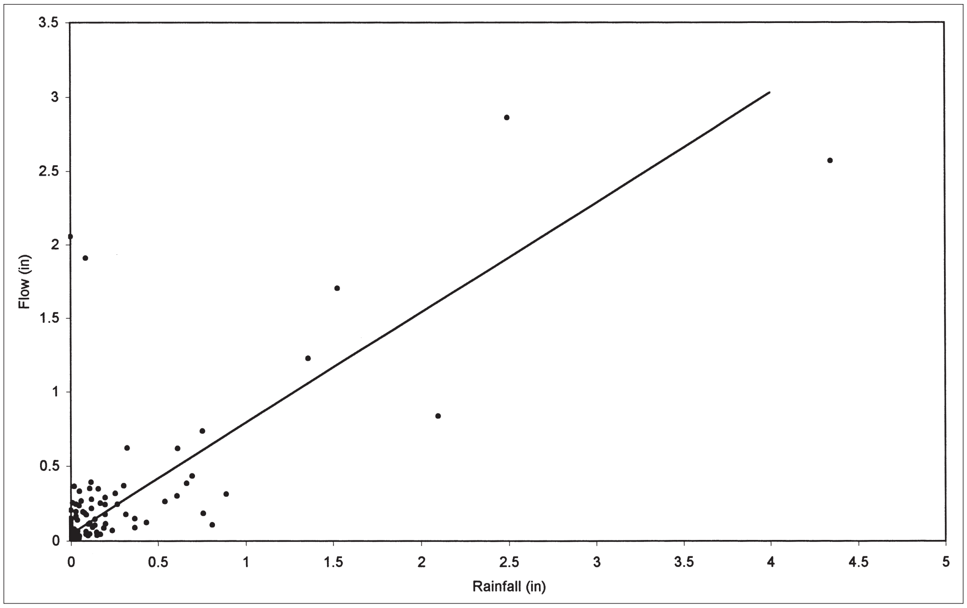


Figure 5-5. Observed flows for Rio Piedras at Hato Rey versus observed rainfall plotted with the best-fit regression line

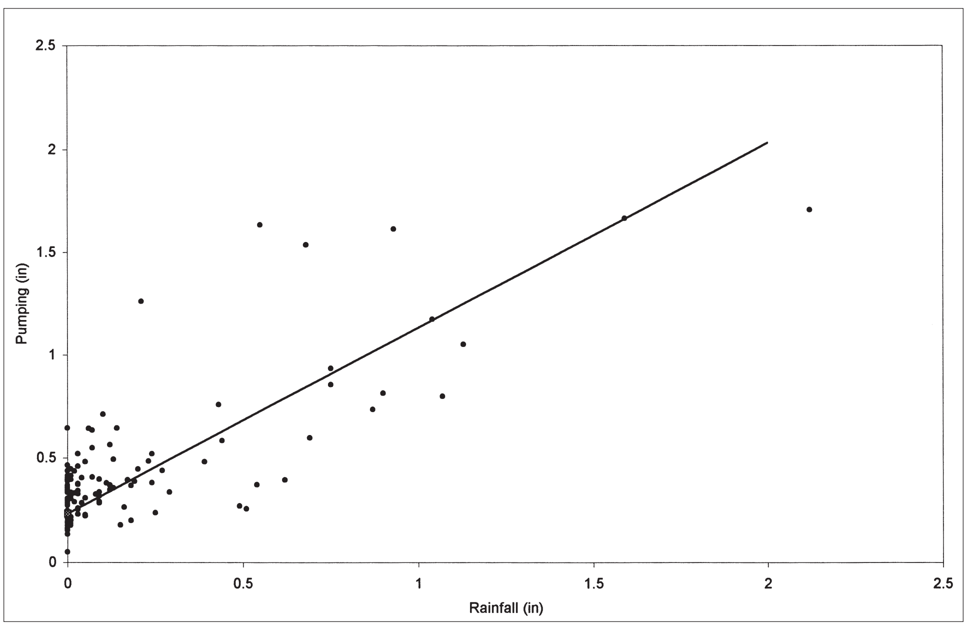


Figure 5-6. Computed flows based on pumping records for Baldorioty de Castro Pump Station versus observed rainfall plotted with the best-fit regression line

Department of Environmental Quality et al. 1994) to estimate runoff flows per unit area (inches/day).

$$q = \frac{\left(rain + 0.2 * \left(\frac{1000}{CN} - 10 \right) \right)^2}{rain + 0.8 * \left(\frac{1000}{CN} - 10 \right)} \tag{5.4}$$

where

rain = rainfall at International Airport, inches/day

CN = SCS Curve Number

Curve Numbers were selected based on land use, land cover, and soil type and are shown in Table 5-3. The unit areal flows computed from Equation 5.4 were used with Equation 5.3 to calculate volumetric flows (m^3/sec). Rationale for re-computing flows for these basins was twofold. The region east of Piñones is undeveloped and flat and would therefore have a longer retention time and slower response than the developed, hilly Rio Piedras watershed. Secondly, flows for the region surrounding Laguna de Piñones were being over-predicted by the regression developed from the Baldorioty de Castro Pump Station. The Santurce region served by the Baldorioty de Castro Pump Station is a highly developed region of the San Juan metropolitan area. Due to limited infiltration as a result of impervious land cover, this region has a high percentage of runoff (90%). In addition, there is a substantial base flow which is thought to be due to leaking sewer pipes and undocumented sewer connections to the storm-water collection system. Neither the base flow nor the high runoff coefficient for the Baldorioty de Castro regression was appropriate for the Piñones and Blasina sub-basins.

Table 5-3.
SJBE Sub-Basin Curve Numbers

Sub-Basin	Name	SCS Curve Number
A9	Quebrada Blasina	98
A10	Eastern Blasina	98
A11	Western Blasina	98
A13	Western End of Airport	84
A16	Eastern End of Airport 1	86
A17	Eastern End of Airport 2	86
A20	Piñones	76
A21	East of Torrecilla	76

Flows for the remaining regions were analyzed in conjunction with hydrodynamic calibration runs. It became apparent that the estimated inflows were also too high in the interior of the system, specifically San José Lagoon. In order to improve the salinity predictions in San José, base flows for the sub-basins flowing into San José were reduced by 50%. Table 5-4 summarizes the sources of and methods used to obtain runoff for each sub-basin.

Table 5-4.
SJBE Sub-Basin Flow Estimation Methods

Sub-Basin	Name	Method
A1	Bayamon	Rio Piedras Regression
A2	San Fernando	Rio Piedras Regression
A3	Rio Piedras	USGS Observed Flows
A4	Martin Peña	Baldorioty de Castro Regression
A5	Juan Mendez	Baldorioty de Castro Regression
A6	Unnamed creek sw Laguna San José	Baldorioty de Castro Regression
A7	Unnamed creek sw Laguna San José	Baldorioty de Castro Regression
A8	Quebrada San Anton	Baldorioty de Castro Regression
A9	Quebrada Blasina	SCS Curve Number Method
A10	Eastern Blasina	SCS Curve Number Method
A11	Western Blasina	SCS Curve Number Method
A12	Old San Juan	SCS Curve Number Method
A13	Western End of Airport	SCS Curve Number Method
A14	Northern End of Airport	SCS Curve Number Method
A15	Southern End of Airport	SCS Curve Number Method
A16	Eastern End of Airport 1	SCS Curve Number Method
A17	Eastern End of Airport 2	SCS Curve Number Method
A18	Santurce	Baldorioty de Castro Records and Regression
A19	Malaria	Rio Piedras Regression
A20	Piñones	SCS Curve Number Method
A21	East of Torrecilla	SCS Curve Number Method

Runoff Concentrations. Runoff concentrations are required to set tributary boundary concentrations and/or to compute tributary and local runoff loads. Most of the runoff entering into the San Juan estuaries system is not routinely sampled. As a result, the most comprehensive database available for the calibration period was the tributary sampling conducted in conjunction with the open water monitoring study conducted for model calibration (Kennedy et al. 1996). Due to the limited number of observations on any one tributary and the similarity of most of the watershed, the data for all were combined together into a database from which a single average value was determined and used (see Table 5-5) for each constituent concentration. These values were held constant for the duration of the calibration simulation and applied with the following exceptions discussed below to estimate all loads, including tributary inflows, local, storm-water runoff, and storm-water pumping plant discharges. With this approach, loads vary with flow since they are the product of flow and concentration. However, the limited information on loadings to the system is a major source for model error and uncertainty and a recognized future monitoring need.

Table 5-5.
Uniform Runoff Concentrations

Constituent	Value Used
Temperature, °C	27.9
Salinity, ppt	0.0
Total Suspended Solids, mg/l	12.0
DOC, mg/l	13.2
POC, mg/l	2.0
NH_4, mg/l	1.035
NO_3, mg/l	0.15
TON, mg/l	0.16
DIP, mg/l	0.23
DOP, mg/l	0.025
POP, mg/l	0.20
DO, mg/l	5.84
Fecal Coliform, mpn/100ml	1.6×10^6

Exceptions to uniform concentrations are presented in Table 5-6. Exceptions included DO concentrations in the flows from Malaria Canal where DO was set to 2.0 mg/l instead of the 5.84 mg/l value used elsewhere (Table 5-5). The highest DO observation in Malaria during the sampling study was 2.53 mg/l, while the lowest was 0.5 mg/l. Malaria is reputed to have poor water quality resulting from sewage overflows and discharges and as such warrants a lower DO concentration. Headwater boundary TSS concentrations on the Rio Piedras were set to 114 mg/l while those on the Quebrada San Anton were set to 57 mg/l. TSS levels in these two streams were much higher than the other tributaries. Chlorophyll loads were introduced for only the sub-basins shown in Table 5-6, whereas for other sub-basins, the chlorophyll load was zero. Finally, fecal coliform bacteria levels for Rio Bayamon were set to 215 mpn/100 ml. This value is the average of the samples collected in that stream. The reason that Rio Bayamon observations were so low is unclear. Rio Bayamon serves as the receptor for cooling water discharges from the Palo Seco Power Plant, one of two power plants in the SJBE System. The intake water for this plant comes from offshore and should have very low levels of fecal coliform. The power plant uses approximately 650×10^6 gal/day or 28.5 m^3/s (1,006 ft^3/s), which when discharged to the Rio Bayamon would then simply be diluting the upstream fecal coliform levels thereby resulting in the low counts obtained during sampling. Tributary loads for Rio Bayamon were computed using only the computed tributary flow based upon drainage area.

Table 5-6.
Modified Runoff Concentrations

Sub-Basin	DO mg/l	TSS mg/l	Chlorophyll μg/l	Fecal Coliform mpn/100 ml
Rio Piedras	5.84	112	3.33	1.6×10^6
Malaria	2.0	12	2.5	1.6×10^6
Bayamon	5.84	12	82	215
San Fernando	5.84	12	27	1.6×10^6
Quebrada Blasina	5.84	12	1	1.6×10^6
Runoff into Eastern Blasina	5.84	12	1	1.6×10^6
Runoff into Western Blasina	5.84	12	1	1.6×10^6
Runoff into Caño Martín Peña	5.84	12	4	1.6×10^6
Juan Mèndez	5.84	47	3	1.6×10^6
Un-named creeks sw Laguna San José	5.84	12	4	1.6×10^6
Un-named creeks Laguna San José	5.84	12	4	1.6×10^6
Quebrada San Antòn	5.84	12	11	1.6×10^6
Runoff into Airport area	5.84	12	4	1.6×10^6
Runoff into Laguna de Piñones	5.84	12	1	1.6×10^6

The second power plant located in the system, the San Juan Power Plant, withdraws and discharges to San Juan Bay near the Military Terminal. The maximum cooling water flow for this facility is 700×10^6 gal/day or 32.8 m^3/s (1159 ft^3/s). These power plants are treated as a special type of boundary in the WQM. At the intakes, water is removed from the model grid. The water is then returned to the model at the outfall location without any change in water quality other than a temperature increase of 5°C resulting from process unit cooling. Concentrations of other constituents are introduced unchanged at the outfall.

Initial sub-basin loads to the WQM were computed by multiplying the daily flows for each sub-basin by the concentrations for the various constituents indicated in Tables 5-5 and 5-6. It is pointed out that for all sub-basins not indicated in Table 5-6, the uniform concentrations of Table 5-5 were used to compute loads. Additional loads were identified and implemented during calibration and are discussed in Chapter 7.

The model requires that loads of organic carbon, nitrogen, and phosphorus be split into model state variables. These variables represent dissolved organic, labile particulate organic, and refractory particulate organic constituents. Laboratory analyses do not always directly indicate these splits. In that case, values observed in other systems are adapted and refined, if necessary, in the model calibration process.

Dissolved organic carbon (DOC) was directly analyzed. Particulate organic carbon (POC) was obtained by subtracting DOC from total organic carbon. POC was split evenly between labile and refractory fractions. This split includes more labile material than is normally employed. In Chesapeake Bay, for example, the split is 10% labile and 90% refractory. More labile material was required in San Juan to create oxygen demand and match observed low dissolved oxygen concentrations in system bottom waters. The split suggests loads to the SJBE system contain more fresh organic matter (algal, raw sewage) than runoff to temperate estuaries.

Total organic nitrogen (TON) was obtained by subtracting ammonium from total Kjeldahl nitrogen (TKN). Guidance for splitting TON into dissolved and particulate forms was obtained from ammonium and TKN data collected in receiving waters adjacent to tributaries. The split was 10% dissolved and 90% particulate. Particulate organic nitrogen was split evenly into labile and refractory fractions, consistent with the splits for POC.

The majority of phosphorus observations in the tributaries were of total phosphorus (TP) and total dissolved phosphorus (TDP). Roughly 20% of the observations also included dissolved inorganic phosphorus (DIP) and particulate inorganic phosphorus (PIP). The DIP measures were used to guide specification of DIP in the loads. Subtraction of DIP from TDP yielded concentration of dissolved organic phosphorus (DOP) for use in the model. Subtraction of TDP from TP yielded total particulate phosphorus. The total particulate phosphorus included labile and refractory organic particles as well as particulate inorganic particles. PIP contains mineral forms that are not biologically available. Since the model does not include detailed representation of PIP chemistry, PIP is assigned to the refractory particulate organic fraction. Consequently, the split of particulate phosphorus into labile and refractory fractions included more refractory matter than for carbon or nitrogen. The splits used in the model were 12.5% labile and 87.5% refractory.

6 Hydrodynamic Model Adjustment and Skill Assessment

As previously discussed, a field data collection effort provided data for boundary conditions as well as interior data for comparison with model results (Fagerburg 1998). Water-surface elevations, salinity, and water-velocity data were collected at several locations throughout the system during June-August 1995. Both long-term as well as short-term data were collected. The short-term data were collected over 17-19 August 1995 when the crew returned to remove the long-term instruments. These data included ADCP data collected over several ranges in an attempt to define the water flux through the connecting canals of the system. Due to fouling of the long-term meters, very little useful long-term velocity and salinity data were obtained. Most salinity data employed were collected by Kennedy et al. (1996) during their collection of water quality data. Locations of data stations used in the skill assessment of CH3D are shown in Figure 6-1. Assessing the ability of the numerical model to simulate the hydrodynamics of the system has primarily revolved around reproducing the observed tides throughout the system, reproducing the extreme stratification in salinity that often exists during storm events, and reproducing the net flux through Caño Martín Peña and Canal Suárez.

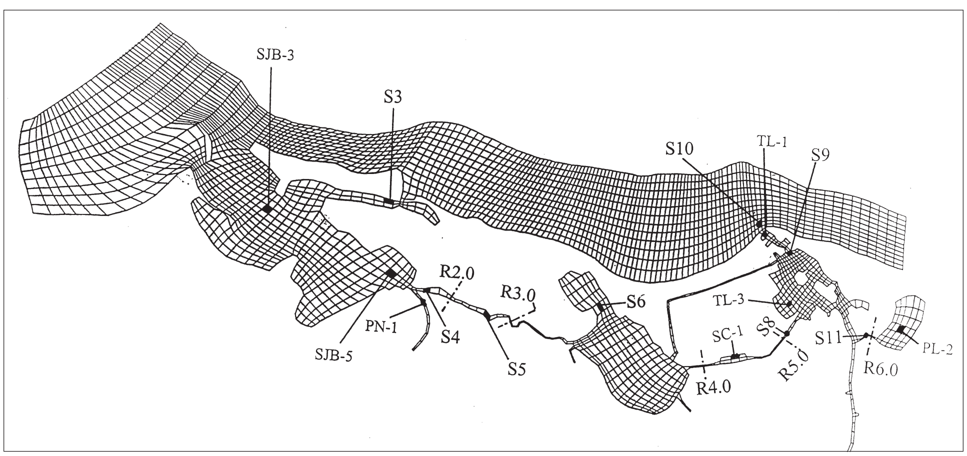


Figure 6-1. Location of data stations

Tide Reproduction

As illustrated in Figure 3-6, the tide in San Juan Harbor is mixed, with the M2 component being the largest. To better illustrate comparisons of the observed and computed tides throughout the system, comparisons for a three-day period in July 1995 are shown in Figures 6-2 - 6-6. It can be seen that the range and phase are reproduced fairly well, with phase errors on the order of perhaps 30 minutes occurring in some places. Figure 6-7 shows the computed and observed tide at a station in Laguna San José. The extreme reduction in the tide in Laguna San José as a result of the constriction in the eastern end of Martín Peña Canal and a bridge constriction in Canal Suárez is clearly illustrated. Obviously, there is little tidal flushing of Laguna San José, resulting in the poor water quality observed there.

Table 6-1 shows a comparison of the M2 and O1 computed and observed harmonic components of the tides at stations in San Juan Bay, Laguna San José, Laguna La Torrecilla, and Laguna de Piñones. Phasing is relative to the tide in San Juan Harbor. The letter **R** stands for the ratio of the ranges and **L** is the lag in phase in hours. It can be seen that the greatest reduction is in the higher frequency components. This agrees with the analytical analysis for a simplified co-oscillating system. Generally the comparison of the computed constituents with those determined from the observed data is good.

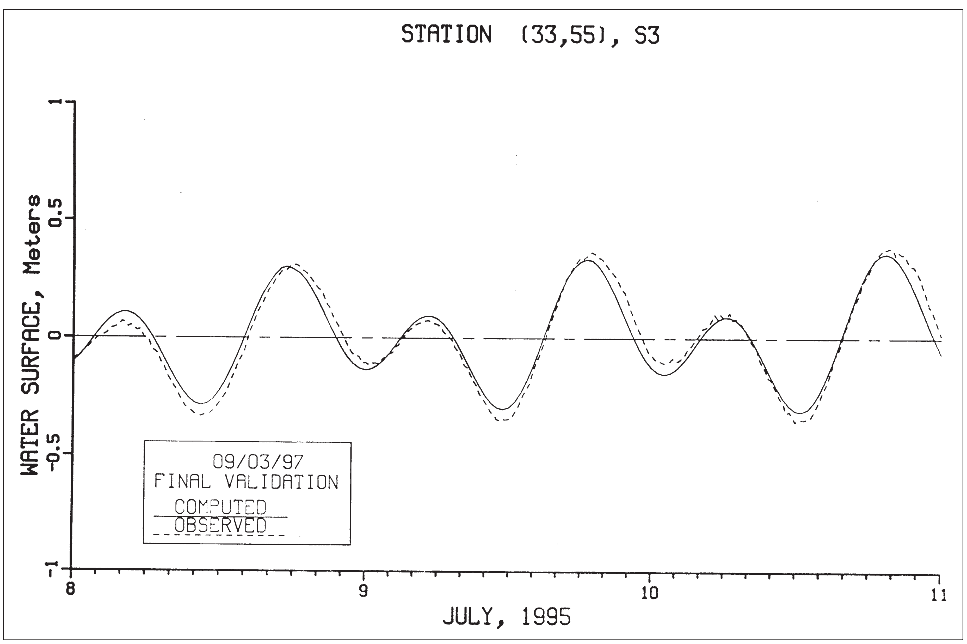


Figure 6-2. Comparison of computed and observed tide at S3

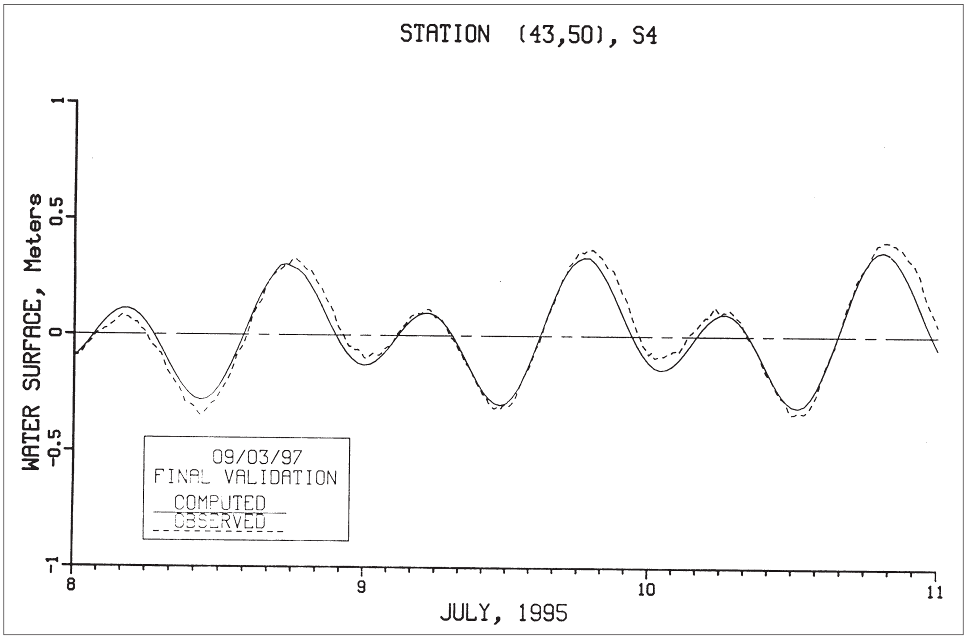


Figure 6-3. Comparison of computed and observed tide at S4

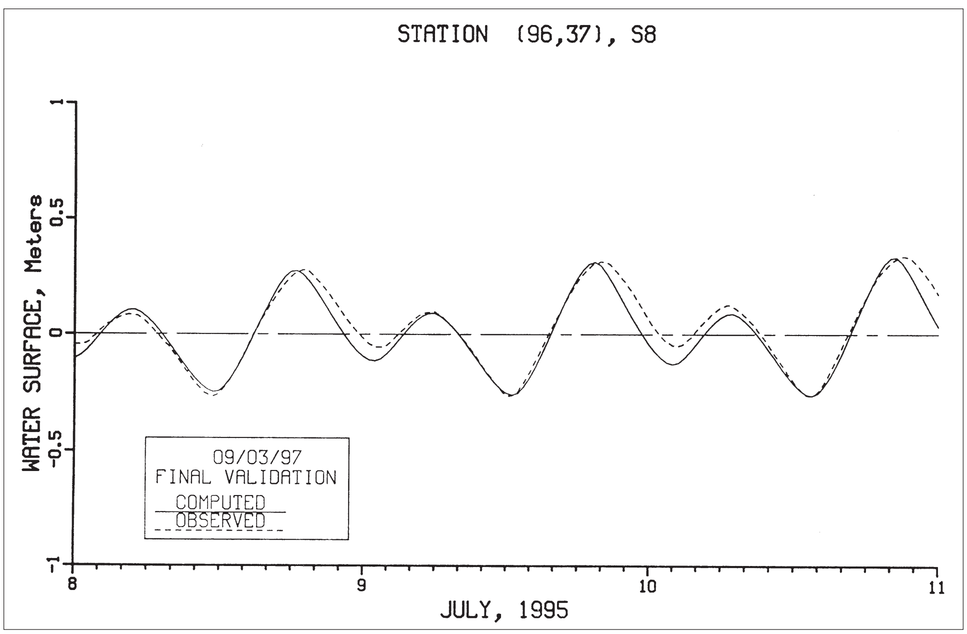


Figure 6-4. Comparison of computed and observed tide at S8

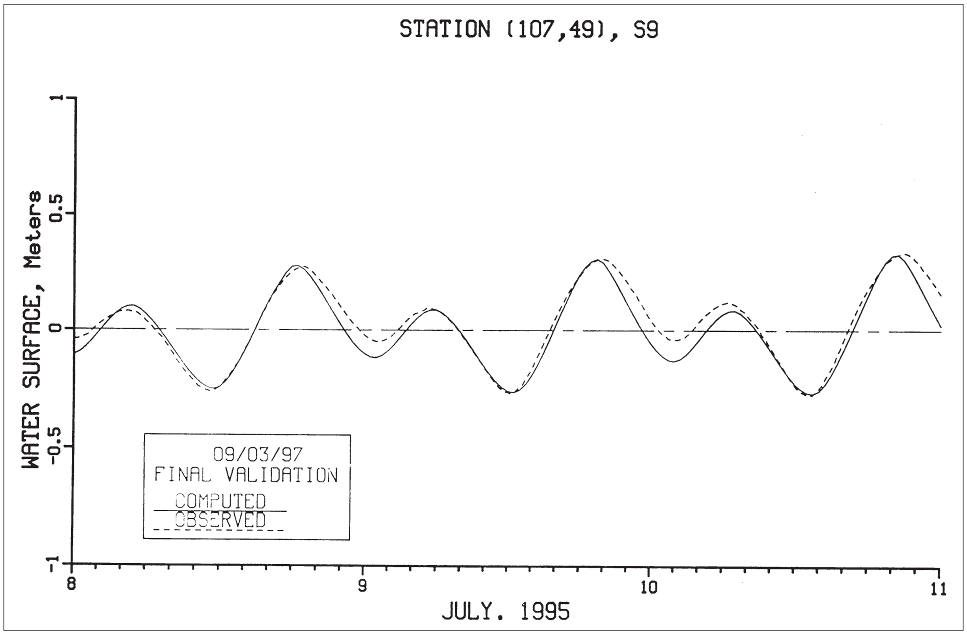


Figure 6-5. Comparison of computed and observed tide at S9

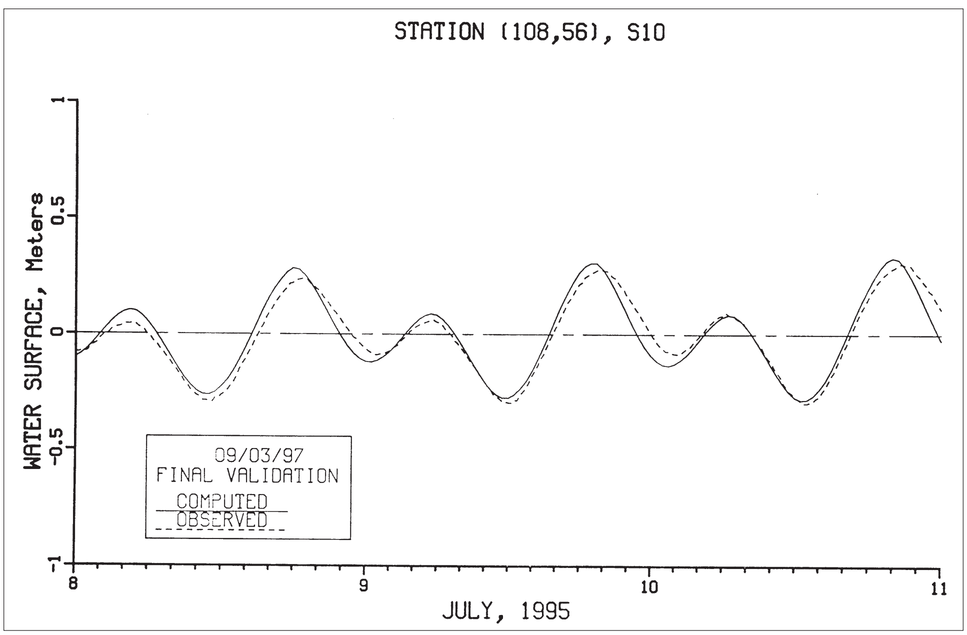


Figure 6-6. Comparison of computed and observed tide at S10

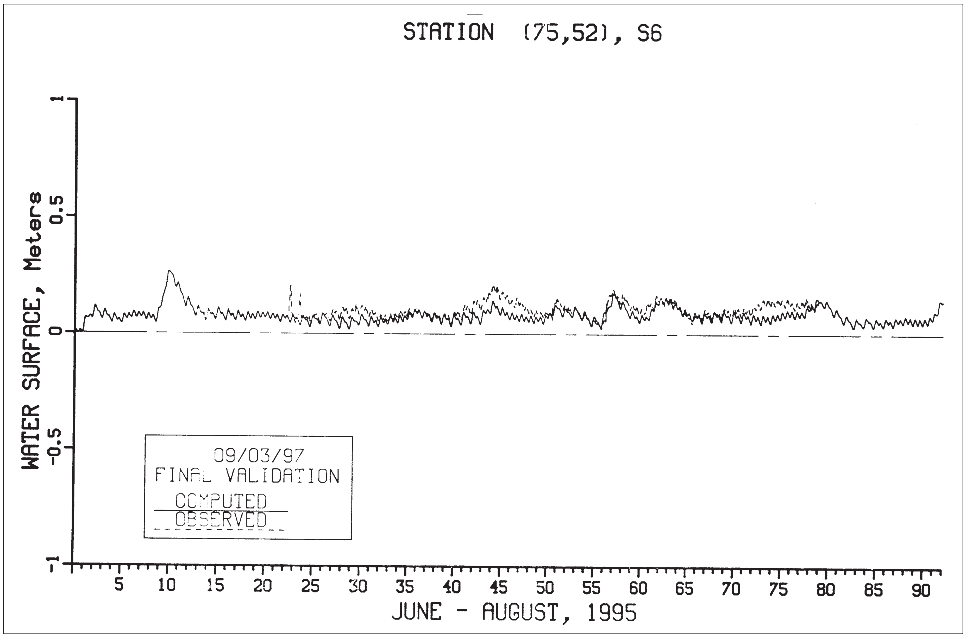


Figure 6-7. Comparison of computed and observed tide at S6

Table 6-1.
Comparison of Harmonic Constituents of Tide Relative to San Juan Bay Tide

	M2				O1			
	Model		Data		Model		Data	
Location	R	L	R	L	R	L	R	L
San José	0.06	3.69	0.06	3.85	0.16	5.42	0.10	6.47
Torrecilla	0.90	0.37	0.81	0.41	0.92	0.64	0.87	0.83
Piñones	0.12	4.01	0.12	3.67	0.23	6.01	0.23	6.18

Salinity Reproduction

The numerical model was run for the period 1 June - 31 August 1995. Boundary forcings are presented and discussed in Chapter 3. Although initial conditions on water-surface elevation and water velocity aren't too important since the effect of those initial conditions are flushed from the system within a few tidal cycles, the specification of the initial salinity field is much more important. Model stability was fairly sensitive to the initial salinity prescribed. In previous applications of CH3D, this behavior has not been observed. To overcome this problem, the model was initiated with a constant salinity over the entire grid and run for the month of June. The computed salinity field was then saved and used as the initial salinity field in all subsequent simulations for the entire three months. This procedure yielded an initial salinity field that was close to observed data and resulted in a stable model.

Figures 6-8 through 6-19 show the ability of the numerical model to reproduce salinity throughout the system. In most plots, both near-surface salinity (layer 30) and near-bottom (layers less than 30) are shown. However, in some locations the depth is so shallow, e.g., Station S6 in Laguna San José (Figure 6-13), that only near-surface salinity is presented. An inspection of the salinity plots reveals that the Kennedy data (Kennedy et. al. 1996) are the primary salinity data available for skill assessment. Due to fouling of the long-term meters in the tropical waters of the SJBE system, most of the salinity data from those meters weren't useful. Figure 6-15 which shows a comparison of salinity at Station S8 collected by a long-term meter with model results is an example. Some salinity data collected during the 17-19 August short-term survey were of use, e.g., see Figure 6-11.

During periods of high freshwater inflow, a freshwater lens of 30-60 cm flows on the surface of some portions of the system, resulting in high salinity stratification. An example of this occurring can be observed in the western end of Martín Peña Canal. Field data show that the surface salinity is reduced to 5-10 ppt with salinity near the bottom being greater than 30 ppt. Figure 6-10 illustrates the model's ability to reproduce this extreme stratification after a large freshwater inflow event (relative to other flows during the study period) that occurred around the 9th of June (see Figure 3-4 showing the freshwater inflows). Note that the Kennedy data displayed in the salinity plots labeled near surface (layer 30) were collected at 0.5 m and 1.0 m, whereas the model results correspond to the middle of the top layer, which varies in thickness with the tide. The observed extreme stratification is reproduced well in the numerical model even though each layer in the vertical is 0.91 m thick.

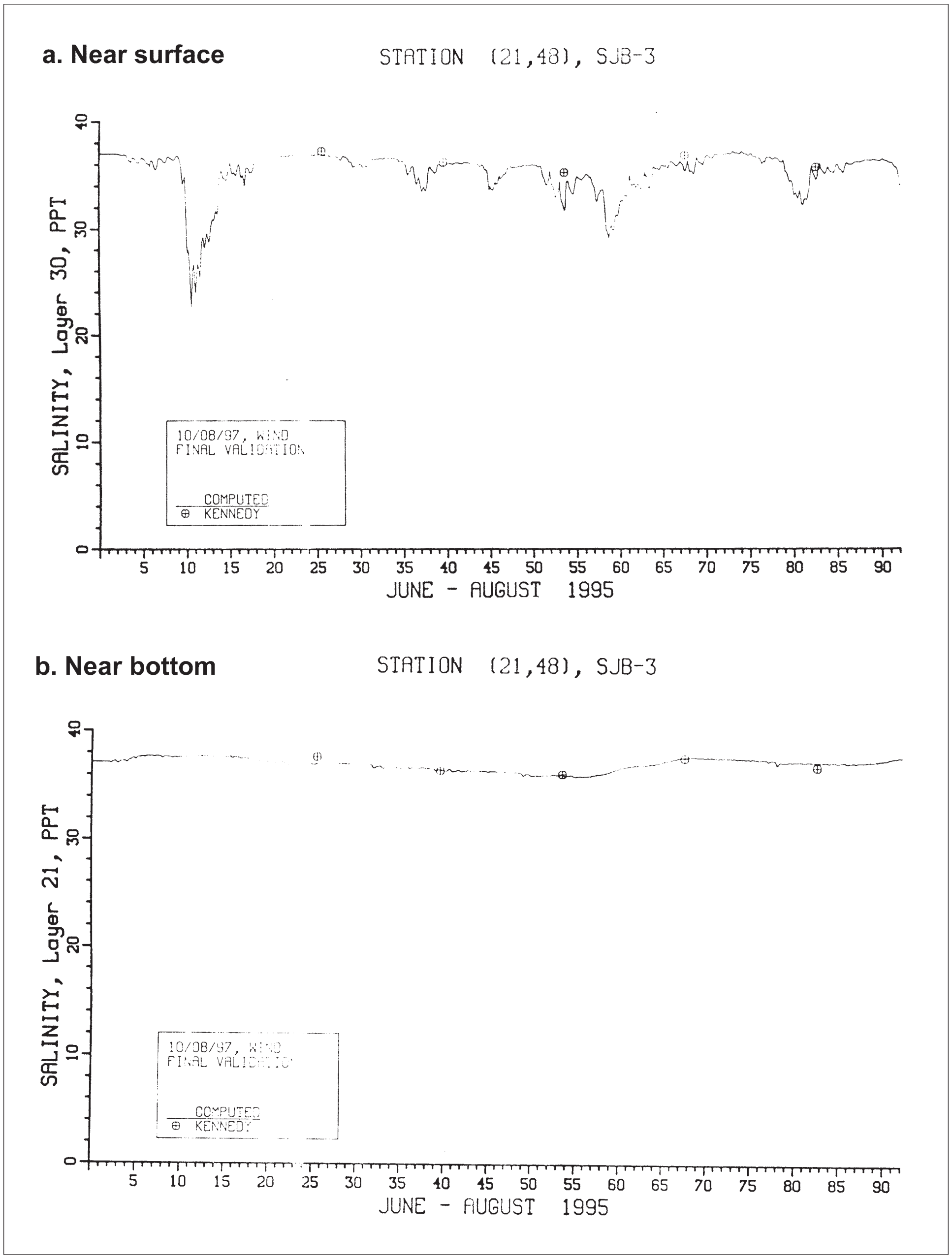


Figure 6-8. Comparison of computed and observed salinity at SJB-3

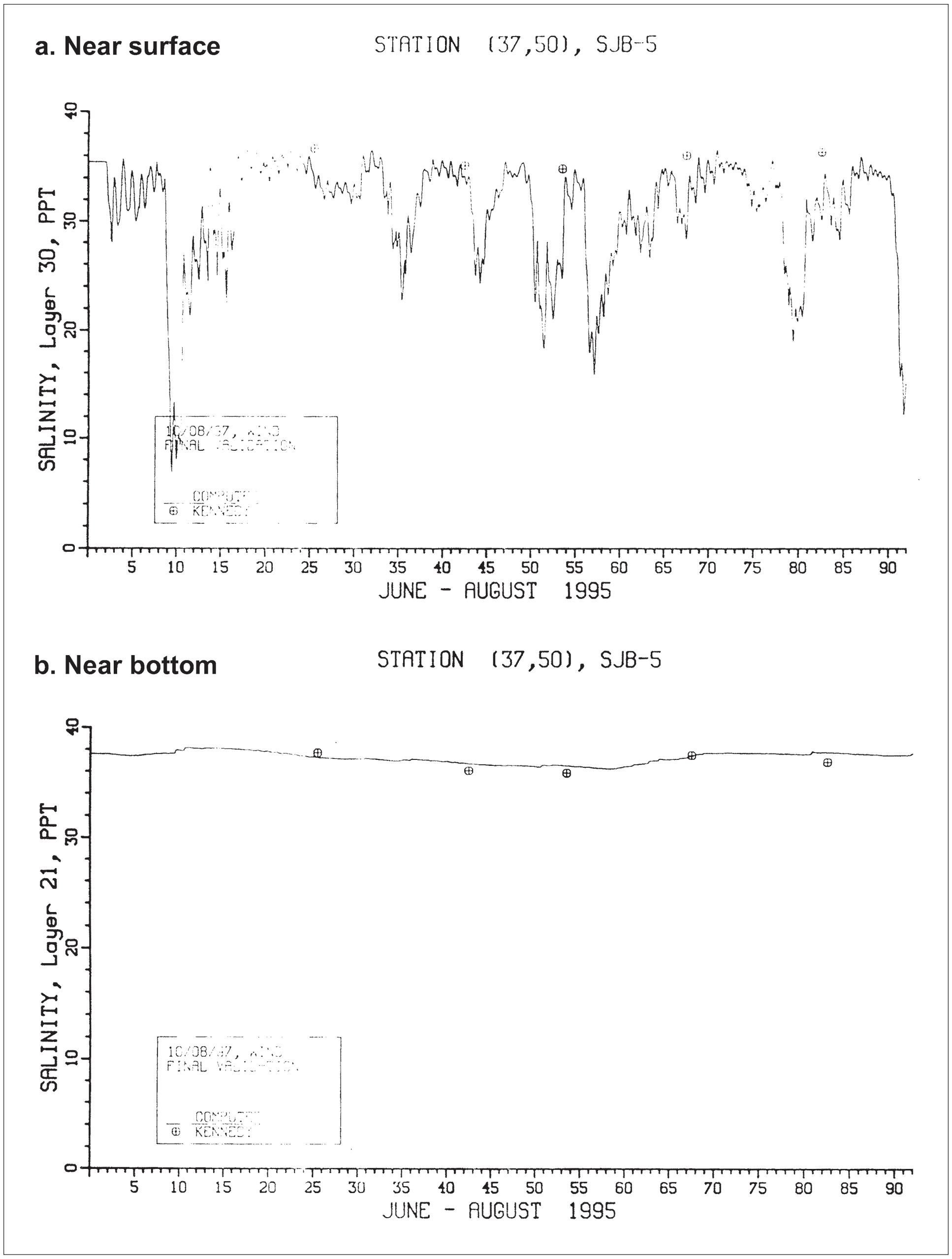


Figure 6-9. Comparison of computed and observed salinity at SJB-5

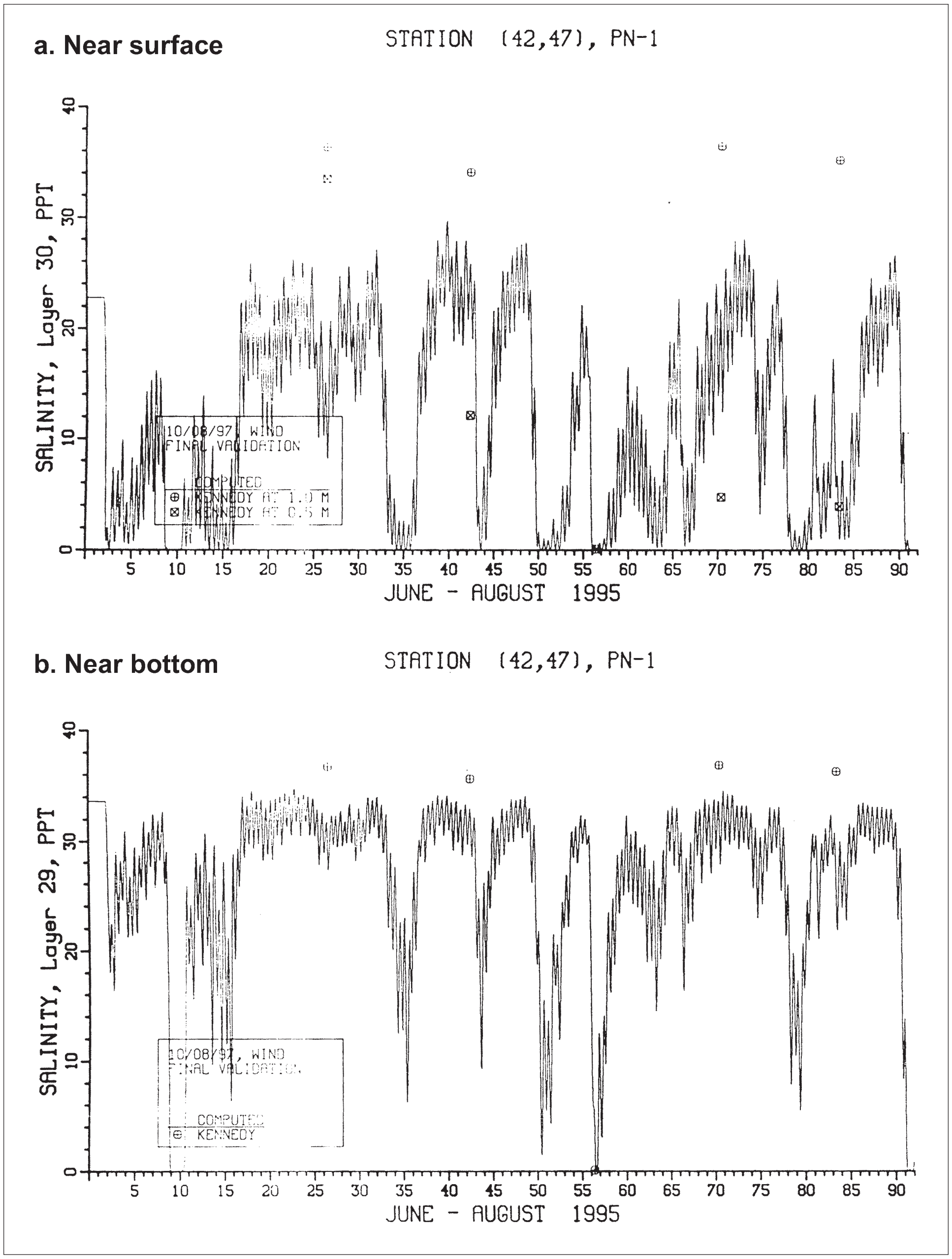


Figure 6-10. Comparison of computed and observed salinity at PN-1

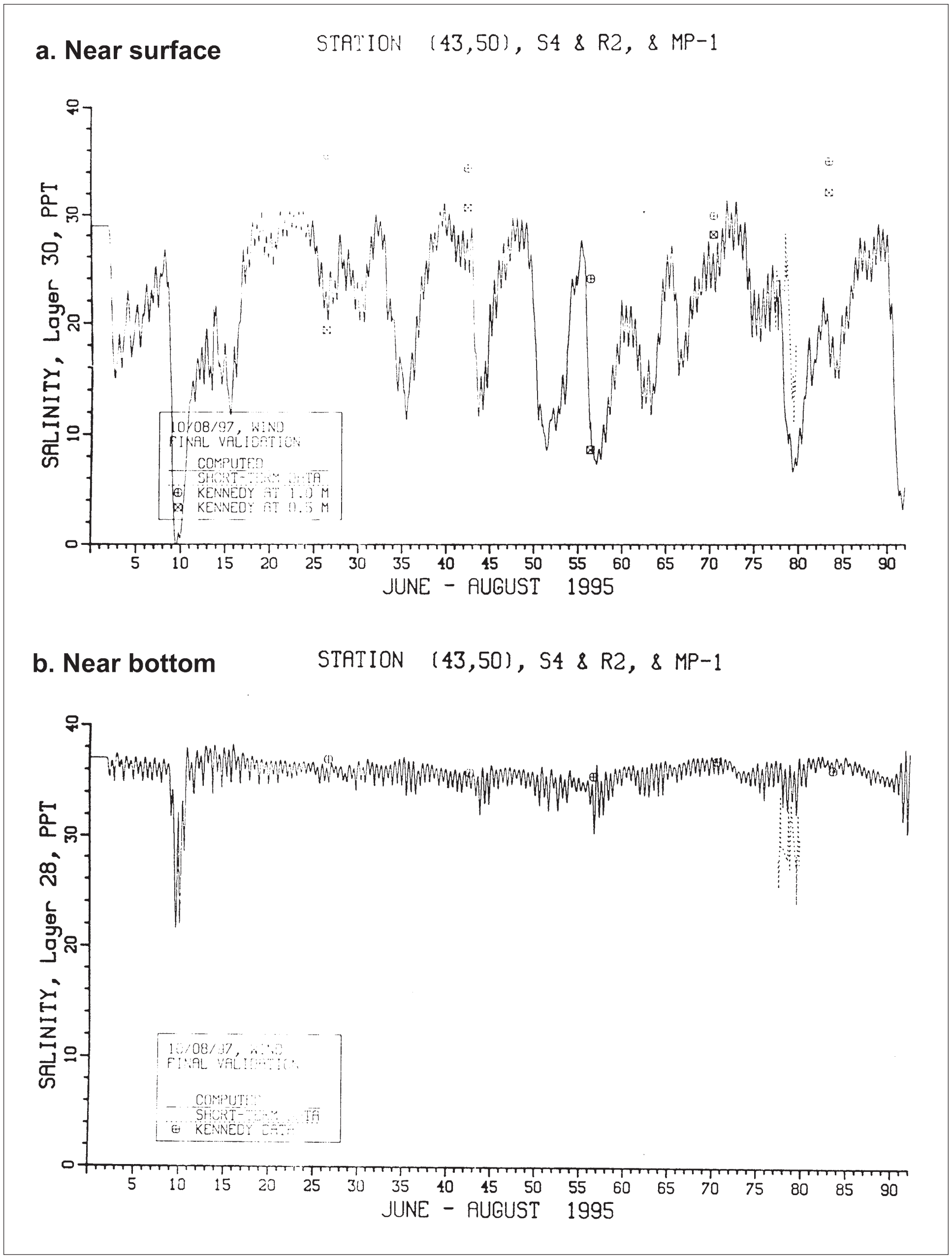


Figure 6-11. Comparison of computed and observed salinity at S4

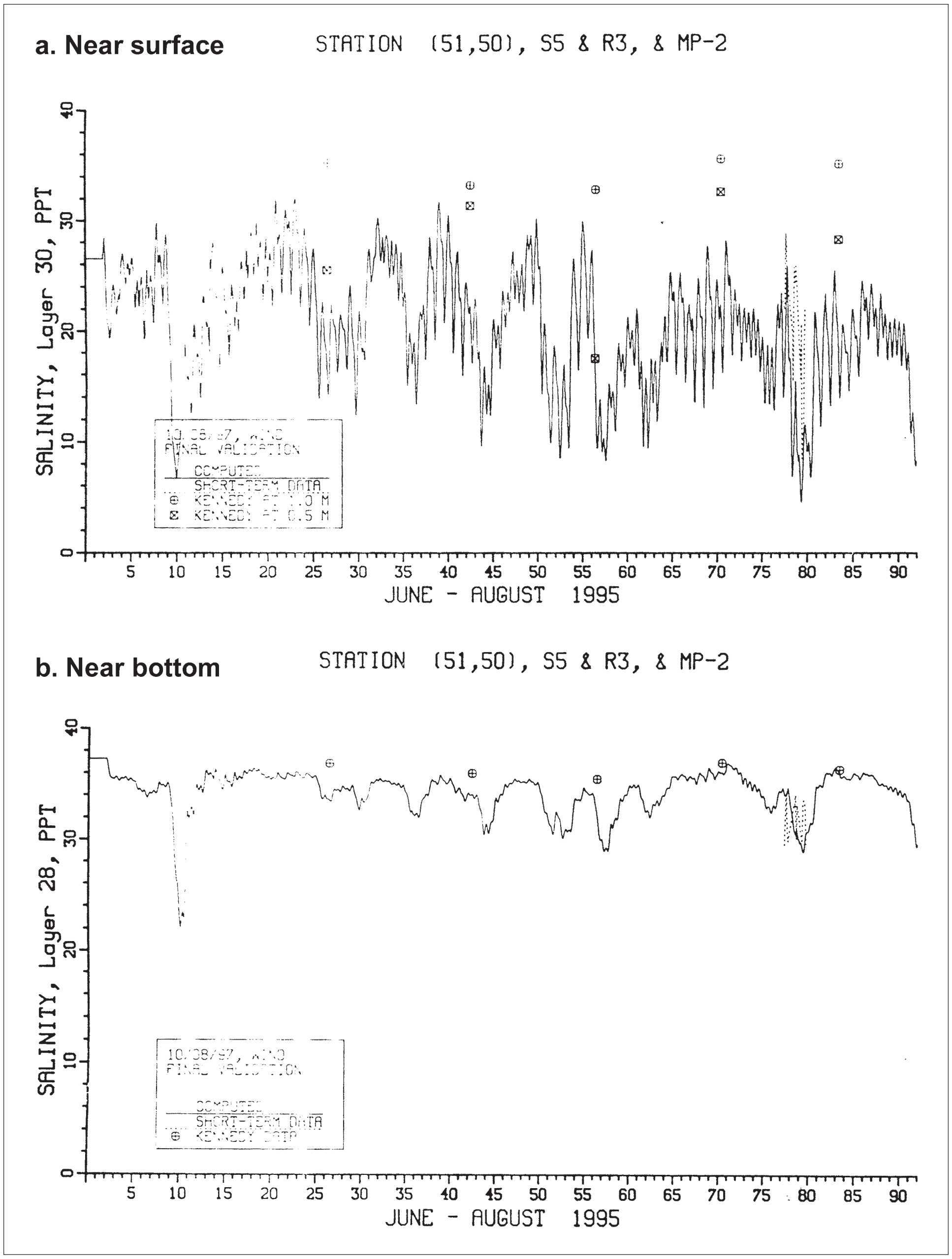


Figure 6-12. Comparison of computed and observed salinity at S5

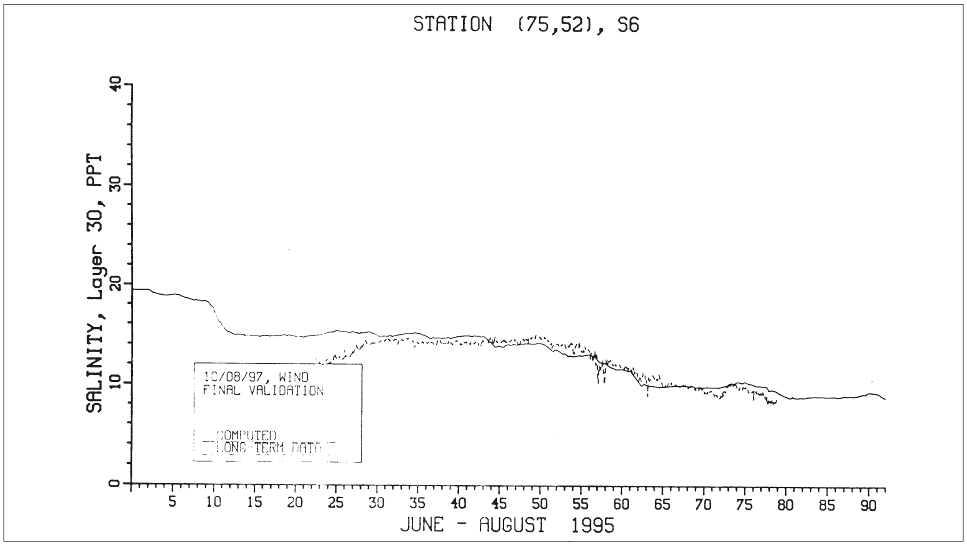


Figure 6-13. Comparison of computed and observed salinity at S6

Reproduction of the Exchange Between Canals

An important component of the skill assessment of the model is the illustration that the model can accurately compute the exchange between the various lagoons, especially the exchange between San Juan Bay and Laguna San José and between Laguna La Torrecilla and Laguna San José since this will have a major impact on water quality computations in Laguna San José and the viability of various management strategies to improve flushing. Figures 6-20 through 6-22 show the computed flux at the eastern end of Martín Peña Canal, the western end of Canal Suárez and between Laguna La Torrecilla and Laguna de Piñoness. Total flux volumes in cubic meters for the entire three months have been computed and are shown on the plots. The net flux through Caño Martín Peña is about 1/4 of that through Canal Suárez and is directed toward San Juan Bay, whereas the flux through Canal Suárez is directed toward Torrecilla. The net flux through the Torrecilla - Piñones canal is directly into Torrecilla. These fluxes, of course, represent the sum of the net freshwater inflows into the various lagoons minus the volume of water evaporated. An evaporation rate of 82 in./yr was assumed in the computations.

The bounds on flux determined from a USGS survey (Ellis et. al. 1976) over one tidal cycle in 1974 are superimposed on the plots. It can be seen that the computed bounds in Canal Suárez and the Torrecilla - Piñones canal agree with the USGS data quite well. The bounds on the computed flux through Martín Peña Canal don't agree as well, but conditions in the eastern end of Martín Peña are different from those that existed in 1974. Significant sedimentation and the disposal of debris has occurred in this part of the system since 1974, resulting in the eastern end of Caño Martín Peña becoming clogged. As a result, special model adjustments were necessary as discussed in the next section.

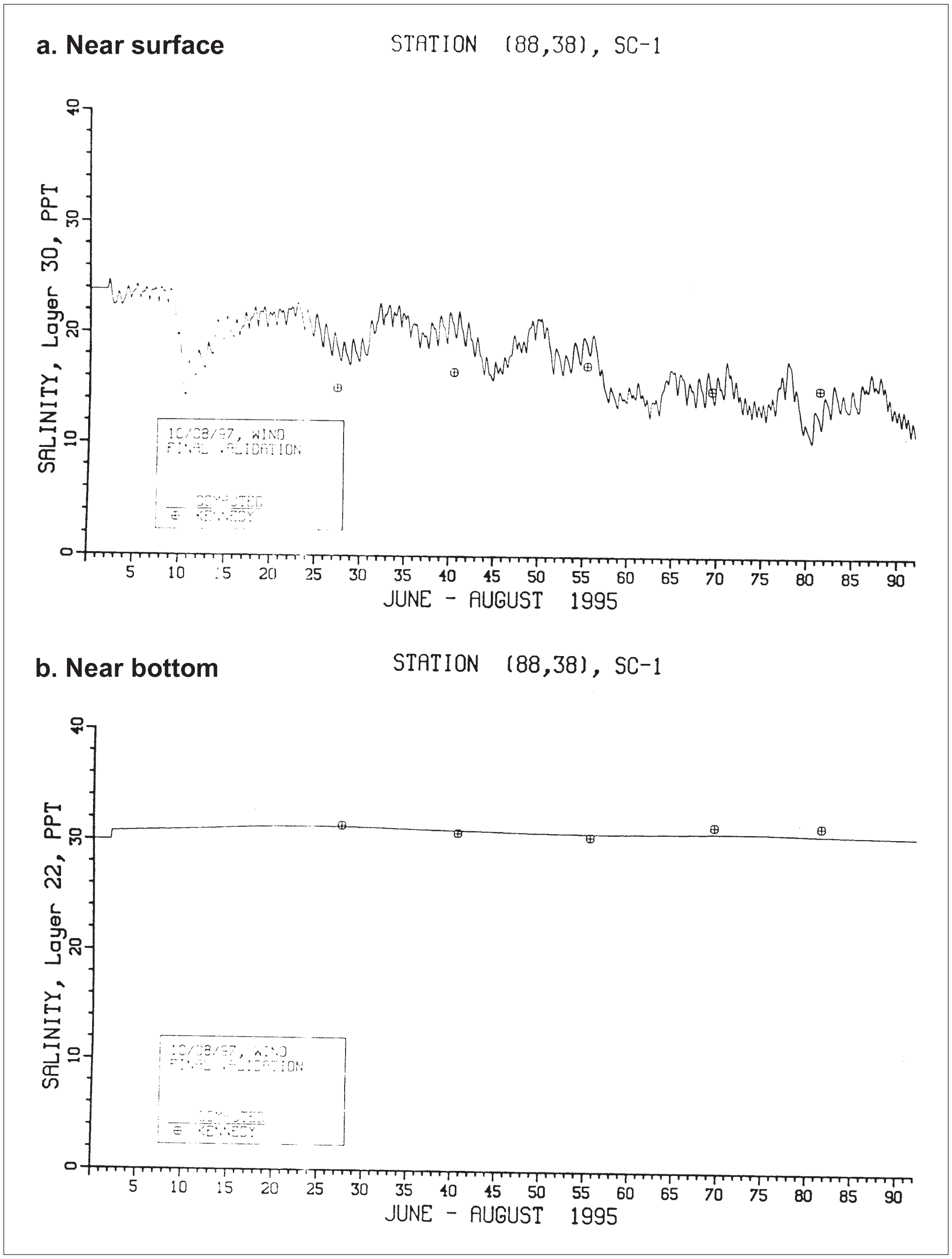


Figure 6-14. Comparison of computed and observed salinity at SC-1

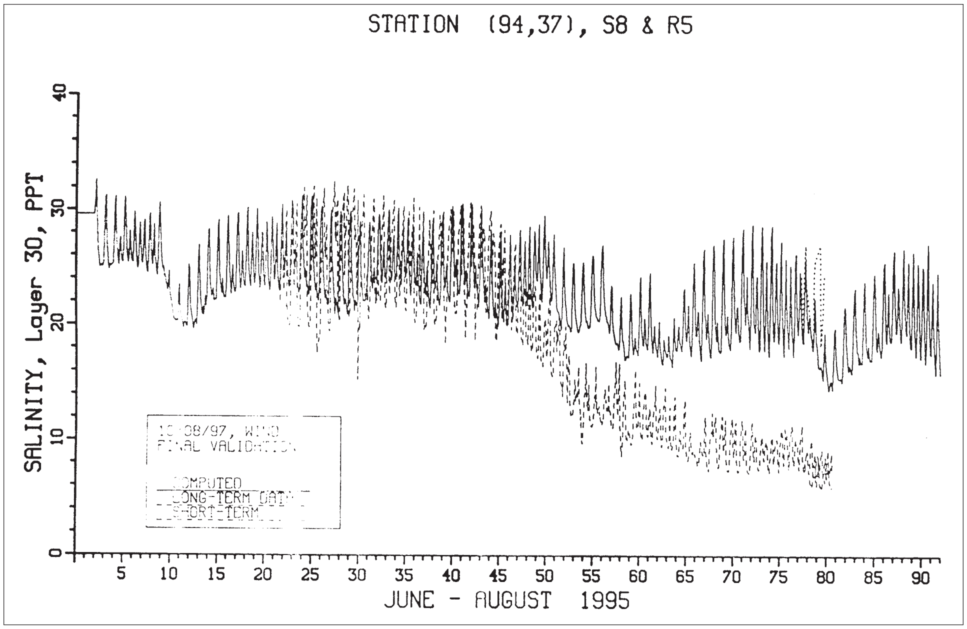


Figure 6-15. Comparison of near surface computed and observed salinity at S8

Figures 6-23 through 6-25 show comparisons of computed flux in Martín Peña Canal, Canal Suárez, and the Torrecilla-Piñones canal with the flux determined from the ADCP data collected during 17-19 August 1995. Generally the agreement is quite good and, with the USGS data agreement, increases confidence that the hydrodynamic model computes the proper exchange between the various bodies of water comprising the SJBE system.

Model Coefficients

The only model parameters available for variation during skill assessment of the hydrodynamic model are the bottom friction, or drag coefficient, horizontal diffusion coefficient, and minimum and maximum values of the vertical diffusion coefficients for momentum and salinity. The value of the bottom drag coefficient was set to 0.002 throughout most of the system. The major exception was in the eastern end of Caño Martín Peña and the canal connecting Torrecilla and Laguna de Piñones. As previously discussed, the eastern end of Martín Peña is severely constricted with debris such as old refrigerators that have been dumped into the canal over the past few years. Values of the bottom drag coefficient specified in these areas were 0.0075 and 0.0040, respectively.

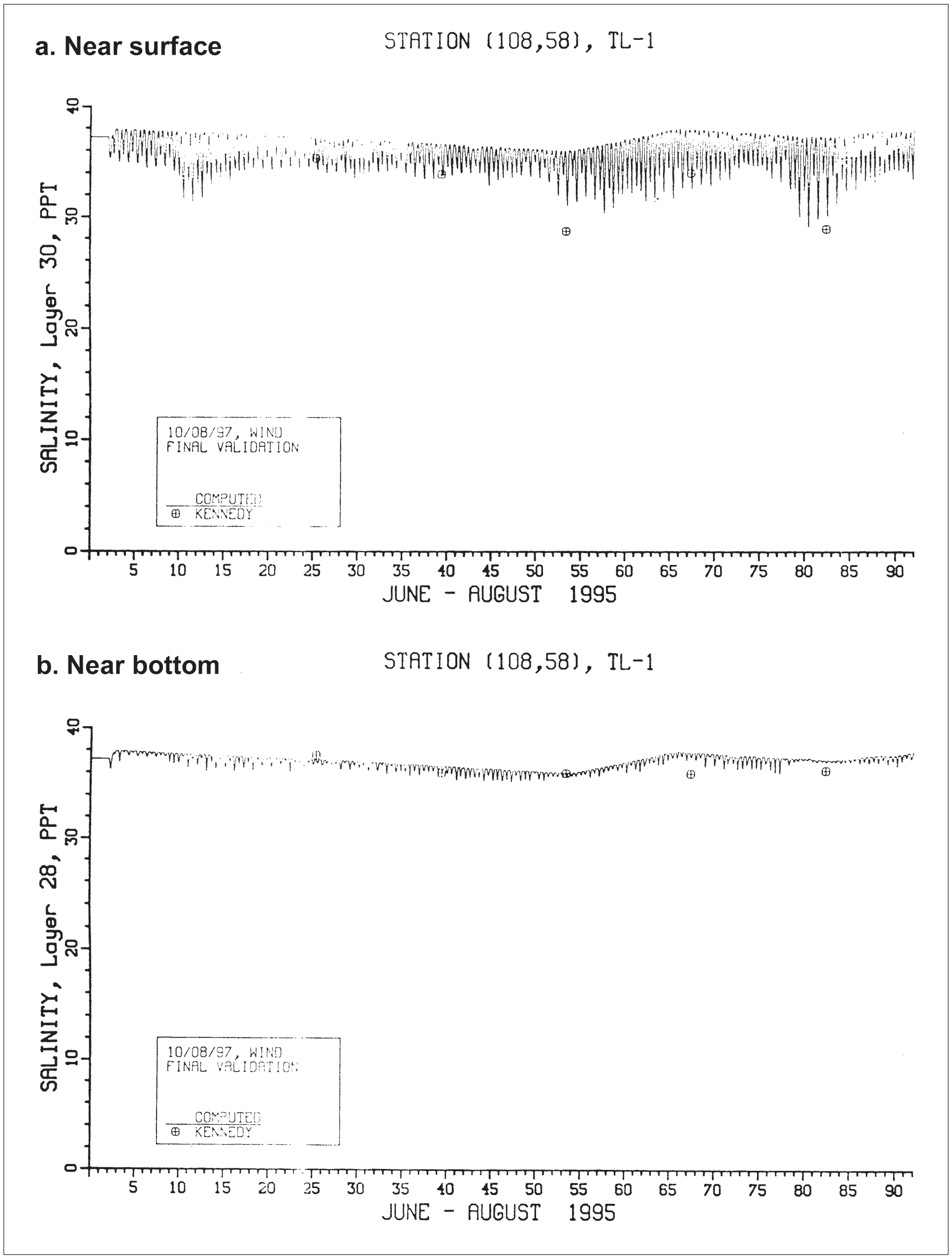


Figure 6-16. Comparison of computed and observed salinity at TL-1

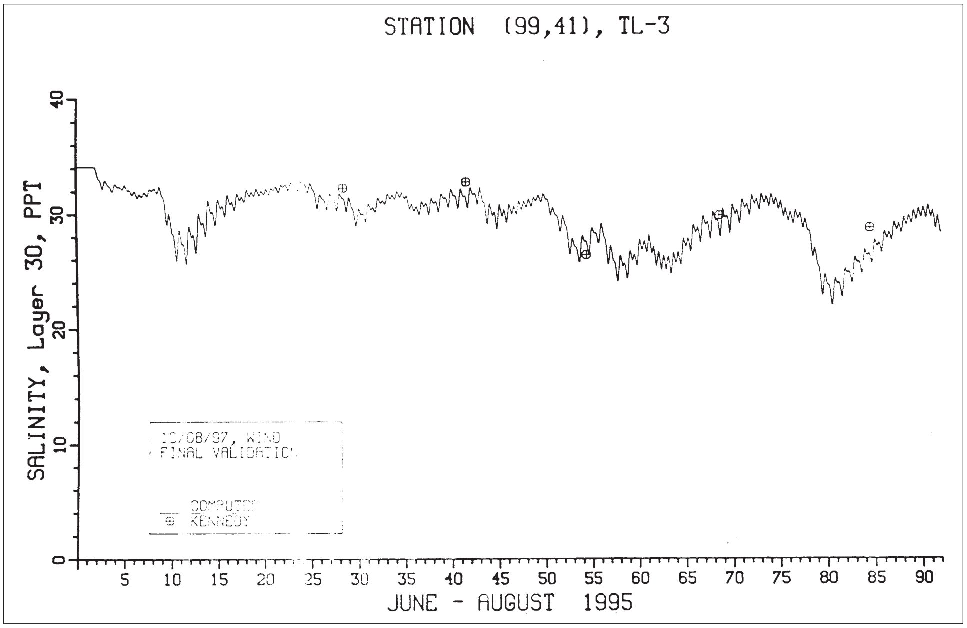


Figure 6-17. Comparison of near surface computed and observed salinity at TL-3

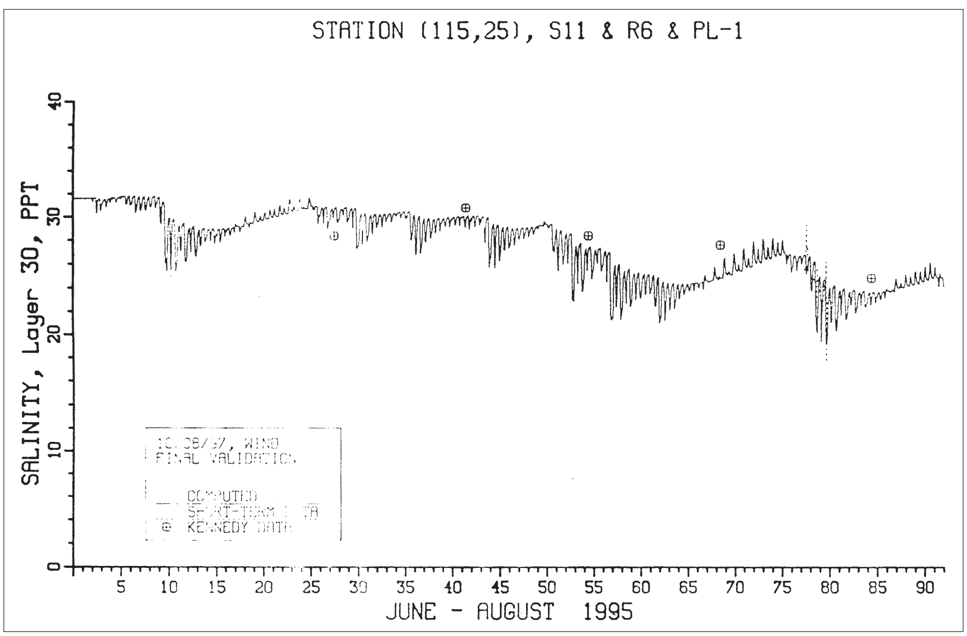


Figure 6-18. Comparison of near surface computed and observed salinity at PL-1

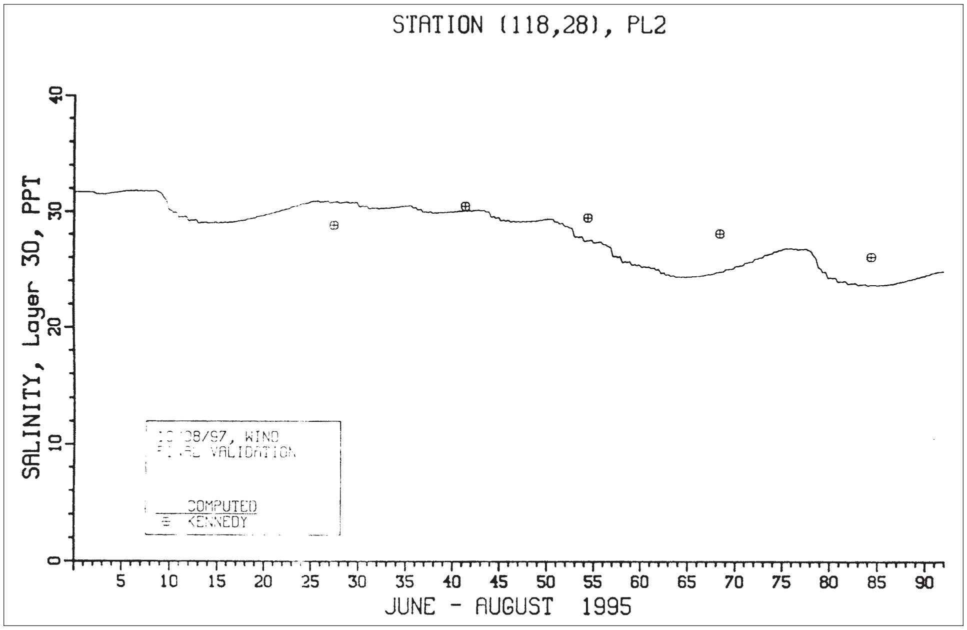


Figure 6-19. Comparison of near surface computed and observed salinity at PL-2

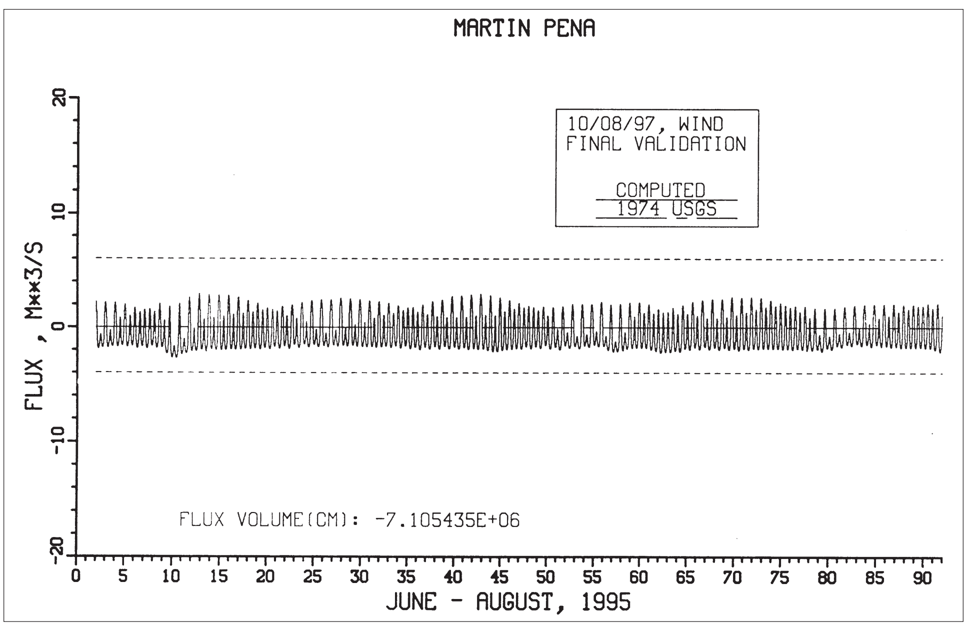


Figure 6-20. Computed flux through Martin Pena Canal compared with USGS data

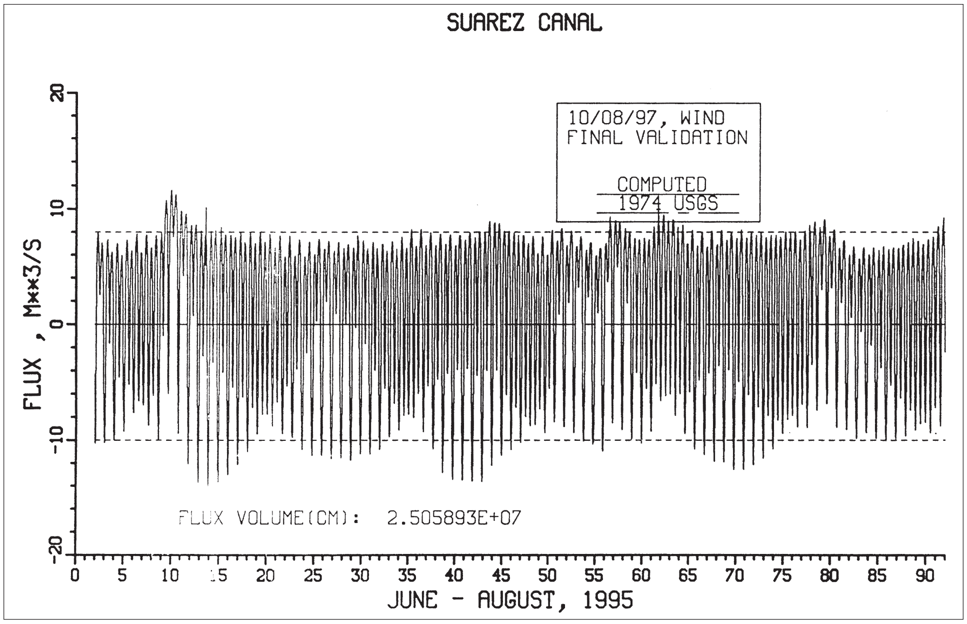


Figure 6-21. Computed flux through Suarez Canal compared with USGS data

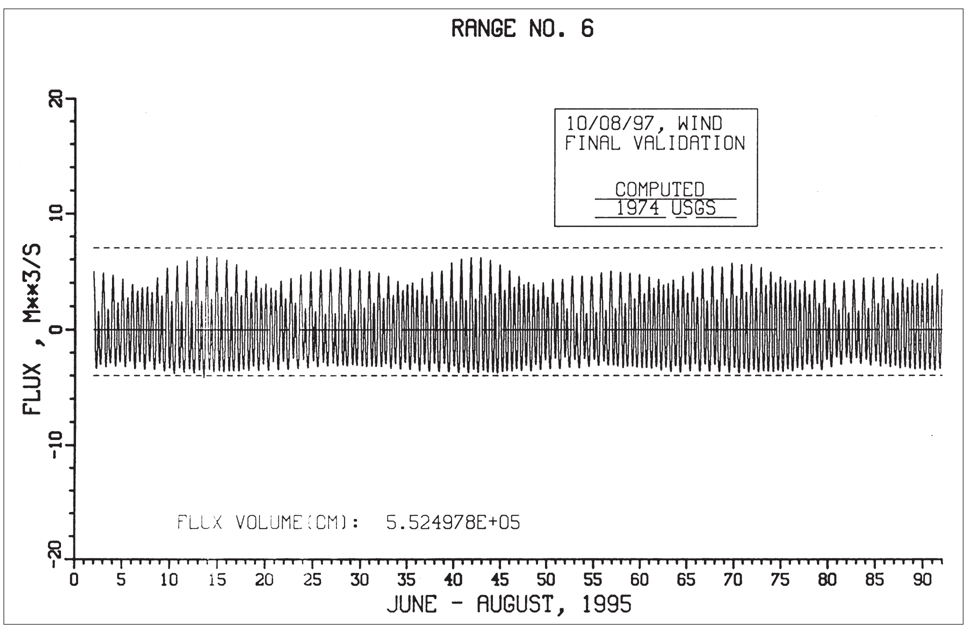


Figure 6-22. Computed flux through Torrecilla - Pinones Canal compared with USGS data

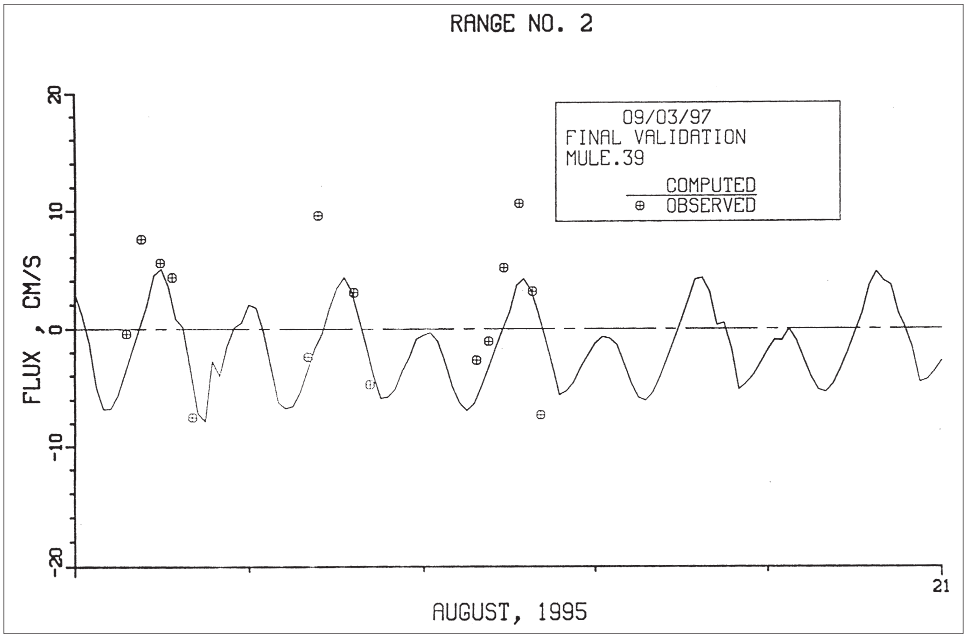


Figure 6-23. Comparison of computed flux at Range 2 with flux determined from ADCP data

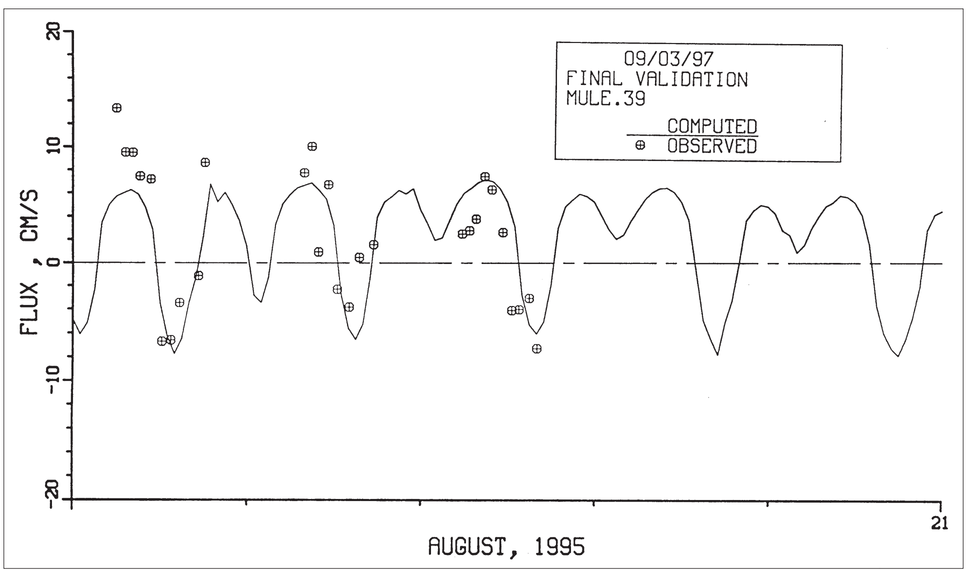


Figure 6-24. Comparison of computed flux at Range 4 with flux determined from ADCP data

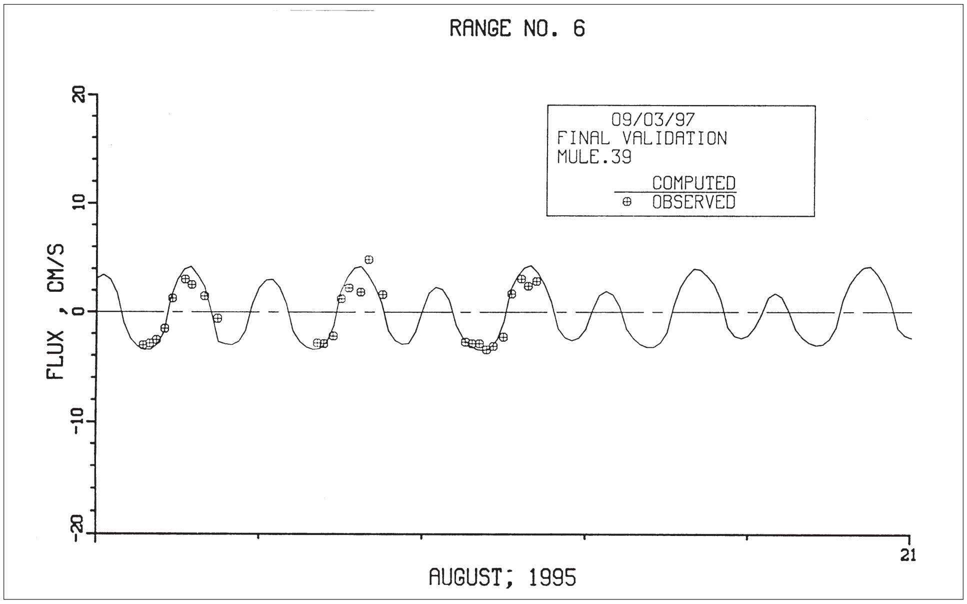


Figure 6-25. Comparison of computed flux at Range 6 with flux determined from ADCP data

The horizontal diffusion coefficient is the same in both horizontal directions. The value selected was 10 m^2/sec. This value is typical of values employed in other studies as well as values reported in the literature by other modelers.

With the coefficients in the vertical turbulence k-e model being considered as universal coefficients, the only parameters available for variation are the bounds on the computed vertical eddy viscosity and diffusion coefficients. The minimum values specified for the vertical viscosity and vertical diffusivity were 5 and 0.001 cm^2/sec, respectively, whereas, the maximum value for both was set to 500 cm^2/sec. These minimum and maximum limits are the same as previously employed in a study on Chesapeake Bay (Johnson et. al. 1991).

Conclusions

Skill assessment of the hydrodynamic model focused on illustrating the ability of the model to reproduce tides throughout the SJBE system; to reproduce the salinity throughout the modeled system, with particular focus on reproducing the extreme stratification that develops during storm events; and to properly compute the exchange of water between the various lagoons in the system. Although data for comparison with the model were limited due to fouling of the long-term meters by the warm tropical waters of the SJBE system, enough data were available to create confidence that the hydrodynamic model reproduces the basic hydrodynamics of the SJBE system so that model results can be used to provide transport for the water quality model.

7 Water Quality Model Calibration and Skill Assessment

The purpose of calibration is to demonstrate that the model can adequately simulate observed conditions. Once this is done, then the model can be used as a predictive tool to determine what effect a proposed action might have. Over 50 simulations were made during calibration. During these simulations, kinetic coefficients were adjusted within accepted tolerances, estimated loads were reviewed and adjusted if necessary, and new processes were added to the WQM. The results presented here represent the culmination of the knowledge gained during the 50 plus calibration simulations. Listed in Table 7-1 are values for the calibration parameters described in Chapter 4 and Table 4-2.

The period 1 June through 31 August 1995 was used for WQM calibration. Model calibration was assessed via plots of model output and observed data. Scatter plots of model output and observed data provide an indication of overall model performance. Calibration period-average longitudinal transect plots were used during calibration as they are indicative of model performance at a variety of locations during the simulation. Time-series plots for selected locations demonstrate the WQM output agreement with observations in specific locations over time.

Table 7-1.
Parameter Values

Symbol	Value	Units
AANOX	0.5	
ANC	0.167	gm N gm^{-1} C
AOCR	2.67	gm O_2 gm^{-1} C
AONT	4.33	gm O_2 gm^{-1} N
ANDC	0.933	gm N gm^{-1} C
APCmin	0.01	gm P gm^{-1} C
APCmax	0.024	gm P gm^{-1} C

(Sheet 1 of 3)

Table 7-1. (Continued)

Symbol	Value	Units
BMr	0.01	day^{-1}
BPR	0.215	day^{-1}
CChl	60	gm C mg^{-1} chl
FCD	0.0	$0 \le FCDx \le 1$
FCDP	0.1	$0 \le FCDP \le 1$
FCLP	0.55	$0 \le FCLP \le 1$
FCRP	0.35	$0 \le FCRP \le 1$
FNI	0.0	$0 \le FNIx \le 1$
FNIP	0.0	$0 \le FNIP \le 1$
FND	1.0	$0 \le FNDx \le 1$
FNDP	0.1	$0 \le FNDP \le 1$
FNL	0.0	$0 \le FNLx \le 1$
FNLP	0.55	$0 \le FNLP \le 1$
FNR	0.0	$0 \le FNRx \le 1$
FNRP	0.35	$0 \le FNRP \le 1$
FPD	1.0	$0 \le FPDx \le 1$
FPDP	0.5	$0 \le FPDP \le 1$
FPI	0.0	$0 \le FPI \le 1$
FPIP	0.2	$0 \le FPIP \le 1$
FPL	0.0	$0 \le FPLx \le 1$
FPLP	0.2	$0 \le FPLP \le 1$
FPR	0.0	$0 \le FPRx \le 1$
FPRP	0.1	$0 \le FPRP \le 1$
FR	5.6	m^{-3} gm^{-1} C day^{-1}
Ih	50	Langleys day^{-1}
Kcod	30	day^{-1}
Kdc	0.025 to 0.25	day^{-1}
Kdcalg	0.0	m^3 gm^{-1} C day^{-1}
Kdn	0.2 to 2.0	day^{-1}
Kdnalg	0.0	m^3 gm^{-1} C day^{-1}
Kdp	0.05	day^{-1}
Kdpalg	0.2	m^3 gm^{-1} C day^{-1}
Keb	0.09 to 2.8	m^{-1}
Kechl	0.029	m^2 mg^{-1}
Kfc	5.0	day^{-1}
KHn	0.01	gm N m^{-3}
KHndn	0.1	gm N m^{-3}
KHnnt	1.0	gm N m^{-3}
KHocod	0.5	gm O_2 m^{-3}
KHodoc	0.5	gm O_2 m^{-3}
KHomb	2.0	gm O_2 m^{-3}
KHont	1.0	gm O_2 m^{-3}

(Sheet 2 of 3)

Table 7-1. (Concluded)

Symbol	Value	Units
KHp	0.001	gm P m^{-3}
KHr	0.5	gm O_2 m^{-3}
Klc	0.15 to 1.5	day^{-1}
Klcalg	0.0	m^3 gm^{-1} C day^{-1}
Kln	0.3 to 3.0	day^{-1}
Klnalg	0.0	m^3 gm^{-1} C day^{-1}
Klp	0.075	day^{-1}
Klpalg	0.0	m^3 gm^{-1} C day^{-1}
Kr	2.44	m day^{-1}
Krc	0.005	day^{-1}
Krcalg	0.0	m^3 gm^{-1} C day^{-1}
Krn	0.005	day^{-1}
Krnalg	0.0	m^3 gm^{-1} C day^{-1}
Krp	0.005	day^{-1}
Krpalg	0.0	m^3 gm^{-1} C day^{-1}
KTb	0.069	$°C^{-1}$
KTcod	0.041	$°C^{-1}$
KTg1	0.008	$°C^{-2}$
KTg2	0.01	$°C^{-2}$
KThdr	0.069	$°C^{-1}$
KTmhl	0.069	$°C^{-1}$
KTnt1	0.09	$°C^{-2}$
KTnt2	0.09	$°C^{-2}$
MBGM	0.0 to 0.16	gm C m^{-2}
NTm	0.07 to 0.7	gm N m^{-3} day^{-1}
PM	3.0	day^{-1}
PO_4dmax	0.01	gm P m^{-3}
Tm	30	°C
Tmnt	30	°C
Tr	30	°C
Trcod	23	°C
Trhdr	20	°C
Trmnl	20	°C
WSl	0.3	m day^{-1}
WSr	0.3	m day^{-1}
WSa	0.05	m day^{-1}

(Sheet 3 of 3)

Scatter Plots

Figure 7-1 contains calibration period scatter plots. The locations of circles indicate the correlation between model predictions and observed data. A perfect match between model and observed data is indicated by the diagonal line on each graph. Circles above the line indicate that the model is overpredicting for that observation. Circles below the line indicate that the model is underpredicting the observation. Observations used in these plots were typically obtained by means of a grab sample or in situ measurement and reflect the conditions in the water column at that instant. Model outputs used in these plots are the daily averages of the constituents of interest in cells corresponding to the sample site location. Some of the scatter in these plots can be attributed to the phasing resulting from comparison of instantaneous observations with daily average model results. Shown with each plot are the mean error (ME), absolute mean error (AME), root mean square (RMS) error, and relative error (RE) which is expressed as percent.

The mean error is a summary of the model tendency to overestimate or underestimate the observed data. Mean error can be zero even though large discrepancies exist in individual model-data comparisons. Mean error is computed as follows:

$$ME = \frac{\sum (O - P)}{n} \tag{7-1}$$

where

ME = mean error

O = observation

P = model prediction

n = number of observations

The absolute mean error is a measure of the average discrepancy between observations and model results. No differentiation is made between overestimation or underestimation. Absolute mean error is computed as follows:

$$AME = \frac{\sum |O - P|}{n} \tag{7-2}$$

where

AME = absolute mean error

The root mean square error is an indication of the average discrepancy between observations and model results. It is computed as follows:

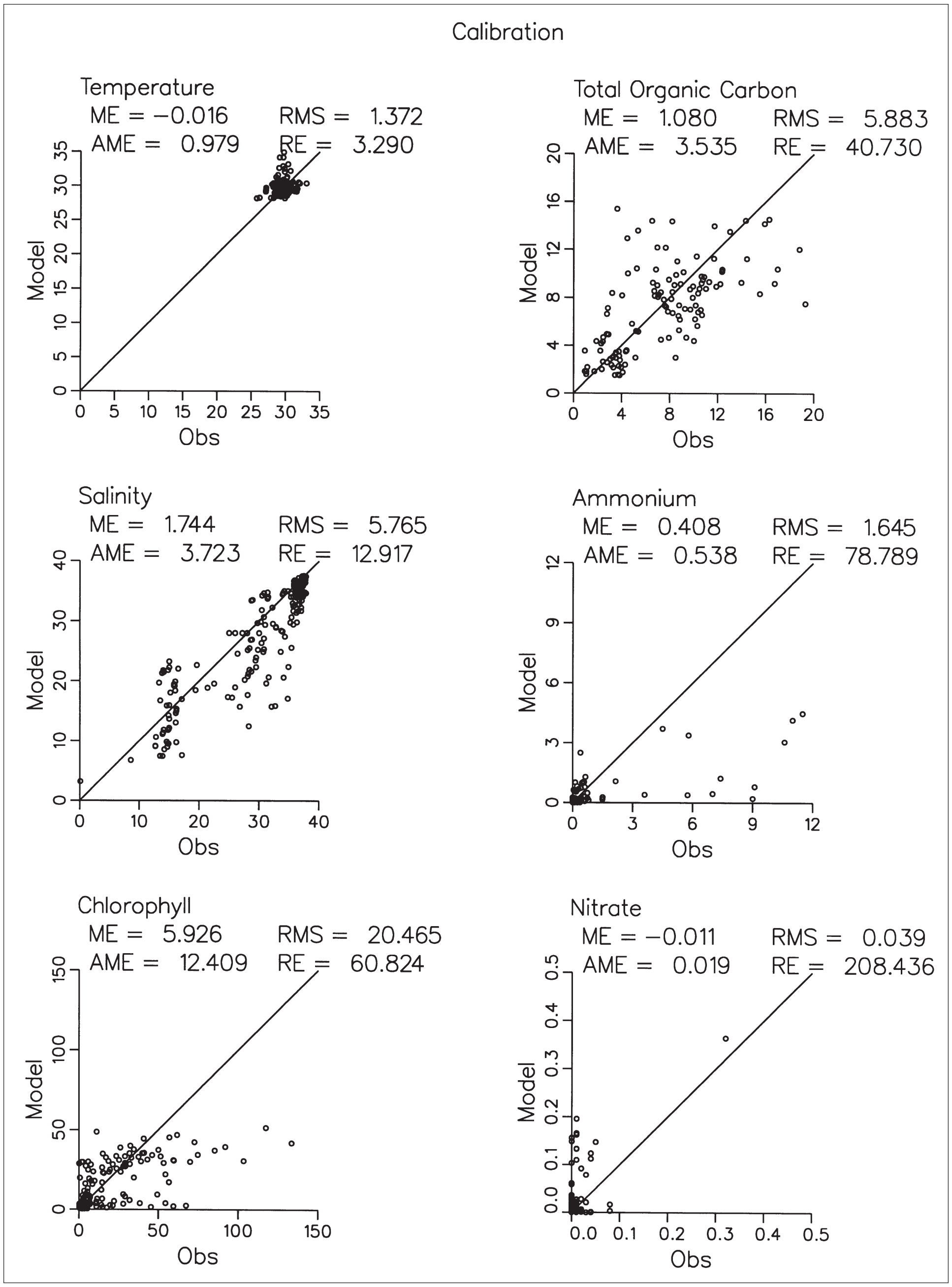


Figure 7-1. Calibration period scatter plots (continued)

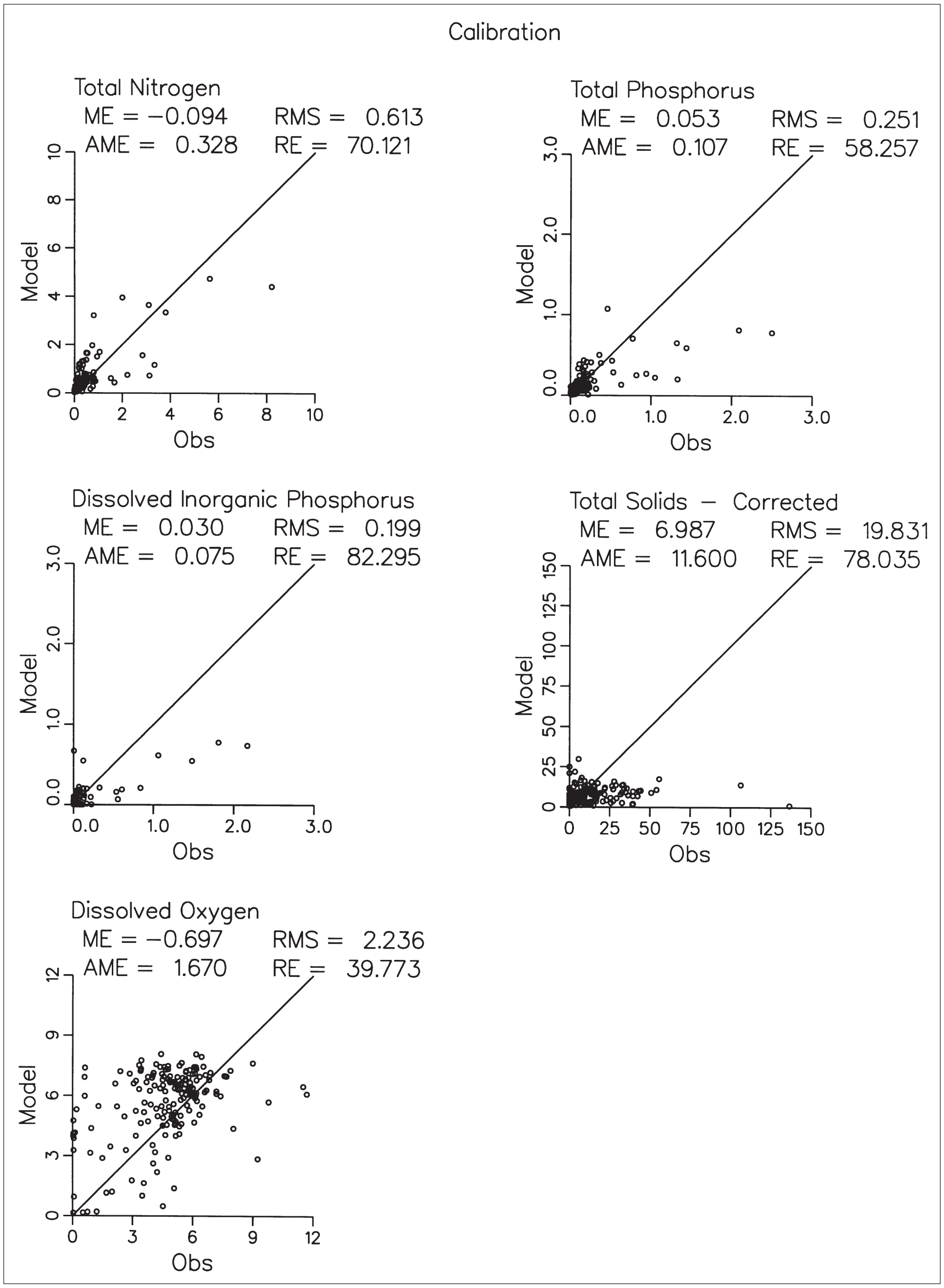


Figure 7-1. (concluded)

$$RMS = \sqrt{\frac{\sum (O - P)^2}{n}} \tag{7-3}$$

where

RMS = root mean square

The relative error is the absolute mean error normalized by the magnitude of the observations. It is expressed as a percent and is computed as follows:

$$RE = \frac{\sum |O - P|}{\sum O} \tag{7-4}$$

where

RE = relative error

Overall, the model does well for all constituents. The scatter plot for temperature indicates that the model results are in agreement with observations. The scatter plot for salinity indicates that model predictions agree reasonably well over a range of conditions. While not evident from these plots, ICM underpredicts salinity in Caño Martín Peña, Laguna de Piñones, and the southern portion of Laguna La Torrecilla. Results for chlorophyll indicate that ICM underpredicts extremely high values (over 75 ug/l) but does reasonably well for lower values. The total organic carbon scatter plot exhibits a significant amount of variability around the diagonal indicating that the model is reasonable over a range of conditions but underpredicts some high values.

The ammonium scatter plot indicates that the model underpredicts when concentrations are greater than 1 mg/l. Concentrations of this level and higher were typically only observed in borrow pits in the interior of the SJBE system. Observed nitrate concentrations were low with most being at or just above detection levels. The model indicates a few higher nitrate concentrations but most are very low, as are the observations. Model predictions agreed well with observations for total nitrogen over the 0- to 3-mg/l range but overpredict for the few observations greater than 3 mg/l.

Model predictions for dissolved inorganic phosphorus and total phosphorus are good with the exception of the model underpredicting concentrations exceeding 1 mg/l.

Overall the model overpredicts DO by about 0.70 mg/l, primarily on the surface in the eastern portion of the system, possibly due to overestimation of reaeration. Generally, bottom DO predictions agree favorably with observations. ICM underpredicts DO when concentrations are greater than 8 mg/l, which are supersaturated DO concentrations for the temperature and salinity of this system. Dissolved oxygen supersaturation is a result of photosynthesis during daylight hours. The model uses calculated daily-average light; thus, photosynthesis and its contribution to DO production are daily-average values, whereas photosynthesis actually follows a sinusoidal pattern that peaks during daylight hours. All observations were collected during the day. Therefore, the model always tends to underpredict DO when supersaturated conditions prevail.

The scatter plot reveals that the WQM overpredicted anoxic and hypoxic conditions in some cases. Upon further investigation it was determined that half of these cases were occurring at stations in upper Laguna La Torrecilla, Blasina Canal, and in the canal leading to Laguna de Piñones. All five bottom observations at TL-5 indicated DO levels lower than 1 mg/l. Corresponding WQM results ranged from 3.14 to 5.3 mg/l. Dissolved oxygen observations in Piñones Canal at station PL-1 ranged from 0.6 mg/l to 3.7 mg/l. Corresponding model predictions ranged from 6.6 to 7.2 mg/l. Reasons for the poor model performance at these locations are several. First, Piñones Canal is influenced by the mangroves which it flows through. Loadings from the mangroves are not accounted for in the model. Second, Piñones Canal is modeled as one layer deep in the model which precludes any simulated stratification. Loads from Piñones Canal are discharged into Blasina Canal at TL-5 which would impact water quality at that location. Furthermore, observations at TL-5 indicate that the water column is stratified. Although Blasina Canal is modeled with two layers, this amount of resolution was insufficient to resolve the rather strong stratification observed in the field in this reach.

Model DO overprediction occurred at station MP-2 in Caño Martín Peña in the surface layer. Surface water at this station was influenced by thin, freshwater lenses which were too thin for the model to accurately resolve. Finally, there are stations where the model computed anoxic DO when anoxic DO existed, such as the bottom layer of MP-2. However, plots of anoxic observations against anoxic model predictions on the scatter plot yielded a single point rather than multiple points, which gives a false impression that the model rarely computes low DO when low, observed DO conditions existed.

The remaining cases where low DO conditions were overpredicted were distributed among the sampling stations. Three were from the bottom of Laguna San José at different sampling stations, one at the bottom of Laguna del Condado, and one at the bottom of San Antonio Canal. Reasons for overpredictions at any of these stations would be speculative. One of these overpredictions occurred at station SJ-1 (Laguna Los Corozos) whose time series results are shown in Figure 7-7. No clear reason is evident for this overprediction. This observation was the first at this station. All subsequent observations were much higher and agreed favorably with model results. Possibly, the first sample was obtained in a slightly different location or in a slug of "dirty water" recently discharged from the Baldorioty de Castro Pump Station.

Total suspended solids scatter plots indicate that the model performs reasonably well. During model calibration a problem with the total suspended solids data was discovered. Total suspended solids data had been collected and filtered but not rinsed with distilled water. Since some of the samples were collected in waters that were saline, the filtered material contained salt. When the filter was dried the salt remained and its weight was incorrectly attributed to suspended solids. In an attempt to compensate for this error, observed total suspended solids data were corrected by using the following relationship.

$$TSS_{new} = TSS_{obs} - \frac{C_{sal}}{C_{ocean}} TSS_{ocean} \tag{7.5}$$

where

TSS_{new} = new total suspended solids concentration

TSS_{obs} = observed total suspended solids concentration

C_{sal} = observed salinity at sampling location

C_{ocean} = observed salinity at ocean boundary

TSS_{ocean} = observed total suspended solids concentration at AO-1 and AO-2 (see Figure 2-1)

With this correction implemented, the agreement of model predictions and observations improved. ICM still underpredicted observations greater than 25 mg/l. All total suspended solids data presented in this report have been corrected in the manner described above.

Longitudinal Transect Comparisons

Calibration period-average longitudinal transect plots were made for a transect beginning at the mouth of San Juan Bay, passing through Caño Martín Peña, Laguna San José, Canal Suárez, ending at the mouth of Laguna La Torrecilla (see Figure 7-2). The route of this transect was selected so as to pass through five of the major features of the SJBE system. Two transects are shown for each constituent. One transect is for cells in the surface layer while the other is for cells in the bottom layer. Due to the bathymetry of the system, there are locations where the grid is only one layer thick which results in the same cell appearing in both the surface and bottom transects. Locations where this occurs include eastern Caño Martín Peña, Laguna San José, and Laguna La Torrecilla. The model average for the calibration period is shown on the transect plots as a solid line. The range of model predictions during the simulation is illustrated by the shaded region. Average values of sampling observations are indicated as a circle while the ranges of observations are indicated by the vertical bar through the circle. The model results presented here are averages over the

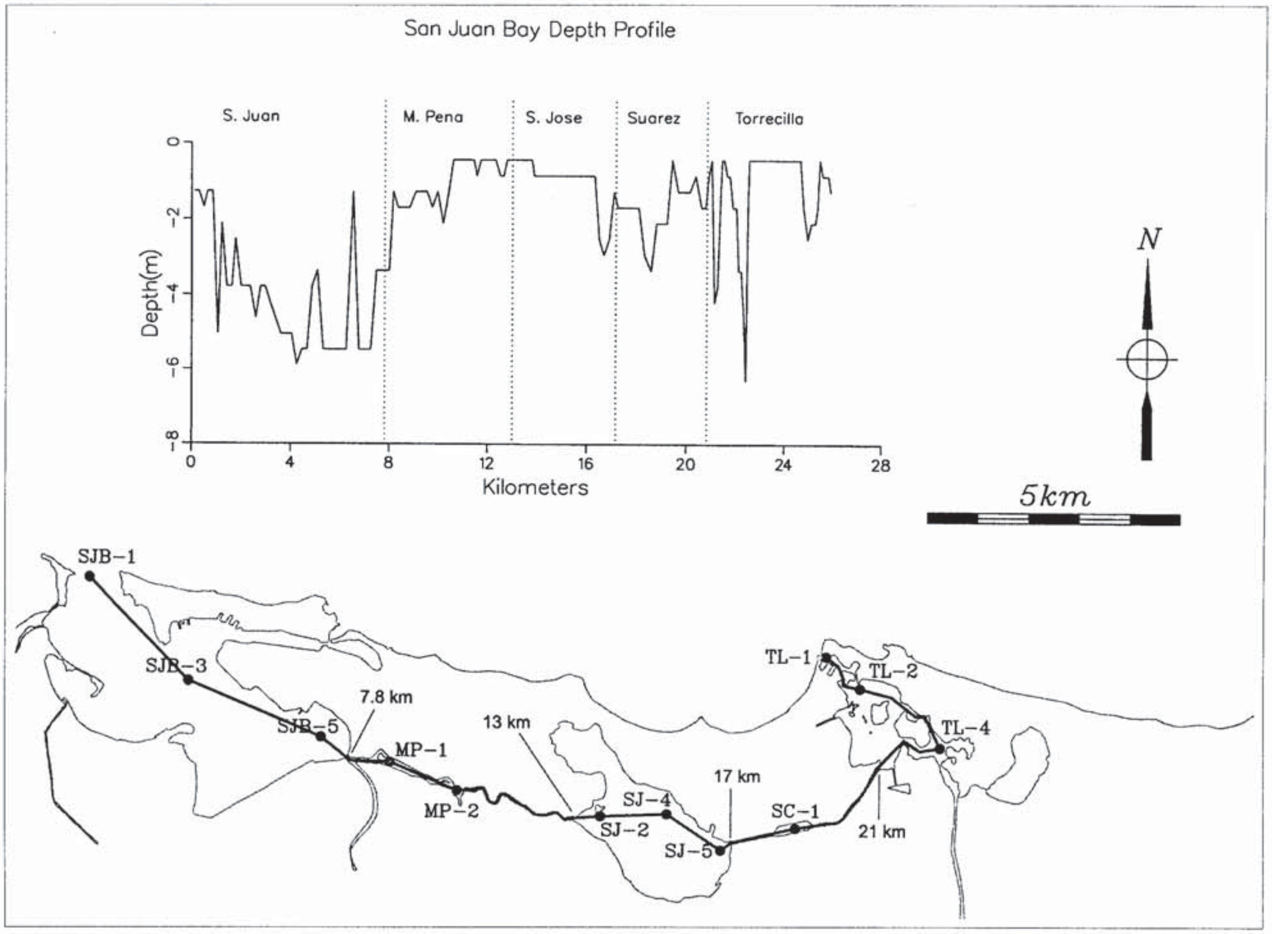


Figure 7-2. Longitudinal transect and observation stations used for preparing calibration-period average transect plots

whole calibration period and as such do not relate the effects of any temporal activity which might be reflected in the observed data.

Overall, as these plots indicate (see Figure 7-3), the model performs well. There are locations where the line denoting the model calibration average and the average of the observed data do not agree. However, the model does capture most of the means of the observations and their range.

As indicated in the description of the transect route, this transect passes through water bodies with very different characteristics. San Juan Bay is well flushed via tidal exchange with the Atlantic Ocean at its mouth and a secondary channel on the northeastern side, i.e., Caño de San Antonio. Due to the extensive exchange with the ocean, water quality in San Juan Bay is similar to that of the ocean. Laguna San José, which is located along the middle of the transect is completely landlocked with only limited exchange with the ocean via Caño Martín Peña and Canal Suárez. As a result, salinity in Laguna San José is less than half of ocean values. Laguna La Torrecilla on the eastern end of the system is a transition region between the interior of the system and the ocean. Water quality near the

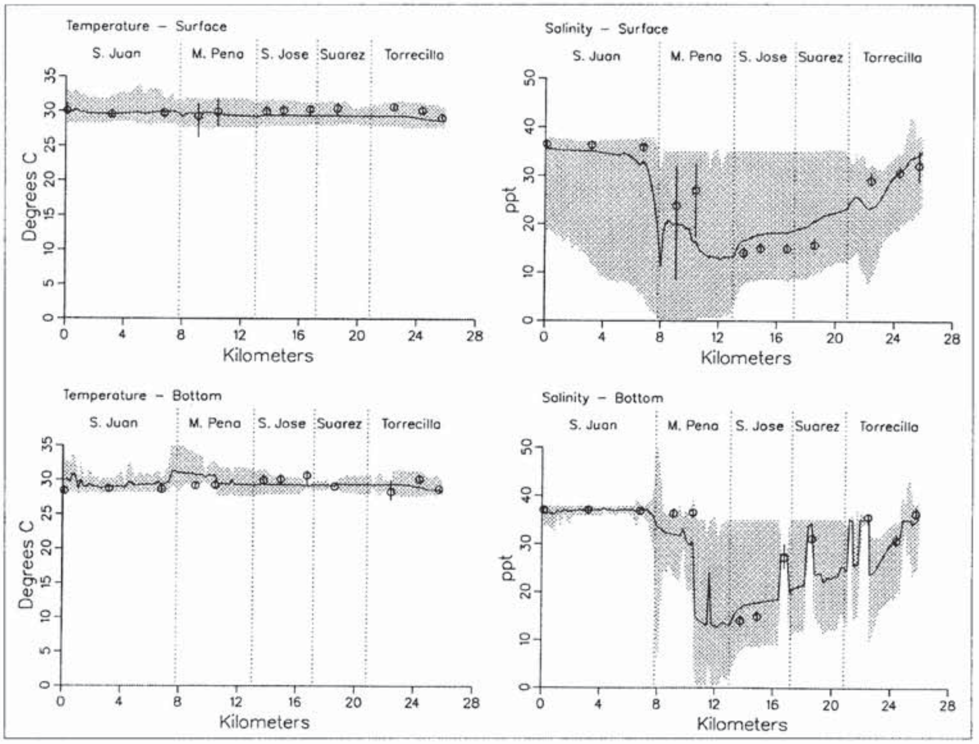


Figure 7-3. Calibration-period average, longitudinal transect plot of computed and observed water quality variables resulting from model calibration for summer 1995 (Sheet 1 of 8)

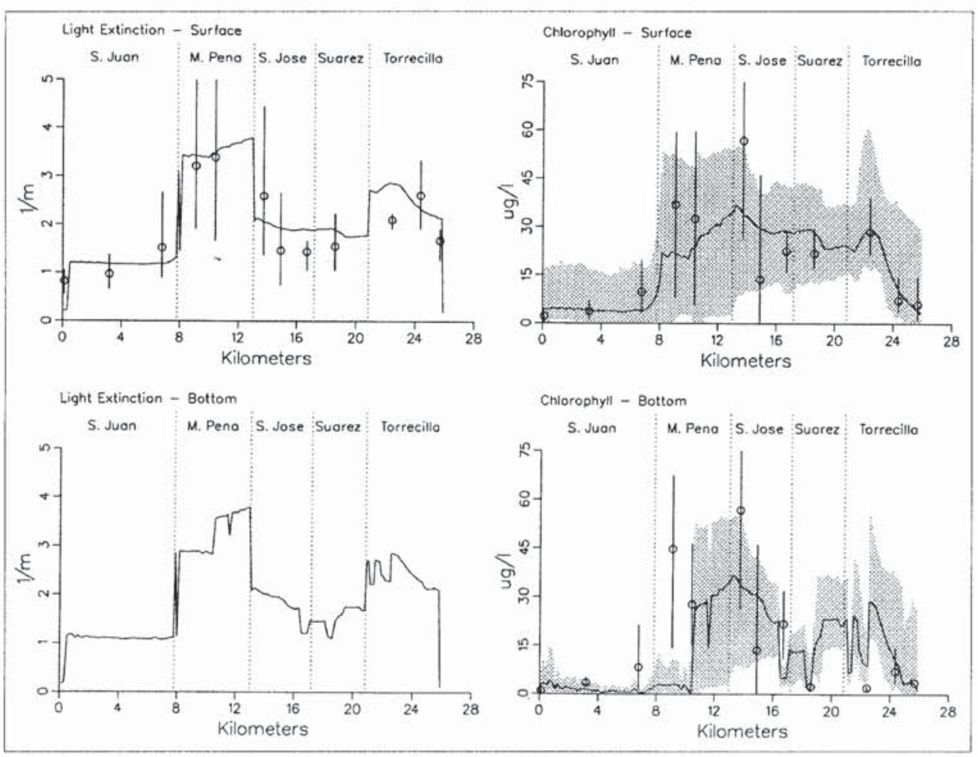


Figure 7-3. (Sheet 2 of 8)

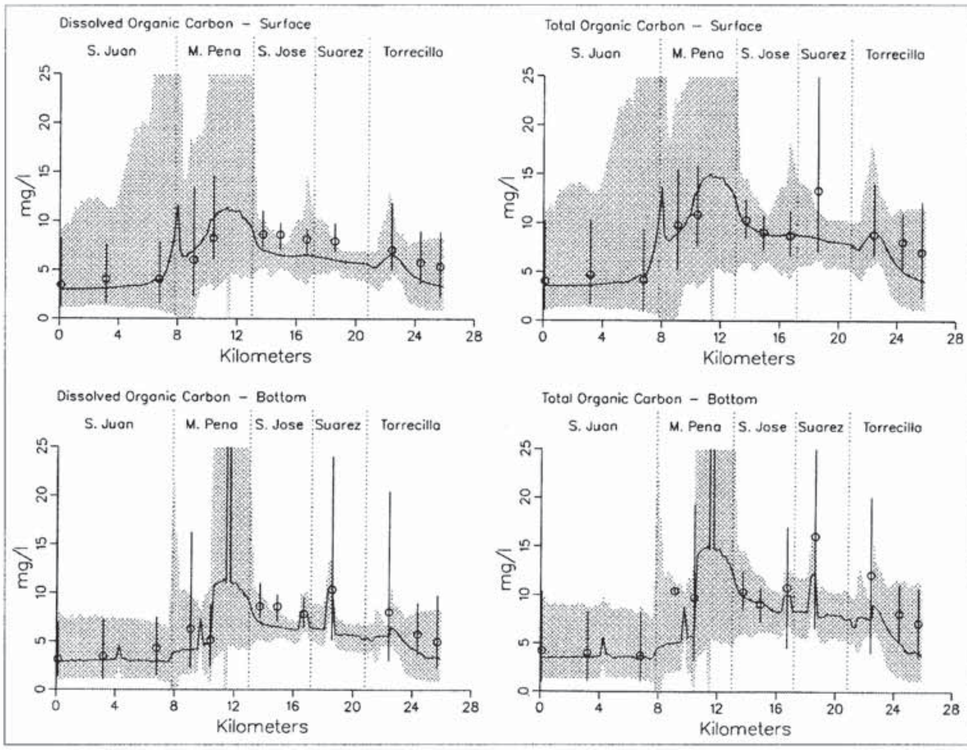


Figure 7-3. (Sheet 3 of 8)

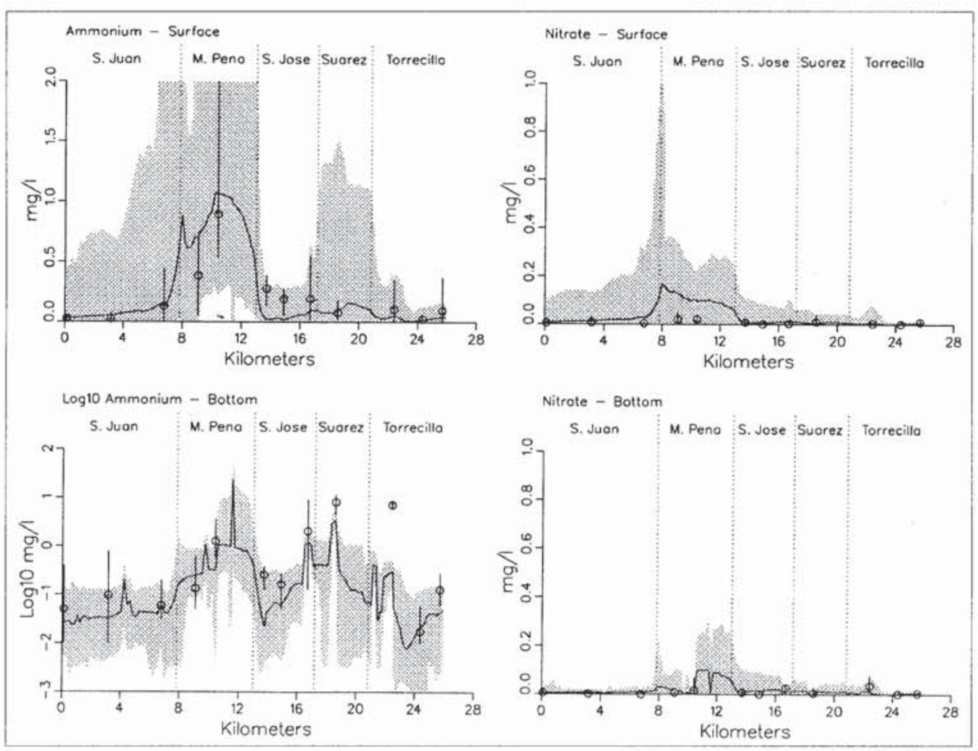


Figure 7-3. (Sheet 4 of 8)

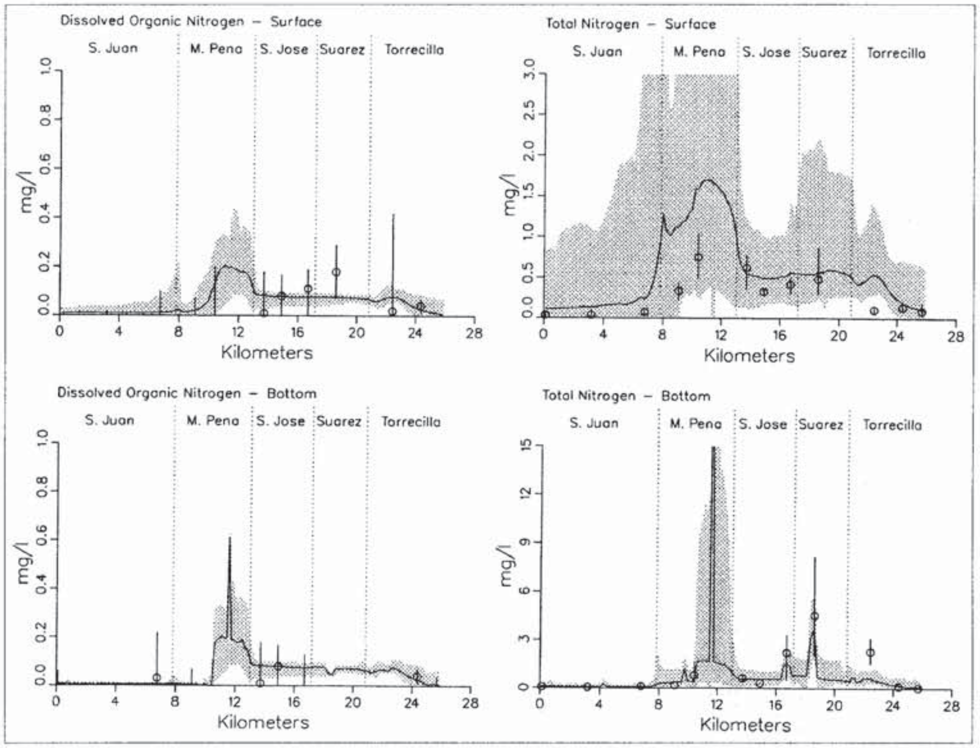


Figure 7-3. (Sheet 5 of 8)

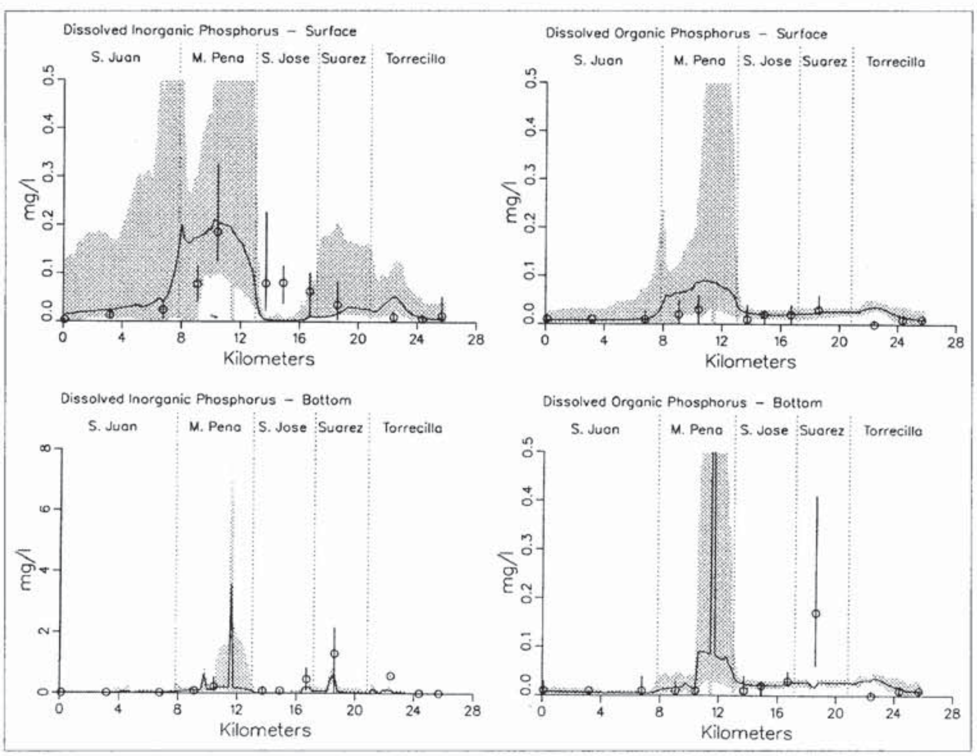


Figure 7-3. (Sheet 6 of 8)

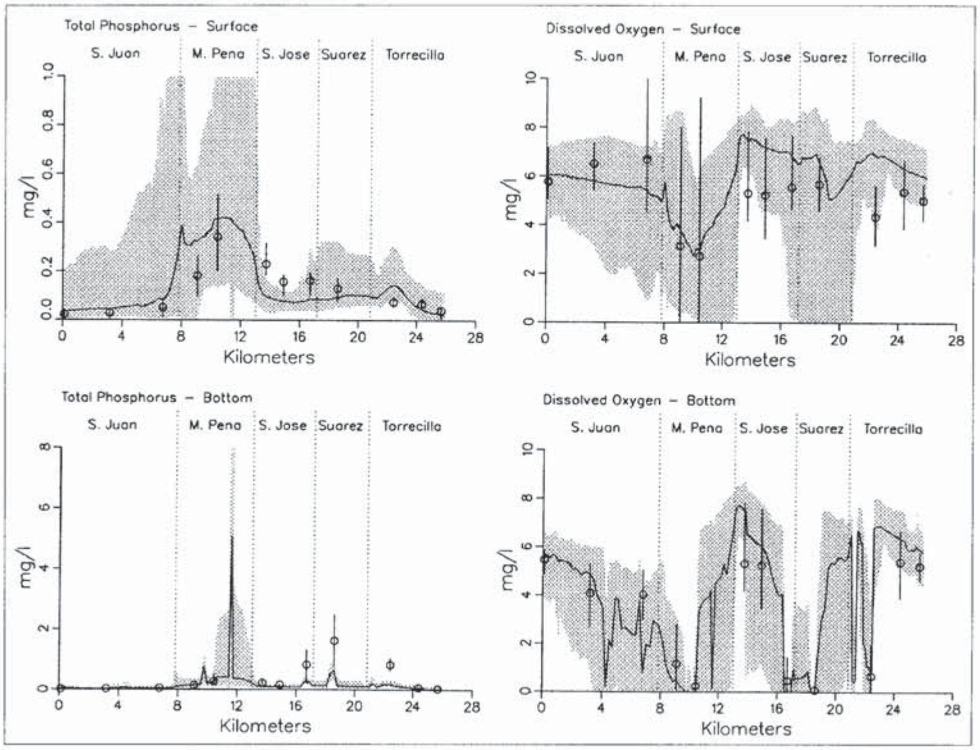


Figure 7-3. (Sheet 7 of 8)

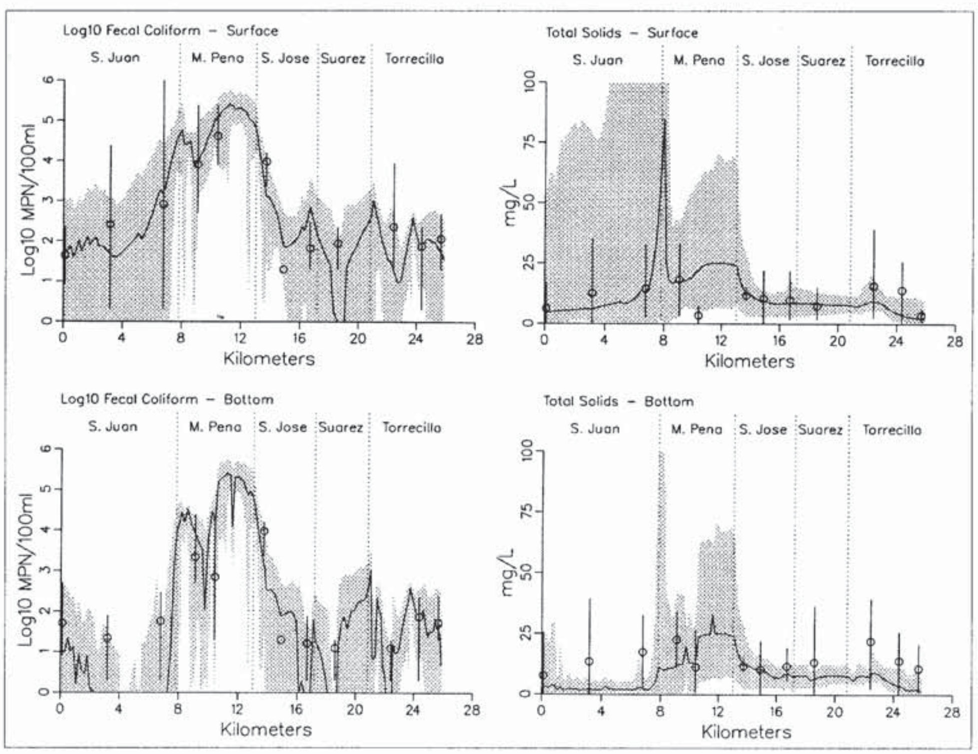


Figure 7-3. (Sheet 8 of 8)

mouth of Laguna La Torrecilla is similar to offshore conditions while water quality in the other areas is more like that found in Canal Suárez. Each constituent is discussed in the order it is presented in the transect plots.

Temperature

Temperature transect plots indicate that there is little variation in the model predictions for temperature along the transect, Figure 7-3. Likewise there was little variation in observed temperature readings. Model results agree favorably with observations indicating that the model is predicting temperature accurately. The lack of significant temperature differences between the surface and bottom transects is an indication that the system is not thermally stratified.

Salinity

Salinity transects, unlike the temperature transects, indicate significant variation. Model results and observed data for San Juan Bay exhibit average salinity approximately equal to that found offshore. Near the mouth of Caño Martín Peña, surface salinity drops in response to freshwater inflows from Rio Piedras and the flow from Caño Martín Peña. Bottom salinity decreases slightly in the dredged portion of Caño Martín Peña with the model average being lower than the observed data. However, the observed data for both surface and bottom samples at this location do fall within the range of model predictions.

The degree of variation in observed salinity supports the model results which indicate that there are significant swings in salinity as a result of fresher flows from eastern Caño Martín Peña and runoff into Laguna San José. These fresher flows remain near the surface and override the bottom waters of western Caño Martín Peña resulting in a 10- to 15-ppt difference in salinity between surface and bottom waters. Eastern Caño Martín Peña is shallow and modeled as one layer in most places. This results in the surface and bottom salinity plots being identical for this region. The only exception occurs near km 12 where there is a small hole. At this location, the model grid is two layers deep while the cells upstream and downstream are only one layer deep. The cell in the "hole" cannot have advection into or out of it due to the one-cell isolation. The only means for moving material into or out of this cell are diffusion and settling. Salinity being a dissolved substance does not settle but can diffuse depending upon the overlying water salinity. At the same time, salinity is not taken up by the sediments so the salinity that diffuses into the "hole" is only removed by diffusion when the overlying water is fresher.

Predicted surface salinity in Laguna San José is slightly higher than observations for the calibration period. The surface and bottom salinity values at SJ-2 and SJ-4 are identical as this is a location where the system is relatively shallow and there is no stratification. At station SJ-5, there is a significant difference in surface and bottom salinity. This location is a dredge material borrow pit which is 6.8 m deep. These pits are located throughout Laguna San José, Canal Suárez, and Laguna La Torrecilla. Just as the small hole in Caño Martín Peña, these holes have limited exchange with surface waters. Some holes are large enough that they cover multiple model cells and can therefore accommodate advection which should allow these holes to freshen. However, observed data indicated that surface salinity at these holes was much lower than bottom salinity. Numerous theories were developed as to why the salinity in these holes should be so much higher than that at the surface. The theories included groundwater intrusion from the ocean into the holes. Whatever the mechanism, it was beyond the capability of CH3D and ICM to simulate it without modification.

In an attempt to incorporate the effects of these holes on water quality, the salinity in these deep holes was "nudged" toward higher values throughout the simulation. The same procedures were used in both the HM and WQM. During each model time-step iteration, the salinity in the holes where nudging was employed was adjusted toward a predetermined, higher concentration according to the relationship

$$C_{new} = C + 0.1 * \left(C_{nudge} - C\right) \tag{7.6}$$

where

C_{new} = new salinity concentration

C = previously computed salinity concentration

C_{nudge} = reference salinity concentration

The result of nudging was that these dredge material borrow pits became pseudo-salinity boundaries representing sources of ocean salinity. Nudging was only employed in cells located more than three layers deep in dredge material borrow pits. A value of C_{nudge} = 28 ppt was used for holes in Laguna San José while a value of C_{nudge} = 35 ppt was used for dredge borrow pits in Laguna La Torrecilla. In locations where nudging was employed, little fluctuation in salinity occurred. Examples of the effects of nudging can be seen in the bottom salinity transect plots between km 16 and km 24.

Transect salinity continues to increase as the transect passes through Canal Suárez. There is a slight decrease in salinity as the transect passes around an island in Laguna La Torrecilla in the vicinity of TL-4 at which time it is exposed more to the fresher Blasina flows. Salinity continues to rise as the transect continues through Torrecilla to the ocean.

Light Extinction

The background light extinction was specified spatially based upon observations. Model values vary some during the simulation due to the effects of algae. Only the model mean values are plotted in Figure 7-3 for interpretive purposes. These values were adjusted so that the model light extinction closely followed the observed. Although the model surface and bottom light extinction values are very similar for surface and bottom layers, the amount of light remaining in the bottom layers can be quite different from that in the surface layers. Light extinction measurements were taken only for the surface.

Chlorophyll

Modeled chlorophyll levels along the transect in San Juan Bay are low, averaging 4 μg/l. There is a slight gradient in the observed values in San Juan Bay with the observations near the mouth of Caño Martín Peña being the highest. The average and range of chlorophyll observations fall within the range of the WQM simulation for San Juan Bay. Chlorophyll levels increase significantly just inside Caño Martín Peña. Model levels remain constant throughout the western dredged portion of Martín Peña and begin to increase once the undredged eastern portion of the canal is reached.

Computed chlorophyll concentrations at the juncture between Caño Martín Peña and Laguna San José are the highest of any location on the transect. Chlorophyll concentrations remain high throughout San José and into Canal Suárez. Average chlorophyll observations in San José exhibited temporal and spatial variability which made calibration problematic. Attempts to make the WQM match the higher chlorophyll observations at SJ-2 would make it overpredict the much lower average at SJ-4 even more. Attempts to obtain a better match at SJ-4 would result in the WQM underpredicting even more at SJ-2 which in turn would cause lower chlorophyll predictions throughout Martín Peña. The surface waters of San José serve as an incubator for chlorophyll with ample light and nutrients to promote growth.

Macrobenthic grazing was added to the model in order to aid in chlorophyll calibration in Laguna San José. Benthic organisms remove algae via filtration of the overlying cell, consequentially, the waters above bivalve beds have lower levels of algae and other particulates. Light penetration increases in the waters above clam beds in response to the decrease in suspended matter.

Bivalve beds were observed at different locations in Laguna San José during the sampling study. Bivalves were placed into the southern half of Laguna San José in the WQM, Figure 7-4. Macrobenthic grazing is dependent upon dissolved oxygen levels. Bivalves require dissolved oxygen to live. In the WQM the higher the dissolved oxygen the better the conditions for grazing, the lower the dissolved oxygen the worse.

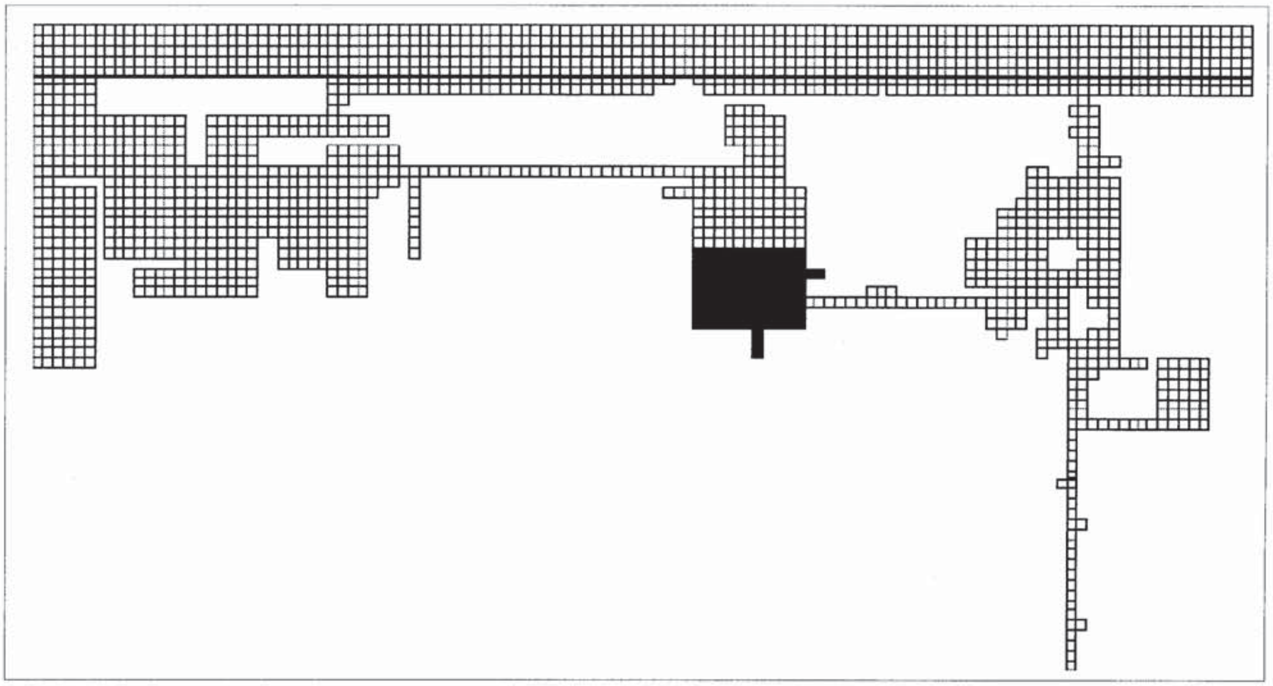


Figure 7-4. Location of clams in the WQM

Macrobenthic grazing will not occur in bottom cells with anoxic conditions even if bivalves are present.

Incorporation of macrobenthic grazing allowed greater spatial variability in Laguna San José chlorophyll concentrations. The net impact was that chlorophyll levels decreased in the southern portion of Laguna San José in the presence of the bivalve beds.

Canal Suárez chlorophyll levels were lower than either Laguna San José or Laguna La Torrecilla but still higher than any other location along the transect. Model surface chlorophyll concentrations along the transect in Torrecilla were highest at TL-4. Levels at TL-1 and TL-2 are relatively low reflecting the influence of the ocean water exchange through the Laguna La Torrecilla inlet.

Bottom chlorophyll concentrations along the transect are typically low. The exception occurs at locations where the model grid is only one layer deep which results in the same cell being on both the surface and bottom transects. Light limitation is the major limiting factor for algal growth in the deeper waters of the system with the exception of the regions offshore. Typically, algae found in the bottom waters were transported there by settling and vertical flows.

Organic Carbon

The WQM simulated three forms of organic carbon: dissolved, labile particulate, and refractory particulate. Results are shown for dissolved organic carbon (DOC) and total organic carbon (TOC) which is the sum of DOC and the two particulate fractions. The DOC and TOC transects have similar shapes which is expected since DOC is the major component of TOC. Concentrations at both the San Juan Bay and Laguna La Torrecilla inlets reflect the conditions offshore. The interior portions of the transect have elevated levels that are the result of anthropogenic loadings. The highest surface concentrations occur at the Rio Piedras - Caño Martín Peña confluence and in the eastern portion of Caño Martín Peña. The high concentrations at the Rio Piedras - Caño Martín Peña juncture result from the Rio Piedras loadings. Transect plots indicate that this load is rapidly disseminated into the waters of San Juan Bay by the combined Rio Piedras and Caño Martín Peña flows.

Surface DOC and TOC concentrations in eastern Caño Martín Peña are high as a result of the organic carbon component of the un-sewered loads. This region is reported to directly receive substantial discharges of untreated wastewater. The exact quantity was unknown and could only be estimated. Based upon calibration results and demographic information, a loading of 400 kg/day of organic carbon split evenly between dissolved and labile particulate fractions was distributed along the eastern half of Caño Martín Peña. In addition, loadings of 62.5 kg/day of ammonia, 37.5 kg/day of dissolved organic nitrogen, 12.5 kg/day of dissolved inorganic phosphorus, and 7.5 kg/day of dissolved organic phosphorus were also added. The carbon/nitrogen/phosphorus (C/N/P) ratio of this load was 20/5/1 which is typical of that indicated for medium strength wastewater (Metcalf and Eddy 1979). Based on a daily per-capita total organic carbon loading of 75 g/person/day (0.17 lb/person/day) this loading was equivalent to that of approximately 5300 persons. The un-sewered loadings into eastern Caño Martín Peña were required not only to bring the DOC and TOC up but to increase the levels of other nutrients and decrease dissolved oxygen. The impact of the un-sewered loads on these and other variables is discussed below in the corresponding sections.

Model surface DOC concentrations match observed data quite well throughout the system except for Laguna La Torrecilla where model predictions were slightly low. One possible explanation for the model being low in this region is that the model does not include the organic carbon loading coming from the mangroves around Torrecilla. Surface model DOC concentrations in San José and Canal Suárez are slightly low in comparison to observed data. However, model predictions for TOC at these stations indicate that the model average agrees with the observed averages at stations SJ-2, SJ-4, SJ-5, and SC-1. Any attempt to increase DOC concentrations in the model would increase TOC concentrations and result in a poorer model performance in San José and Canal Suárez.

Model bottom DOC levels are similar to surface levels for most of the transect. In the dredged western portion of western Caño Martín Peña, bottom DOC levels are lower than surface waters. A possible reason for this is that there is some salinity stratification in this portion of the canal which decreases surface-bottom water mixing. Over the remainder of the transect, model surface and bottom DOC concentrations are comparable except for holes and dredge material borrow pits. At these locations, DOC concentrations are elevated as a result of the dissolution of settled particulate organic carbon and the respiration and decay of algae that settle into these cells. As a result, the DOC levels in these holes are higher as there is no mechanism to readily remove the DOC other than vertical diffusion. Observed bottom DOC and TOC concentrations at SJ-5, SC-1 and TL-4 indicate elevated concentrations similar to those predicted by the model.

Nitrogen

Results for three model constituents, ammonium, nitrate, and dissolved organic nitrogen (DON) are shown as well as results for total nitrogen. The dominant feature of the nitrogen transects are the high observed values of ammonium in Caño Martín Peña. The high observed ammonium levels in Caño Martín Peña are further evidence of substantial discharges of untreated wastewater directly into Caño Martín Peña. The sources of this ammonium are direct loading, mineralization of DON, and diagenesis of settled particulate organic nitrogen in the sediments. Mineralization occurs in the water column but as indicated in the transect plots, little DON was observed in Caño Martín Peña. Diagenesis occurs in the sediments and is a likely source of the ammonium especially in the holes and dredged borrow pits. At these locations, particulate organic matter in these cells will eventually be settled and undergo diagenesis. The ammonium released can only be removed via diffusion. Consequentially observed ammonium levels greater than 1 mg/l were observed and predicted along the bottom.

In the deeper portions of Caño Martín Peña, Laguna San José, and Canal Suárez, sediments act as a source of ammonium to the water column. Model sediment fluxes of 25 mg/m^2/day or greater are common in Laguna San José and Canal Suárez. Benthic algae in the shallow portions of the eastern portion of Caño Martín Peña and Laguna San José take up ammonium as it is being released from the sediments to the water column. Without these algae, ammonium levels in Caño Martín Peña and Laguna San José would be even higher. The spatial extent of the benthic algae is limited by the availability of light and nutrients.

Computed and observed nitrate levels were low throughout the system. The model slightly overpredicts nitrate in Caño Martín Peña, possibly due to under-estimation of sediment denitrification or algal uptake of nitrate. Computed and observed dissolved organic nitrogen is also relatively low with more present in the eastern half of the system. Surface transect plots indicate that model total nitrogen levels were higher in Caño Martín Peña than observed values but agreed well with observations in Laguna San José. Total nitrogen transect plots for the bottom indicate that the model performs well for the whole system. Model predictions are low for the first station in Laguna La Torrecilla, TL-4, but this is mainly the result of the ammonium prediction for this station being low.

Phosphorus

Dissolved inorganic phosphorus (DIP) transects have a look similar to that of ammonium. Low predicted and observed surface concentrations occurred throughout the system with the exception of Caño Martín Peña. DIP concentrations approaching 0.2 mg/l were predicted for the length of Caño Martín Peña which matched well with observations at MP-2 but were slightly above the observations at MP-1. The sediments of the dredged western portion of Caño Martín Peña are a source of DIP with sediment flux rates reaching a maximum of 20 mg/m^2/day near MP-2. Eastern Caño Martín Peña sediments serve as a sink for DIP with the benthic algae community at this location taking DIP from the water column. Eastern Caño Martín Peña receives a phosphorus loading of 20 kg/day as part of the un-sewered area loadings. Surface water predictions from the model are lower than observations in Laguna San José but are representative in Canal Suárez and Laguna La Torrecilla. The reason for low predictions in Laguna San José appear to be benthic and planktonic algal nutrient uptake. Much of Laguna San José is relatively shallow so that the bottom waters at certain locations receive adequate light for benthic algae to flourish. Where benthic algae are active their role is the sequestration of sediment releases of nutrients, notably DIP and ammonia. If conditions are appropriate, the benthic algae can uptake the complete sediment release of a nutrient and still remove nutrients from the overlying water column. Incorporation of benthic algae into the WQM improved the calibration by muting sediment releases at certain locations and increasing the uptake of nutrients from the water column.

Model predictions for DIP for the bottom transect agree well with observed data. Again the holes and dredged borrow pits have elevated levels of DIP which the model captures. Model results for surface water dissolved organic phosphorus indicate that the model slightly overpredicts in Caño Martín Peña but does well in the remainder of the system. Overall, transects for total phosphorus demonstrate that the model tracks well with the observed data for both surface and bottom waters throughout the system.

Dissolved Oxygen

Observed data for the surface water dissolved oxygen (DO) transect indicate that levels are relatively high throughout the system with the exception of Caño Martín Peña. The least variability in DO is observed at the stations located at the mouths of San Juan Bay and Laguna La Torrecilla. These locations are the most influenced by the ocean and therefore reflect ocean conditions of constant salinity, temperature, and low levels of algae. Model predictions for DO decrease slightly along the transect between the mouth of San Juan Bay and Caño Martín Peña. Averages for observed data at stations SJB-3 and SJB-5 are higher than model predictions along the surface but the range of observations overlap the range of model predictions. The highest of the observed DO concentrations exceed saturation and are indicative of the diurnal effects of algal photosynthesis. The inability of the WQM to capture DO supersaturation at these stations is probably due to the fact that ICM does not incorporate diurnal effects in the algal process computations.

Model surface calibration average and range match observed data well in Caño Martín Peña. Observed data in this region indicate large fluctuations in DO which the model is able to capture. Model surface DO levels increased in eastern Caño Martín Peña as a result of algal photosynthesis. Calibration averages were slightly higher than observed data averages in Laguna San José and Canal Suárez; however, the range of model predictions encompassed the observed averages.

Bottom water model calibration results indicate numerous locations with anoxic conditions. Portions of Caño Martín Peña are anoxic on the bottom due to high DO demands exceeding reaeration. Additionally, holes and dredged borrow pits are anoxic as a result of sediment releases of ammonium in addition to poor circulation and exchange with the aerated surface waters. Sediment oxygen demand (SOD) also removes DO from the water column but only in areas where the water has DO. Consequentially, locations with high SODs are also locations where the bottom water is not anoxic but instead has adequate DO.

Fecal Coliform

The only source of fecal coliform bacteria in the model is from external loads. Once introduced to the system, fecal coliform can only be transported and die. Highest fecal coliform levels are found near the loading sources. The highest fecal coliform observation occurred in the interior of the system in Caño Martín Peña and western Laguna San José. Transect plots indicate that model output matches observations well for both the average and range throughout the system.

Total Suspended Solids

Total suspended solids (TSS) include both inorganic and organic suspended solids. TSS plots indicate that the model performs well along the transect. Model predictions are higher than observations at MP-2 but match observations at the closest two stations MP-1 and SJ-2. The dominant feature of the surface transect is the spike at km 8. This spike results from the Rio Piedras sediment load. As indicated by the plot, this load is disseminated rapidly in the system. The plot for the bottom transect indicates that the model performs well in the interior of the system but tends to be low in San Juan Bay and Laguna La Torrecilla.

Benthic Algae

ICM has no mechanism for the transport, transplantation, or propagation of benthic algae from one cell to another. Consequentially, benthic algae exist at the sediment water interface of every water column in the model. If the light or nutrients are inadequate, the algae are dormant and have no effect on water quality or sediment processes. Where nutrient and light levels are conducive the algae grow. The kinetic processes of benthic algae are similar to those of phytoplankton which were described earlier in Chapter 4. Specific information of benthic algal processes can be found in Cerco and Seitzinger (1998). As indicated in Figure 7-5, the presence of benthic algae in an appreciable amount is limited to relatively few locations along the transect. Nutrients are abundant for the length of the transect and throughout the SJBE system. However light at the sediment water interface is adequate at only a few locations. Most locations along the transect are too deep and the light extinction too high for appreciable levels of light to penetrate to the sediment water interface. The highest benthic algae biomass levels were at the mouths of San Juan Bay and Laguna La Torrecilla where levels approaching 20 g C/m^2 were computed. Light extinction at these locations is low as a result of water clarity and low chlorophyll levels. Adequate nutrients from the interior of the system are also available which allow the benthic algae to thrive. Two locations in the interior of the system, one in Laguna San José and one in Canal Suárez, also have elevated levels of benthic algae. Both of these locations are shallow and represented in the model as one layer deep. Benthic algae at the Laguna San José location receive ample nutrients from Caño Martín Peña while the Canal Suárez benthic algae receive nutrients exiting from Laguna San José via Canal Suárez.

In Laguna La Torrecilla and Caño Martín Peña there are locations where the benthic algal biomass is between 0.1 gm C/m^2 and 2 gm C/m^2. Even at these levels the algae play an important role in the water quality of the system. At all locations along the transect where benthic algae are growing, it is sequestering sediment nutrient releases notably ammonium and phosphate. At these locations the sediments are sinks for ammonium and phosphate while at the locations where benthic algae are dormant the sediments can be sources.

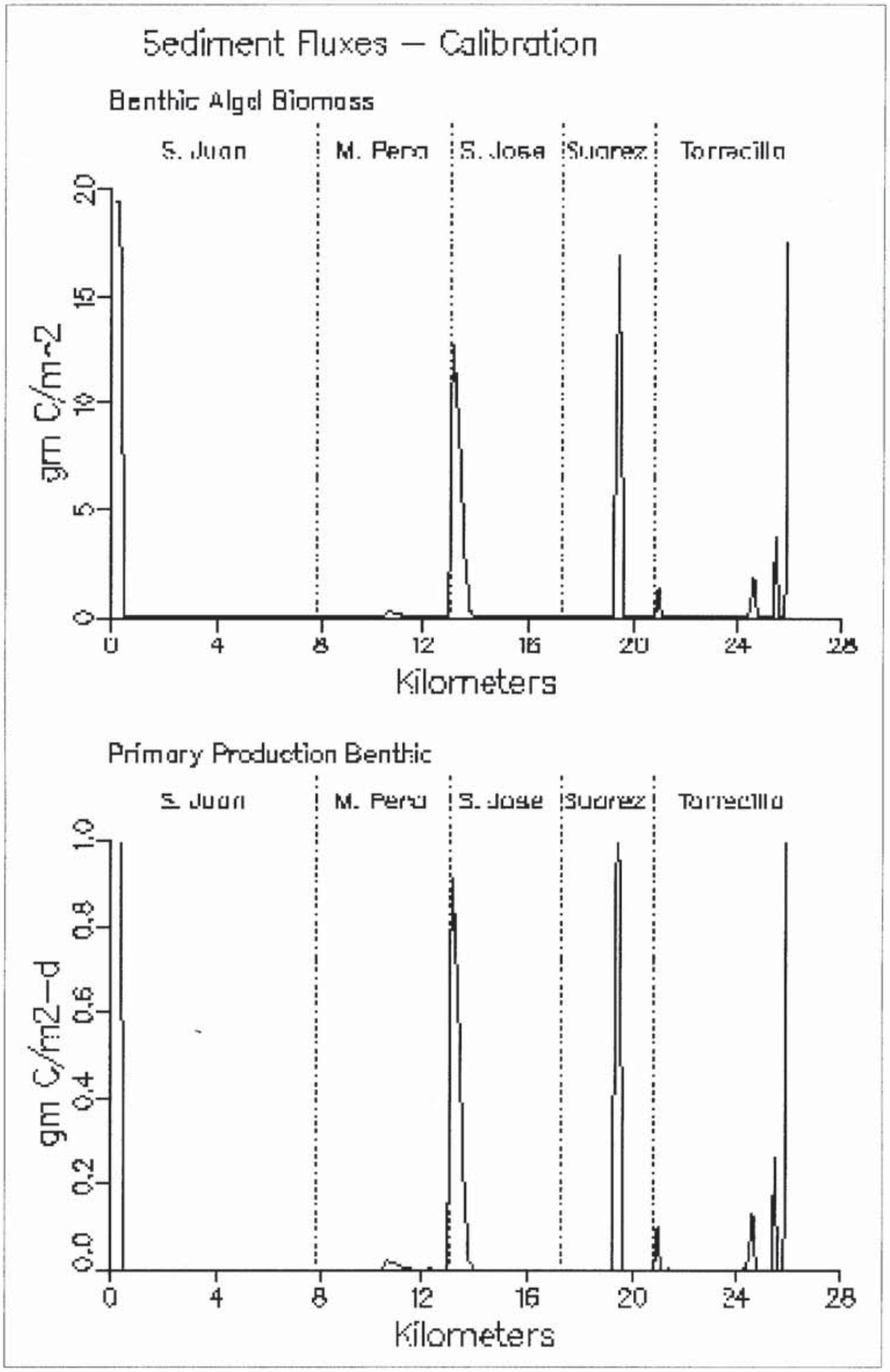


Figure 7-5. Longitudinal transect calibration period average benthic algae

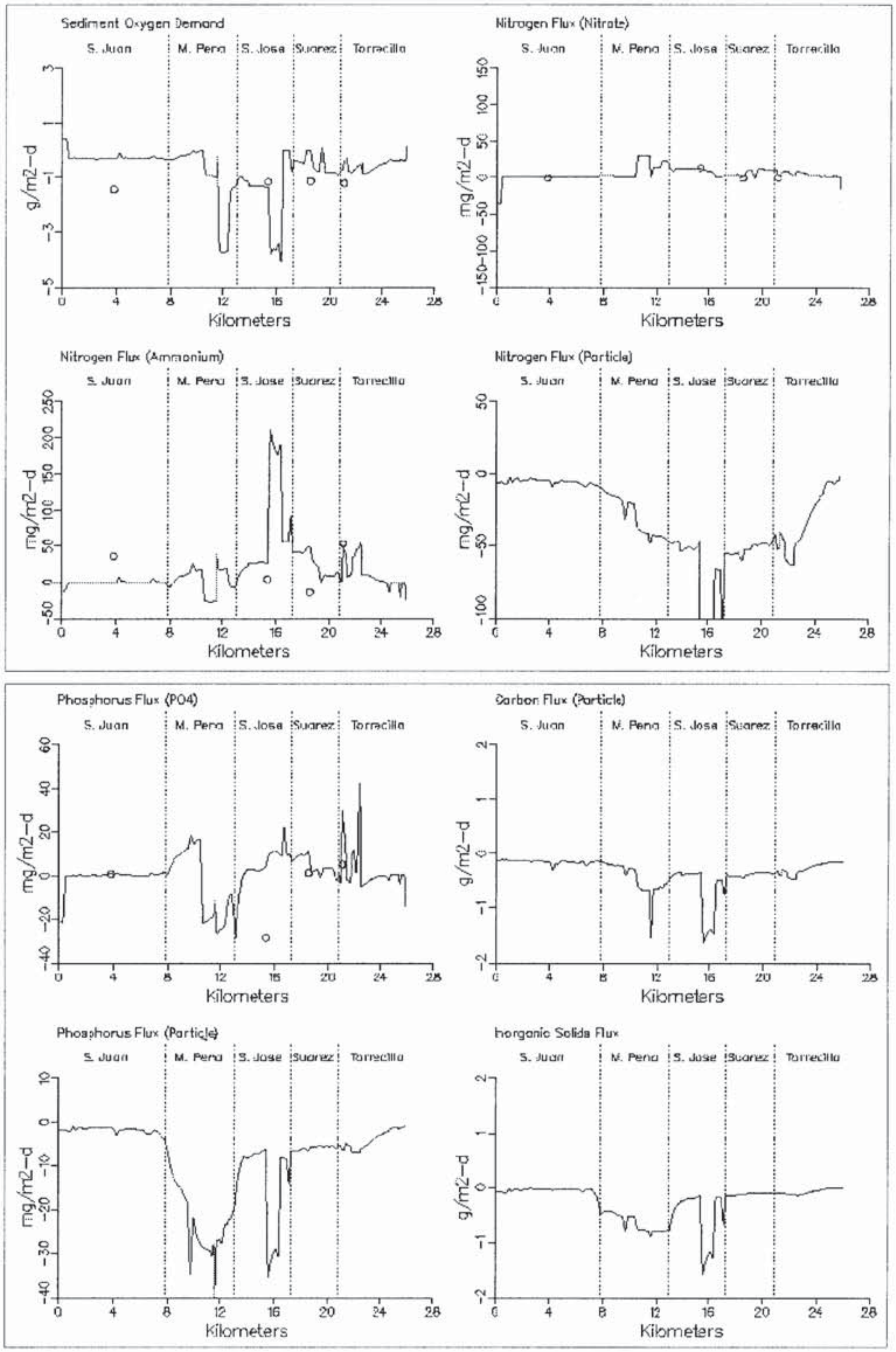


Figure 7-6. Longitudinal transect calibration period average sediment fluxes

Sediment Fluxes

Calibration period averages for sediment fluxes along the transect are shown in Figure 7-6. Negative values indicate that there is a transfer from the water column to the sediment while positive values indicate that there is a transfer from the sediments to the water column.

The calibration period average for sediment oxygen demand indicates that except for Caño Martín Peña and Laguna San José the sediment oxygen demand was between 0 and -1 gm/m^2 -day. In eastern Caño Martín Peña and eastern Laguna San José the sediment oxygen demand increases to -4 gm/m^2 -day. These high sediment oxygen demand rates occur in the vicinity of holes and borrow pits which have limited flushing. An oddity of sediment oxygen demand is that there must be oxygen present in the water column for the sediment oxygen demand to have a value as the sediment oxygen demand is indicative of the *transfer* of oxygen from the water column to the sediments. The processes that create a sediment oxygen demand continue in the absence of water column dissolved oxygen. Under these conditions, the demand is transported to the water column as a chemical oxygen demand. Consequently, the highest sediment oxygen demands are in the areas adjacent to the anoxic holes and borrow pits. The sediment oxygen demand in the cells comprising the anoxic pits and borrow holes are 0 gm/m^2 -day. On both ends of the transect and at one location in Canal Suárez, the sediment oxygen demand was greater than 0 gm/m^2 -day which is indicative of the sediments being a dissolved oxygen source (i.e. releasing dissolved oxygen to the water column). Conditions at these locations (adequate light and nutrients) are conducive to benthic algal growth and photosynthesis which is the source of the dissolved oxygen.

Sediment ammonia fluxes along the transect varied from -25 mg/m^2-day to 200 mg/m^2-day. Locations where the ammonia flux was negative are due to the presence of active benthic algae which are taking up ammonia releases from the sediments and ammonia from the water column. Sediment fluxes for Caño Martín Peña, Laguna San José, and Canal Suárez indicate that the sediments in the interior of the system serve as an ammonia source. The highest fluxes tend to be associated with holes and borrow pits in which dissolved oxygen is low or absent.

The highest nitrate fluxes occur in the central portion of Caño Martín Peña on the western end of the undredged eastern portion. Fluxes approaching 30 mg/m^2 -day were predicted for this location. Lower positive fluxes were predicted along the remainder of the transect through Laguna San José, Canal Suárez, and Laguna La Torrecilla.

Particulate nitrogen flux results indicate that the Caño Martín Peña, Laguna San José, Canal Suárez, and Laguna La Torrecilla all are sinks for particulate nitrogen. The bathymetry of this portion of the system when combined with the proximity of the tributary and anthropogenic loads results in the high level of deposition occurring.

Phosphorus sediment flux plots had many similarities to the nitrogen sediment flux plots. Benthic algae located at the mouths of San Juan Bay and Laguna La Torrecilla cause the sediments at these locations to be phosphate sinks. There is little sediment flux of phosphate is San Juan Bay due to the low deposition rate of particulate phosphorus at this location and to the oxic bottom dissolved oxygen levels. The sediments of the dredged western end of Caño Martín Peña are a source of phosphate for the water column while the undredged eastern end is a sink. The bottom waters of the western end have low dissolved oxygen or are anoxic which contributes to the sediment phosphorus release. The eastern end of Caño Martín Peña has high dissolved oxygen due to reaeration and its shallow depth. In addition, this reach of Caño Martín Peña receives the un-sewered loads. These factors combine to cause the eastern part of Caño Martín Peña to act as a sink for dissolved inorganic phosphorus. The water column of Caño Martín Peña has the highest levels of dissolved inorganic phosphorus found in the SJBE system. Most of this phosphorus originates with the un-sewered and lateral inflow loads into Caño Martín Peña. Elevated dissolved inorganic phosphorus flux rates occur in eastern Laguna San José and Laguna La Torrecilla in the vicinity of hypoxic pits and dredge borrow pits.

Time Series Comparisons

Located in Laguna Los Corozos, which is in the northern portion of Laguna San José, is station SJ-1 (see Figure 2-1). This portion of the bay is the receiving water for the Baldorioty de Castro Pump Station. ICM results for temperature agree well with observations at SJ-1 for the duration of the calibration period, Figure 7-7. Surface salinity results indicated that ICM agrees favorably with the first three observations but slightly underpredicts observations at the end of the calibration period. ICM chlorophyll results agree well with the first four observations but are much lower than the fifth observed concentration of 92 mg/l. ICM results agreed well with surface ammonium and nitrate observations for SJ-1 which were low for the duration of the calibration period. The time series plot for total nitrogen indicates that overall the model is performing adequately for nitrogen at this station. Dissolved inorganic phosphorus results from ICM underpredict the first two observations but agree well with the last three. Time series of total phosphorus indicate that the model performs adequately.

Algal growth in the surface layer is limited by nitrogen availability more so than phosphorus. The average concentration of 0.01 mg/l of phosphorus available is more than adequate to maintain algal levels at their current state. Under some conditions, nitrogen is even more limiting than light at this location. Occasionally nitrogen limitation on algal growth relaxes when large flows and accompanying loads are discharged from the Baldorioty de Castro storm water pump station.

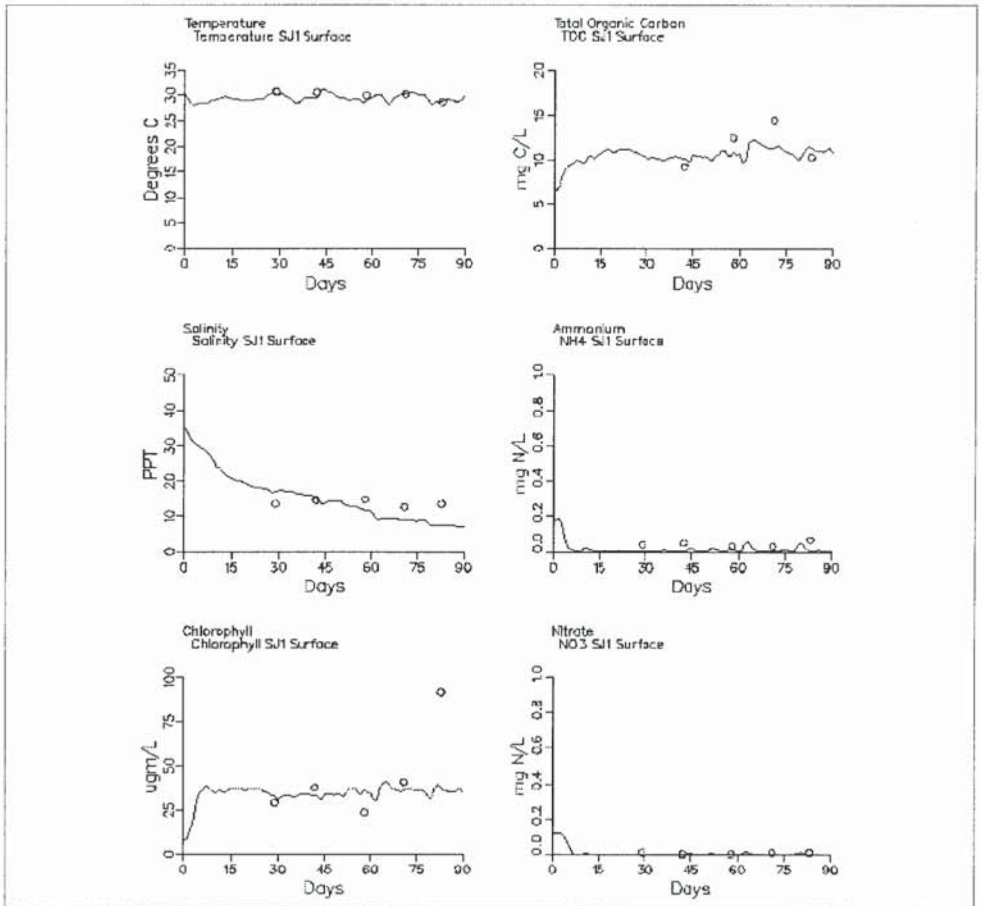


Figure 7-7. Laguna Los Corozos (Northern Laguna San José) calibration period time series (Sheet 1 of 4)

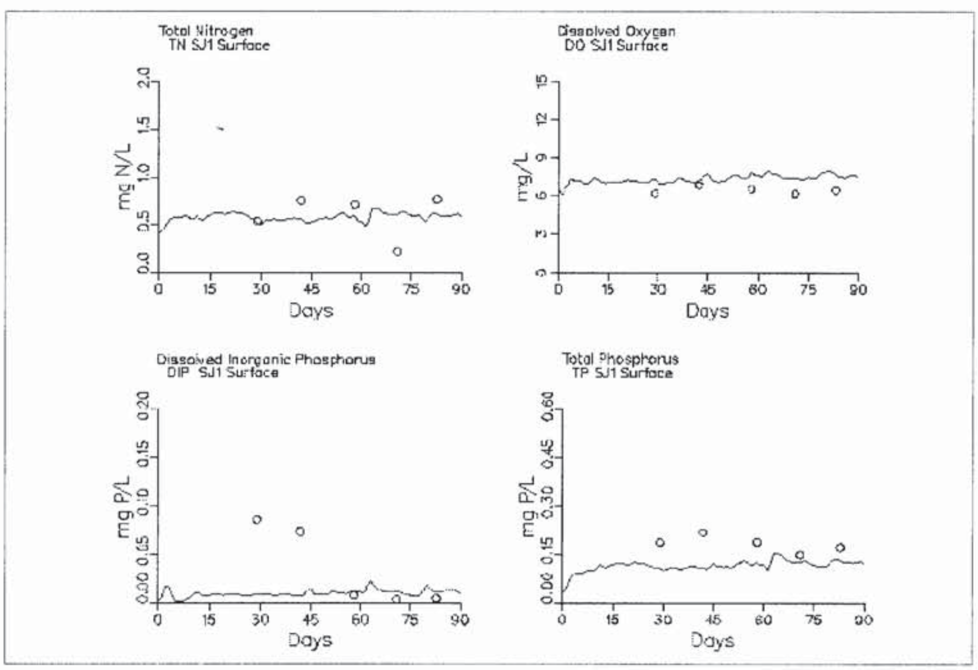


Figure 7-7. (Sheet 2 of 4)

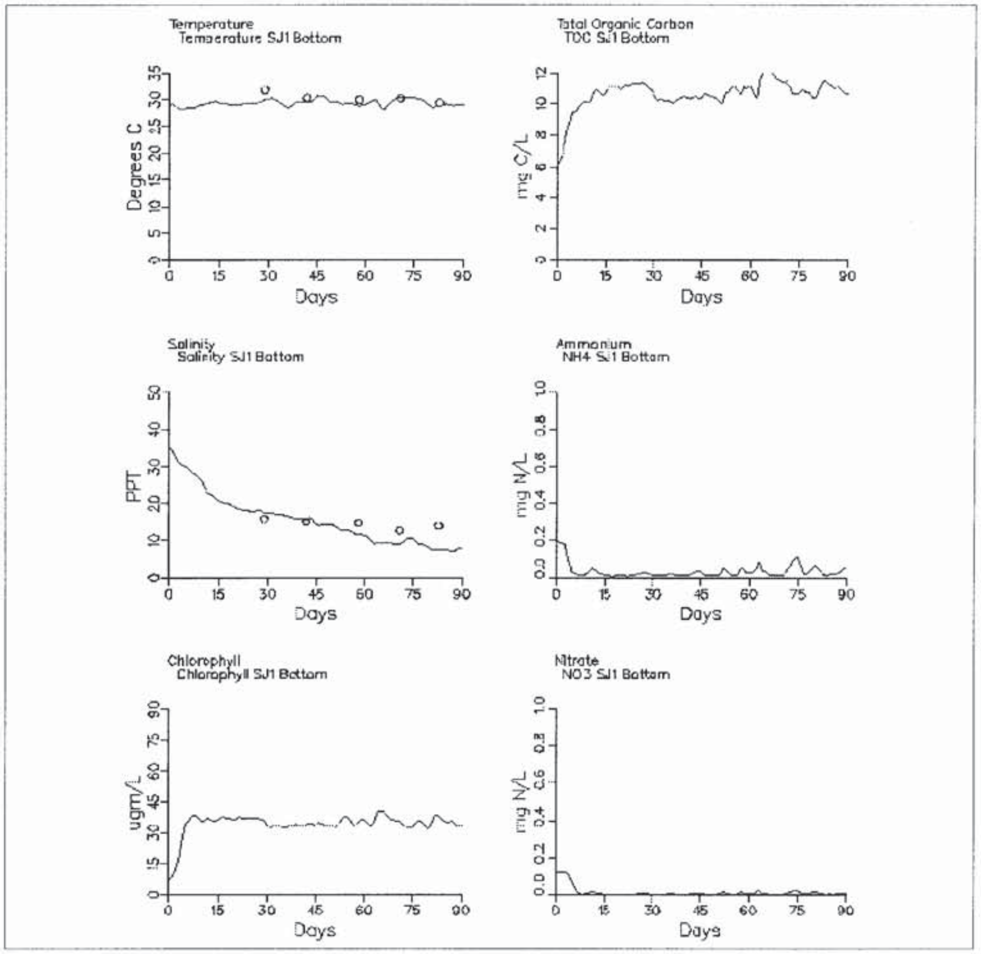


Figure 7-7. (Sheet 3 of 4)

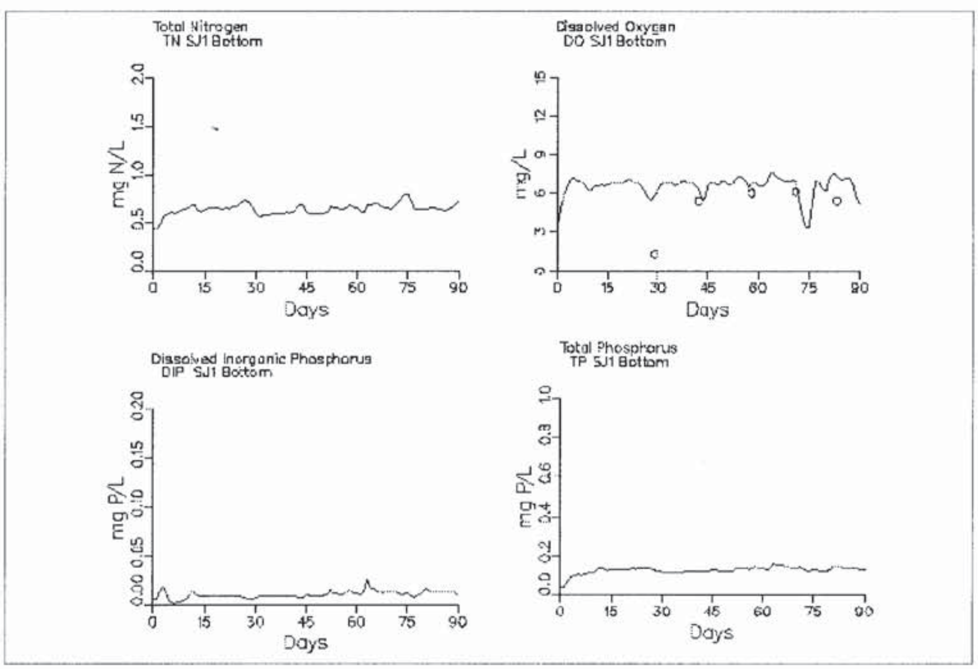


Figure 7-7. (Sheet 4 of 4)

Dissolved oxygen observations are slightly lower than model predictions in the surface layer. The model predictions are near saturation for the salinity and temperature conditions in this system. Sampling results indicate that the surface water dissolved oxygen was consistently around 6 mg/l. Both the model and the observed data indicate that dissolved oxygen levels are relatively high in spite of the high organic carbon concentrations. Algal photosynthesis maintains surface dissolved oxygen levels near saturation for the temperature and salinity conditions present. Dissolved oxygen results for the bottom layer indicate more variability than the dissolved oxygen in the surface layer. The observed data indicate that there was little difference in surface and bottom dissolved oxygen on four of the five sampling dates. This observation when combined with the salinity and temperature surface and bottom time series observations indicate that there is little stratification at this location.

Time series plots for station MP-2 located in Caño Martín Peña are shown in Figure 7-8. This station is located midway between San Juan Bay and Laguna San José at the eastern end of the dredged channel. Water quality at this location is affected by the conditions in Laguna San José, eastern Caño Martín Peña, the Caño Martín Peña watershed, and San Juan Bay.

ICM results for surface water temperature at MP-2 matched observed values well. Temperature predictions for the bottom layer were slightly higher than the observations. Surface salinity observations varied from 17.1 to 32.7 ppt. ICM surface salinity results also indicated significant variation but were still less than the observed data. Salinity swings of 10 ppt were repeatedly predicted at MP-2 during calibration. The timing of these salinity swings corresponds with the occurrence of increases in runoff in the Caño Martín Peña watershed in response to a storm event, Figure 3-3. It must be noted that the ICM results are daily averages while the salinity observations are instantaneous. As such, a portion of the difference between the ICM results and the observed salinities could be attributed to timing.

Bottom salinity observations at this station ranged from 35.4 to 37 ppt during the calibration period. Salinity observations this high indicate that salt water is intruding along the bottom of Caño Martín Peña. Station MP-2 is located near the farthest extent of the intrusion as it is at the end of the dredged section of the canal. ICM bottom salinity results, while lower than the observations, are consistently over 30 ppt. Just as with the surface salinity, some fluctuations are evident in response to runoff events in the Caño Martín Peña sub-basin. When both the surface and bottom observations are viewed together, it is evident that the surface salinity is consistently lower than the bottom salinity. This difference is due to the lower salinity "fresh" water from Laguna San José and eastern Caño Martín Peña overriding the denser high salinity water infiltrating up western Caño Martín Peña from San Juan Bay. A review of the salinity transect plots, Figure 7-3, indicates that this salinity stratification continues to the western end of Caño Martín Peña. Rio Piedras inflows aid in keeping the surface salinity decreased in western Caño Martín Peña.

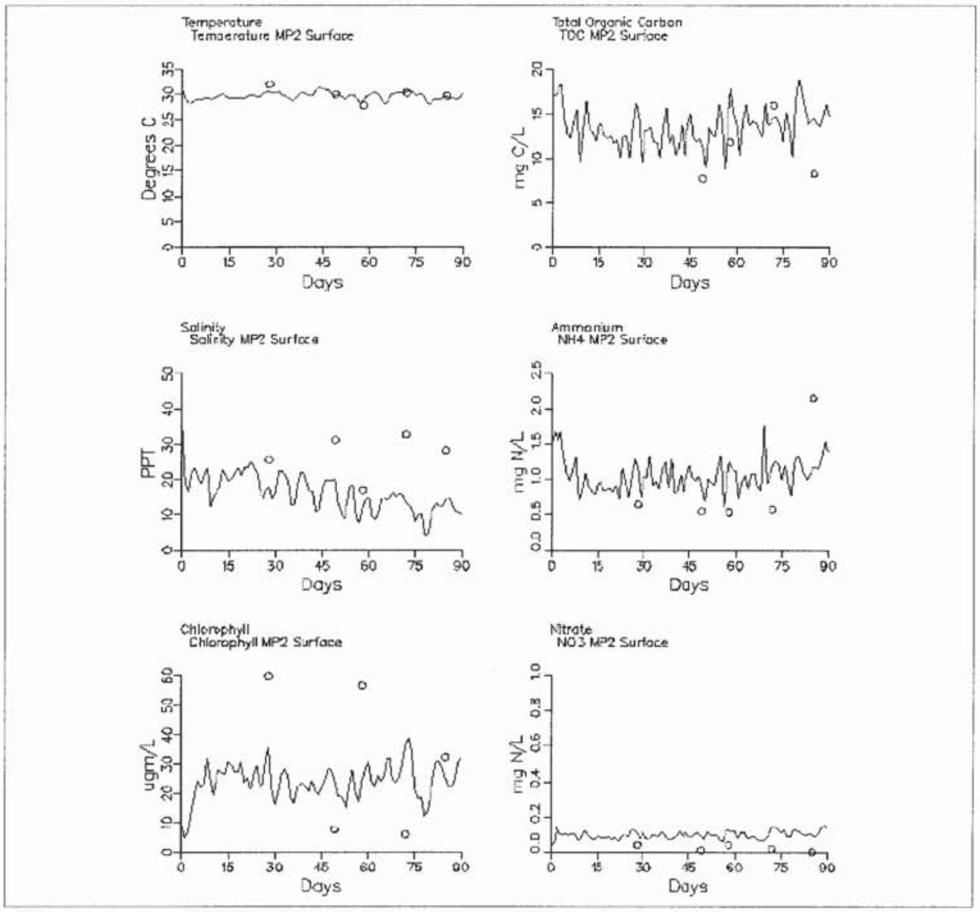


Figure 7-8. Caño Martín Peña station MP-2 calibration period time series (Sheet 1 of 4)

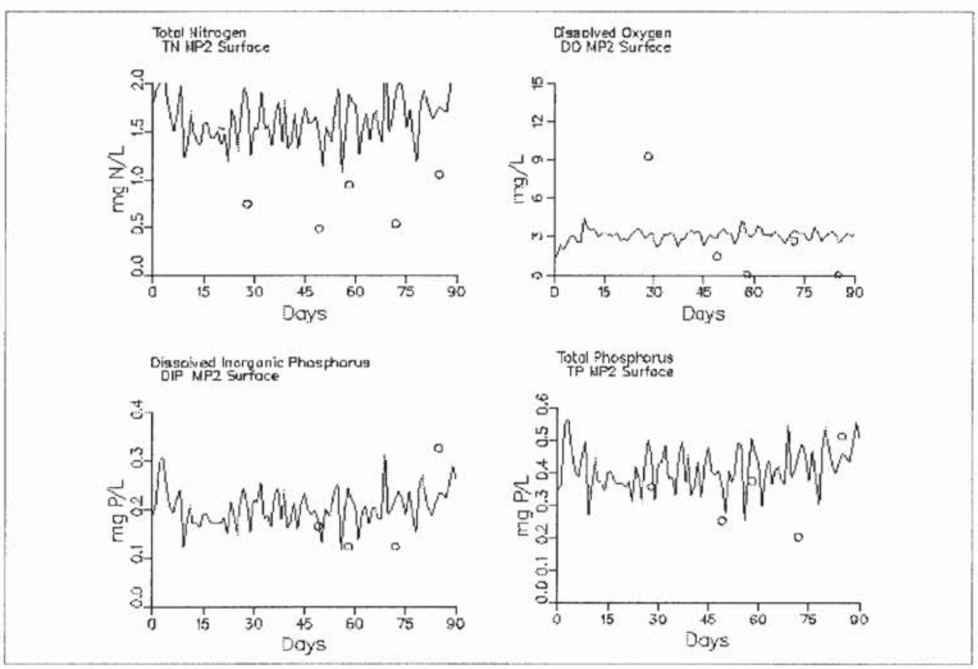


Figure 7-8. (Sheet 2 of 4)

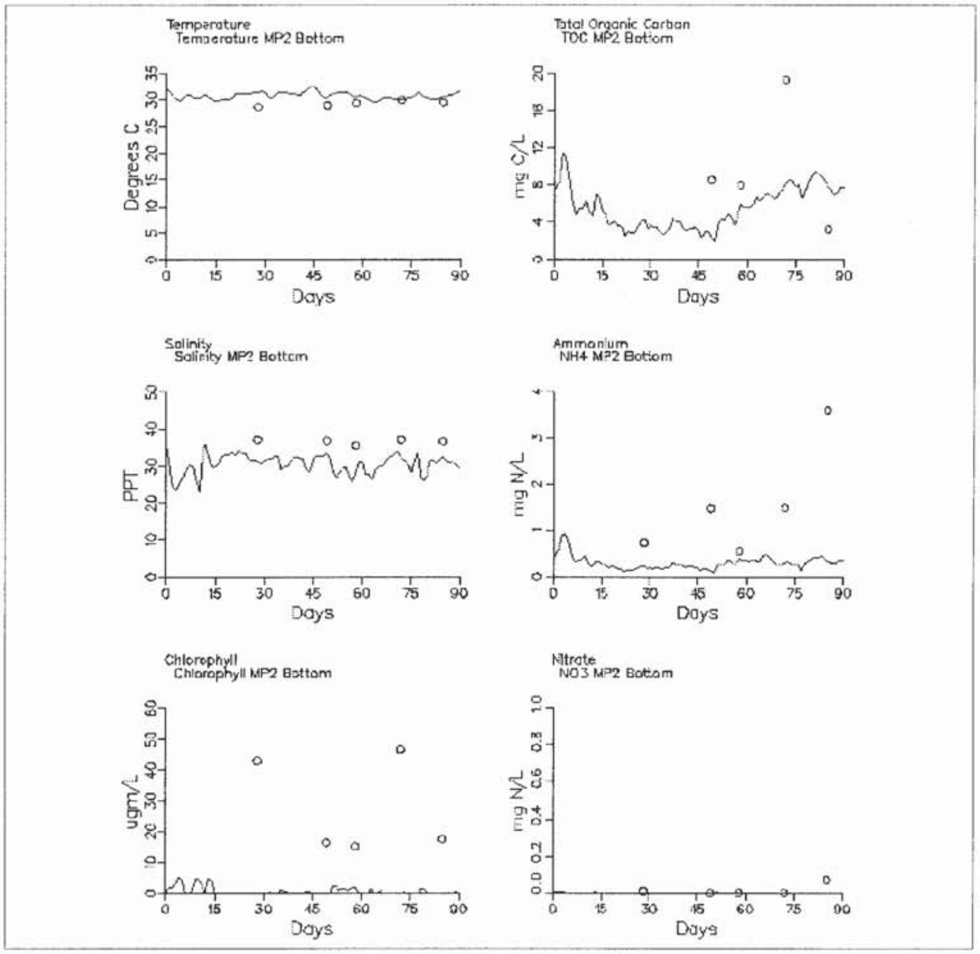


Figure 7-8. (Sheet 3 of 4)

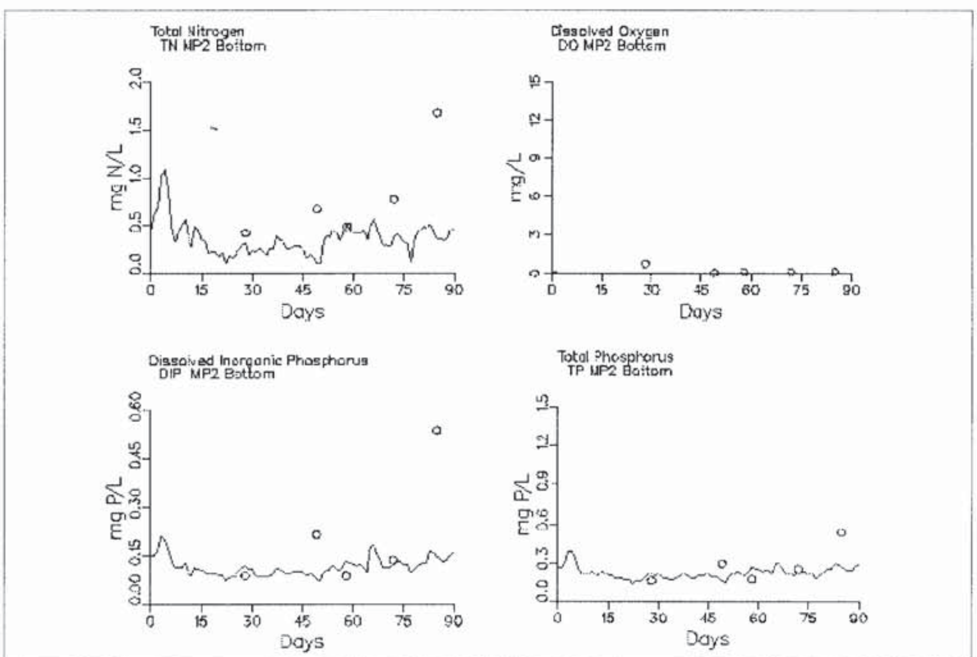


Figure 7-8. (Sheet 4 of 4)

Observed chlorophyll levels at MP-2 varied from 6 ug/l to 60 ug/l. Algae observed at station SJ-2 most likely originate in Laguna San José and are flushed down Caño Martín Peña by runoff-producing events. This is substantiated by the following. The two highest chlorophyll observations at MP-2 correspond to the lowest salinity concentrations. The lowest two chlorophyll observations correspond to the highest surface salinity observations. Runoff events generate higher flows in Caño Martín Peña which transport the chlorophyll quickly past MP-2. High light extinction and resulting low water column light levels in Caño Martín Peña are not conducive to algal growth, so the only way that elevated levels can exist is that they are generated elsewhere. ICM chlorophyll results exhibit significant variation in response to flow conditions. However, they do not indicate the degree of variability seen in the observations. As with salinity, this could be the result of comparing daily average model output with instantaneous observations at a location where things are sensitive to tidal action and flow conditions. Bottom chlorophyll observations exhibited significant variation too. Observations ranged from 15 ug/l to 47 ug/l. ICM chlorophyll results at this location are low. The only means by which algae can reach the bottom waters at station MP-2 are settling or transport with the intruding salt water. There are ample nutrients in the water to support algae but negligible light. The absence of light results in algal mortality before adequate time has passed for the algae to reach this location.

Total organic carbon surface observations ranged from 7.6 to 15.9 mg/l while bottom observations were between 7.9 mg/l and 19.3 mg/l. ICM results for the surface ranged from approximately 9 mg/l to 19 mg/l. The ICM results exhibited considerable variation in response to tidal action and eastern Caño Martín Peña flows but were representative of the observations. ICM bottom total organic carbon results were lower than the surface results and tended to be lower than the observed data. This is expected since the chlorophyll predictions were low at this location.

Observed ammonium levels in the surface water were elevated. Four of the observations were between 0.54 mg/l and 0.68 mg/l while the fifth was 2.15 mg/l. ICM results showed considerable fluctuation in response to hydrodynamic conditions but overall were representative of the observed data. Bottom water ammonia predictions were lower than the observations but still relatively high. Ammonium sediment flux rates at this station average 25 mg/m^2 day. Since the surface water ammonium levels are higher than the bottom water levels and the sediment flux of ammonia is not huge, it appears that the source of the ammonium in the surface water at MP-2 is eastern Caño Martín Peña. Little nitrate is found in the water at MP-2. ICM surface nitrate levels at MP-2 were slightly higher than the observations which were in the 0-mg/l to 0.04-mg/l range. ICM bottom nitrate predictions for MP-2 were essentially 0 mg/l which matched four of the five observations. Sediment nitrate fluxes at MP-2 were essentially 0 mg/m^2 day. Anoxic conditions along the bottom prevent nitrification from transforming ammonia into nitrate.

ICM dissolved oxygen concentrations in the surface fluctuated around 3 mg/l throughout the calibration period. Four of the observations during the calibration period were less than 3 mg/l with two being less than 0.12 mg/l. One observation was in excess of 9 mg/l which was in excess of saturation for the temperature and salinity at that time. A dissolved oxygen level this high results from algal photosynthesis. Bottom dissolved oxygen observations ranged from 0.04 mg/l to 0.79 mg/l. ICM results for bottom dissolved oxygen were 0 mg/l for the duration of the calibration period. When both surface and bottom dissolved oxygen concentrations are considered, ICM does a good job of matching observed conditions. The conditions existing at MP-2 result from two things. First, the high nutrient and organic carbon loading of eastern Caño Martín Peña. These oxygen-depleting substances remove the dissolved oxygen from the water faster than reaeration can replace it. Secondly, its location at the upper end of the dredging allows the waters from eastern Caño Martín Peña to override the denser waters infiltrating from San Juan Bay. Limited mixing between the surface and bottom waters at this location contributes to the dissolved oxygen depletion.

Overall ICM performs well at station MP-2. Conditions at this location are very dynamic. Major influences at this site are two. First is the flow from San José Bay into eastern Caño Martín Peña which is high in nutrients, algae, and oxygen demand. Second is the infiltration of salt water along the bottom of western Caño Martín Peña from San Juan Bay. ICM is able to reproduce many of the conditions observed during calibration even though conditions at this site are continually changing.

Station LC-1 is located in Laguna Condado. Temperature and salinity plots of results indicate that ICM matches observations in LC-1 well, Figure 7-9. Both temperature and salinity at this location reflect offshore conditions. ICM results match surface chlorophyll observations which are low, ranging from 0.5 to 3.2 ug/l. Total organic carbon observations for the surface and bottom exhibit the same behavior which mimics the observations at AO-1.˜ ICM total organic carbon results indicate the same pattern as the observations. Ammonia observations at the surface ranged from 0 mg/l to 0.41 mg/l and from 0 mg/l to 0.6 mg/l at the bottom. ICM ammonia results were low, typically less than 0.05 mg/l in both the surface and bottom. ICM ammonia results were much lower than the extreme observations at this location. The validity of the extreme values at this station is uncertain since they are much greater than the TKN observations. At the end of the calibration period ICM ammonia concentations are increasing in response to increases in the ammonia concentration specified at the ocean boundary. Nitrate levels, observed and computed in ICM, are near or are 0 mg/l for the duration of the calibration period in both surface and bottom waters. ICM dissolved inorganic phosphorus and total phosphorus levels agreed well with observations in both the surface and bottom waters at station LC-1. ICM dissolved oxygen results agreed well with all but one dissolved oxygen observation.

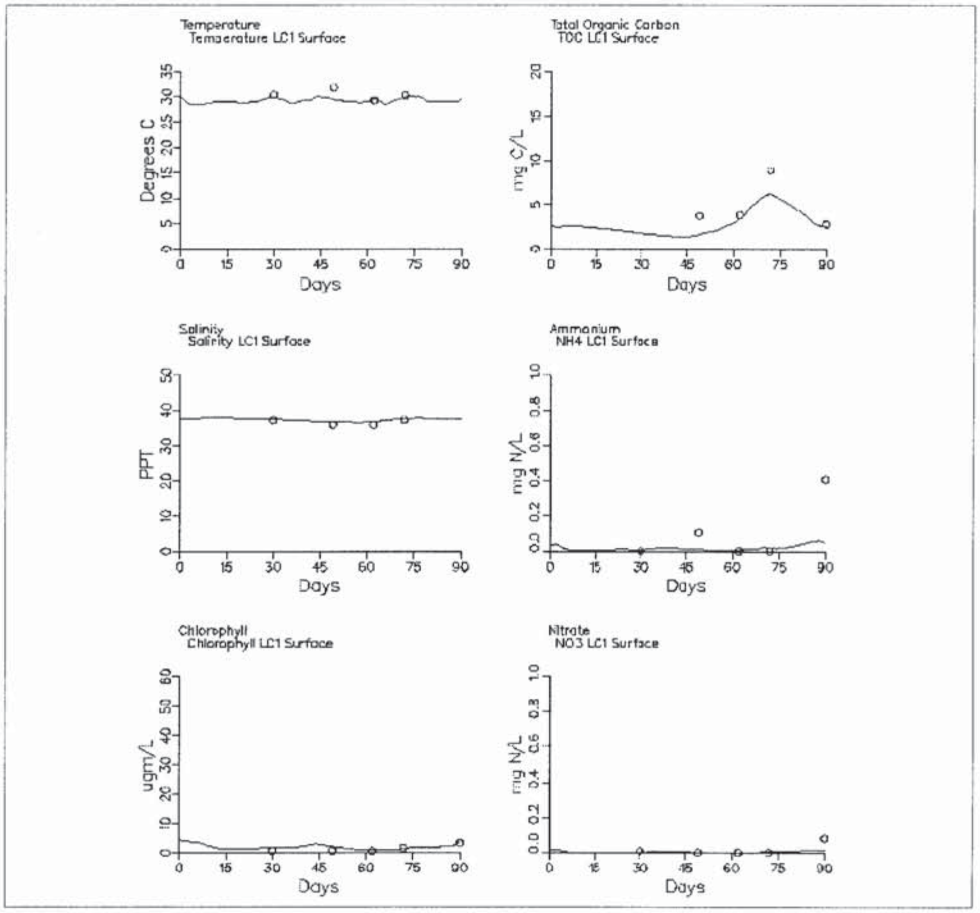


Figure 7-9. Laguna Condado station LC-1 calibration period time series (Sheet 1 of 4)

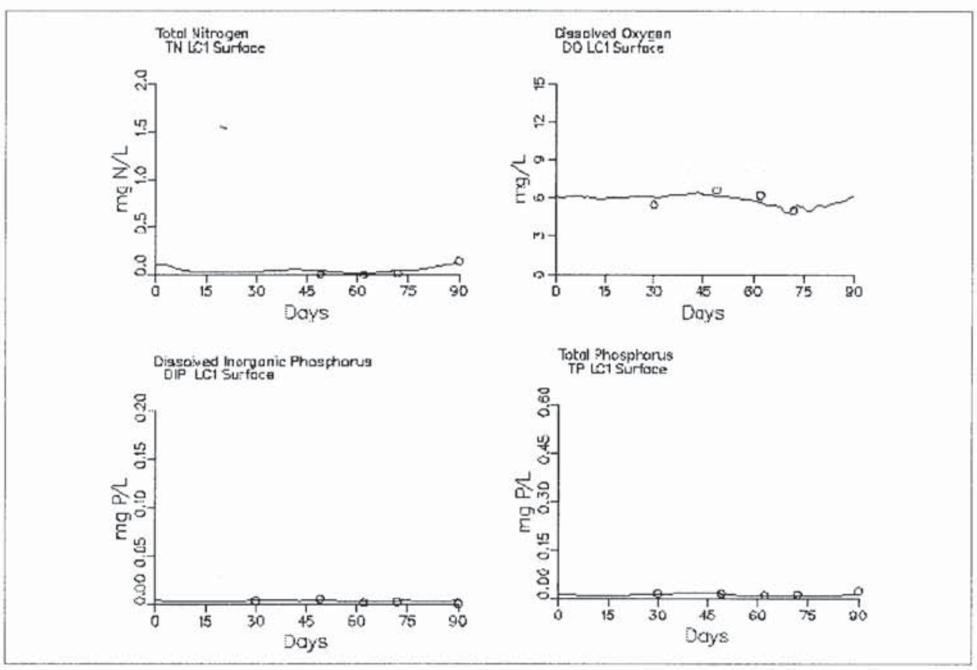


Figure 7-9. (Sheet 2 of 4)

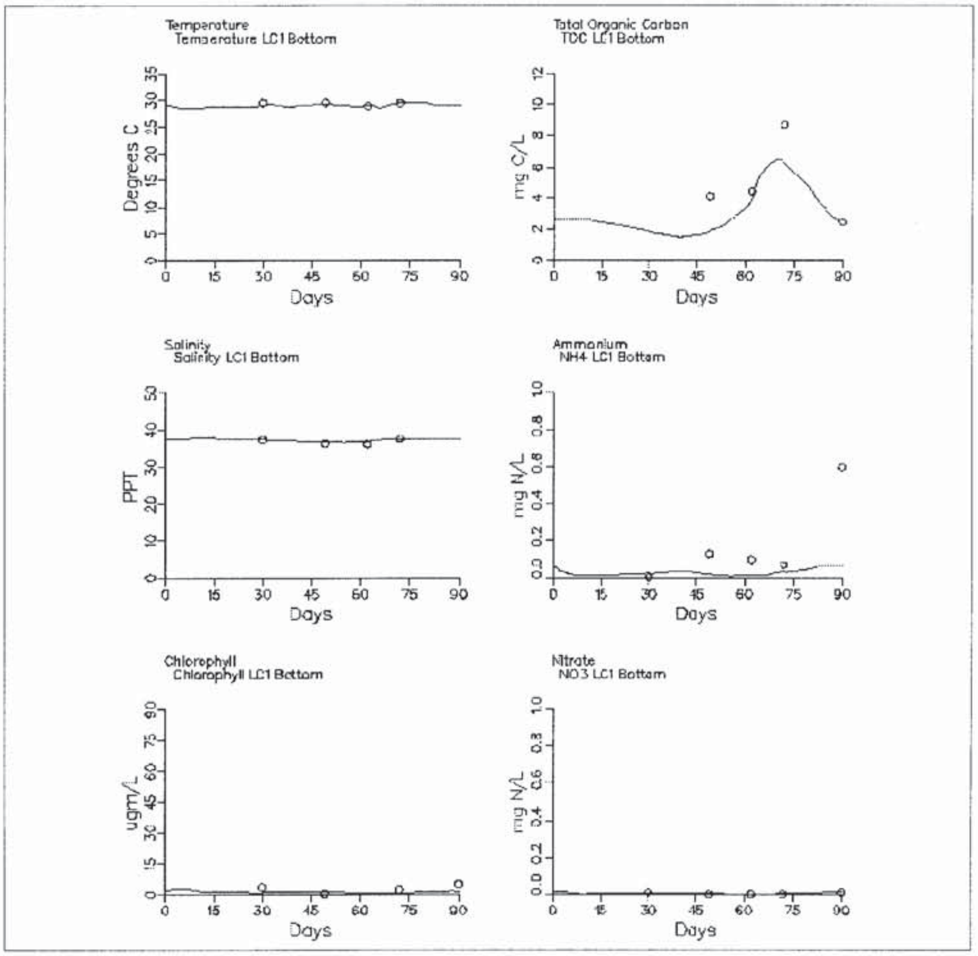


Figure 7-9. (Sheet 3 of 4)

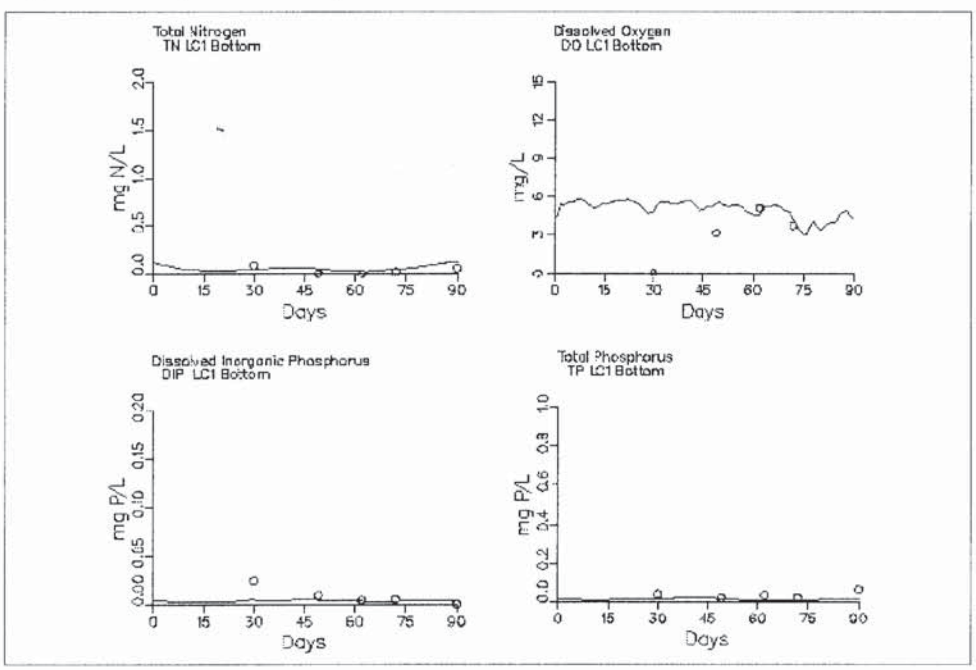


Figure 7-9. (Sheet 4 of 4)

Overall, the results indicate that ICM is performing well at this location. No attempts were made to calibrate ICM for Laguna Condado. A large part of ICM's performance at this location is attributable to the amount of exchange that occurs between Laguna Condado and the ocean. Constituent concentrations in Laguna Condado are similar to those specified at the ocean boundary. This is further evidence of the dominance of offshore conditions on this body.

Station SA-1 is located in Caño San Antonio which lies along the northeast side of San Juan Bay. Temperature and salinity observations in the surface and at the bottom at SA-1 location reflect conditions observed offshore at stations AO-1 and AO-2 indicating a high degree of exchange with the ocean. ICM results for both temperature and salinity correspond well with these observations, Figure 7-10. Surface chlorophyll observations were less than 5 ug/l. ICM chlorophyll results for the surface were typically 2 ug/l or less. Bottom water observations were less than 2.5 ug/l with the exception of one observation which was 17.6 ug/l. ICM results for the bottom of SA-1 indicated that chlorophyll levels were of 1-2 ug/l which agreed well with all but one observation. Total organic carbon surface and bottom observations at SA-1 demonstrated the same behavior observed at the offshore stations AO-1 and AO-2 with an increase in total organic carbon at calibration day 68. ICM results were similar to these observations. ICM results for ammonia, nitrate, and total nitrogen agreed well with both surface and bottom observations at SA-1. Dissolved organic phosphorus and total phosphorus ICM results likewise agreed well with surface and bottom observations at SA-1. Surface dissolved oxygen observations at SA-1 ranged from 5.16 to 9.78 mg/l while bottom dissolved oxygen levels ranged from 3.57 to 4.71 mg/l. As the ranges of observations indicate, the bottom dissolved oxygen concentration was considerably lower than the surface. ICM results adequately matched both surface and bottom dissolved oxygen levels when it is remembered that ICM results are daily averages and do not reflect any diurnal variation due to algal activity.

Laguna de Piñones is one of the major bodies of water in the SJBE system. Its location prevented its inclusion in the transect. Laguna de Piñones is located to the east of Laguna La Torrecilla and resides within a mangrove forest. Laguna de Piñones is connected to the southern end of Laguna La Torrecilla via a narrow canal. The region surrounding Laguna de Piñones is largely undeveloped and the flows and loads it receives are naturally occurring. Laguna de Piñones is shallow and was modeled as one layer in ICM.

Two stations are located in Laguna de Piñones. PL-1 is located in the canal that connects Laguna de Piñones and Laguna La Torrecilla. PL-2 is located on the eastern side of the lagoon. Model results indicate only slight fluctuations in temperature during the calibration period at both stations (Figure 7-11). Salinity predictions are adequate for the first portion of the calibration period but are low by day 90 of the simulation. This is indicative of freshwater flows from the watershed possibly being too high

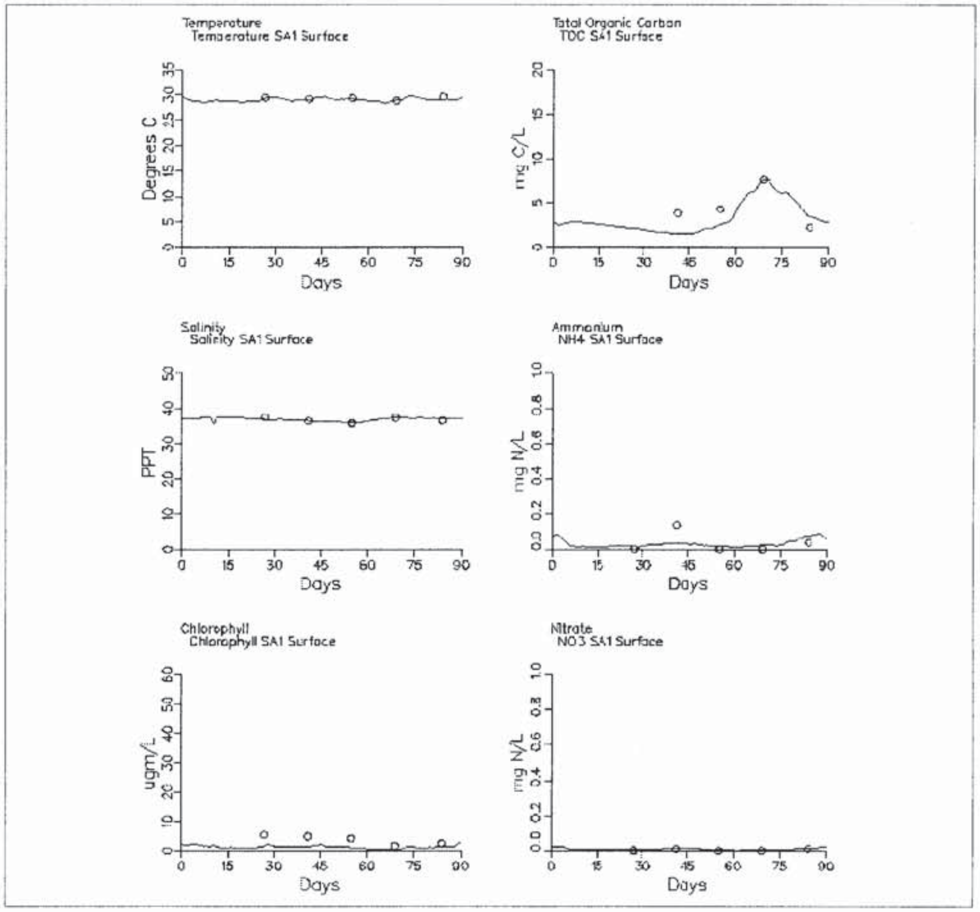


Figure 7-10. Caño San Antonio station SA-1 calibration period time series (Sheet 1 of 4)

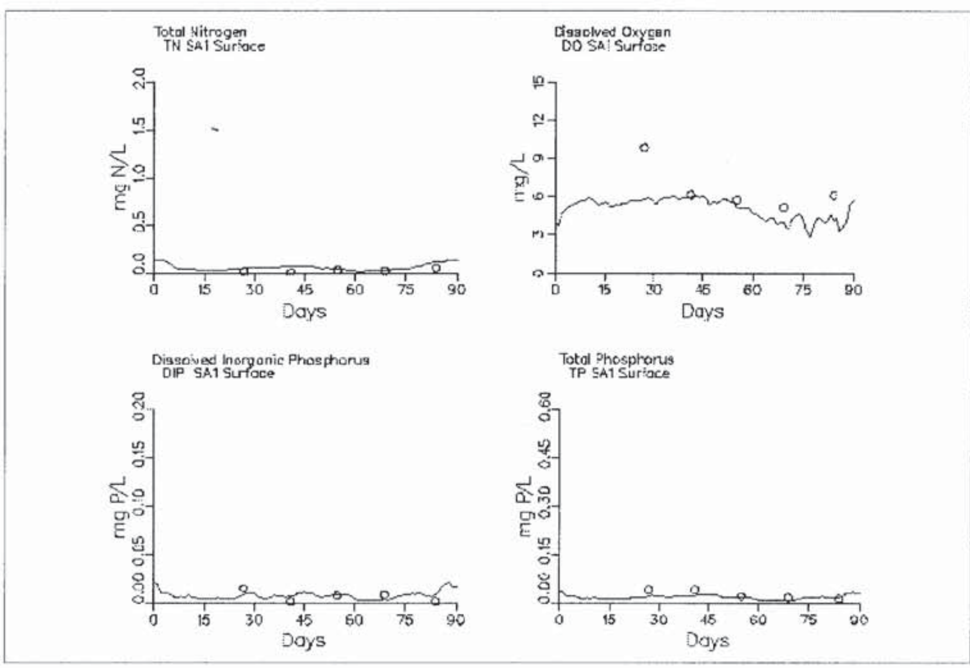


Figure 7-10. (Sheet 2 of 4)

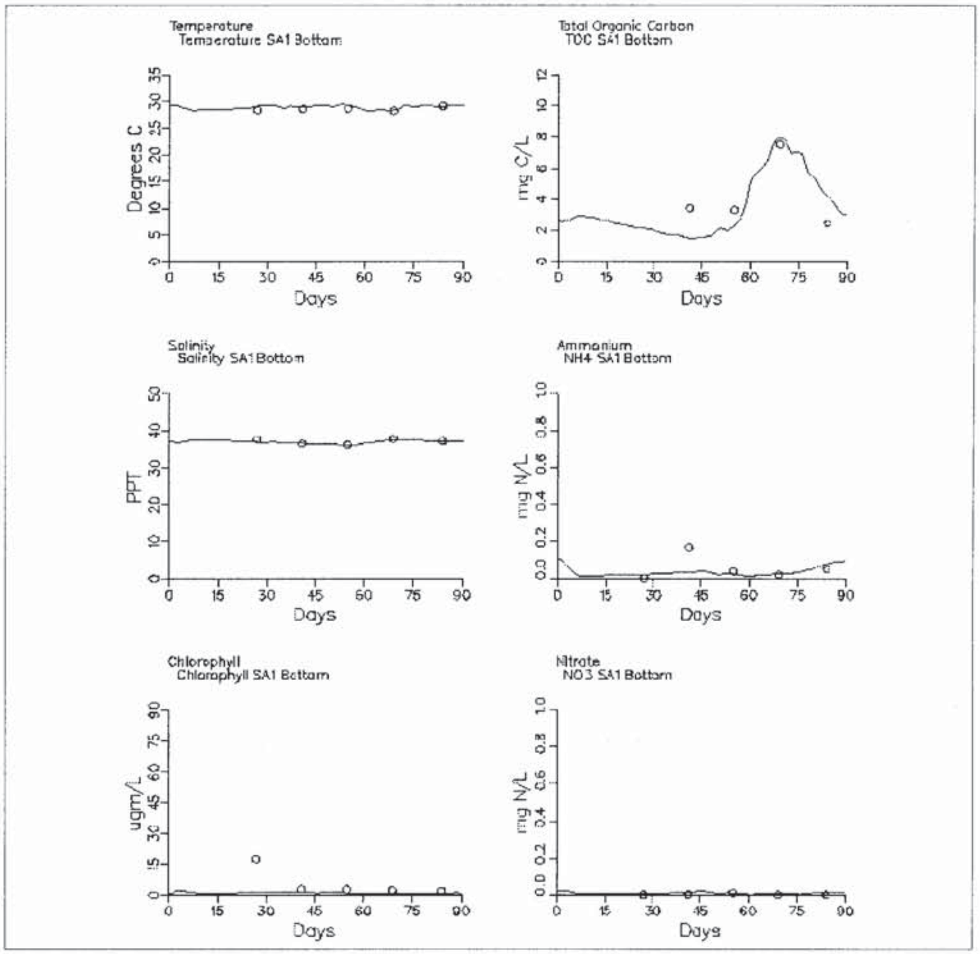


Figure 7-10. (Sheet 3 of 4)

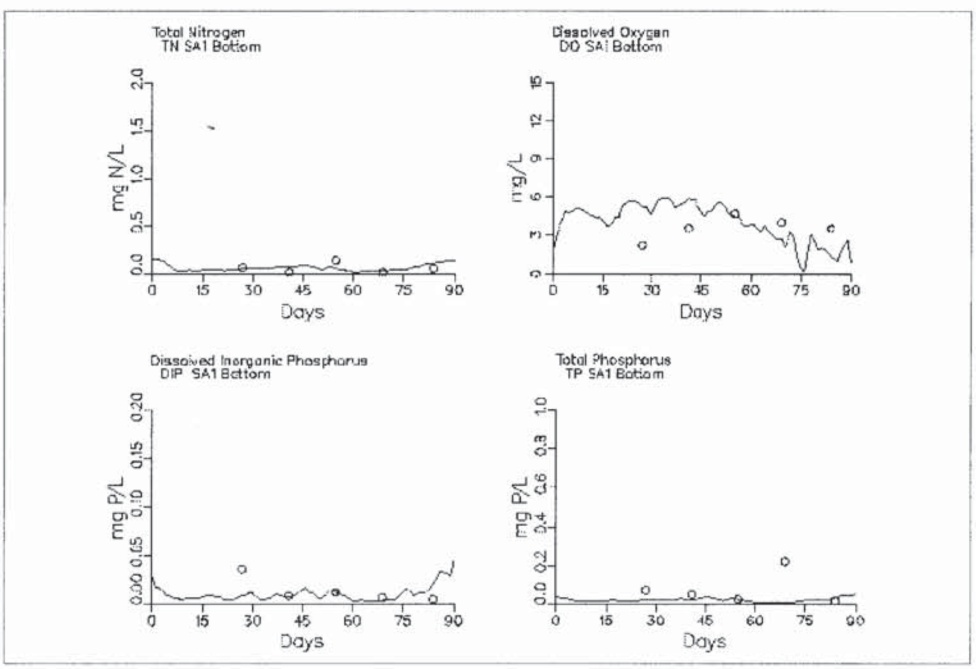


Figure 7-10. (Sheet 4 of 4)

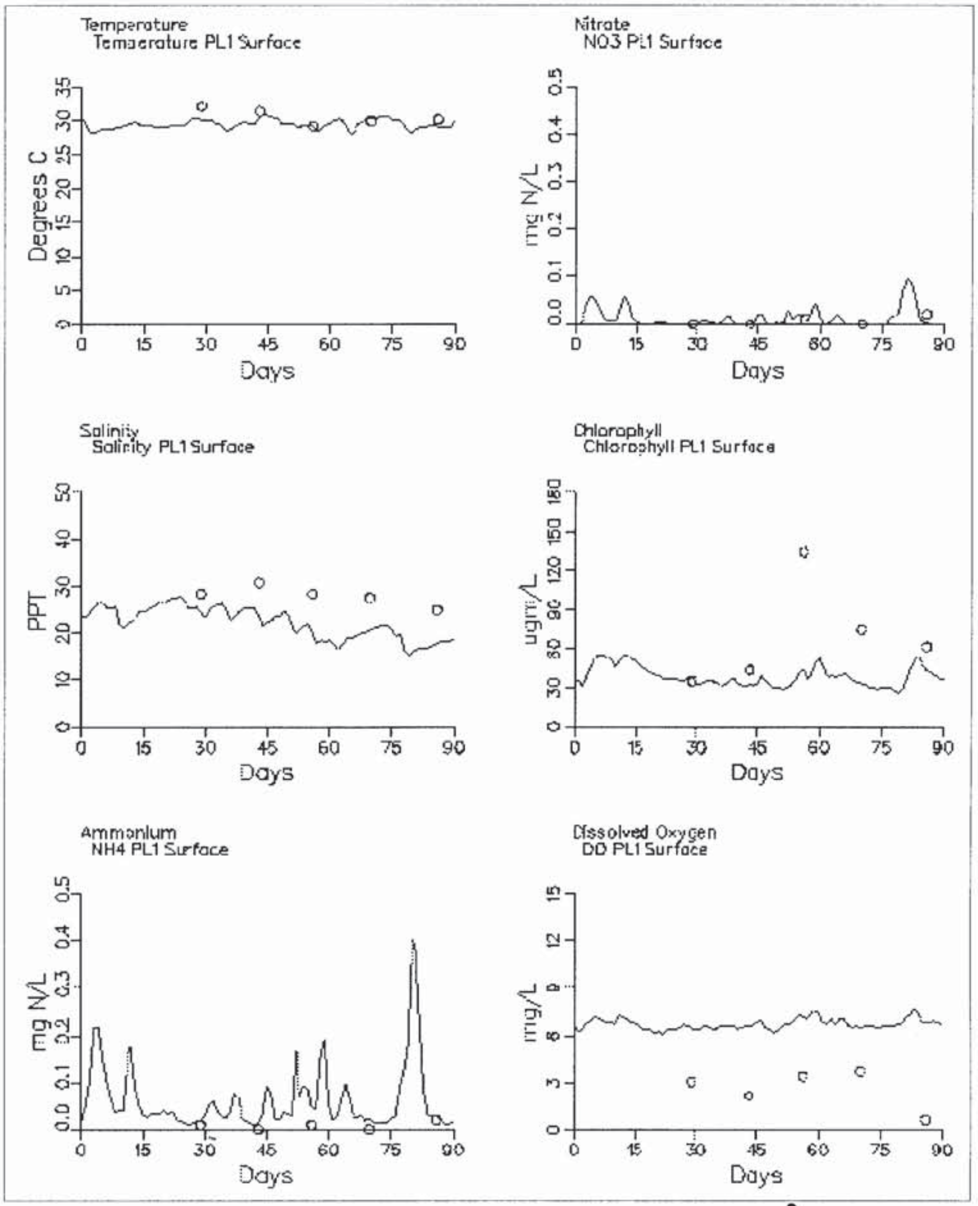


Figure 7-11. Computed and observed water quality variables at stations PL1 and PL2 (Laguna de Pinones) resulting from model calibration for summer 1995 (Sheet 1 of 4)

or too little salt water being able to enter Laguna de Piñones from Laguna La Torrecilla. Early on during calibration it was evident that the original loadings to Piñones were too low. Algae were too low as were nitrogen and organic carbon while dissolved oxygen was too high. Additional loads of nitrogen and carbon were added to the Piñones inflows to compensate for irregular inflow events and possible underestimation of loads. Organic carbon loads were increased from a daily average of 31.4 kg/d to 314.5 kg/day and total nitrogen loadings were increased from 4.5 kg/day to 36.1 kg/day. With these loads model chlorophyll predictions did increase but remained slightly low as a result of nutrient limitations retarding algal growth. Results for ammonium and dissolved inorganic phosphorus

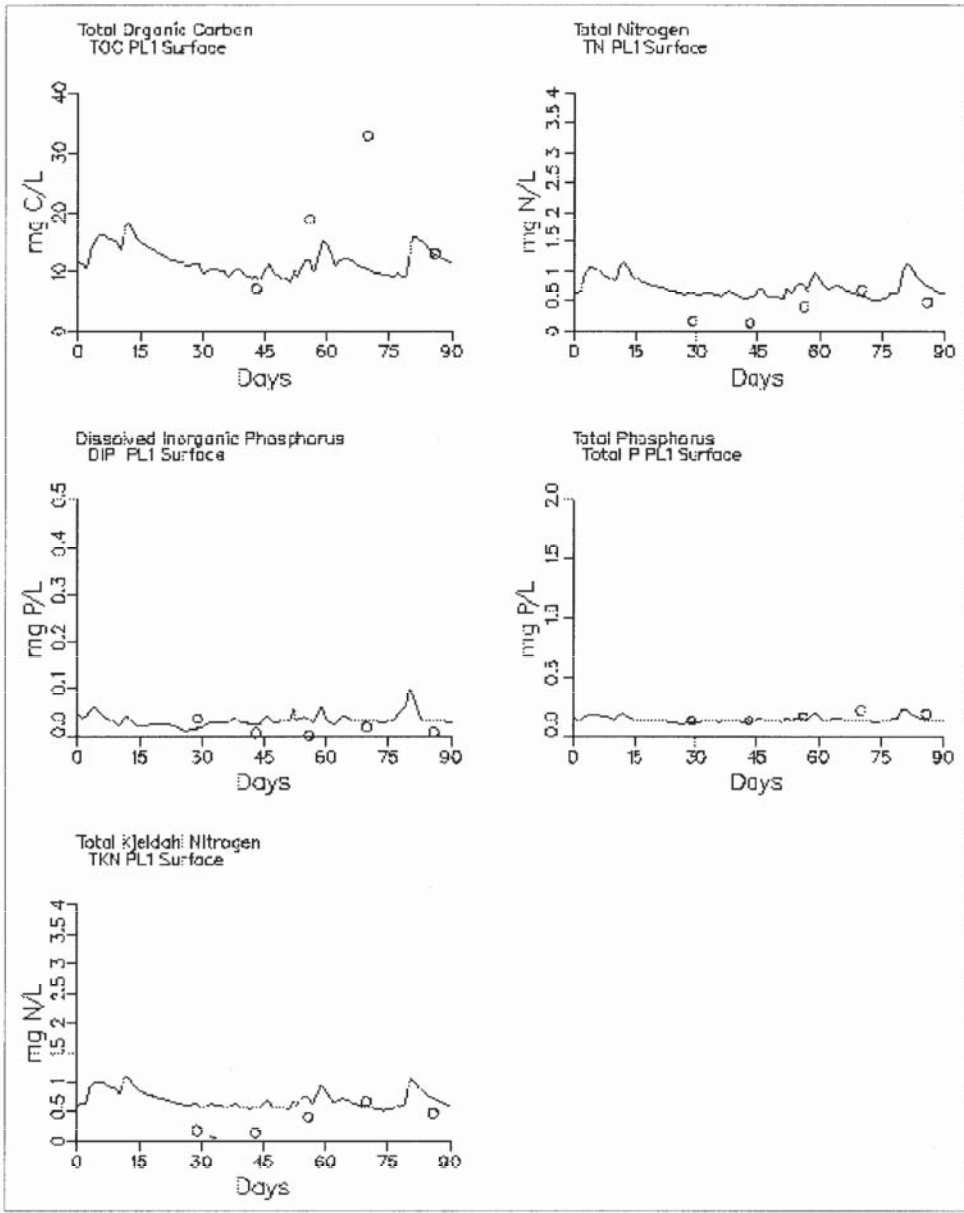


Figure 7-11. (Sheet 2 of 4)

indicate that as soon as a runoff event has deposited these nutrients into the system, algal growth (expressed by chlorophyll levels) increases until the nutrients are removed. At that time, chlorophyll levels cease to increase and actually begin to decrease until the next influx of nutrients occurs. Model predictions for total nitrogen and total phosphorus match the observations well. Model output for total organic carbon underpredicted the observed data continually even with the additional loading. Underprediction of TOC is possibly due to the presence of the mangrove forest which contributes organic carbon. No attempt was made to simulate the effects of the mangroves surrounding the lagoon. Model dissolved oxygen levels remained relatively constant throughout the

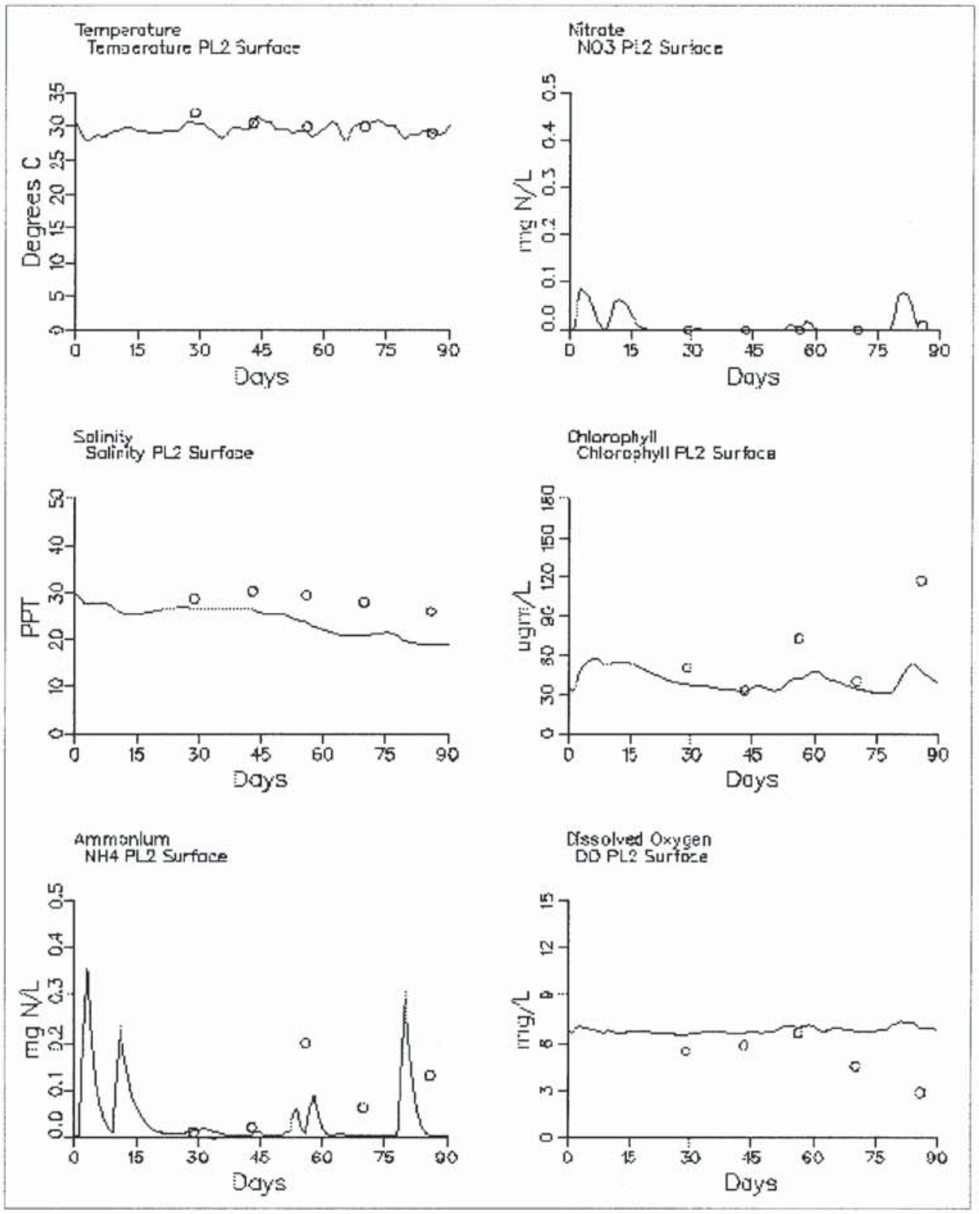


Figure 7-11. (Sheet 3 of 4)

calibration period and are overpredicted compared with observed, especially in the lagoon connecting canal. Possibly SOD is underpredicted due to TOC loadings from the mangroves, or the problem could be related to the inability of the model to resolve thin layers of stratification. Stratified water columns with thin (i.e., < 0.5 m) freshwater lenses are common in estuaries such as the SJBE.

Laguna de Piñones is located on the periphery of the SJBE system. None of the scenarios conducted involved Laguna de Piñones. Thus, the calibration results for Laguna de Piñones are adequate for the purposes of this study.

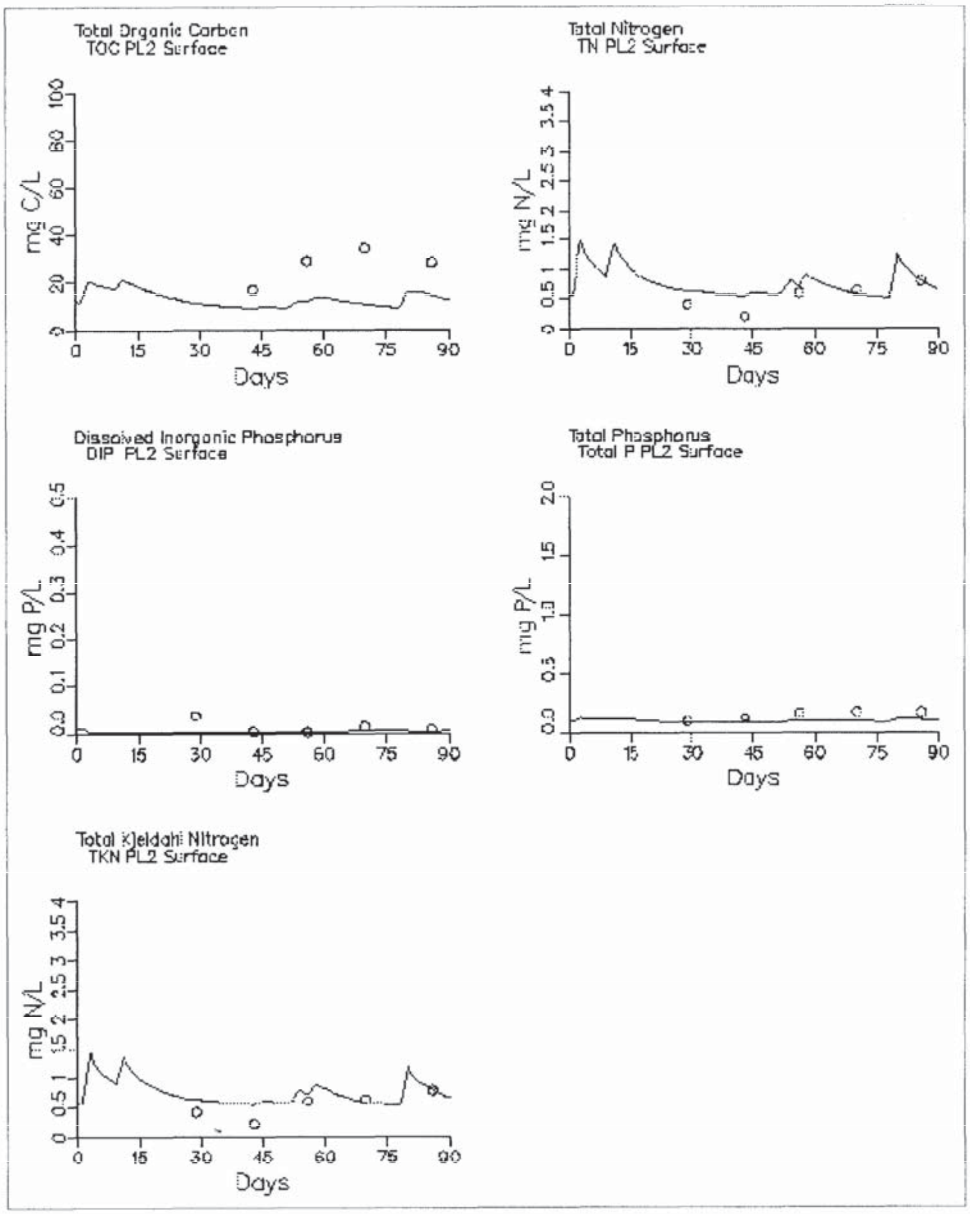


Figure 7-11. (Sheet 4 of 4)

Calibration Conclusions

Model calibration has resulted in a useful tool which adequately replicates observed behavior in the SJBE system. Though the SJBE system is not large it is very heterogenous with numerous bays, lagoons, and canals which complicated WQM calibration and affected performance. Often, attempts to improve calibration in one constituent or region had detrimental consequences on the calibration elsewhere. Further improvements in calibration were hindered by the limitations of the loading data. A comprehensive database of loading information did not exist and the loads used for calibration were estimates. The actual SJBE system is subjected to highly variable (both spatially and temporally) loadings resulting from runoff events and localized anthropogenic loadings. Great effort was expended in developing and implementing loads in the WQM which would be representative of these conditions. However, these estimates might not always agree with actual loads resulting from short-term events. Consequently, model calibration is impacted as the WQM may not match observations at locations with large temporal fluctuations in water quality resulting from runoff.

Another consideration when reviewing calibration results is the scale at which processes occur in the real system. Vertical resolution in the WQM is limited to the layer thicknesses used in the hydrodynamic model which were in turn limited by model stability requirements. Consequentially, processes such as stratification in shallow water or the simulation of over-riding, thin, freshwater lenses are beyond the capability of the WQM to resolve.

Overall model calibration was judged to be acceptable for scenario testing by the modelers and the model review group. In scenario testing, the model is run with a modification (scenario) and the results compared to a simulation with no modifications (base) and the relative differences determined. Any calibration deficiencies are present in both the base and scenario simulations and therefore tend to cancel out when the focus is on relative differences between base and scenario results.

8 Management Scenarios

Methods

The model was used to evaluate the effectiveness of various management alternatives (i.e., scenarios) for improving water quality. This section describes the methods used for conducting the management scenario simulations.

The overall strategy consisted of developing a scenario test period (STP) that was used for all scenarios so that comparisons of the relative worth of various management options could be evaluated. Both the HM and WQM had to be executed for each scenario, since the flows from the HM are used to drive the WQM, and in most cases the proposed management alternative affects the flows. However, as discussed further below, it was not necessary to run the HM for the same length of time as the WQM since the HM output is saved and can be used in a repetitive fashion throughout the WQM simulation, as was done for WQM calibration. To properly compare different management options, the WQM was run until it reached an equilibrium condition, i.e., a cyclic, steady-state condition. As the hydrodynamics, inflows, and loadings of the STP were cycled multiple times through the WQM, the WQM eventually arrived at an equilibrium condition that was time-varying, but repeated itself for each STP cycle. The time to reach equilibrium depended on the time it took for the sediments and water column to reach equilibrium, which was on the order of about 8 months.

The calibration period of summer 1995 was chosen for the STP. This period was chosen since it allowed comparison of each scenario against baseline conditions that existed in 1995 when observed data were available. The STP extended for one complete lunar month (28.25 days) using the conditions extending from 10 July through 7 August 1995, which contained a storm event around 1 August. A few extra days were executed on the front end of each HM run for model spin-up. The observed conditions for tides, wind, and freshwater flows were used. Output from the HM was saved and used repeatedly by the WQM throughout the longer, multimonth WQM simulation. Thus, the hydrodynamics used for each month of the WQM simulation were identical for a given scenario. When recycling hydrodynamics in this fashion, there is a requirement that the system water depths and volumes be nearly equivalent at the beginning and end of the HM simulation to avoid building up or depleting too much water over the long-term WQM simulation. This requirement was satisfied by carefully choosing the beginning and ending time for the STP.

Each WQM scenario STP was run for eight times to spin-up the new conditions, thus achieving a new dynamic steady-state. Only results from the final 28.25-day STP are presented here.

The STP constituent loadings for the WQM were the same as those used for the calibration, except for the loading reduction scenarios where loads were reduced. Meteorological conditions for the WQM for all scenarios were based upon the average July period of record observations at San Juan International Airport and are presented in Table 8-1. Observed, hourly varying July winds were used for the HM scenario runs since winds can affect residual circulation.

Table 8-1.
Scenario Meteorological Conditions

Dry Bulb Temperature	82°F
Dew Point Temperature	73°F
Wind Speed	8.5 mph
Cloud Cover	60%

Scenario Descriptions

Ten sets of simulations (Table 8-2) were run to assess the impact proposed remediation management strategies would have upon water quality. Scenario 1a was a base condition against which the other nine would be judged. Five scenarios (1b, 1c, 2, 3, and 4) involved some form of channel/bathymetric modification in either Caño Martín Peña, Laguna San José, or Canal Suárez and Laguna La Torrecilla which would result in a redistribution of flows. Scenarios 5a and 5b involved only loading reductions while scenarios 6a and 6b combined channel/bathymetric modifications and loading reductions. The channel/bathymetric modifications called for by many of these scenarios resulted in a reconfiguration of ICM grid (see Table 8-3) as well as running new conditions in the HM (see Table 8-2). The scenarios evaluated are described further below, and the results are discussed in the subsequent sections of this chapter.

Table 8-2.
Management Water Quality Scenarios

Scenario	Description	Hydrodynamic Scenario
1a	Base condition with approved dredging in San Juan Bay and Rio Piedras implemented	1a
1b	1a plus clearing and widening eastern end of Caño Martín Peña to 50 ft	1b
1c	1a plus widening Caño Martín Peña to 150 ft and deepening to 9 ft	1c
2	1a plus filling all dredge material borrow pits to 6-ft depth	2
3	1a plus removing the constriction at the Loiza Expressway bridge on Suárez Canal by widening by 100 ft and deepening to 12 ft	3
4	Conditions of Scenario 3 plus installation of 1-way tide gate in Canal Suárez	4
5a	1a plus loading reduction in Caño Martín Peña Canal (removal of un-sewered loadings)	1a
5b	1a plus loading reduction in San José (removal of Baldorioty de Castro pump station loadings)	1a
6a	1c plus 5a and 5b	1c
6b	6a plus 2	6b

Table 8-3.
ICM Grid for Each Scenario

Scenario	Surface Cells	Total Cells	Total Flow Faces	Horizontal Flow Faces
1a	1923	10731	28230	19422
1b	1923	10731	28230	19422
1c	1923	10769	28309	19463
2	1923	10341	27451	19033
3	1923	10734	28238	19427
4	1923	10734	28238	19427
5a	1923	10731	28230	19422
5b	1923	10731	28230	19422
6a	1923	10769	28309	19463
6b	1923	10379	27530	19047

Scenario 1a, Baseline Conditions

The baseline simulation was similar to conditions that existed during the summer of 1995 and used the same boundary conditions and loadings as those used for model calibration. The geometry and bathymetry of the system were the same as the *existing* conditions with the exception of minor geometric changes related to dredge and fill improvements that were approved and have either been implemented or are underway. These improvements involved deepening the San Juan Harbor channel to 11.9 m (39 ft) and deepening the Puerto Nuevo flood control channel to 7.32 m (24 ft). Scenario 1a served as the baseline, or *existing*, conditions against which all other scenarios were compared to evaluate their effectiveness.

Scenarios 1b and 1c, Channel Improvements in Caño Martín Peña

The eastern portion of Caño Martín Peña is considered to severely hinder flushing of the inner part of the system. Thus, two scenarios simulations were conducted to evaluate channel improvements for the eastern portion of Caño Martín Peña. The first channel improvement, Scenario 1b, consisted of clearing the channel to a nominal 15.2-m (50-ft) width from about 7 m (25 ft). The model bottom drag coefficient was also changed to reflect clearing of the channel for Scenario 1b. The second channel improvement, Scenario 1c, consisted of a channel widened to a minimum width of 45.7 m (150 ft) and deepened to a minimum depth of 2.74 m (9 ft). Both scenarios were run with all other conditions and configurations set the same as those for Scenario 1a. The HM grid was modified for each channel configuration, and the HM was executed for the STP to generate flows for the WQM. Then the WQM was run to equilibrium using the new HM output and *existing* loads for the STP.

Scenario 2, Filling of Submerged Borrow Pits

This scenario consisted of Scenario 1a conditions plus filling of submerged borrow pits within Laguna San José and Laguna La Torrecilla. These pits are the result of sand and fill mining for development of residential and service facilities. The deep holes have low DO and are sources for nutrients that diffuse from bottom sediments under low DO conditions. The bathymetry for model grids cells representing the pits was reduced to a depth of 1.83 m (6 ft). The HM was executed for the STP with the new depths. The WQM was then run to equilibrium using this HM output and *existing* loads.

Scenario 3, Loiza Epressway Bridge Constriction in Suárez Canal Removed

For the most part, Suárez Canal does not restrict flushing, with the exception of a constriction at the Loiza Expressway bridge, where the canal is only about 15 m (50 ft) wide and 0.91 m (3 ft) deep. Thus, a scenario was conducted to investigate removing the Loiza Expressway bridge constriction by enlarging the canal at the bridge to 30.5 m (100 ft) wide by 3.66 m (12 ft) deep. The HM grid was adjusted to represent the proposed Suárez Canal improvement, and the model was run using Scenario 1a conditions for all other geometric features and boundary conditions. The WQM was then run to equilibrium using this HM output and *existing* loads.

Scenario 4, Tide Gate in Suárez Canal with Bridge Constriction Removed

Scenario 4 investigated a tide gate installed and operated in Suárez Canal where the gate was open during flood flow through Suárez Canal and closed during ebb flow to force water out through Caño Martín Peña. The HM was modified to allow simulation of a tide gate operating in the western portion of Suárez Canal, and the HM was executed for the STP with the tide gate combined with Scenario 1a conditions plus the bridge constriction removed (Scenario 3). The bridge constriction was removed too for this scenario since this improvement is considered likely to occur if a tide gate is built. The WQM was then run to equilibrium using this HM output and *existing* loads.

Scenarios 5a and 5b, Loading Reductions

Considerable loadings of nutrients and fecal coliform bacteria occur within the SJBE system. Therefore, management actions to reduce these loadings is a potential effective means of improving water quality. To evaluate the effectiveness of loading reductions, it was necessary to conduct these simulations with *existing* conditions for other boundary conditions and system geometry and bathymetry. Therefore, the loading reductions were conducted with Scenario 1a hydrodynamics imposed. So it was not necessary to re-run the HM for Scenarios 5a and 5b. The loadings in the WQM prescribed in Scenario 1a were reduced as described below, and the WQM was run to a new equilibrium condition.

Scenario 5a consisted of eliminating local, nonpoint source loadings along Caño Martín Peña. These loads are significant and represent untreated sewage from un-sewered residential areas. Removing these loads is a very likely management scenario.

Scenario 5b consisted of diverting all pollutant loadings that enter Laguna San José via the Baldorioty de Castro storm water pump station.

The flows from the plant were still introduced, but the constituent concentrations were removed.

Scenarios 6a and 6b, Combinations

Following review of results from the previous scenarios, the SJBEP recommended two combination scenarios be run to evaluate the cumulative effectiveness.

Scenario 6a consisted of the combination of management alternatives prescribed by Scenarios 1c, 5a, 5b. Thus, Scenario 6a contained the improved Caño Martín Peña (45.7 m or 150 ft wide and 2.74 m or 9 ft deep) along with the elimination of loadings in Caño Martín Peña and from the Baldorioty de Castro storm water pump station. Otherwise, other geometry, bathymetry, and boundary conditions were the same as those for Scenario 1a. Thus, HM output from run 1c was used to drive the WQM to a new equilibrium condition using the reduced loadings for Scenarios 5a and 5b.

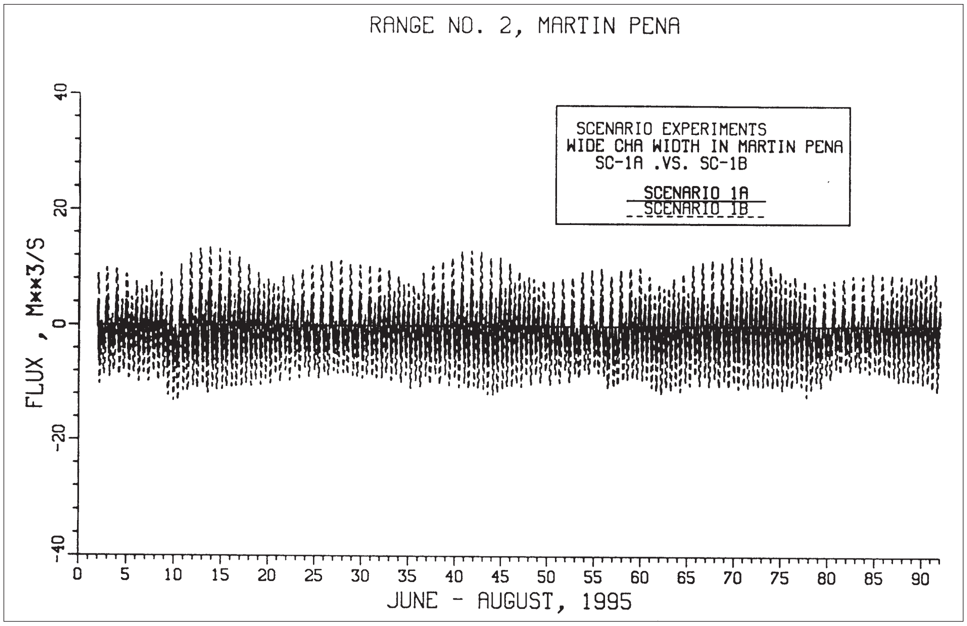
Scenario 6b consisted of the combination of management alternatives prescribed by Scenarios 1c, 2, 5a, and 5b. Thus, Scenario 6b included conditions for Scenario 6a plus Scenario 2, i.e., submerged borrow pits filled. Scenario 6b required re-running the HM with the combination of Scenarios 1c and 2 management alternatives. These HM results were used to drive the WQM to a new equilibrium condition with Scenarios 5a and 5b loading reductions imposed.

Hydrodynamic Model Results

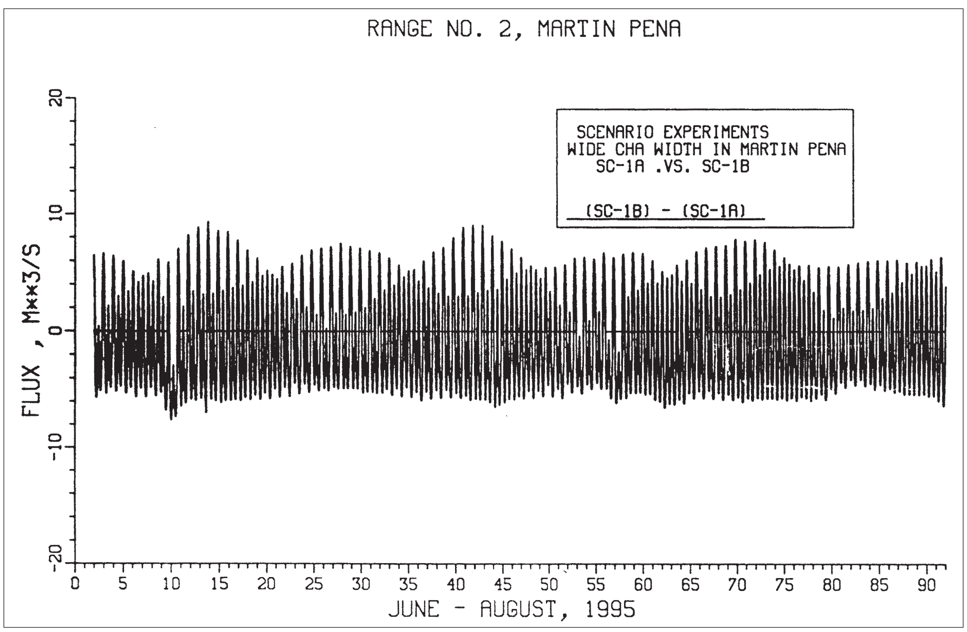
This section discusses the scenarios that were simulated by the HM. Comparisons of HM results from each of the scenarios with results from Scenario 1a are presented and discussed below.

Scenario 1b Results

As can be seen from Figures 8-1 and 8-2, the impact of slightly widening the eastern end of Martín Peña and reducing the friction is to increase the tidal flux through the Martín Peña Canal while slightly decreasing the flux through Canal Suárez. Figure 8-3 shows essentially no change in the tidal range in Laguna San José, but a slight setdown in the water level is computed. This is likely due to more of the Laguna San José freshwater inflow being able to move out of the lagoon more quickly through the improved Martín Peña Canal. As a result of the increased flow of freshwater, one might expect that the salinity in Martín Peña would decrease. Figure 8-4 shows this to be the case. Likewise, due to the decreased amount of San José freshwater inflow moving out through the Canal

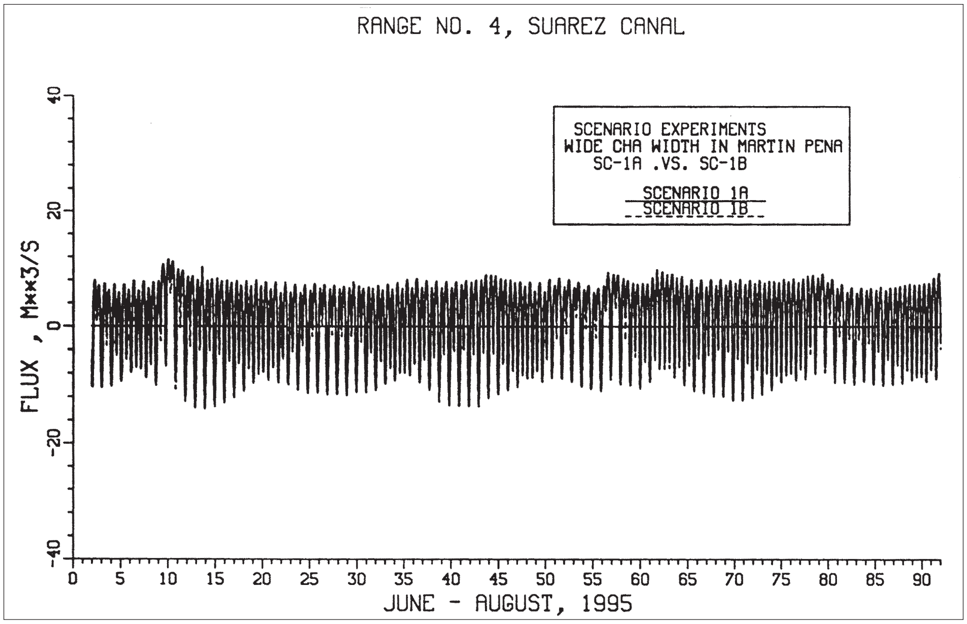


a. Both 1a and 1b

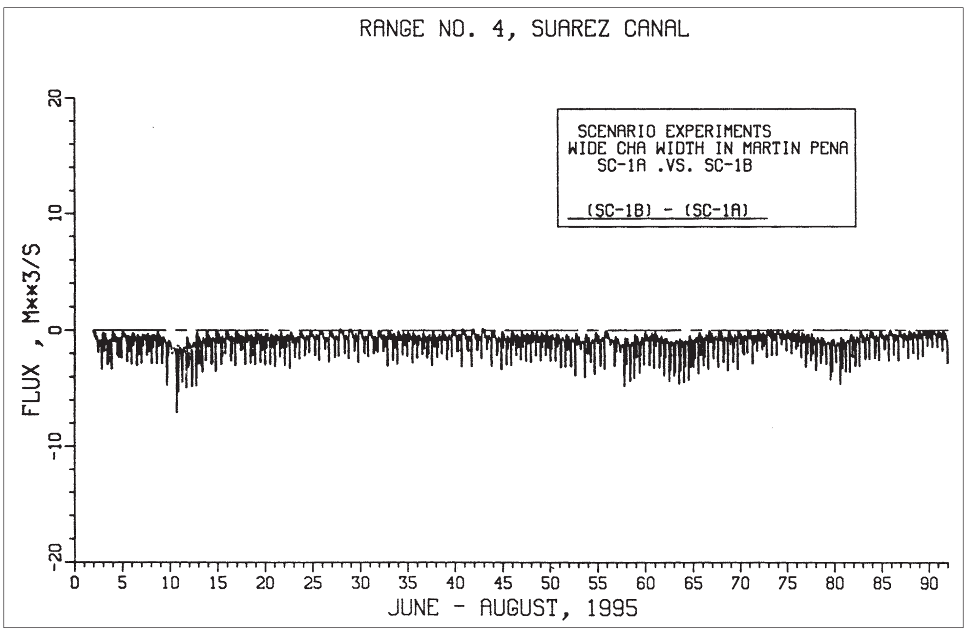


b. Difference between 1a and 1b

Figure 8-1. Comparison of flux through Martin Pena Canal between Scenarios 1a and 1b



a. Both 1a and 1b



b. Difference between 1a and 1b

Figure 8-2. Comparison of flux through Suarez Canal between Scenarios 1a and 1b

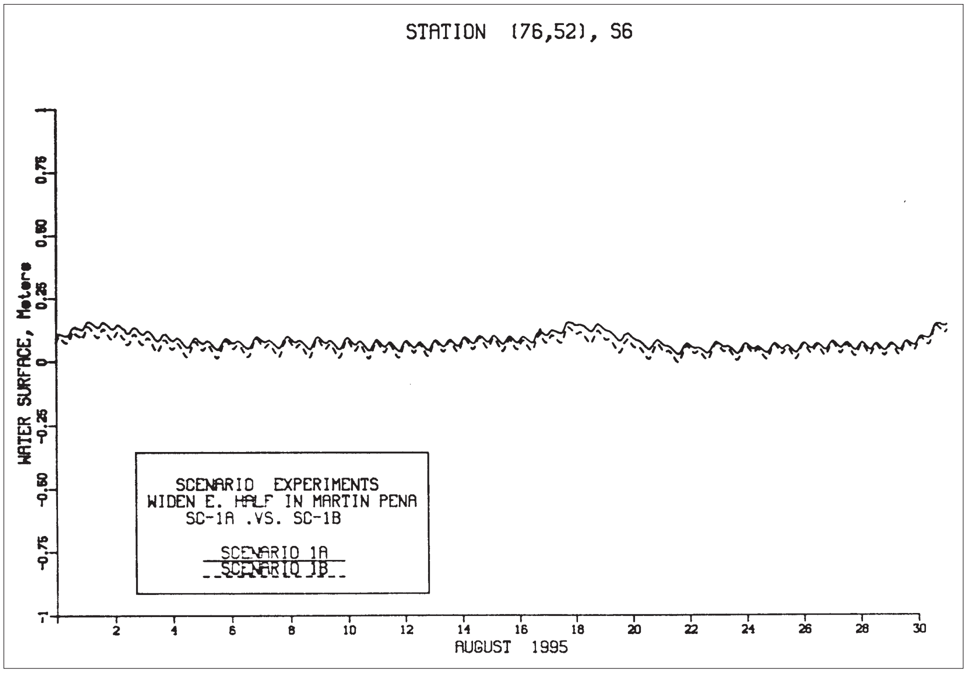


Figure 8-3. Comparison of tide at S6 between Scenarios 1a and 1b

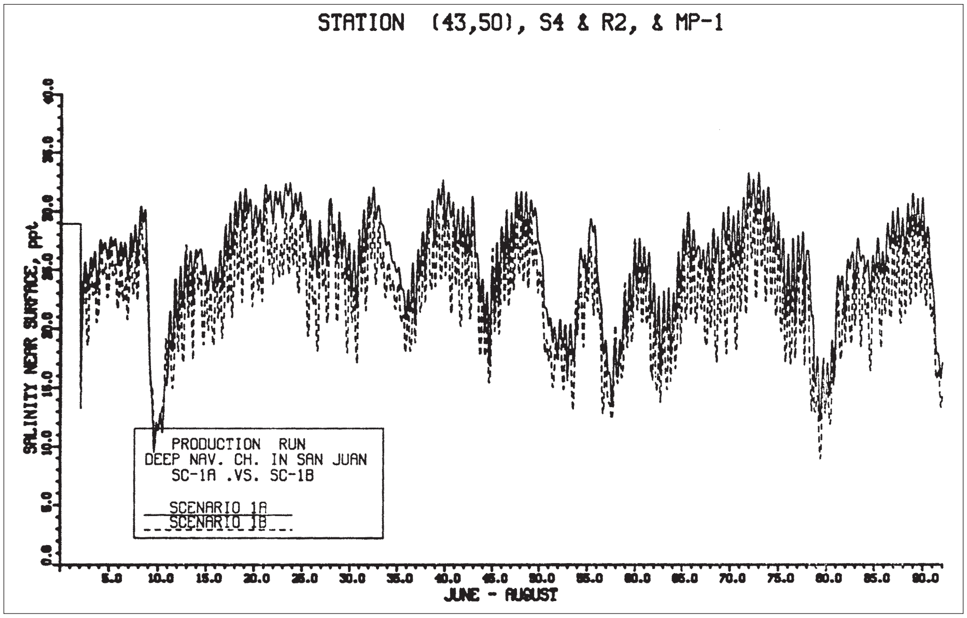
Suárez, Figure 8-5 shows that the salinity in Suarez increases. With the salinity in Suarez being higher, higher saline water flows into Laguna San José during flood, resulting in higher salinity in San José. This is illustrated in Figure 8-6.

Scenario 1c Results

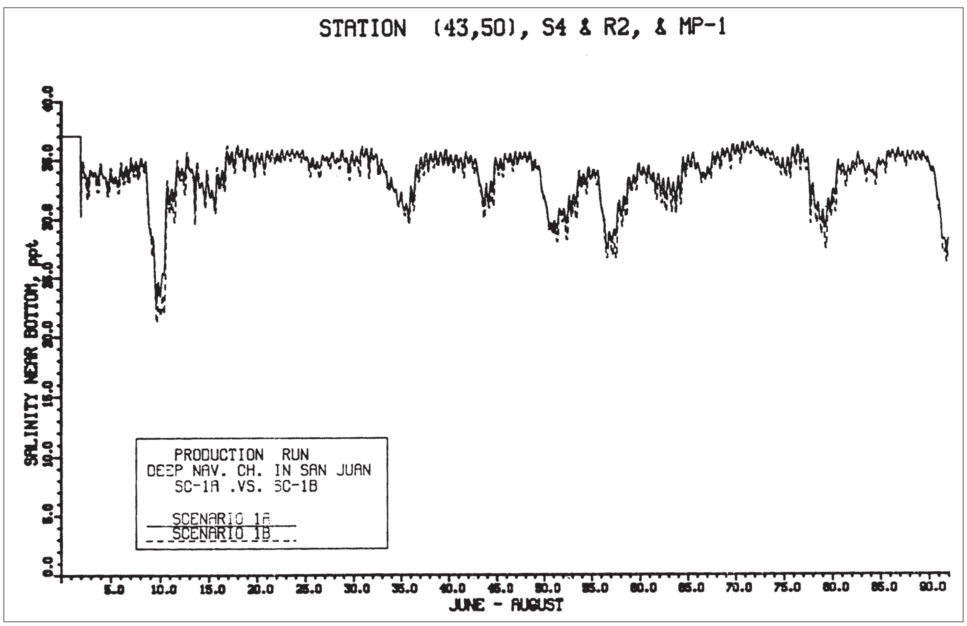
With a substantial increase in width and depth in Martín Peña Canal for this scenario, Figure 8-7 illustrates that the tide range in Laguna San José increases from less than 5 cm (0.164 ft) to 30-35 cm (0.984 - 1.148 ft). As illustrated in Figure 8-8, the tidal flushing between San Juan Bay and Laguna San José increases by more than an order of magnitude. However, as with Scenario 1b, improvements in Martín Peña Canal result in less flushing through Canal Suárez (Figure 8-9). With the tremendous increase in tidal flushing through Martín Peña Canal, the high saline waters of San Juan Bay move into Laguna San José, resulting in increases in salinity in Martín Peña and San José (Figures 8-10 and 8-11). Likewise, with the increased salinity in San José, as water moves from San José into Canal Suárez, salinity in Canal Suárez increases (Figure 8-12).

Scenario 2 Results

As illustrated in Figures 8-13 - 8-15, filling the holes in the system had virtually no impact on flux through the canals nor on the tidal range in Laguna San José. However, as shown in Figures 8-16 - 8-18, decreases in salinity in Martín Peña, San José, and Suarez were computed. Data from

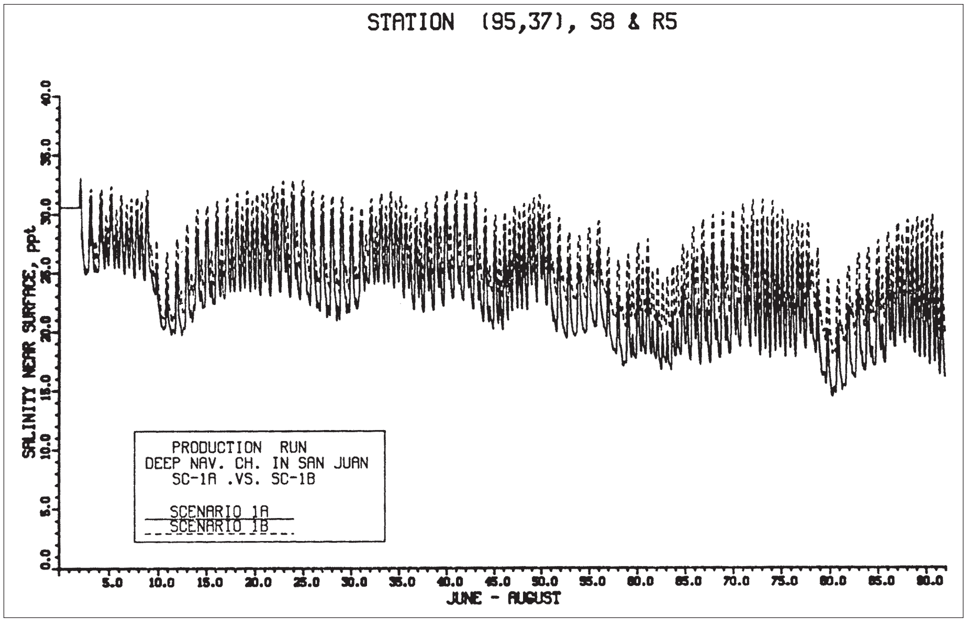


a. Near surface

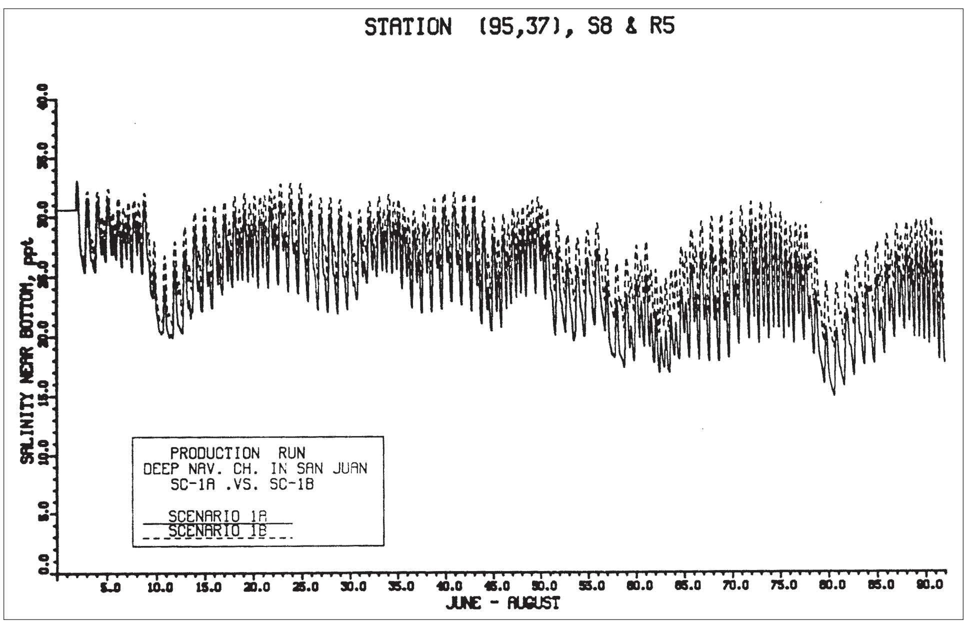


b. Near bottom

Figure 8-4. Comparison of salinity at S4 between Scenarios 1a and 1b



a. Near surface



b. Near bottom

Figure 8-5. Comparison of salinity at S8 between Scenarios 1a and 1b

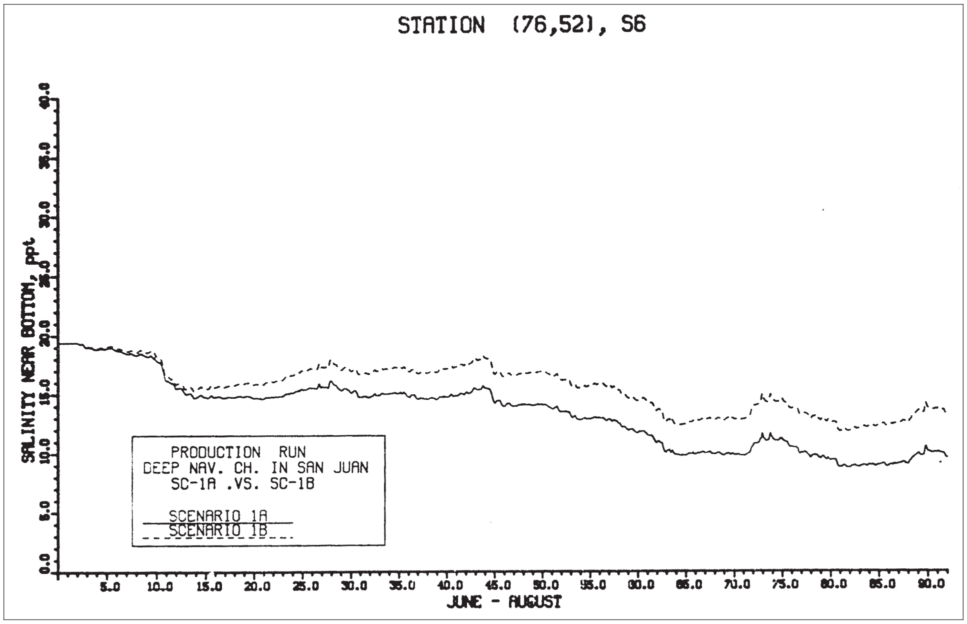


Figure 8-6. Comparison of salinity at S6 between Scenarios 1a and 1b

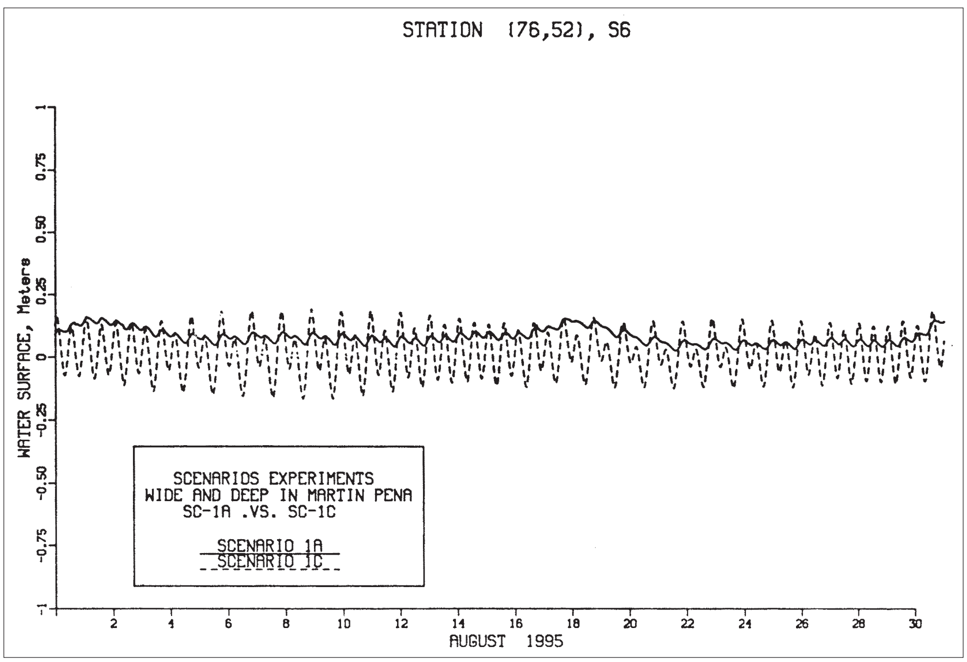
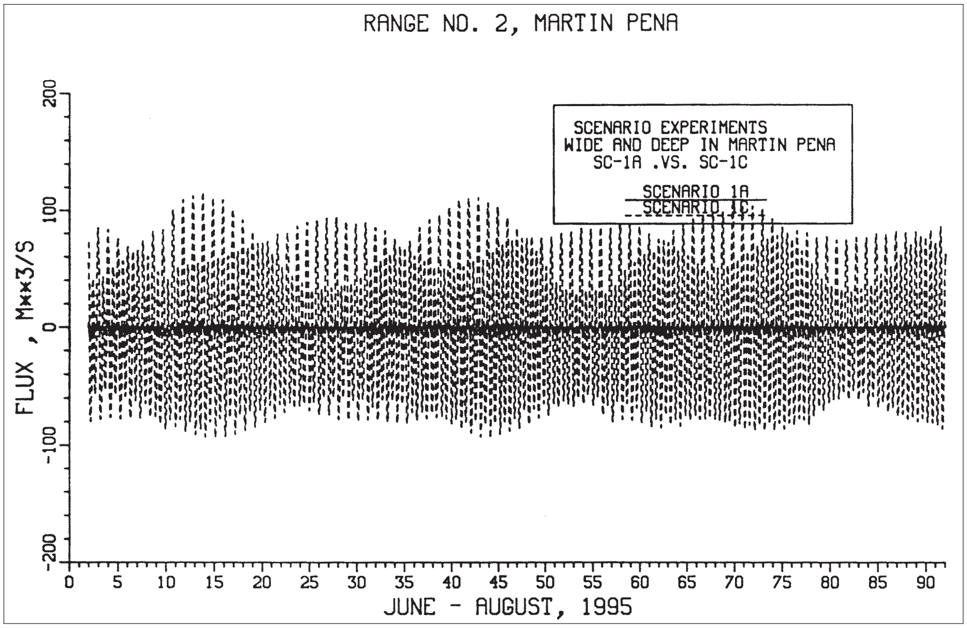
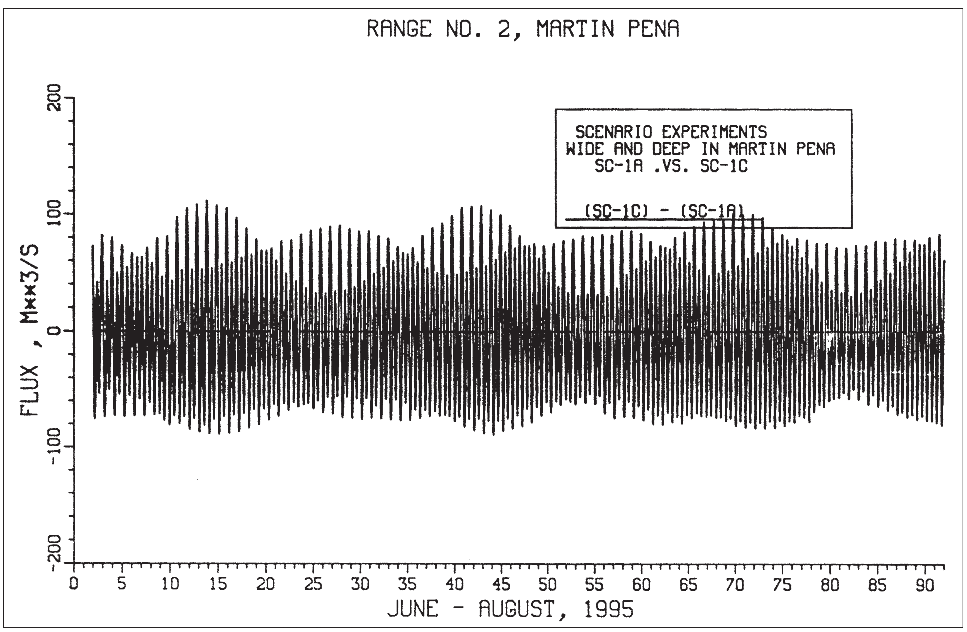


Figure 8-7. Comparison of tide at S6 between Scenarios 1a and 1c

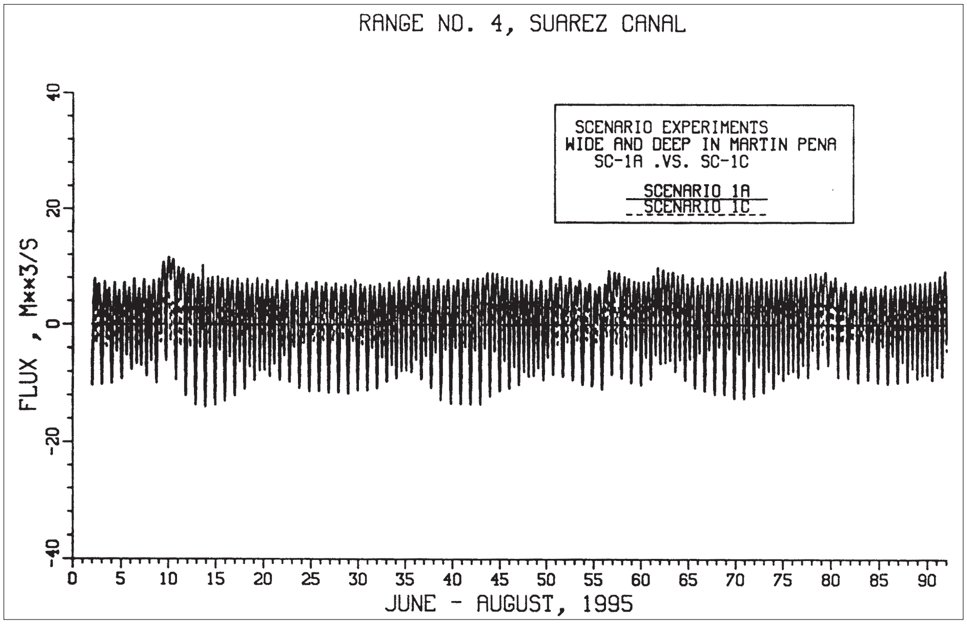


a. Both 1a and 1c

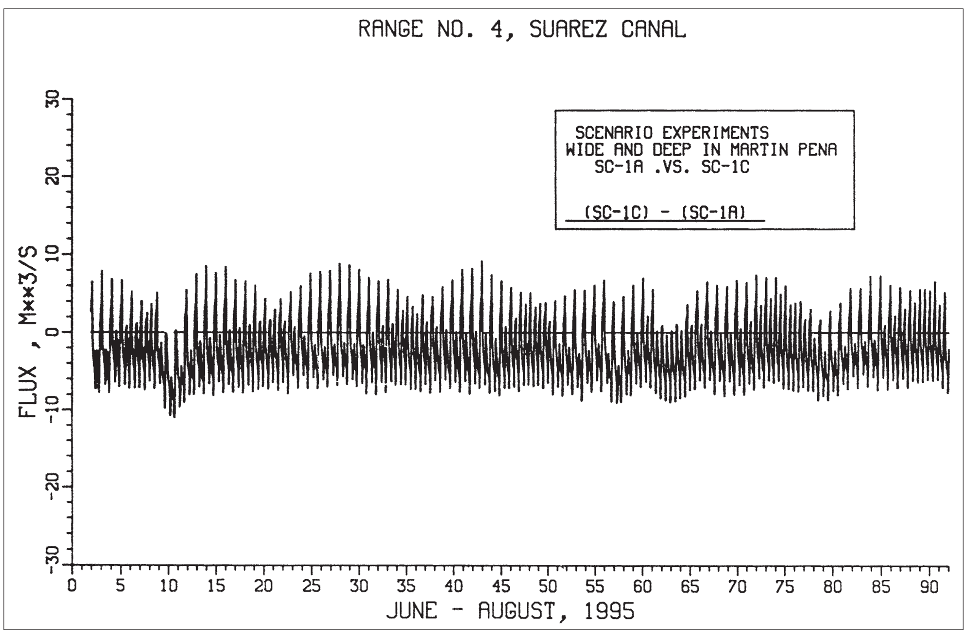


b. Difference between 1a and 1c

Figure 8-8. Comparison of flux at Range 2 between Scenarios 1a and 1c

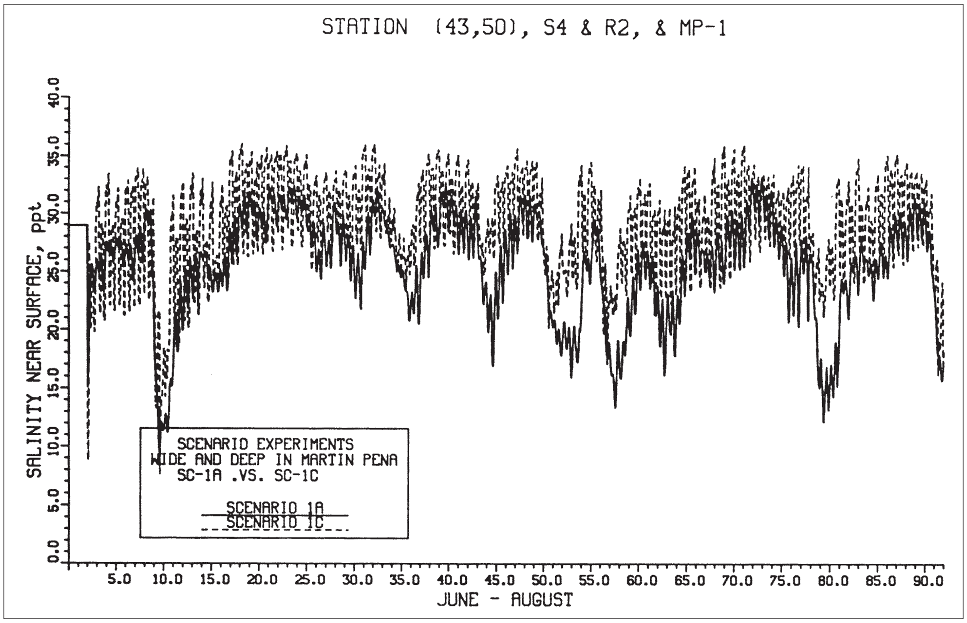


a. Both 1a and 1c

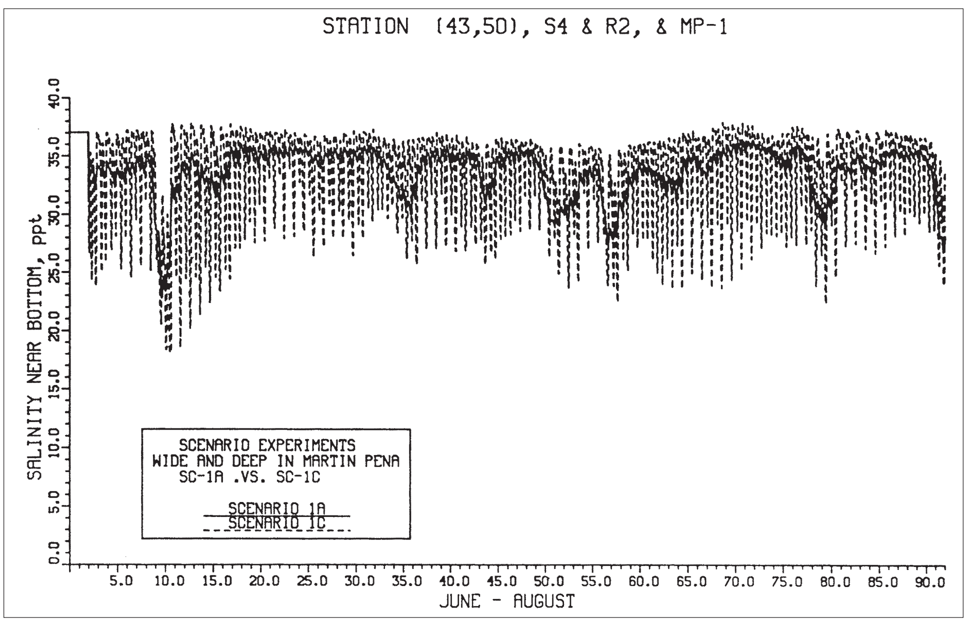


b. Difference between 1a and 1c

Figure 8-9. Comparison of flux at Range 4 between Scenarios 1a and 1c



a. Near surface



b. Near bottom

Figure 8-10. Comparison of salinity at S4 between Scenarios 1a and 1c

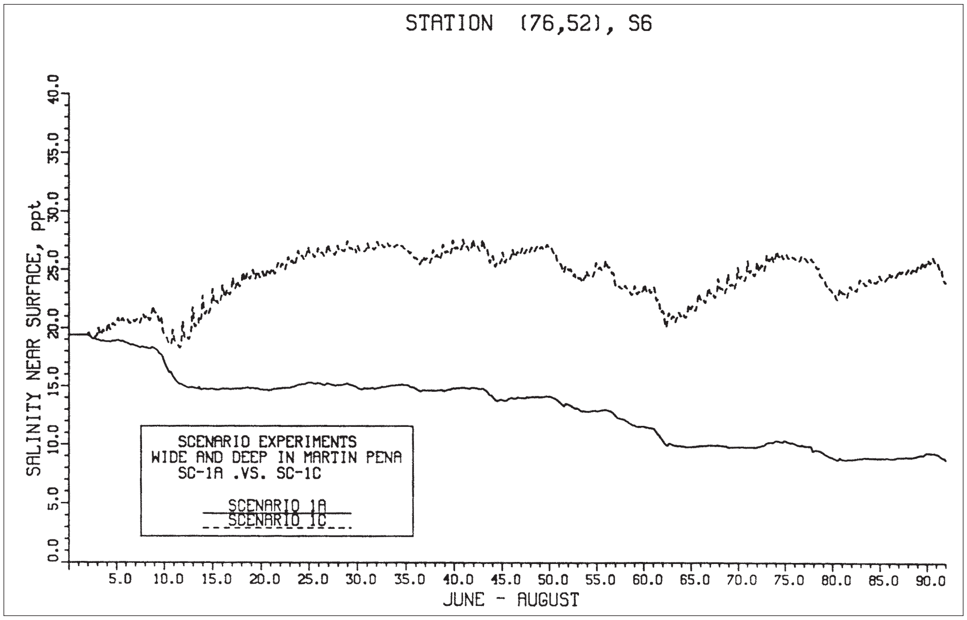
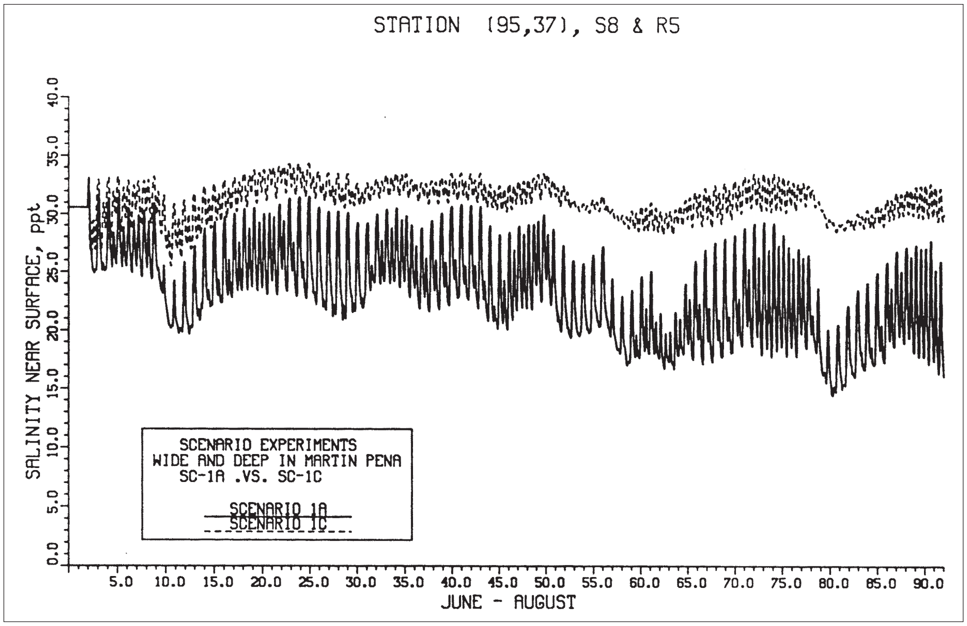


Figure 8-11. Comparison of salinity at S6 between Scenarios 1a and 1c

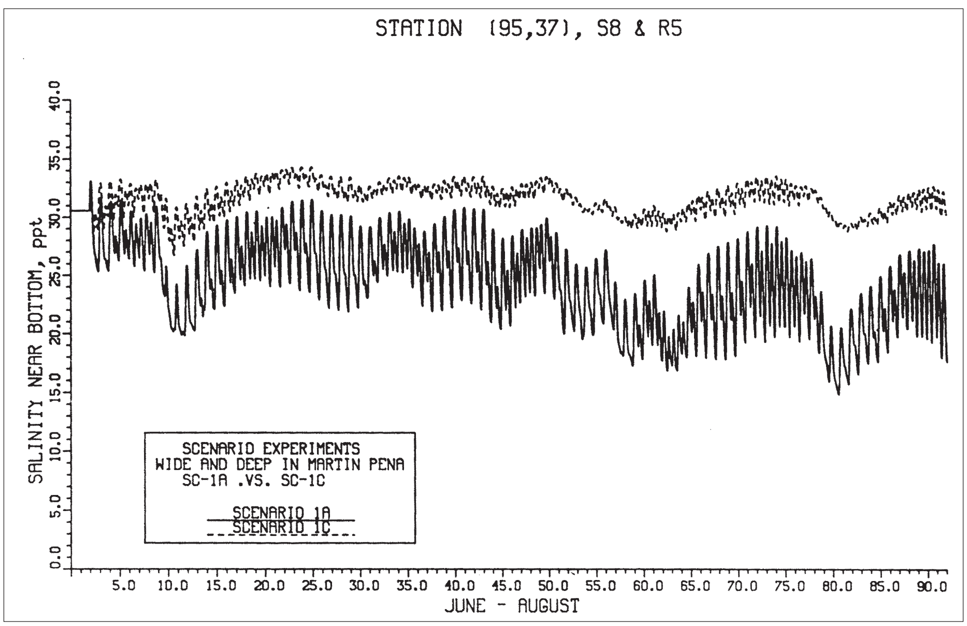
the field collection effort previously discussed show that high salinity exists in the dredged holes in Laguna San José and one hole in Canal Suárez. It has been speculated that high salinity groundwater from the ocean maintains the high salinity in the holes. To simulate this behavior in the model, salinity in the holes was nudged (see Chapter 7) to match the field data. Thus, when the holes were filled, this source of salinity was removed, resulting in the lower computed salinity in Laguna San José and Canal Suárez.

Scenario 3 Results

This scenario involved widening and deepening the constriction in Canal Suárez. As can be seen from Figure 8-19, opening this constriction results in the tide range in San José increasing from less than 5 cm (0.164 ft) to 20-25 cm (0.656 - 0.820 ft), with the resulting tidal flux through Canal Suárez (Figure 8-20) being increased by a factor of 5 or so. Figure 8-21 shows that the impact on the flux through Martín Peña is to increase the flux slightly on flood (water moving into Laguna San José). This results in the salinity in Martín Peña being slightly increased (Figure 8-22). With the increased tidal exchange between San José and Laguna La Torrecilla, salinity in both San José and Suarez increases (Figures 8-23 and 8-24). One noticeable exception in Suarez is around the 9th of June when a storm event resulted in a considerable runoff of freshwater into Laguna San José (see inflows in Figure 3-3). With the less constricted Canal Suárez, a larger portion of the San José freshwater inflow moves through the canal than before.

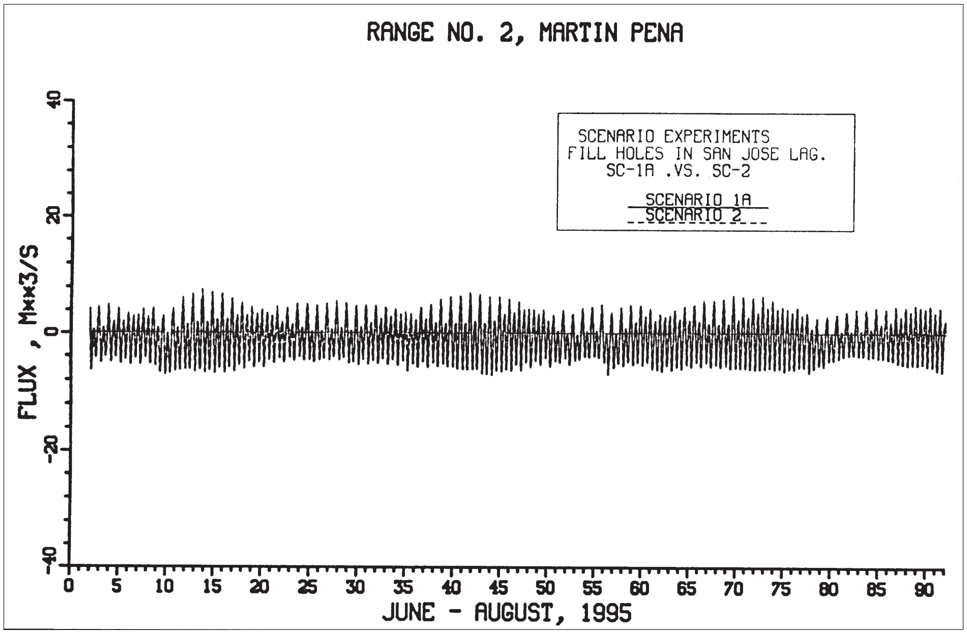


a. Near surface

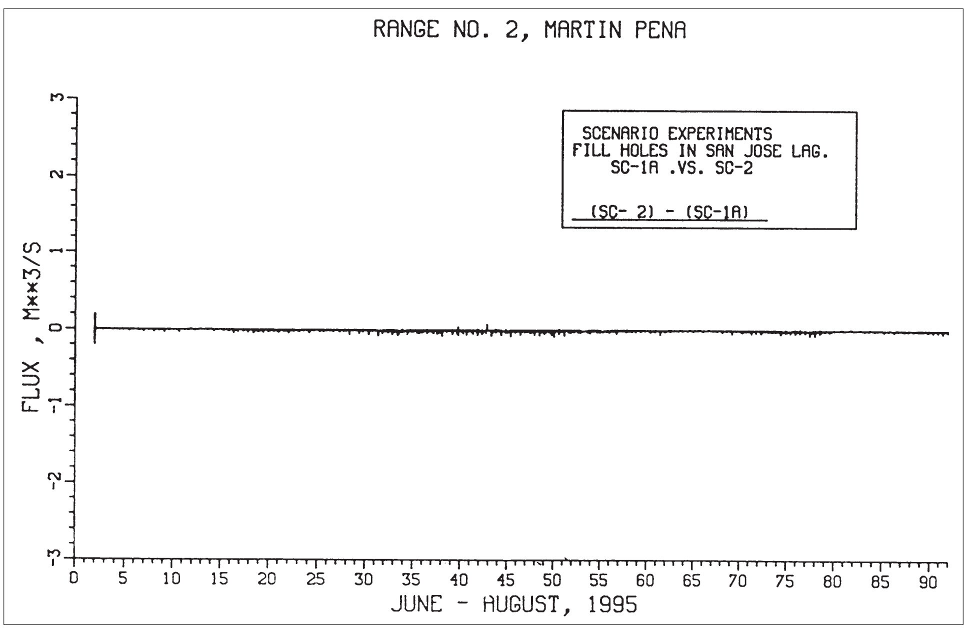


b. Near bottom

Figure 8-12. Comparison of salinity at S8 between Scenarios 1a and 1c

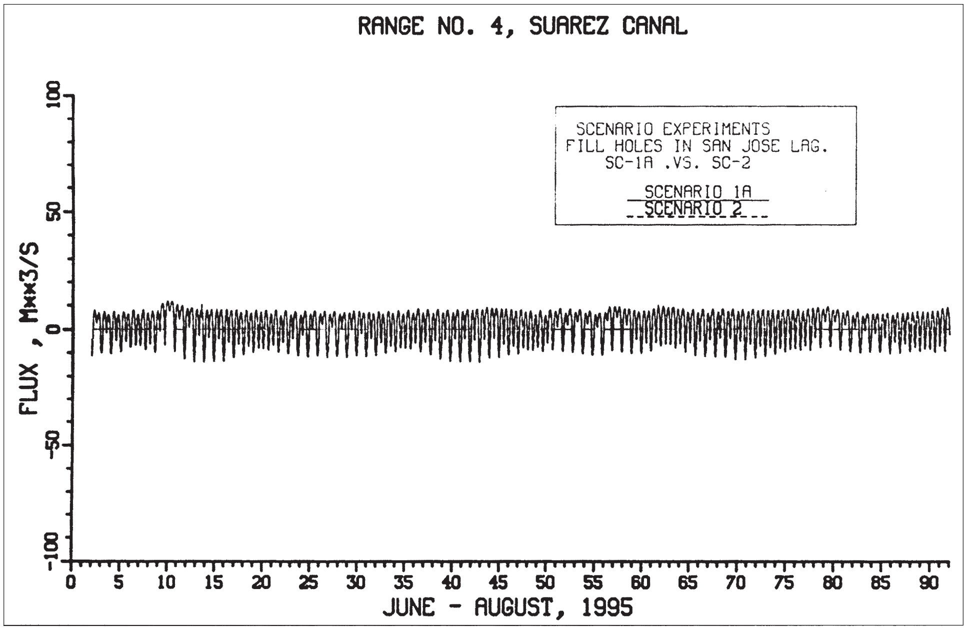


a. Both 1a and 2

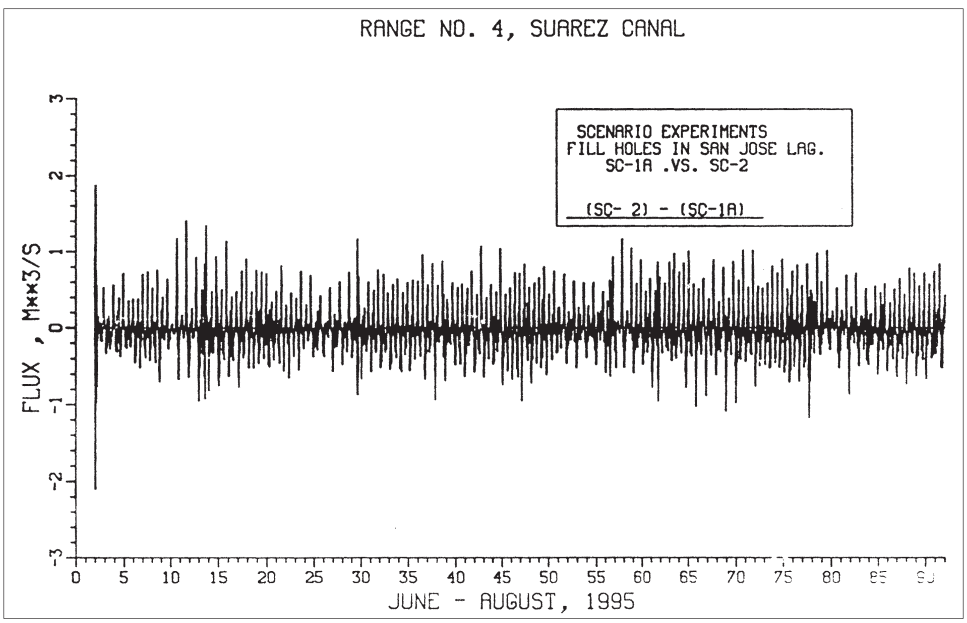


b. Difference between 1a and 2

Figure 8-13. Comparison of flux at Range 2 between Scenarios 1a and 2



a. Both 1a and 2



b. Difference between 1a and 2

Figure 8-14. Comparison of flux at Range 4 between Scenarios 1a and 2

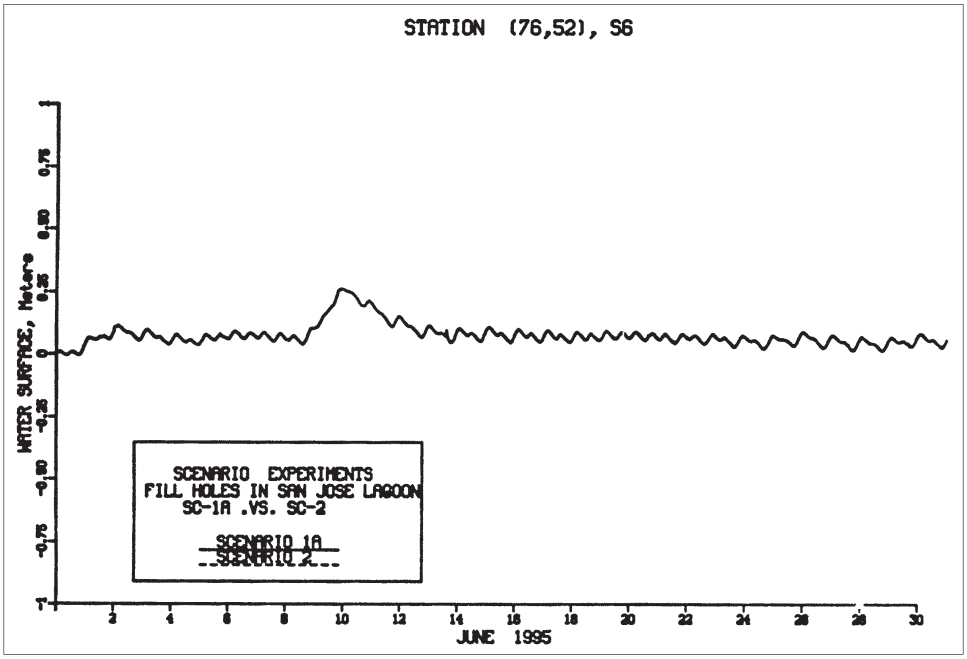
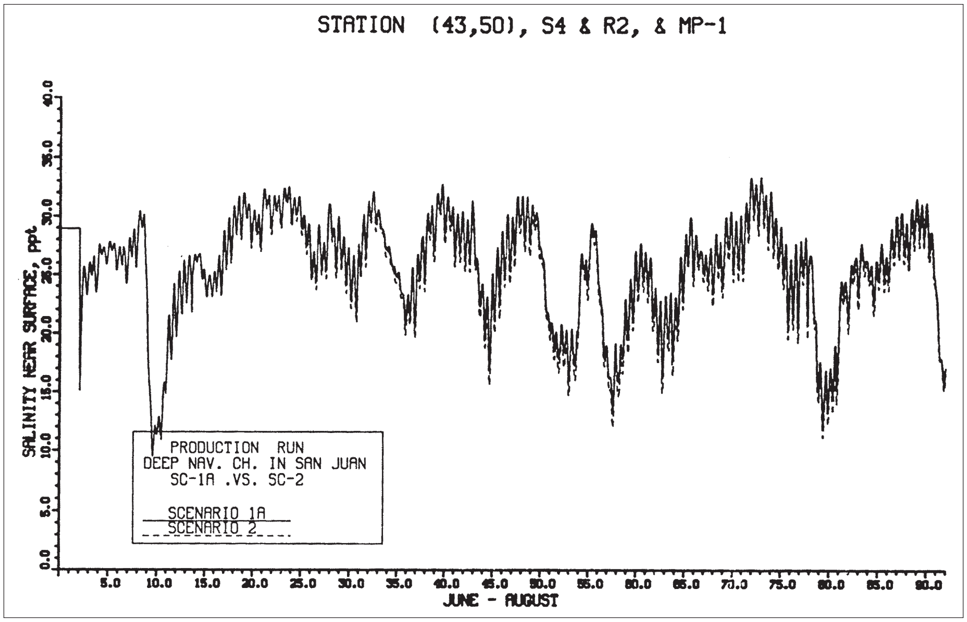


Figure 8-15. Comparison of tide at S6 between Scenarios 1a and 2

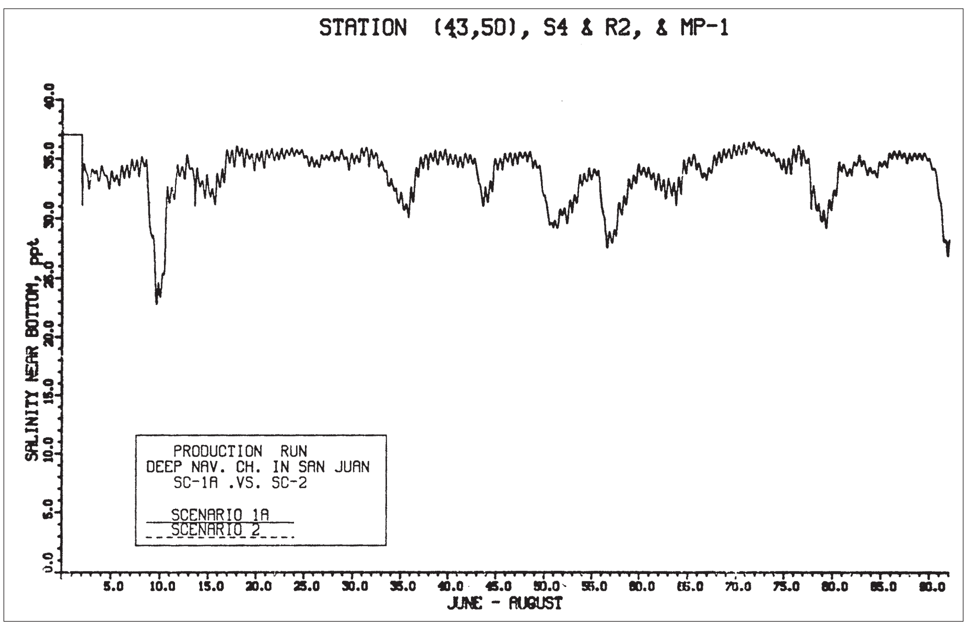
Scenario 4 Results

Scenario 4 has the Loiza Expressway bridge constriction removed in the Canal Suárez along with a tide gate installed in the canal. Simulation of the tide gate was accomplished by setting an internal boundary condition to cut off flow from San José through Canal Suárez to Torrecilla when the water surface elevation is higher on the San José side of the gate. The basic operation of the tide gate was expected to be such that tidal-floodwaters from Torrecilla would move into San José and would then be trapped in San José and forced to flow out through Martín Peña Canal. However, for the vast majority of the time, the water-surface elevation on the San José side of the gate remains higher than on the Torrecilla side of the gate, resulting in virtually no flux through Canal Suárez (Figure 8-25). Thus, only occasionally does the gate allow tidal-floodwaters from Laguna La Torrecilla into Laguna San José. The reason is that with the Martín Peña Canal so constricted, water can't easily pass out of San José, resulting in a buildup of the water-surface elevation in Laguna San José. This buildup of the San José water-surface elevation can be seen in Figure 8-26. Figure 8-27 shows the increased flux during ebb (water moving toward San Juan Bay) through Martín Peña.

An interesting observation from Figure 8-26 is that there is essentially no tidal fluctuation in Laguna San José with Canal Suárez blocked. Thus, the small tidal fluctuation observed in San José for the existing state of the system (Figure 6-7) is almost totally due to the tide moving through Canal Suárez. The tidal effect on Laguna San José due to Martín Peña Canal is essentially zero.



a. Near surface



b. Near bottom

Figure 8-16. Comparison of salinity at S4 between Scenarios 1a and 2

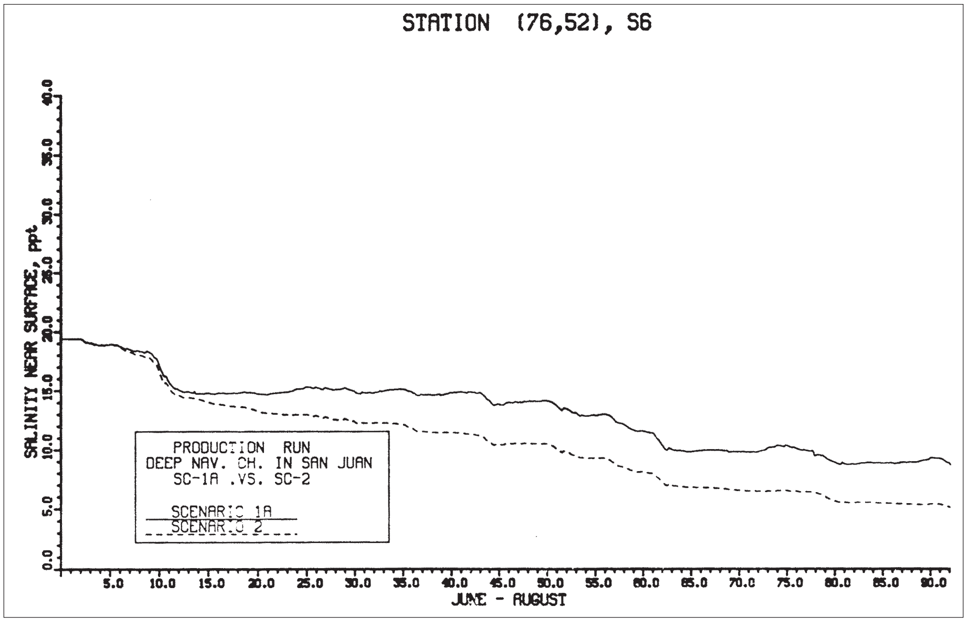
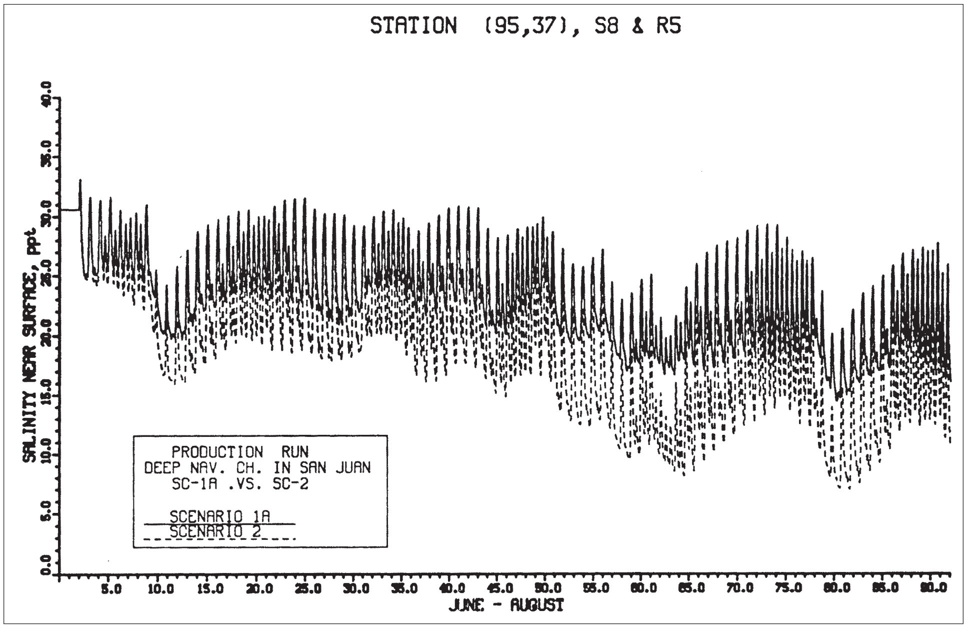


Figure 8-17. Comparison of salinity at S6 between Scenarios 1a and 2

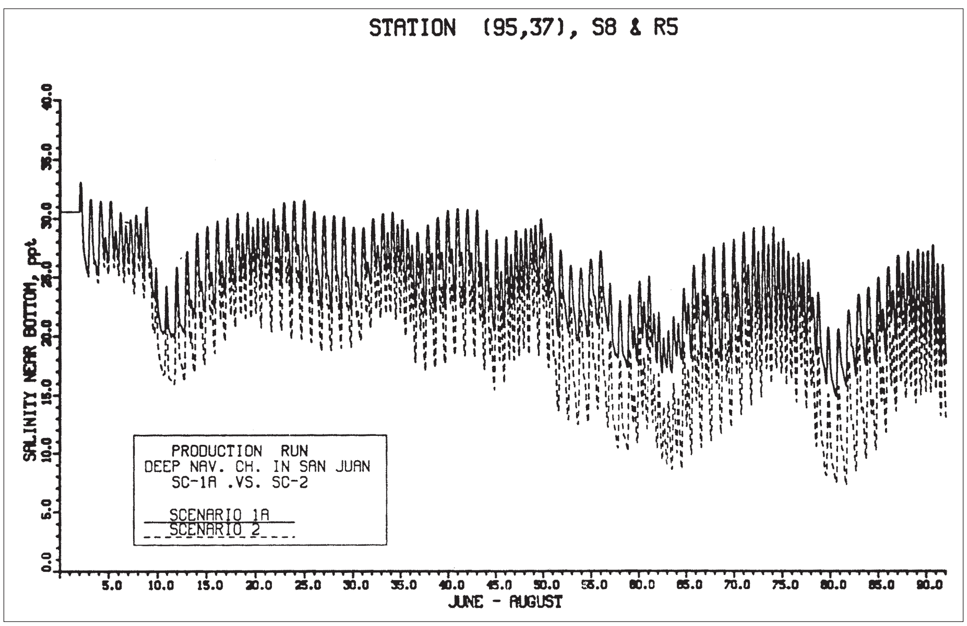
With all of the freshwater inflow into Laguna San José having to pass through Martín Peña Canal, Figure 8-28 shows that the impact is a reduction in salinity in Martín Peña. However, as illustrated in Figures 8-29 and 8-30, salinity in Laguna San José and Canal Suárez increases. With no flow from Laguna San José into Torecilla Lagoon, salinity in Suarez on the Torecilla side of the tide gate builds up. Thus, during the few times that tidal-flood flow in the Canal Suárez is allowed through the tide gate into San José, much higher salinity is flushed into San José, resulting in increased salinity in Laguna San José.

Scenario 6b Results

As previously discussed, this scenario is a combination of Scenario 1c and Scenario 2. In other words, the eastern end of Martin Peña is widened to a minimum of 150 ft (45.7 m) and deepened to 9 ft (2.74 m) and the dredged holes are filled. An inspection of the results from this scenario (Figures 8.31 -8.36) along with those from Scenario 1c (Figures 8.7 -8.12) reveals virtually no difference in the computed tide in Laguna San José nor in the computed flux and salinity in the Martin Peña and Canal Suarez from those obtained for Scenario 1c. Although Scenario 2 by itself does result in a decrease in salinity in Laguna San José and the connecting canals (Figures 8.16 - 8.18), evidently the hydrodynamic impact of Scenario 1c is so large that the influence of Scenario 2 is miniscule when the two are combined. An inspection of Figure 8.8 of the flux through Canal Martin Peña for Scenario 1c shows that during flood (flow into Canal Martin Peña from San Juan Bay) the average flux is about 50 m^3/sec. Thus, on each flood cycle about 2.25 million m^3 of high saline San Juan Bay water moves into Laguna San José. With the total volume of Laguna San



a. Near surface



b. Near bottom

Figure 8-18. Comparison of salinity at S8 between Scenarios 1a and 2

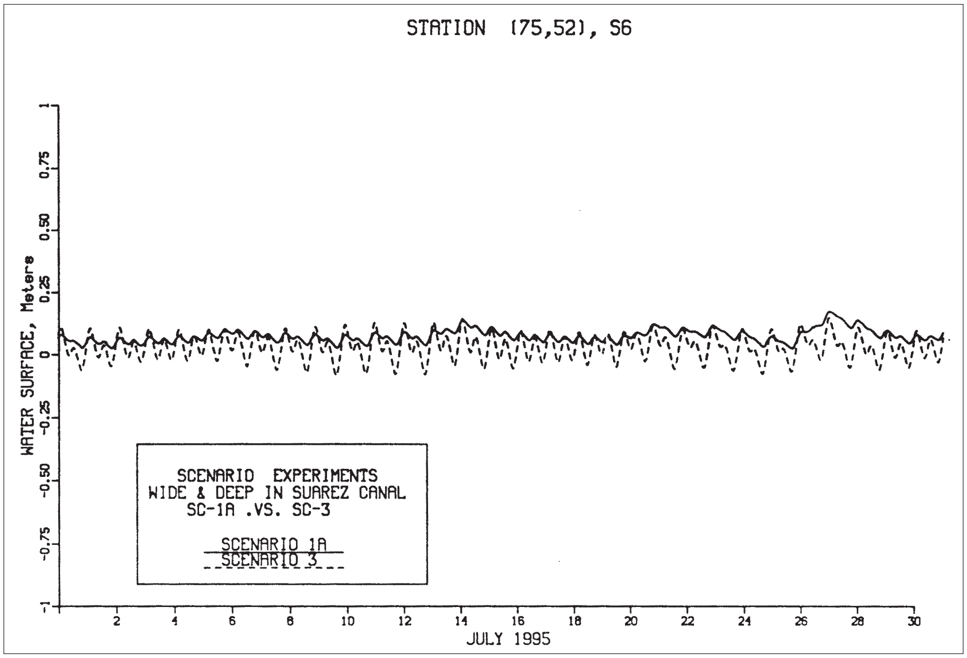


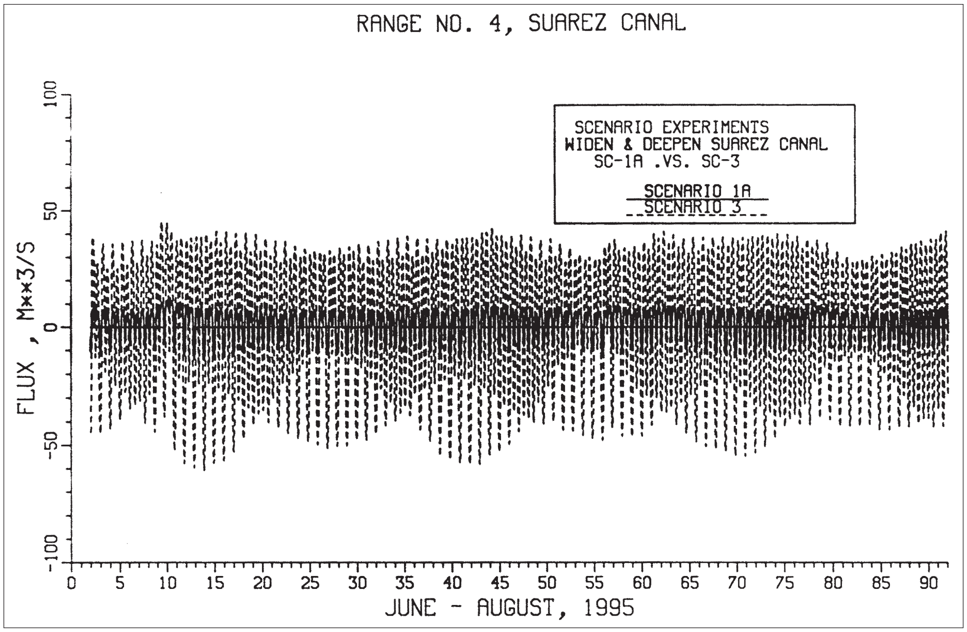
Figure 8-19. Comparison of tide at S6 between Scenarios 1a and 3

José being about 7.5 million m^3, it only takes three to four flood cycles to totally replace the waters of Laguna San José. This illustrates the enormous impact of Scenario 1c.

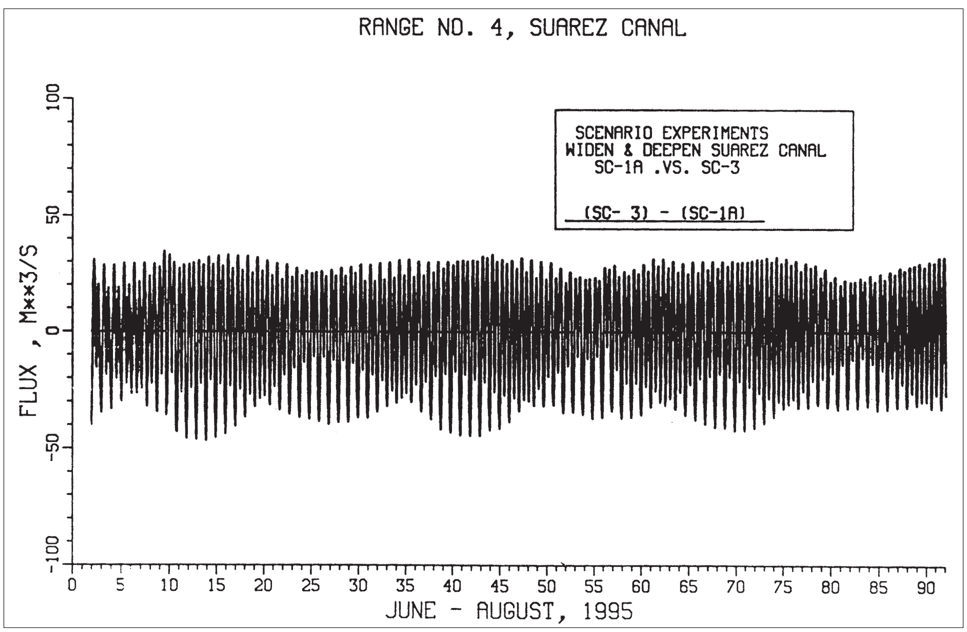
Conclusions

The major goal to be accomplished through physical changes to the SJBE system is to increase tidal flushing in Martín Peña Canal and Laguna San José. The results from the various scenarios discussed above show that Scenario 1c accomplishes this goal the best, if the desire is to increase the exchange between San José and San Juan Bay. Scenario 3 also significantly increases the tidal flushing of Laguna San José, but the exchange is with Laguna La Torrecilla waters rather than San Juan Bay waters. It is doubtful that mixing the relatively polluted San José waters with the relatively clean waters of Torrecilla is desirable.

The final scenario simulated was a combination of Scenario 1c and Scenario 2. Although Scenario 2 has little impact on tidal flushing in Laguna San José, the belief (from a HM perspective without including any benefits of pollutant load reductions) is that with the increased tidal flushing resulting from significantly widening and deepening the Martín Peña Canal, along with filling the highly polluted deep holes in San José and other areas of the system, the combination of Scenarios 1c and 2 offers the best hope for improving the water quality of Laguna San José.

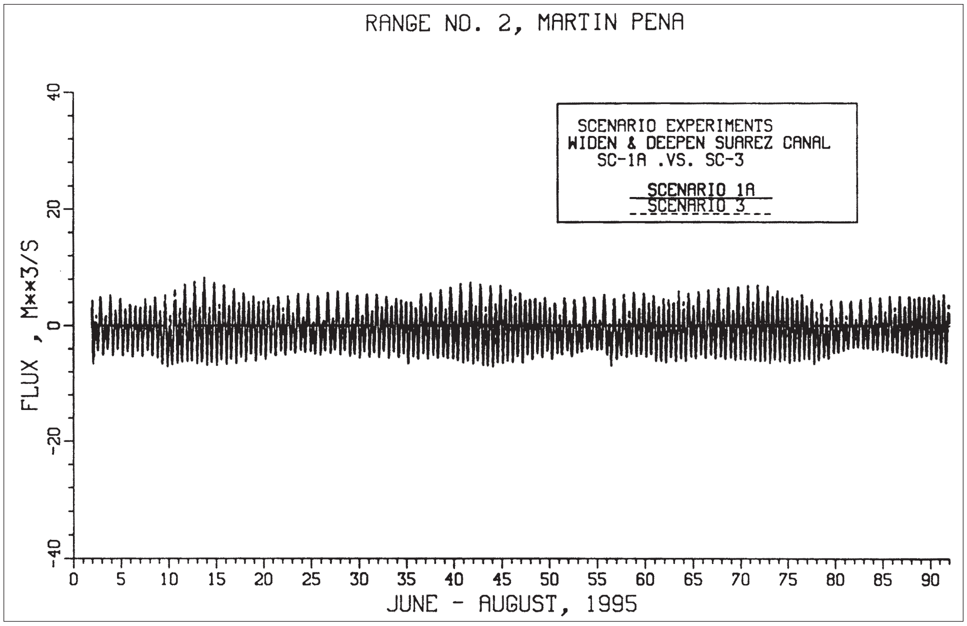


a. Both 1a and 3

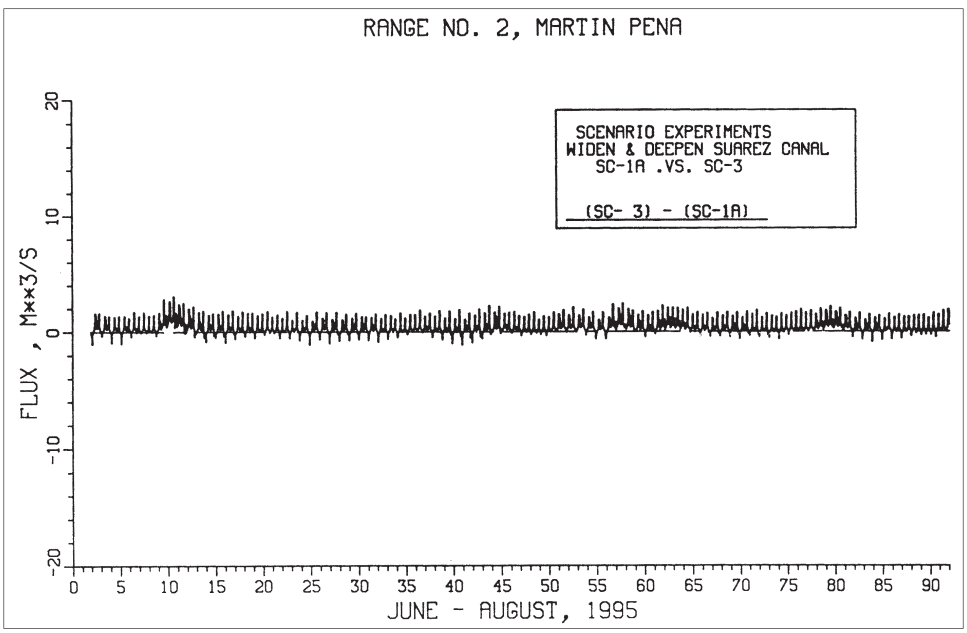


b. Difference between 1a and 3

Figure 8-20. Comparison of flux at Range 4 between Scenarios 1a and 3

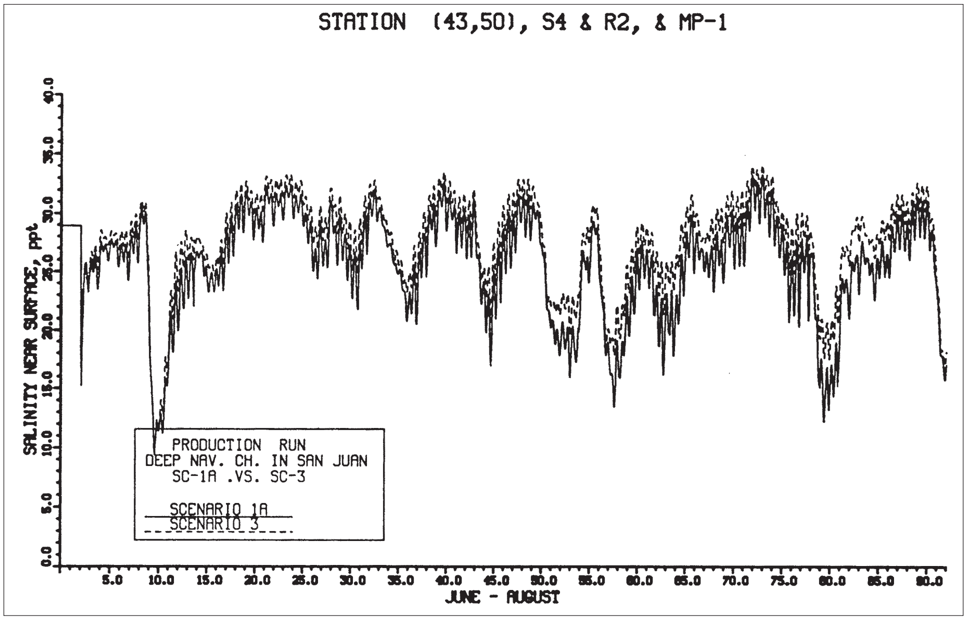


a. Both 1a and 3

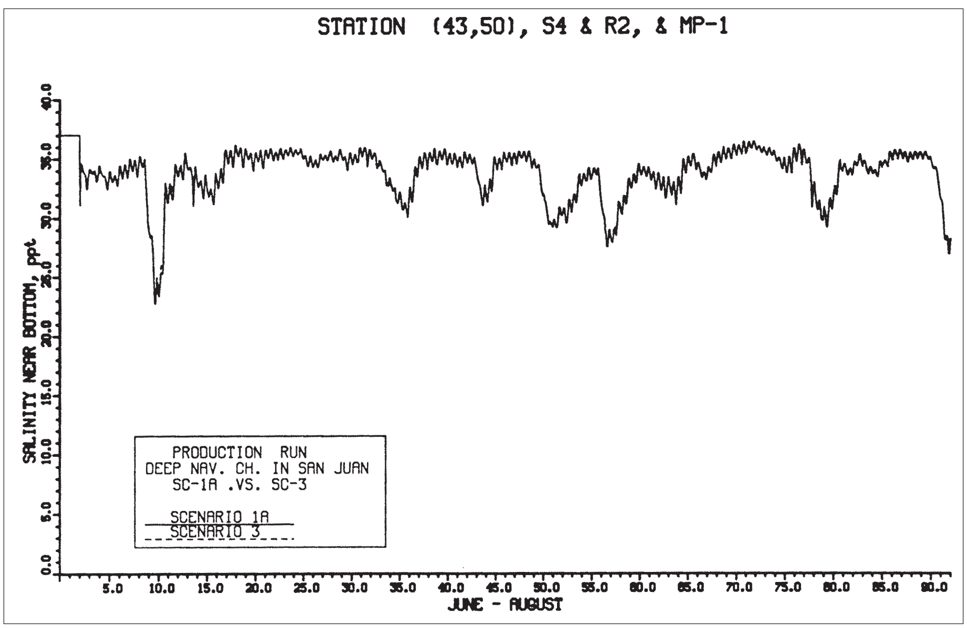


b. Difference between 1a and 3

Figure 8-21. Comparison of flux at Range 2 between Scenarios 1a and 3



a. Near surface



b. Near bottom

Figure 8-22. Comparison of salinity at S4 between Scenarios 1a and 3

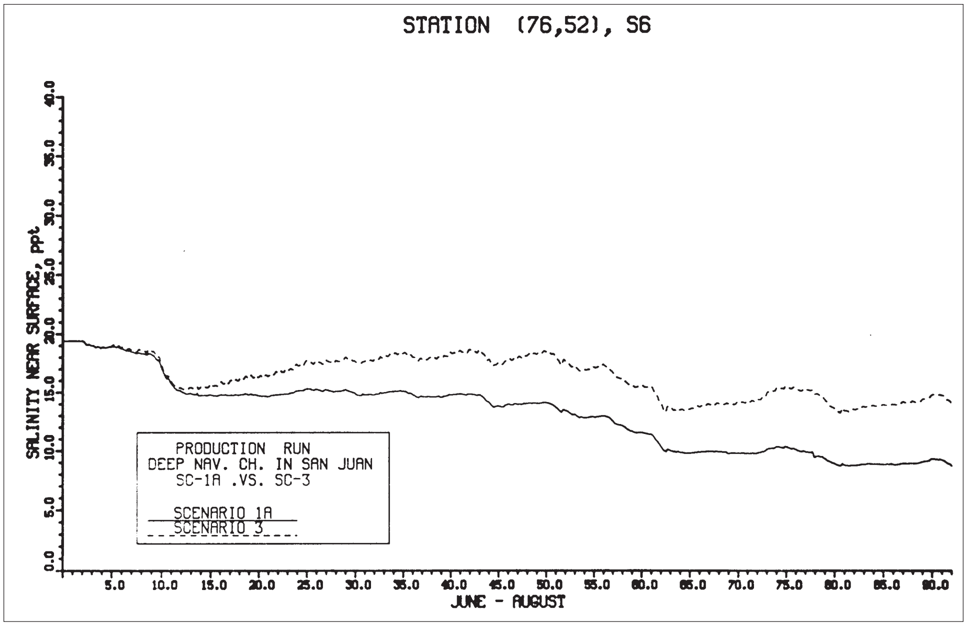
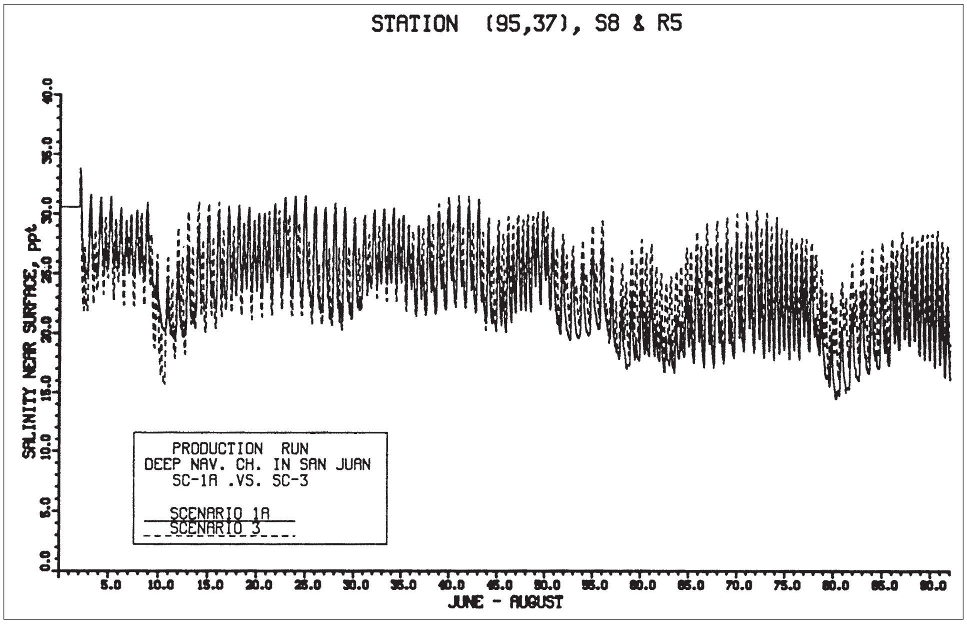
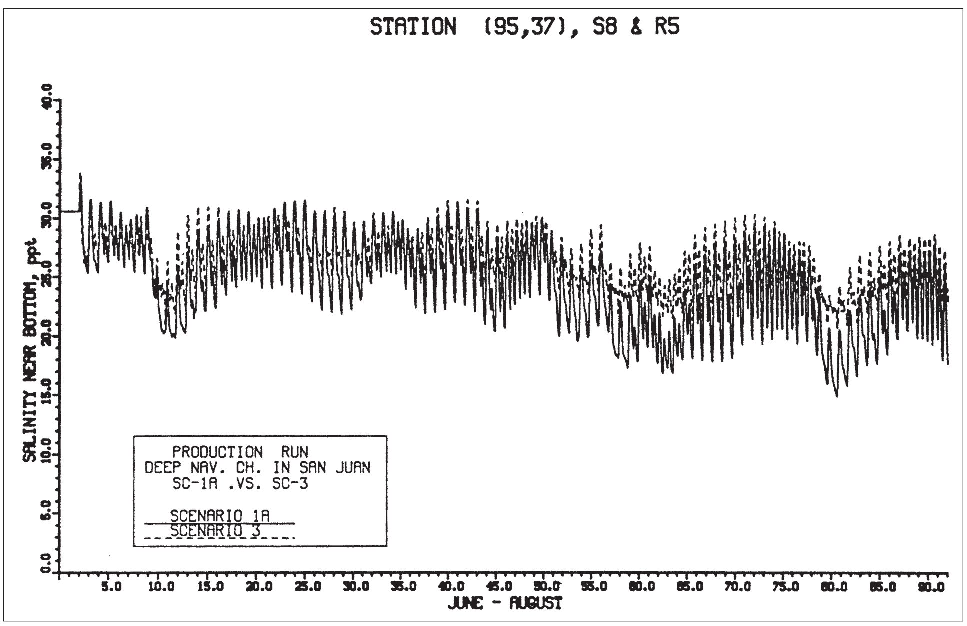


Figure 8-23. Comparison of salinity at S6 between Scenarios 1a and 3

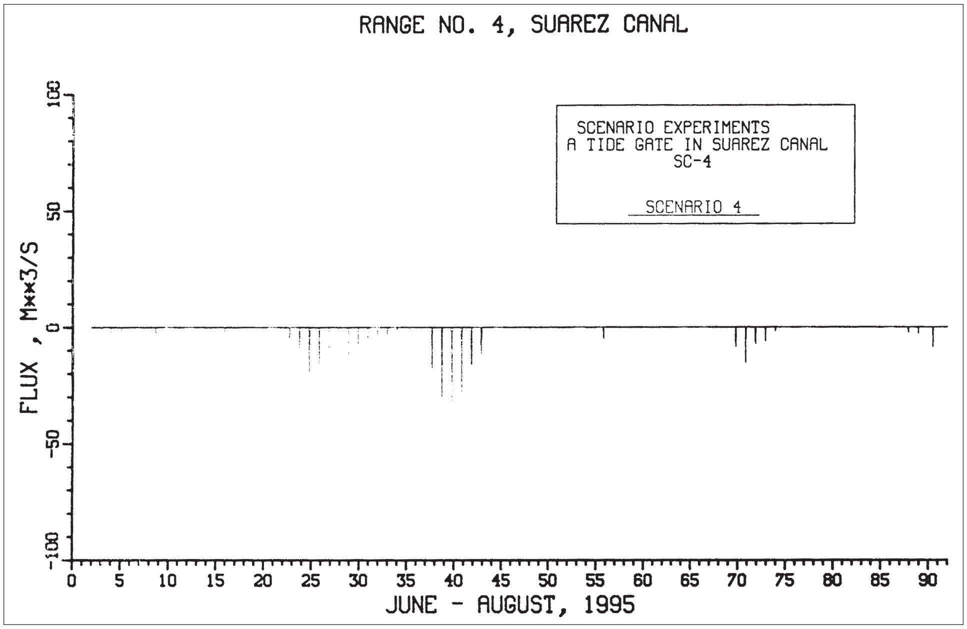


a. Near surface

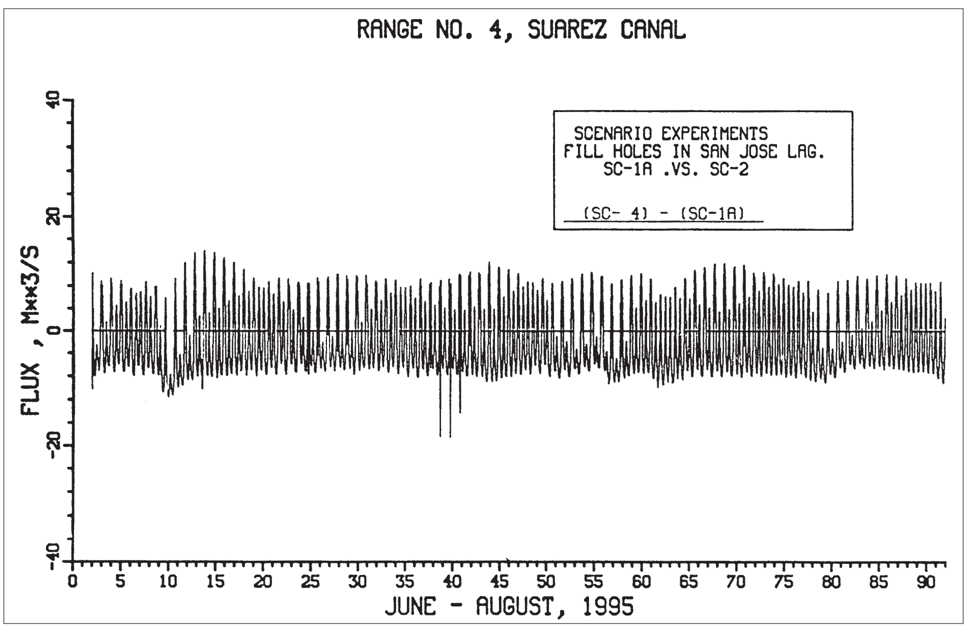


b. Near bottom

Figure 8-24. Comparison of salinity at S8 between Scenarios 1a and 3



a. Only 4



b. Difference between 1a and 4

Figure 8-25. Comparison of flux at Range 4 between Scenarios 1a and 4

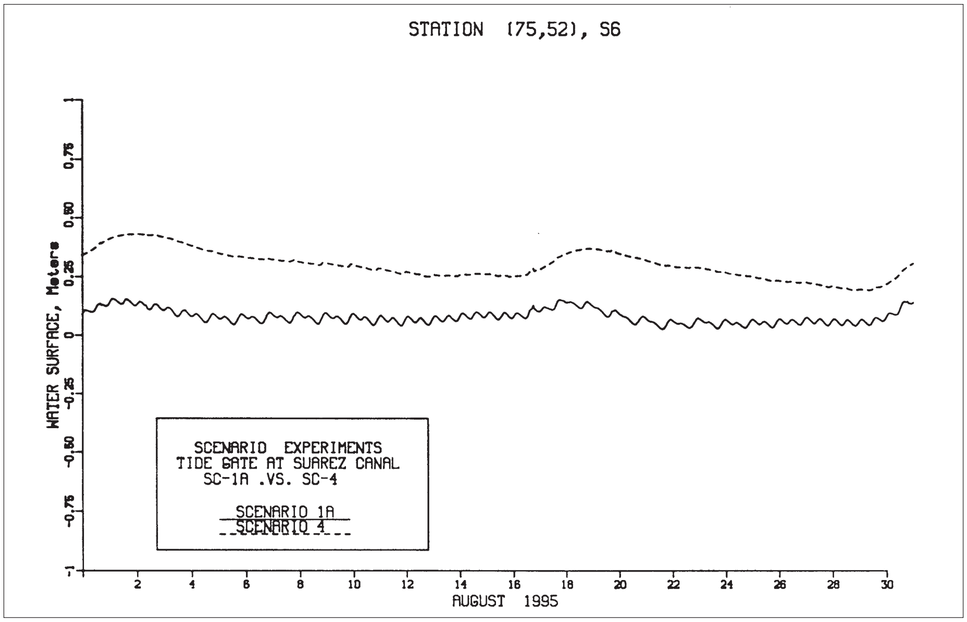
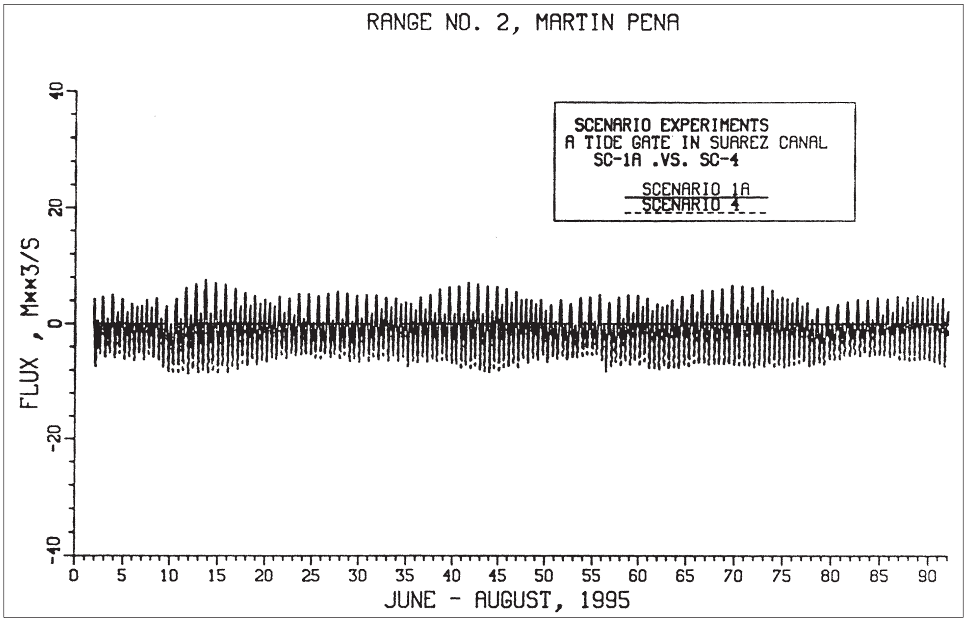
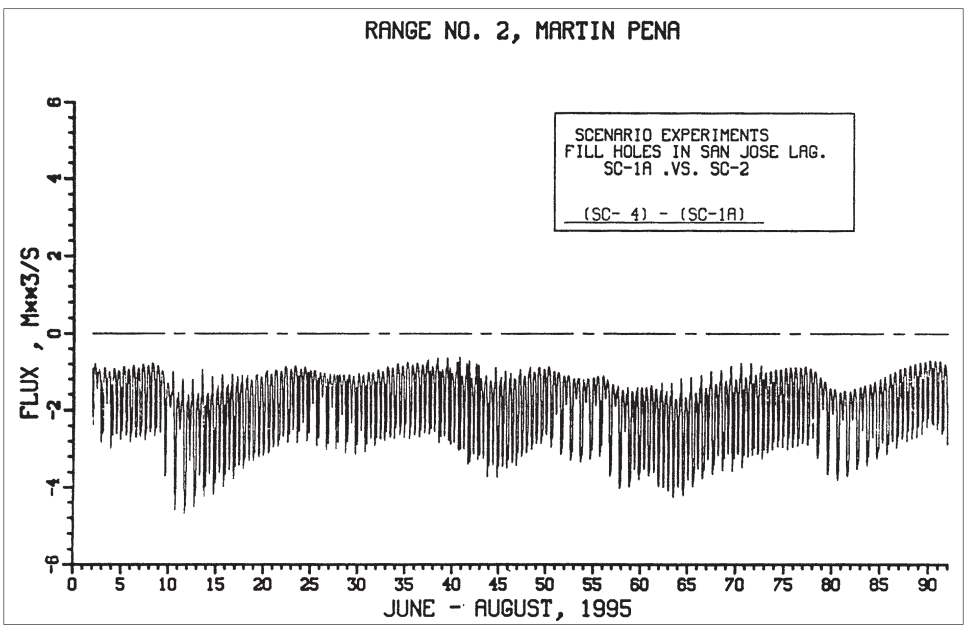


Figure 8-26. Comparison of tide at S6 between Scenarios 1a and 4

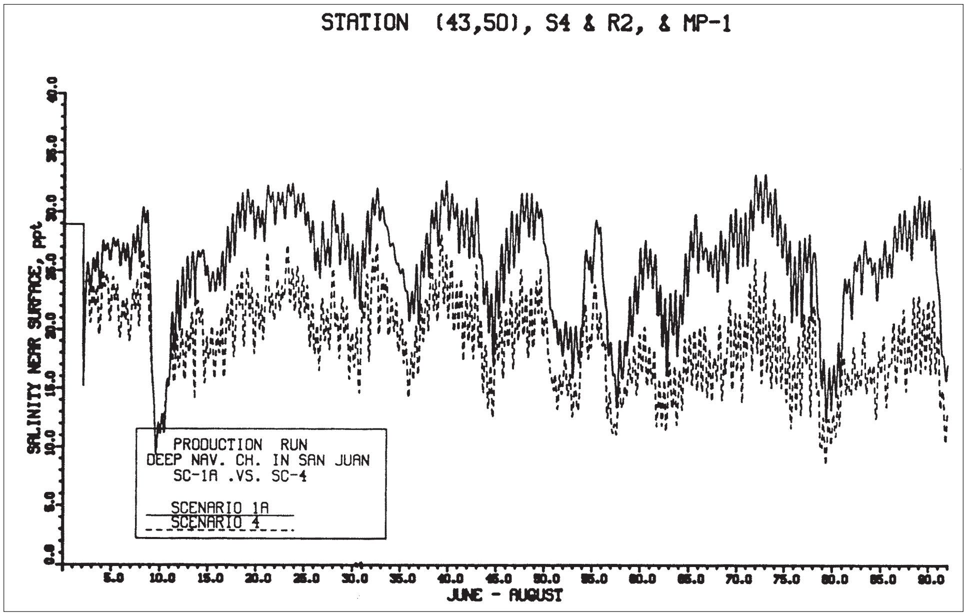


a. Both 1a and 4

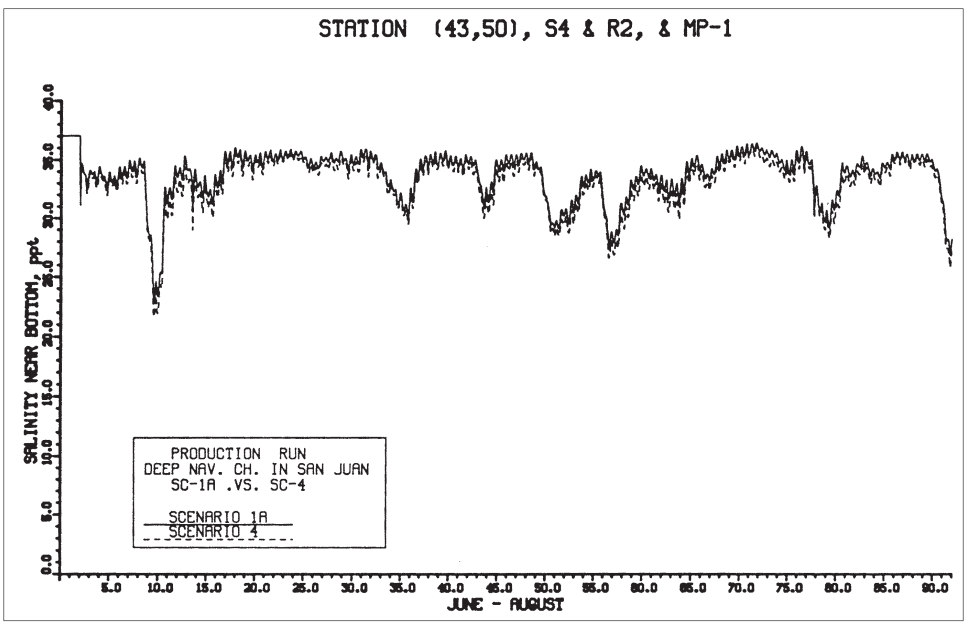


b. Difference between 1a and 4

Figure 8-27. Comparison of flux at Range 2 between Scenarios 1a and 4



a. Near surface



b. Near bottom

Figure 8-28. Comparison of salinity at S4 between Scenarios 1a and 4

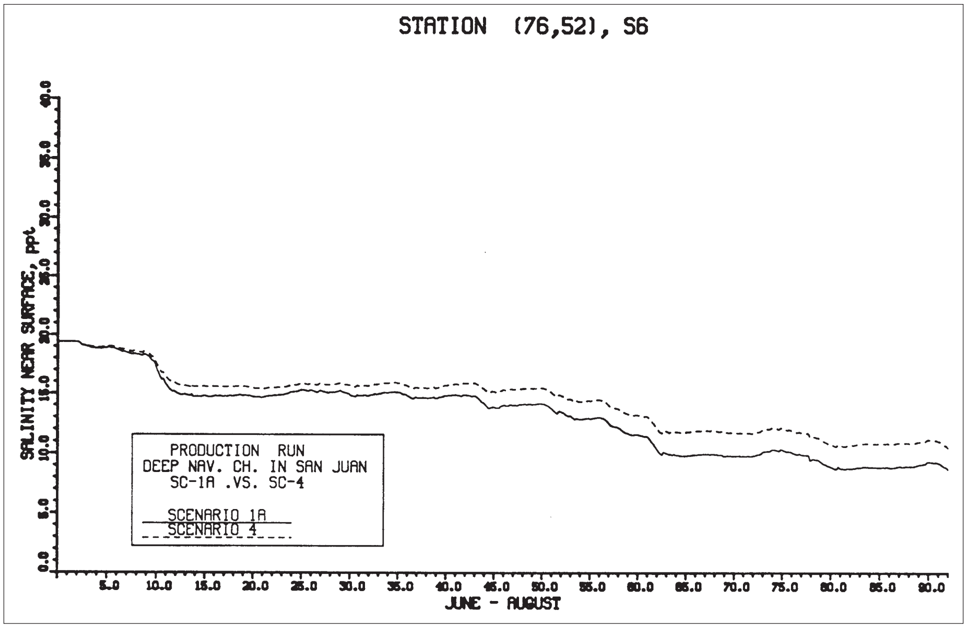
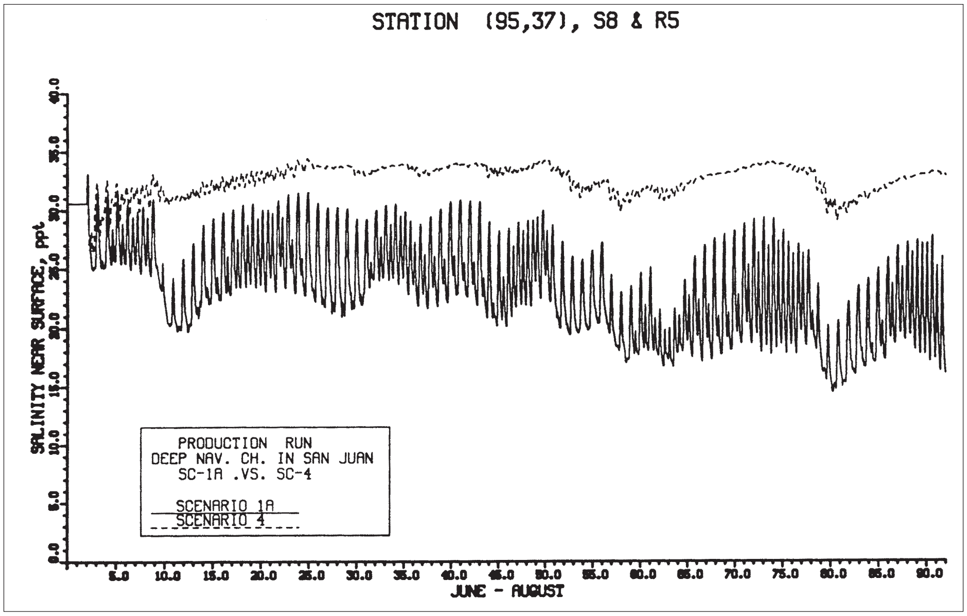
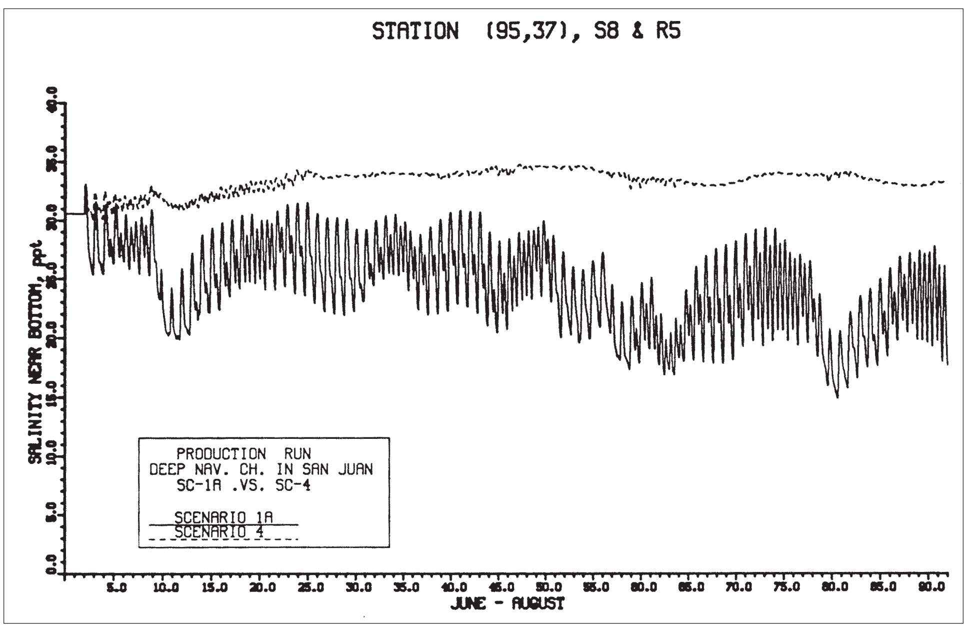


Figure 8-29. Comparison of salinity at S6 between Scenarios 1a and 4



a. Near surface



b. Near bottom

Figure 8-30. Comparison of salinity at S8 between Scenarios 1a and 4

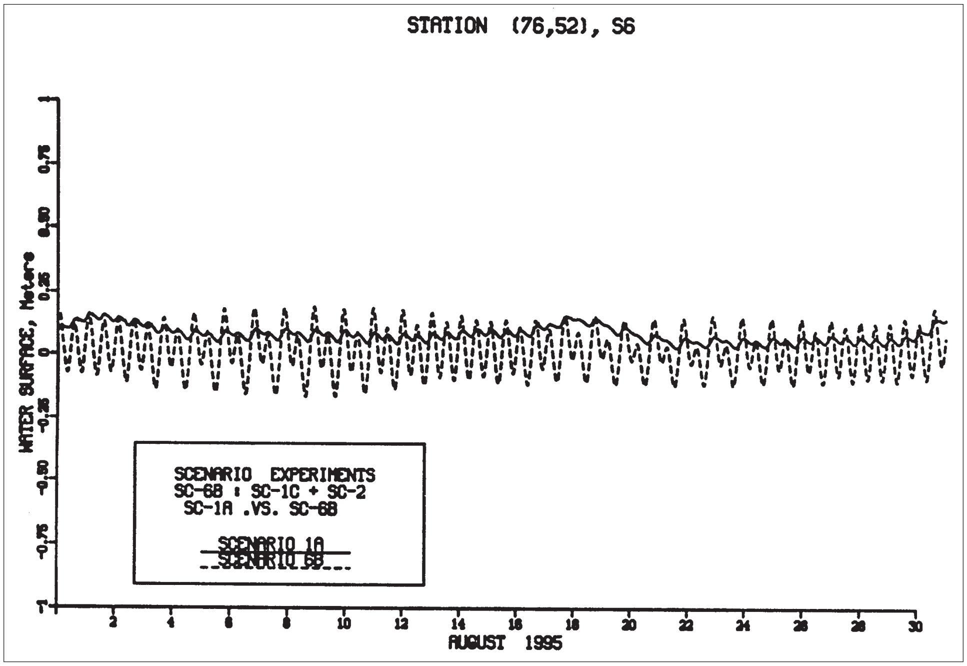
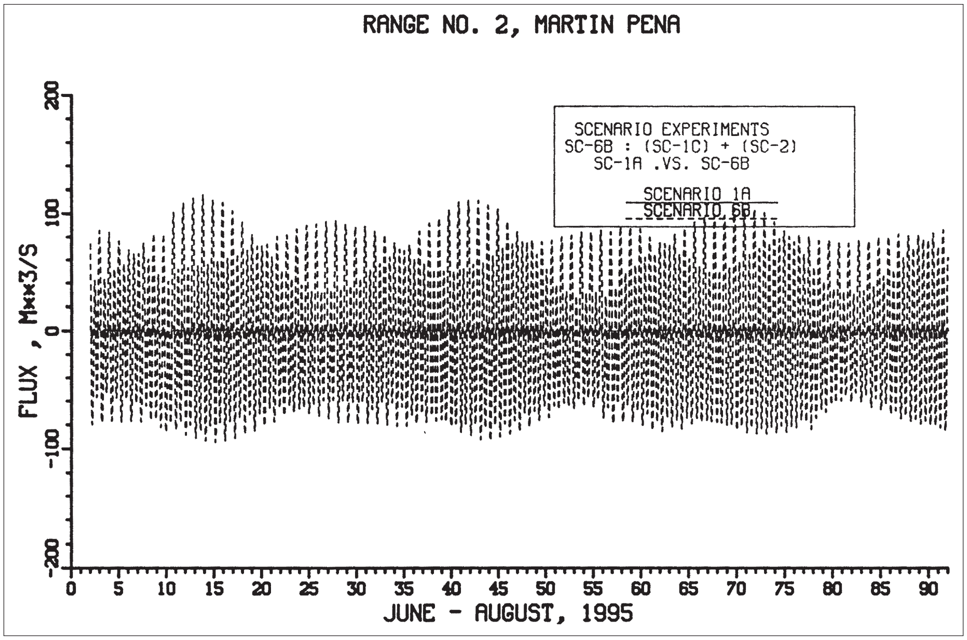
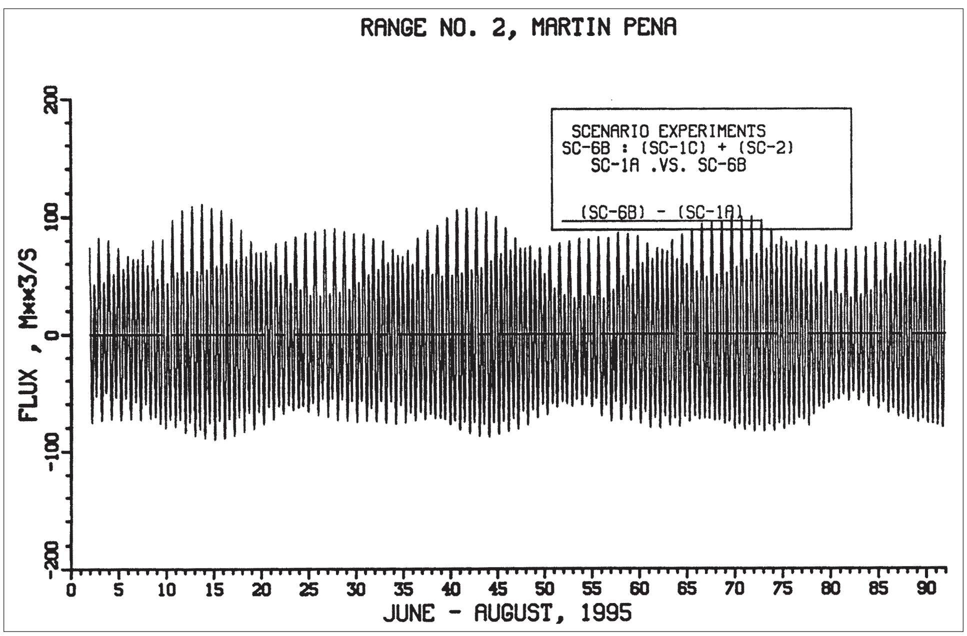


Figure 8-31. Comparison of tide at S6 between Scenarios 1a and 6b

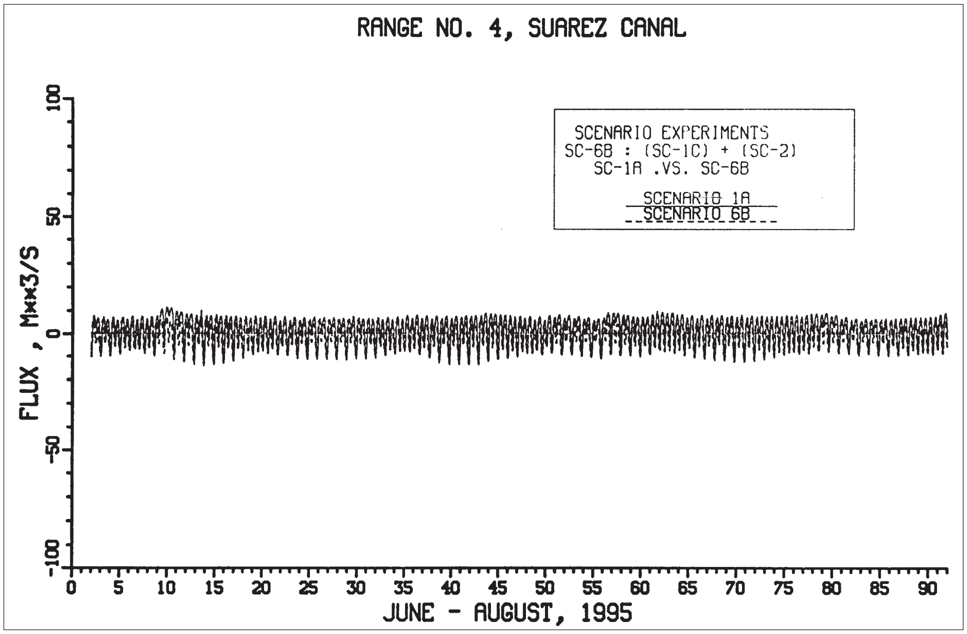


a. Both 1a and 6b

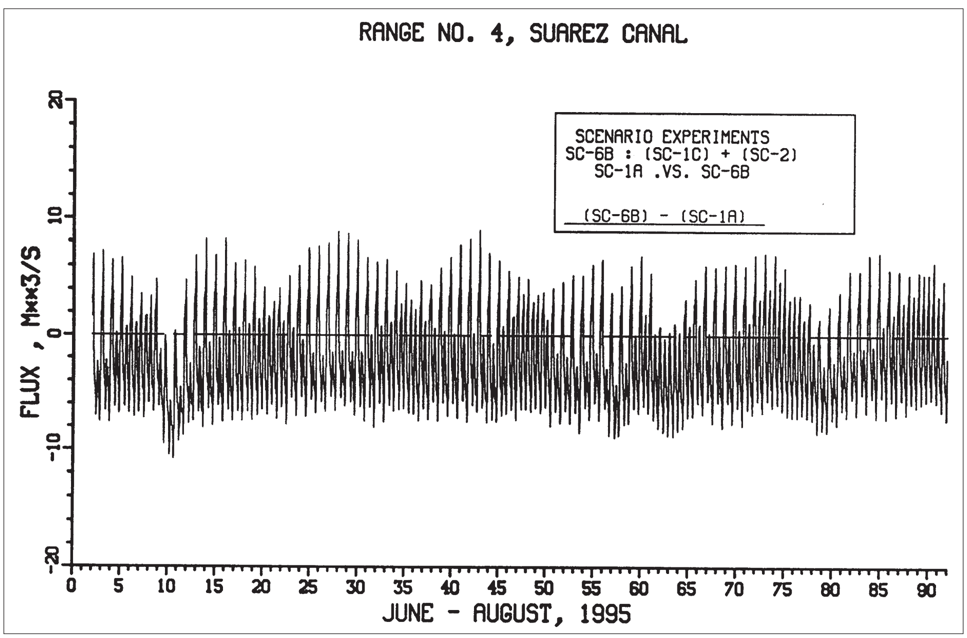


b. Difference between 1a and 6b

Figure 8-32. Comparison of flux at Range 2 between Scenarios 1a and 6b

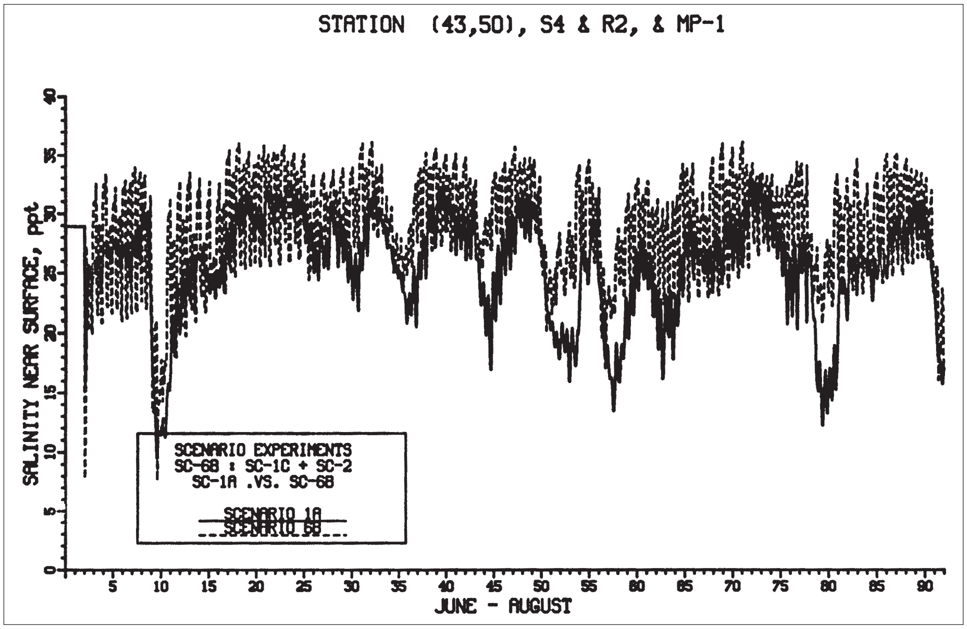


a. Both 1a and 6b

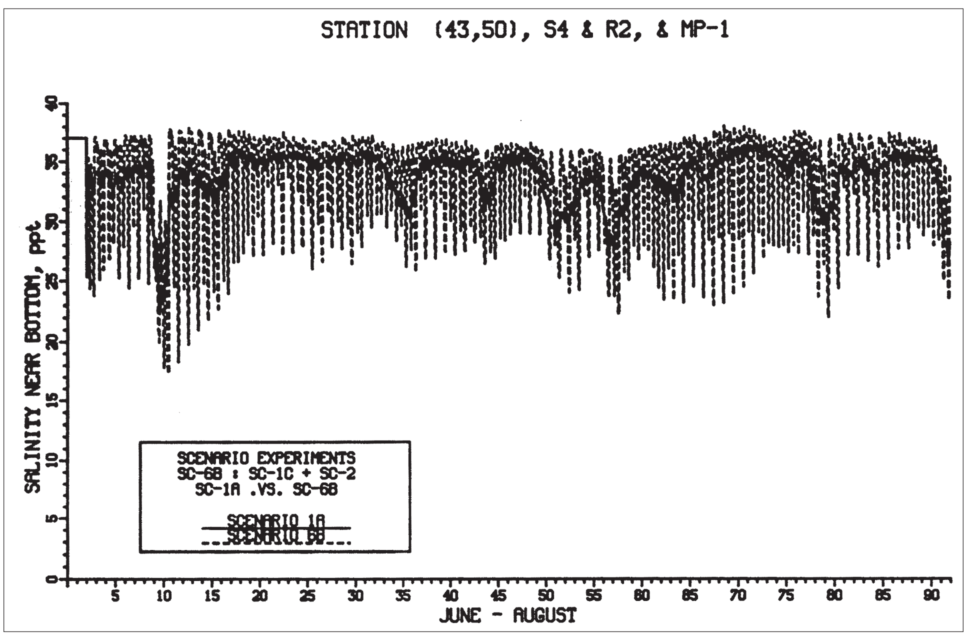


b. Difference between 1a and 6b

Figure 8-33. Comparison of flux at Range 4 between Scenarios 1a and 6b

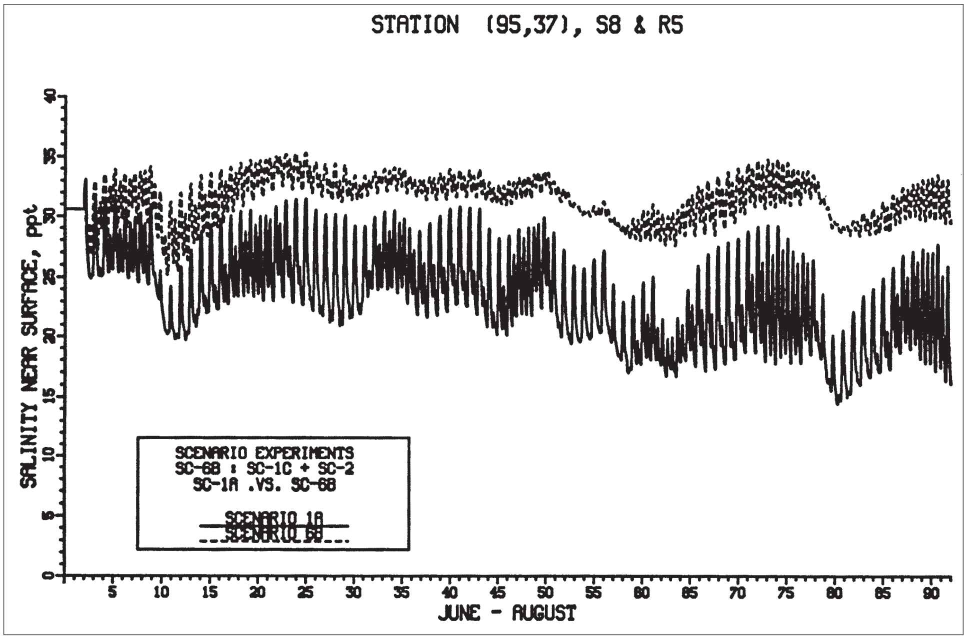


a. Near surface

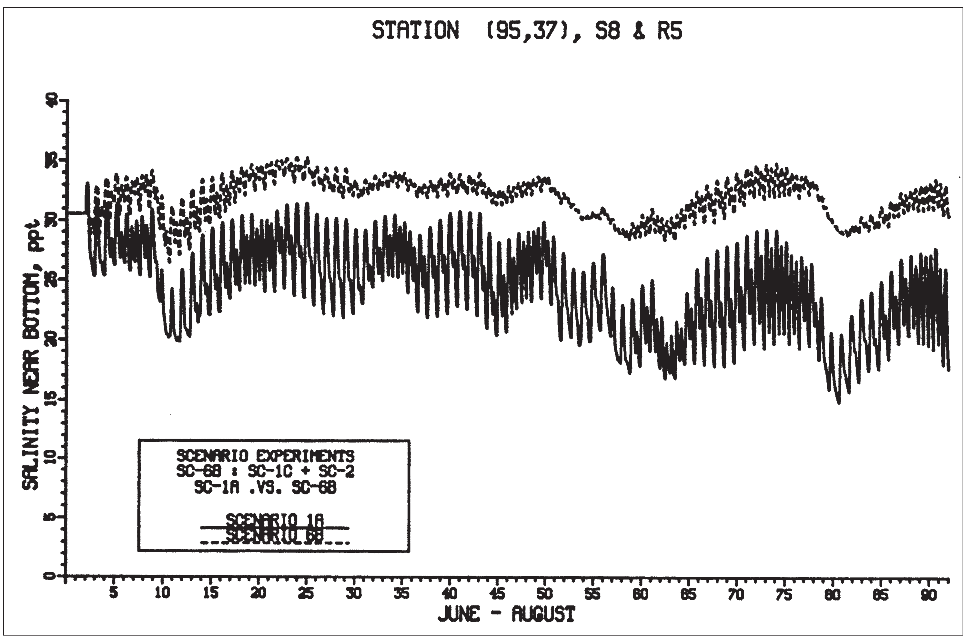


b. Near bottom

Figure 8-34. Comparison of salinity at S4 between Scenarios 1a and 6b



a. Near surface



b. Near bottom

Figure 8-36. Comparison of salinity at S8 between Scenarios 1a and 6b

Water Quality Model Results

All scenarios required a common set of initial conditions for the water column and the sediments so that any differences observed between the scenarios would be attributable to the modifications imposed by the scenario. Ideally, the spatially varying set of initial conditions for the water column and sediments generated during calibration would be used. Unfortunately, the addition and deletion of water quality cells resulting from channel modification caused the number of cells and cell numbering to vary among scenarios. All scenarios had the same plan view so the number of surface cells remained unchanged, only subsurface cells were added or deleted in response to scenario dredging and filling activities.

To circumvent the problems with cell numbers and numbering in the scenarios, each scenario began with a uniform set of initial conditions in the water column as shown in Table 8-4. The WQM was run for the duration of the scenario, the final concentrations saved to a file which was then used as the initial conditions for the next run of that scenario. Sediment initial conditions were more problematic. Since sediments respond more slowly to changes in flow patterns and loadings than the water column does, beginning each scenario with a spatially uniform set of sediment initial conditions was undesirable due to the length of simulation required to reach a dynamic steady-state condition. Instead, the first run of every scenario began with the same sediment initial conditions used during calibration. These had been established over numerous calibration runs and were in equilibrium with calibration water column conditions.

Scenario results were compared using the same longitudinal transect as used during calibration. Results from each scenario were averaged over the STP and plotted with results from the base scenario, 1a, in order to assess the impact resulting from the scenario. Since all conditions in the scenarios were identical except for the change mandated by that scenario, deviations between the results of an individual scenario and 1a were wholly due to the conditions of the scenario.

Results from Scenarios 1b through 4 indicate changes in water quality that are totally due to changes in circulation resulting from channel/bathymetric modifications in Caño Martín Peña, Laguna San José, Canal Suárez, and Laguna La Torrecilla. As such, results from these scenarios all have similar characteristics.

In the following sections, Scenarios 1b through 6b are discussed. Results from all are compared to the base scenario, 1a. Observations are made as to the effects of the scenario conditions on each water quality constituent.

Table 8-4. Scenario Uniform Initial Conditions for Water Column		
Constituent	**Value**	**Units**
Temperature	30	ppt
Salinity	30	°C
Total Solids	10	g m^{-3}
Algae	0.6	g m^{-3}
Dissolved Organic Carbon	5	g m^{-3}
Labile Particulate Organic Carbon	1	g m^{-3}
Refractory Particulate Organic Cargon	1	g m^{-3}
Ammonium	0.1	g m^{-3}
Nitrate	0.02	g m^{-3}
Dissolved Organic Nitrogen	0.05	g m^{-3}
Labile Particulate Organic Nitrogen	0.2	g m^{-3}
Refractory Particulate Organic Nitrogen	0.2	g m^{-3}
Total Phosphorus	0.03	g m^{-3}
Dissolved Organic Phosphorus	0.02	g m^{-3}
Labile Particulate Organic Phosphorus	0.04	g m^{-3}
Refractory Particulate Organic Phosphorus	0.04	g m^{-3}
Chemical Oxygen Demand	0.1	g m^{-3}
Dissolved Oxygen	6	g m^{-3}
Fecal Coliform	100	mpn/100ml

Scenario 1b

The WQM grid for Scenario 1b was the same as the one used in 1a as widening Caño Martín Peña did not change the number of cells or flow faces. Figure 8-37 indicates the effect Scenario 1b had on the various water quality constituents. Temperature was unchanged between Scenario 1a and 1b as was expected. Salinity levels in San Juan Bay were only slightly changed but both surface and bottom salinity levels along the remainder of the transect were altered significantly. Surface salinity in western Caño Martín Peña decreased slightly in Scenario 1b while salinity in the eastern portion increased. This is due to the widening of the channel promoting increased exchange between the eastern and western ends of the canal. Surface salinity increased in Laguna San José as a result of increased flushing with San Juan Bay through Caño Martín Peña. Net flow from Laguna San José to Caño Martín Peña increased from 0.5 m^3/s to 1.45 m^3/s. Surface salinity also increased in Canal Suárez and La Torrecilla as a result of more of the freshwater flows into Laguna San José being removed via Caño Martín Peña. Net flow from Laguna San José to Canal Suárez decreased from 1.98 m^3/s to 1.08 m^3/s. Bottom salinity also increased throughout the interior portion of the system as a result of greater exchange with San Juan Bay and the ocean.

Chlorophyll levels in the surface layer of western Caño Martín Peña increased as a result of additional flushing from Laguna San José. Correspondingly, there were decreases in chlorophyll over the eastern end of the transect as a result of chlorophyll leaving Laguna San José. The redistribution in chlorophyll had a slight effect on predicted light extinction values in the interior portions of the system as the self-shading component was affected. Phytoplankton production decreased in San José from 6093 kg C/day in 1a to 5825 kg C/day in 1b as a result of lower algae levels due to increased flushing.

Transect plots for carbon indicate that levels in the interior portions of the system decrease in Scenario 1b. This results from increased exchanges between Caño Martín Peña and San Juan Bay and Laguna San José and Caño Martín Peña. Carbon daily flux rates between Laguna San José and Caño Martín Peña increase from 454 kg/day in 1a to 1311 kg/day in 1b, while daily flux rates from Caño Martín Peña to San Juan Bay increased from 4860 kg/day to 5674 kg/day. As a result of the widening of Caño Martín Peña, less carbon was leaving Laguna San José by Canal Suárez in 1b (769 kg/day) than in 1a (1631 kg/day) which results in a decrease in carbon levels expressed as DOC and TOC in Canal Suárez and Laguna La Torrecilla.

Results similar to those for carbon were seen for nitrogen and phosphorus. The widening of Caño Martín Peña in Scenario 1b resulted in more nitrogen and phosphorus leaving Laguna San José via Caño Martín Peña rather than through Canal Suárez. This did not have much effect on concentrations in Laguna San José as concentrations were already low. There was a slight decrease in sediment ammonium flux rates over the length of Canal Suárez which resulted in ammonium release for Scenario 1b dropping to 8.9 kg/day from 10.2 kg/day in 1a. Both surface and bottom ammonium concentrations in Canal Suárez dropped in response to this and the decrease in nitrogen fluxes from Laguna San José. Nitrogen levels in surface and bottom waters decreased in Caño Martín Peña as a result of increased flushing and a slight decrease in ammonium releases from 3.95 kg/day in 1a to 3.67 kg/day in 1b. Dissolved organic phosphorus and dissolved inorganic phosphorus concentrations dropped in both the surface and subsurface waters of Caño Martín Peña. Again the decrease appears to be the result of increased flushing moving the flow and loading out of Caño Martín Peña faster.

Dissolved oxygen levels improved considerably over the length of Caño Martín Peña in 1b. The largest increase occurred near the middle of Caño Martín Peña at the end of the dredged portion where dissolved oxygen levels increased from 3 mg/l to over 5.5 mg/l. Bottom dissolved oxygen levels increased slightly in eastern Caño Martín Peña, Canal Suárez, and Laguna La Torrecilla. Fecal coliform levels remained relatively unchanged along the transect except for a slight decrease in eastern Caño

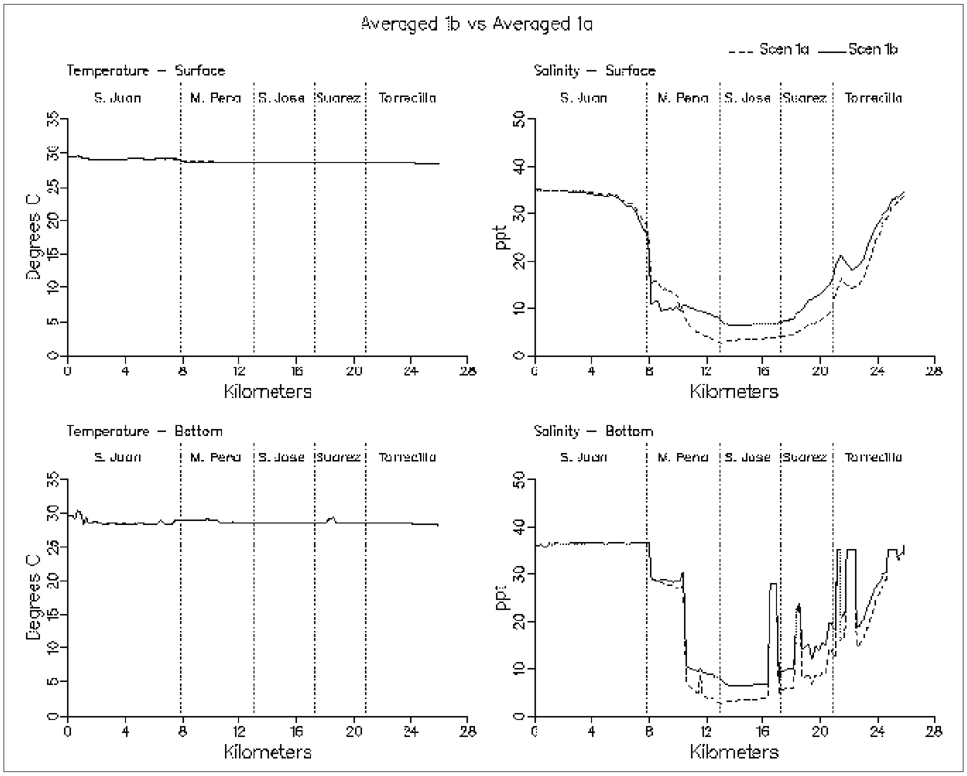


Figure 8-37. Simulation averaged transect plots and sediment flux plots comparing Scenario 1b with Scenario 1a (Sheet 1 of 11)

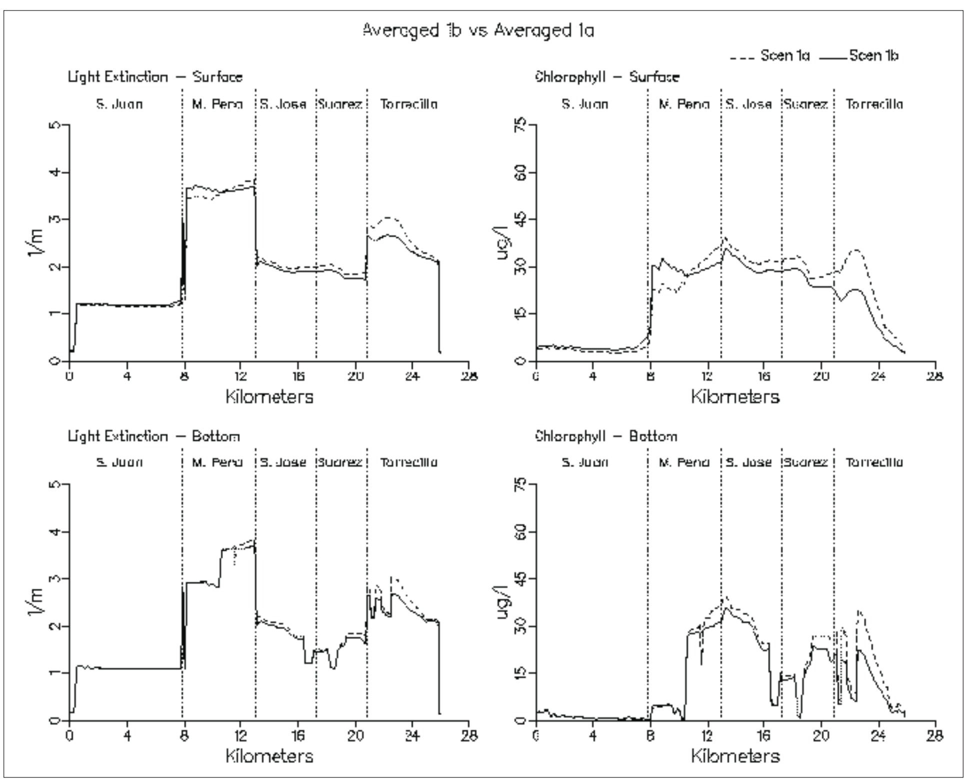


Figure 8-37. (Sheet 2 of 11)

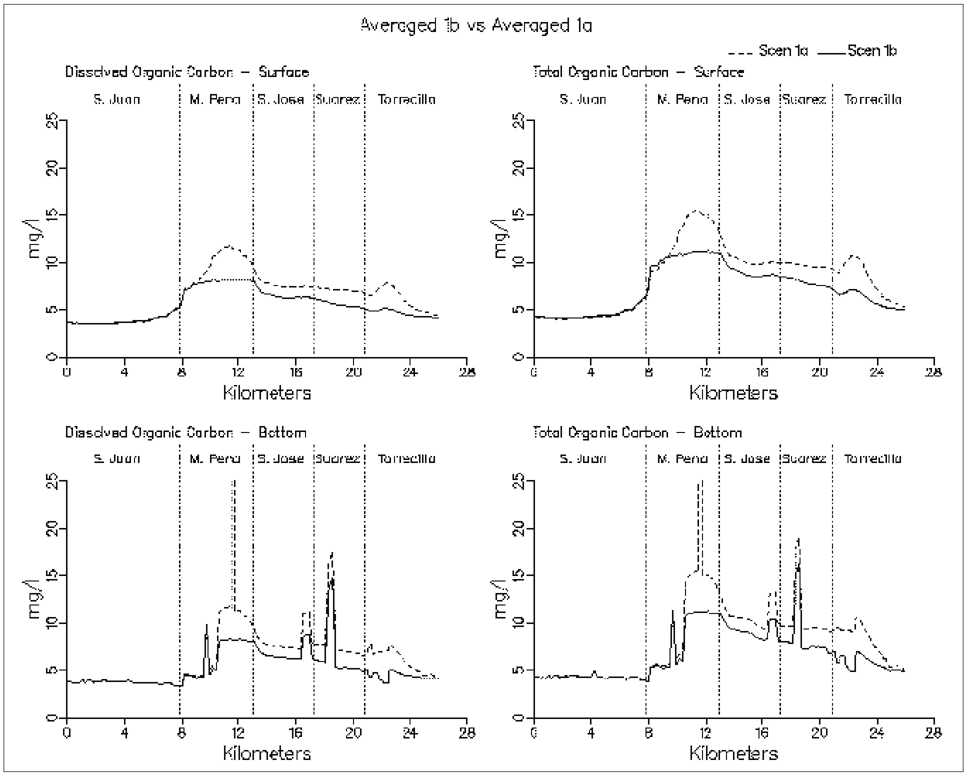


Figure 8-37. (Sheet 3 of 11)

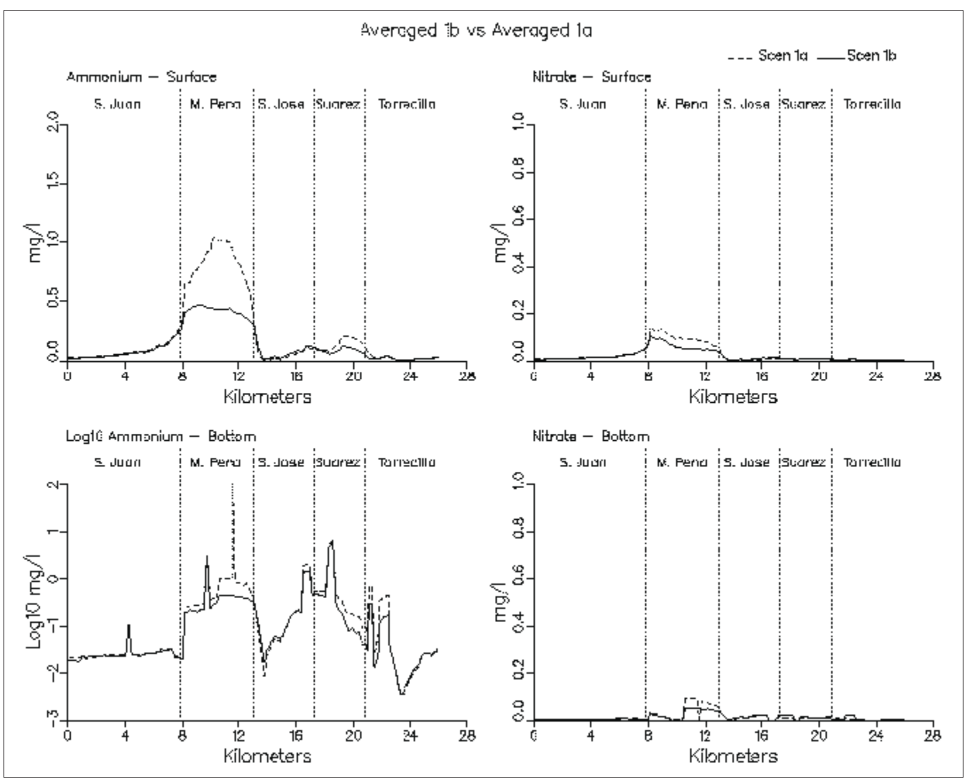


Figure 8-37. (Sheet 4 of 11)

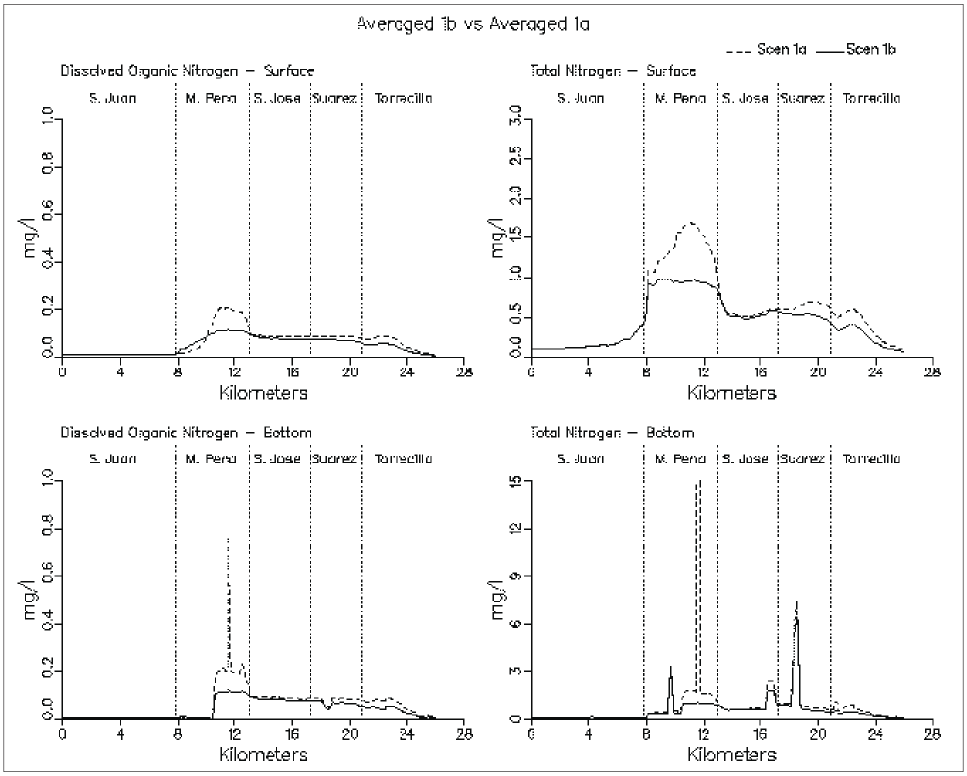


Figure 8-37. (Sheet 5 of 11)

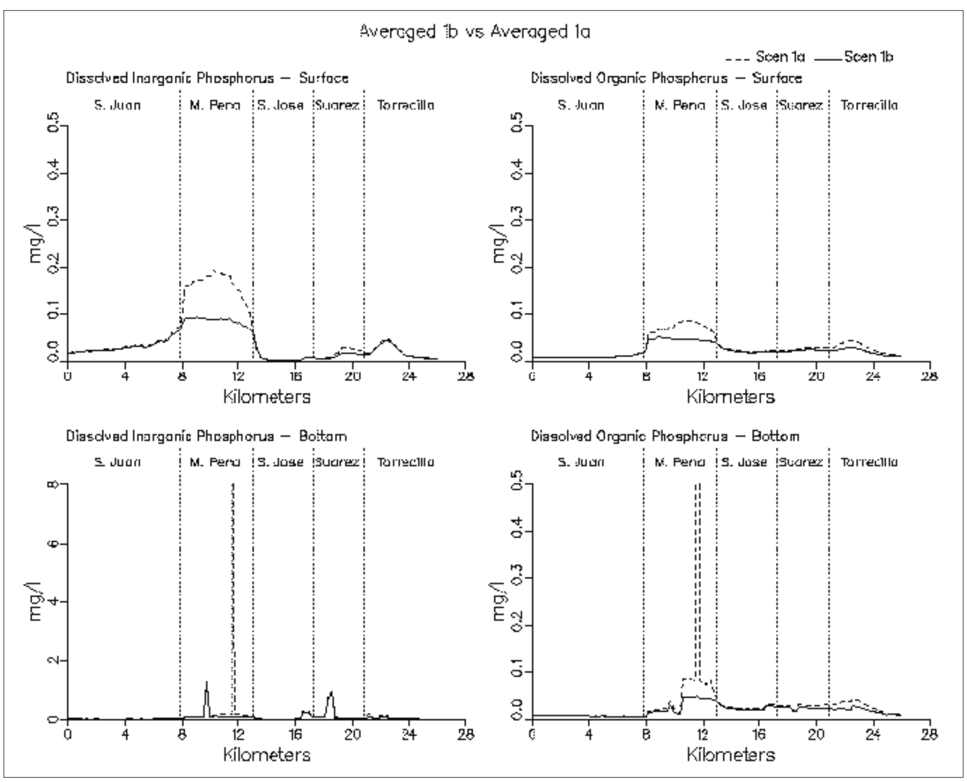


Figure 8-37. (Sheet 6 of 11)

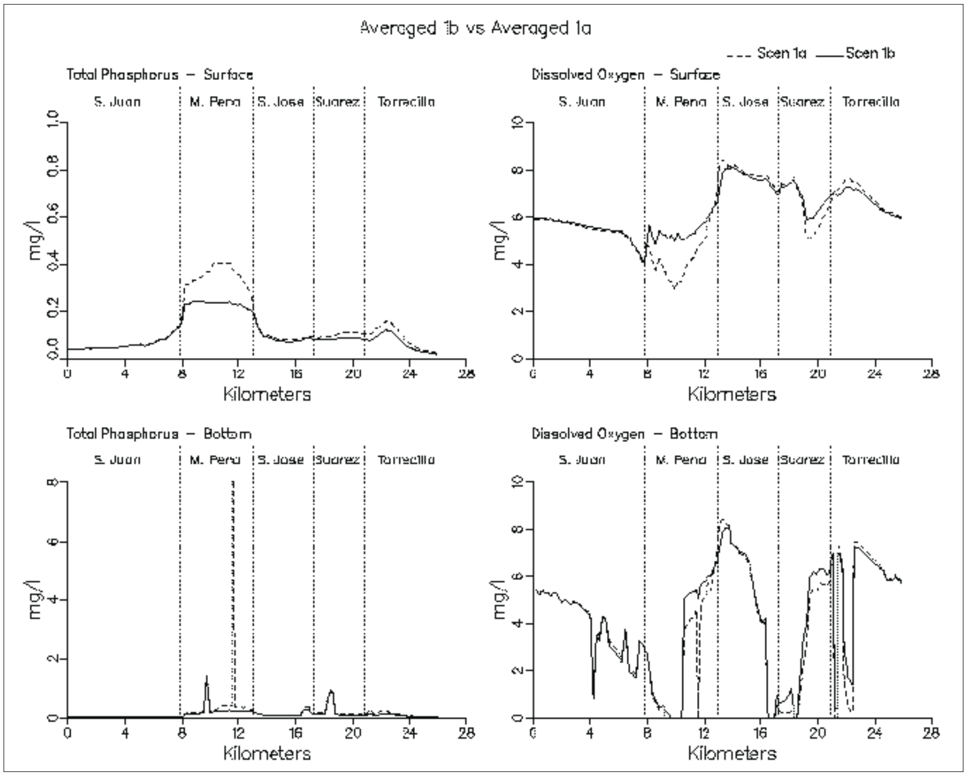


Figure 8-37. (Sheet 7 of 11)

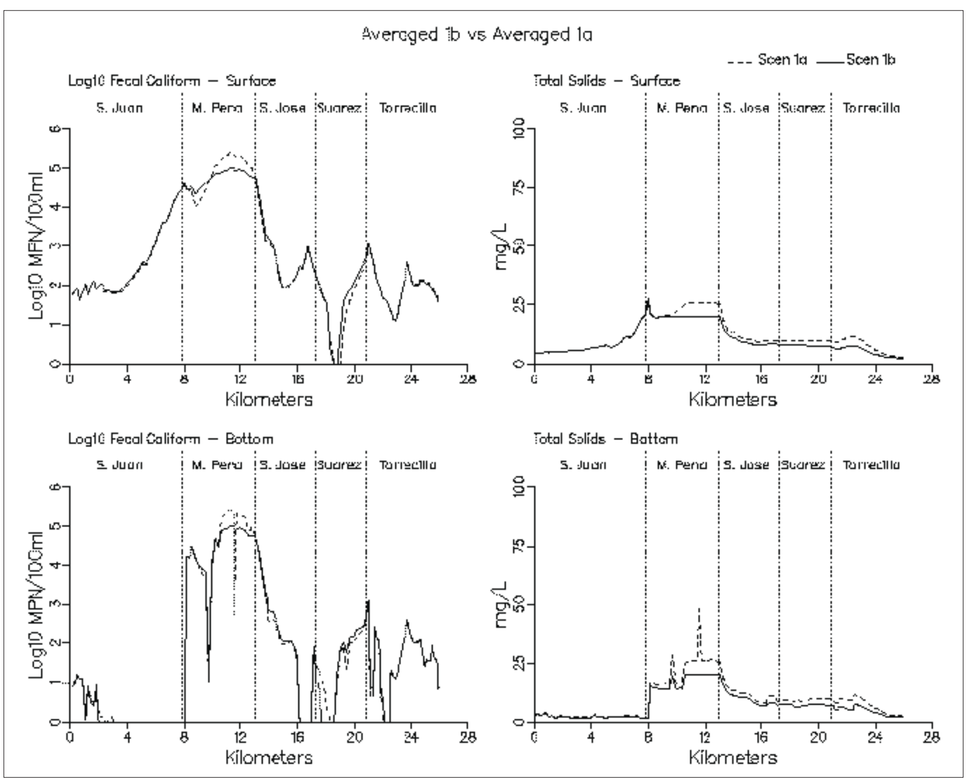
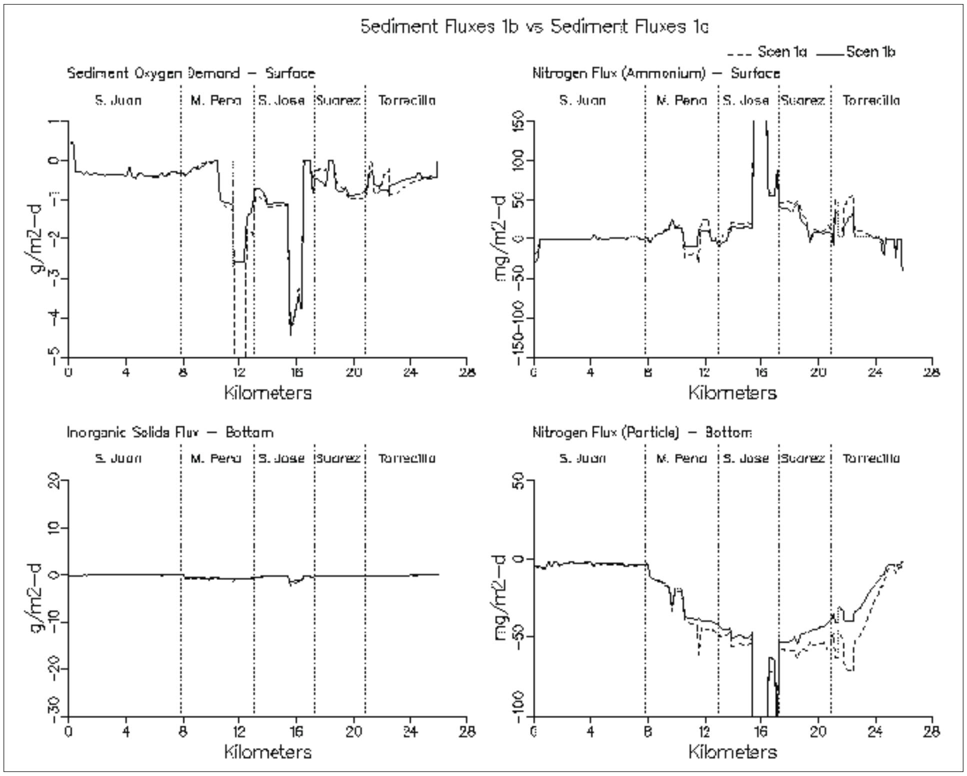


Figure 8-37. (Sheet 8 of 11)



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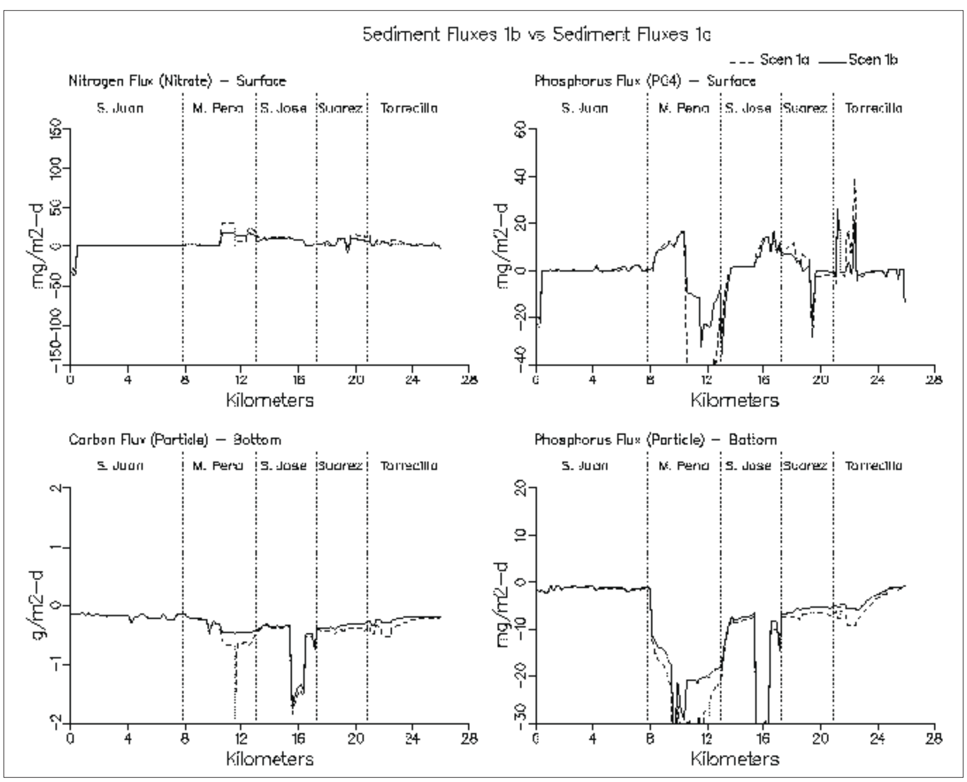


Figure 8-37. (Sheet 10 of 11)

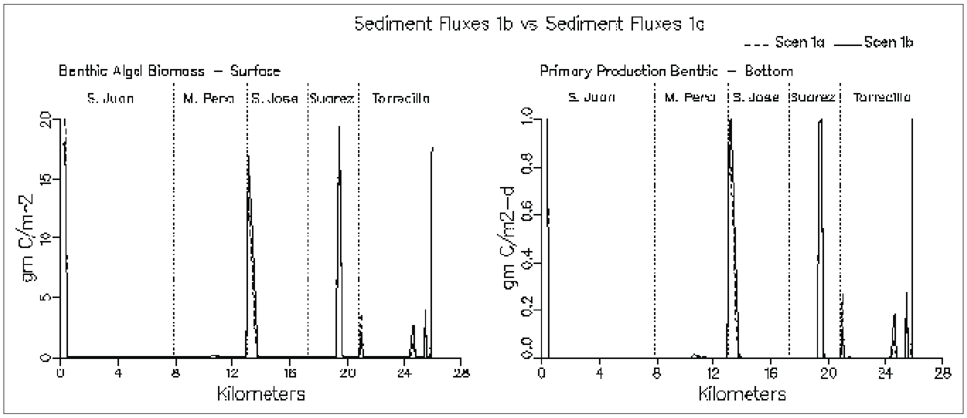


Figure 8-37. (Sheet 11 of 11)

Martín Peña as a result of increased flushing. Total solids transect plots also indicated decreases in the interior of the system as a result of additional flushing.

In summary, Scenario 1b resulted in an increase in the flow from Laguna San José through Caño Martín Peña. At the same time, there was a corresponding decrease in flow from Laguna San José through Canal Suárez. There were corresponding decreases in the mass of carbon, nitrogen, and phosphorus leaving Laguna San José via Canal Suárez which had the end result of improving water quality by decreasing nutrients and increasing salinity in Canal Suárez. The decrease in Laguna San José flow through Canal Suárez had the result of increasing ocean water influx through the Laguna La Torrecilla inlet which raised salinity levels. Nutrient levels in Caño Martín Peña were typically decreased by the nearly three-fold increase in flushing through the eastern end of the canal. The additional load due to the flux of Laguna San José waters through Caño Martín Peña was more than offset by the additional exchange with San Juan Bay.

Scenario 1c

The channel modifications for this scenario required that a new grid be generated (Table 8-3). Widening and deepening Caño Martín Peña had a significant effect on the distribution of flows from Laguna San José. Average discharge from Laguna San José through Caño Martín Peña increased to over 3 m^3/s. In the base Scenario 1a, discharge through this same path was only 0.5 m^3/s. Flow from Laguna San José via Canal Suárez in the base scenario had been nearly 2 m^3/s. In Scenario 1c, there is a reversal of the net flow so that there is now an average inflow of water from Canal Suárez to Laguna San José of 0.4 m^3/s. In effect, a clockwise circulation pattern has been established through the interior of the system from Laguna La Torrecilla to the mouth of San Juan Bay.

The change in circulation described above had significant effects upon water quality. Average salinity levels in Caño Martín Peña, Laguna San José, and Canal Suárez increased to approximately 23 ppt, Figure 8-38. There was a slight decrease in surface salinity in San Juan Bay as a result of more of the freshwater flows from Laguna San José being discharged through Caño Martín Peña. Bottom water salinity levels in Caño Martín Peña, Laguna San José, and Canal Suárez had increases similar to those of the surface waters, reaching concentrations of 25 ppt or greater. Chlorophyll levels in Caño Martín Peña, Laguna San José, Canal Suárez, and Laguna La Torrecilla decreased. Only San Juan Bay indicated any increase in chlorophyll when compared to Scenario 1a. Surface chlorophyll concentrations increased to 7 µg/l in San Juan Bay as a result of chlorophyll from Laguna San José being transported down Caño Martín Peña. Phytoplankton production levels increased in San Juan Bay in 1c to 5300 kg C/day. In 1a , phytoplankton production levels were 3586 kg C/day. By comparison, phytoplankton production levels in Laguna San José were 5860 kg C/day in Scenario 1c and 6093 kg C/day in Scenario 1a. So while there was a significant change in chlorophyll levels between 1a and 1c in Laguna San José, the change was not the result of decreased algal activity but was instead the result of algae being discharged to San Juan Bay via Caño Martín Peña. A slight change in light extinction rates occurs along the transect as a result of changes in algal self-shading due to changes in algae concentration.

Surface dissolved organic carbon levels decreased in Caño Martín Peña, Laguna San José, Canal Suárez, and Laguna La Torrecilla. Concentrations in eastern Caño Martín Peña decreased from 12 mg/l to 5 mg/l. To some degree decreases in this area can be attributed to the canal dredging increasing receiving water volume for the un-sewered loadings. Total organic carbon levels showed results similar to those of dissolved organic carbon. Particulate organic carbon sediment deposition rates were decreased in eastern Caño Martín Peña from 0.5 g/m^2-day to 0.1 g/m^2-day. Carbon fluxes from Laguna San José to Caño Martín Peña in Scenario 1c were 3530 kg/day. Carbon fluxes from Canal Suárez to Laguna San José were 166 kg/day. Therefore, Canal Suárez transferred organic carbon into Caño Martín Peña for 1c.

Surface and bottom ammonium levels decreased all along the transect with the exception of a slight increase (0.05 mg/l) in the vicinity of station SJ-2 in Laguna San José. The greatest decreases in surface waters occurred in eastern Caño Martín Peña where ammonium levels decreased from as high as 1 mg/l to 0.1 mg/l. Surface levels decreased in western Caño Martín Peña but not to the same degree as in the eastern end of the canal. One possible explanation for this is the effects of the Rio Piedras inflows into Caño Martín Peña at its juncture with San Juan Bay. Ammonium levels decreased in the anoxic holes throughout the system. The most substantial decreases occurred in Caño Martín Peña as a result of the channelization removing the hole from the eastern end. The decreases in eastern Laguna San José, Canal Suárez, and Laguna La Torrecilla result from the clockwise circulation pattern established through the interior.

Nitrate levels decreased in the surface waters of Caño Martín Peña and were unchanged elsewhere. Dissolved organic nitrogen levels decreased along the transect from Caño Martín Peña eastward. An insignificant increase occurred in San Juan Bay at its confluence with Caño Martín Peña. Laguna San José discharged 186.7 kg/day of nitrogen into Caño Martín Peña and imported 5 kg/day from Canal Suárez.

Phosphorus results for Scenario 1c were similar to nitrogen results. Laguna San José discharged 15.3 kg/day of phosphorus into Caño Martín Peña and imported 2.3 kg/day from Canal Suárez. Dissolved inorganic phosphorus levels dropped in Caño Martín Peña surface waters and in the bottom waters all along the transect. Dissolved organic phosphorus levels also dropped in Caño Martín Peña in 1c and remained unchanged elsewhere along the transect. Total phosphorus results indicated the greatest decrease occurred in Caño Martín Peña. Slight decreases in total phosphorus occurred in Canal Suárez and Laguna La Torrecilla as a result of the flow reversal from 1a to 1c in Canal Suárez.

Surface dissolved oxygen levels increased in Caño Martín Peña to the 5-mg/l to 6-mg/l range in 1c. No bottom waters in Caño Martín Peña were anoxic in 1c although at least one location had an average dissolved oxygen less than 1 mg/l. Overall, bottom water dissolved oxygen levels in Caño Martín Peña were greater than 3 mg/l. Laguna San José, Canal Suárez, Laguna La Torrecilla all saw some degree of dissolved oxygen decrease in the surface and bottom waters. These decreases appear to be the result of diminished algal concentrations resulting in less photosynthesis. Bottom anoxic conditions at the confluence of Laguna San José and Canal Suárez were raised to a minimum of 2 mg/l and as high as 5 mg/l. Only the deep hole in Canal Suárez remained anoxic.

Fecal coliform levels decreased in Caño Martín Peña by an order of magnitude in part due to additional receiving water volume being present. Levels increased insignificantly in San Juan Bay as a result of additional flushing through Caño Martín Peña. A slight increase also occurred along the transect in Laguna San José as a result of Caño Martín Peña being opened. Total solids levels decreased throughout the system in 1c with the greatest decreases occurring in Caño Martín Peña.

In summary, Scenario 1c resulted in an increase in the discharge of Laguna San José through Caño Martín Peña. At the same time, there was a reversal in net flow in Suárez Canal which resulted in the establishment of a clockwise circulation pattern through the interior of the system. Canal Suárez exported nutrients into Laguna San José in 1c. All water quality variables, except DO, showed improvement in Scenario 1c when compared to 1a in all bodies of water examined. There were decreases in surface dissolved oxygen levels in Laguna San José, Canal Suárez, and Laguna La Torrecilla as a result of decreased algal photosynthesis. Nevertheless, surface dissolved oxygen levels in these waters remained in the 6-mg/l to 7-mg/l range and were the highest along the transect.

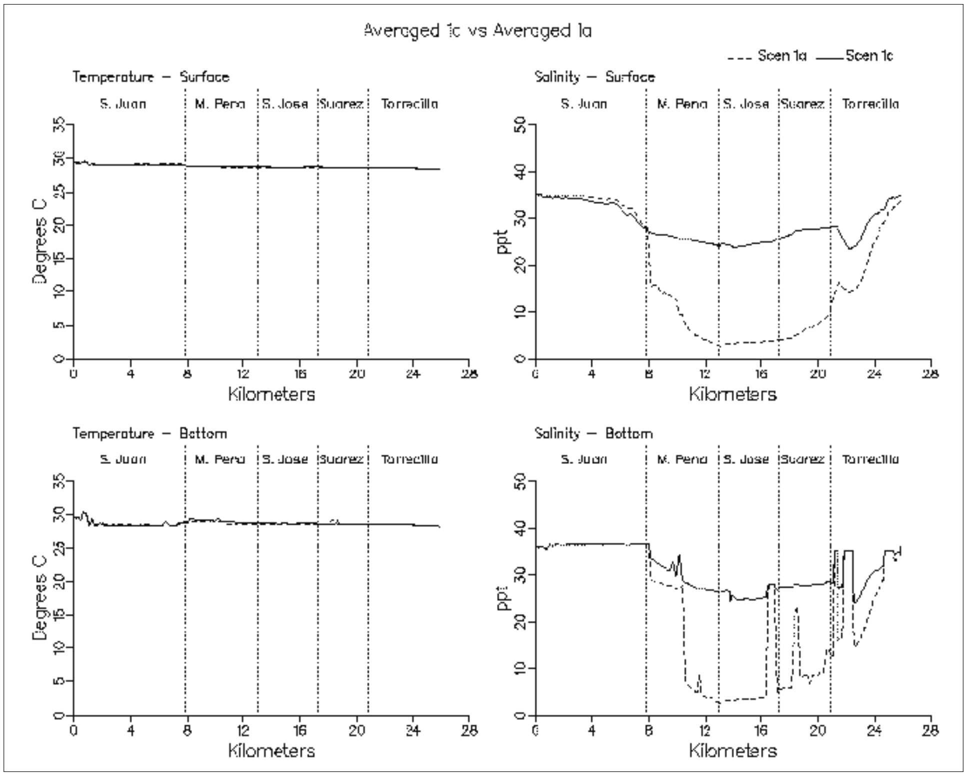


Figure 8-38. Simulation averaged transect plots comparing Scenario 1c with Scenario 1a (Sheet 1 of 11)

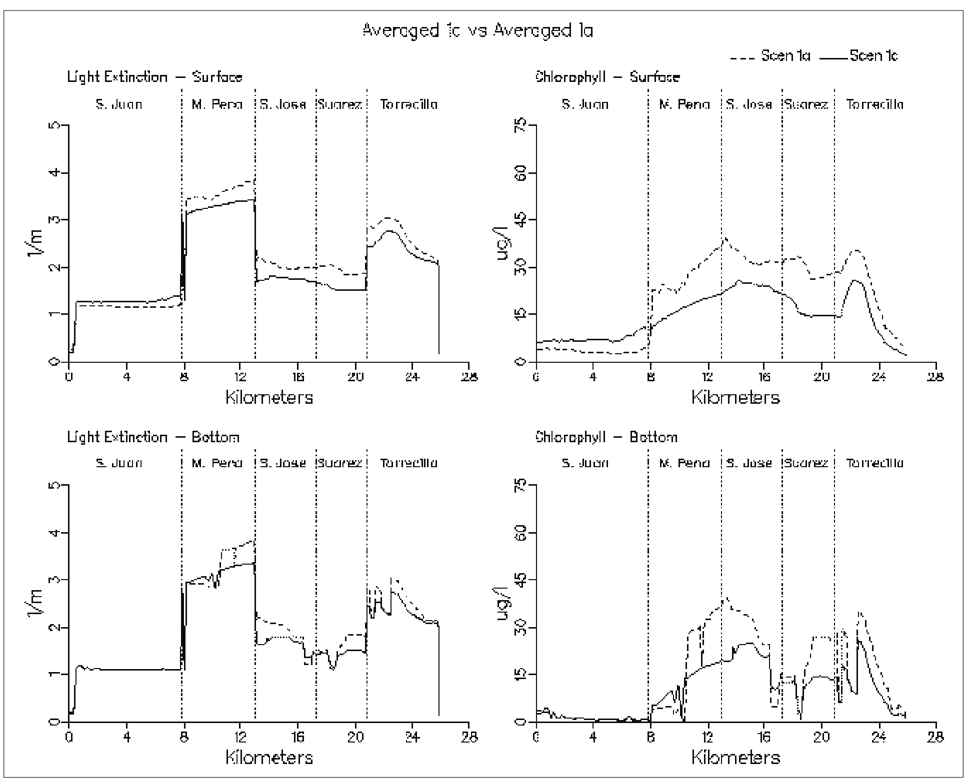


Figure 8-38. (Sheet 2 of 11)

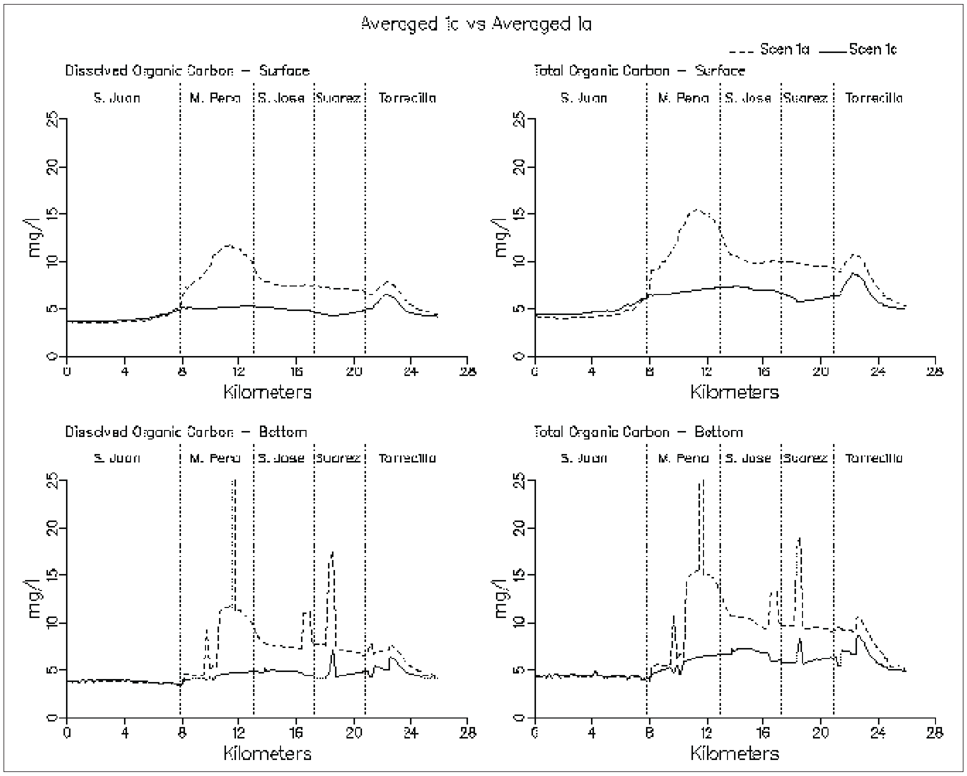
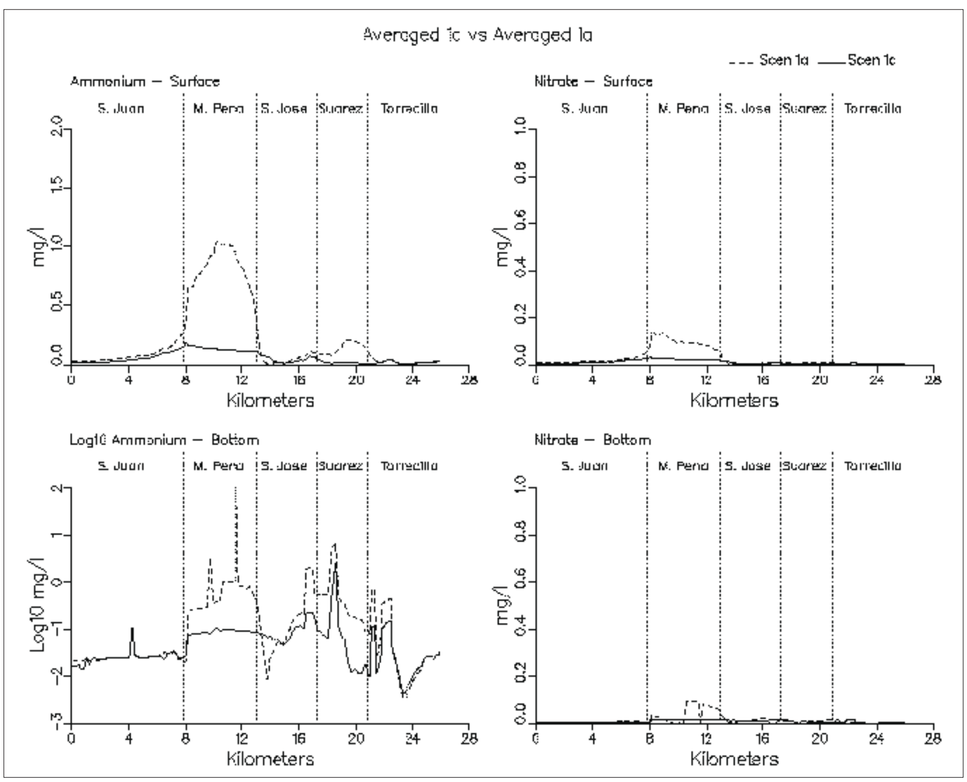


Figure 8-38. (Sheet 3 of 11)



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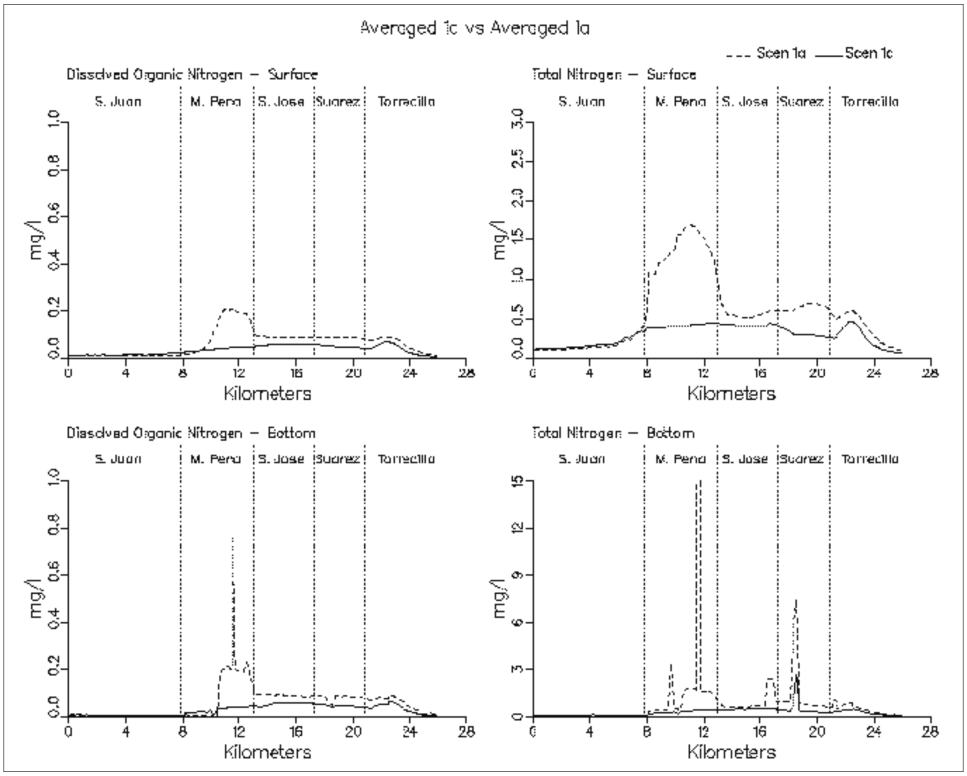

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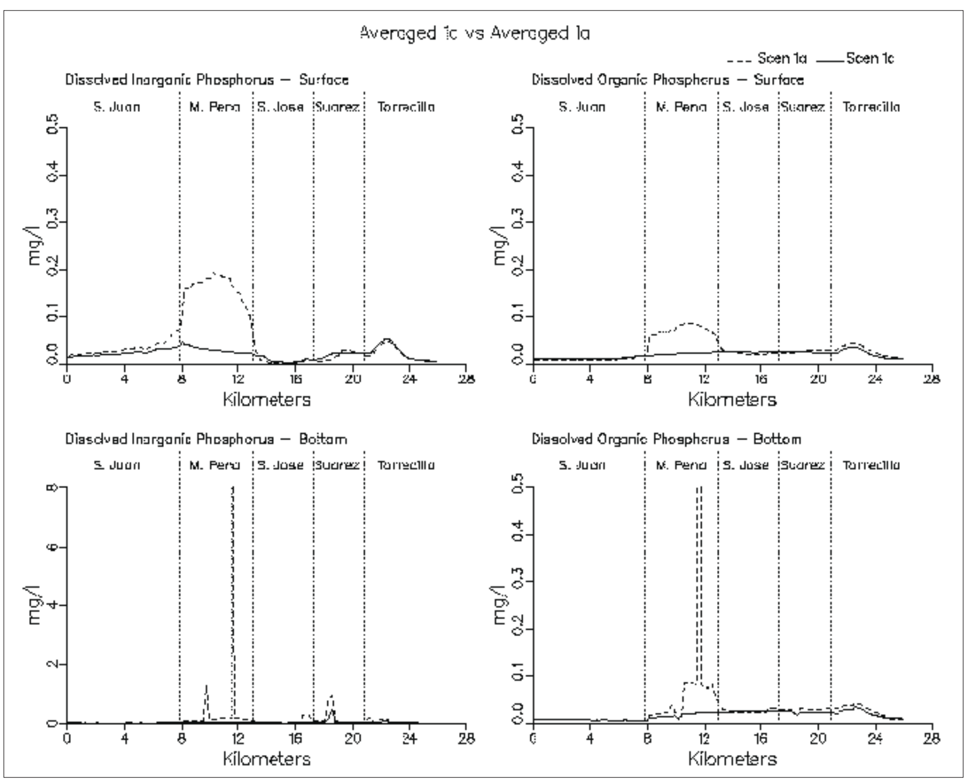

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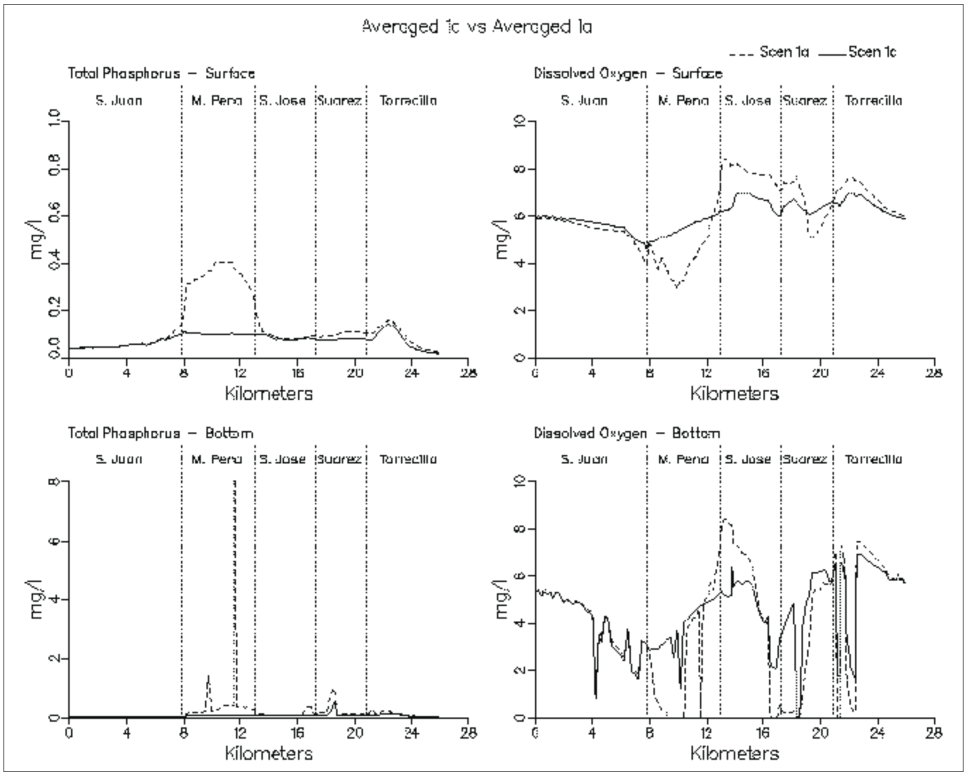

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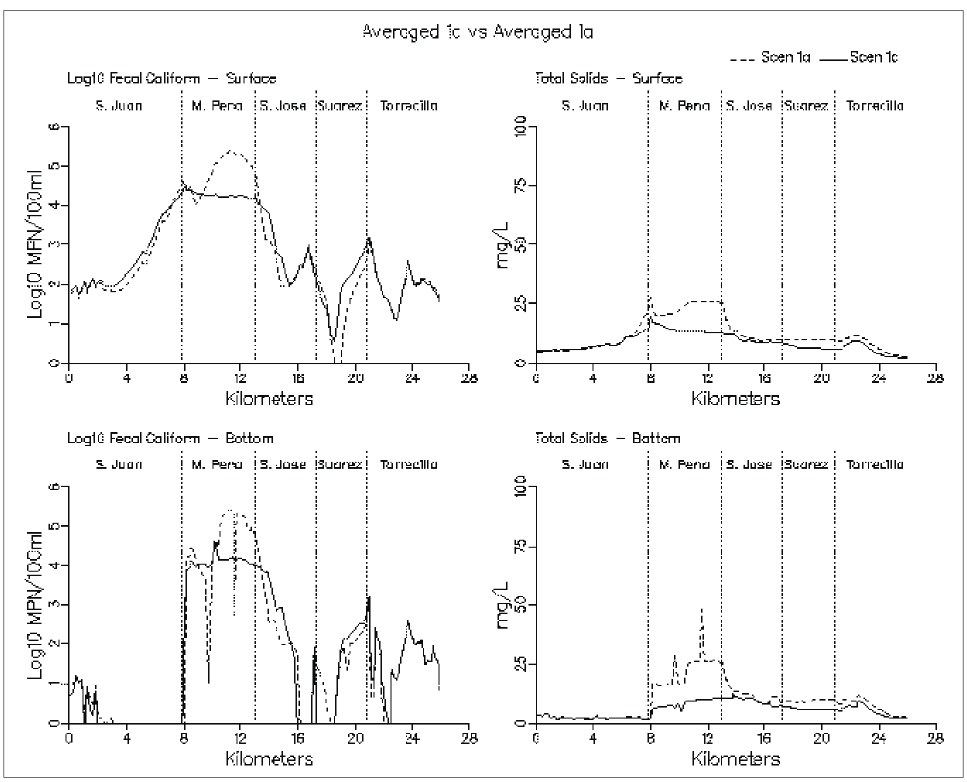

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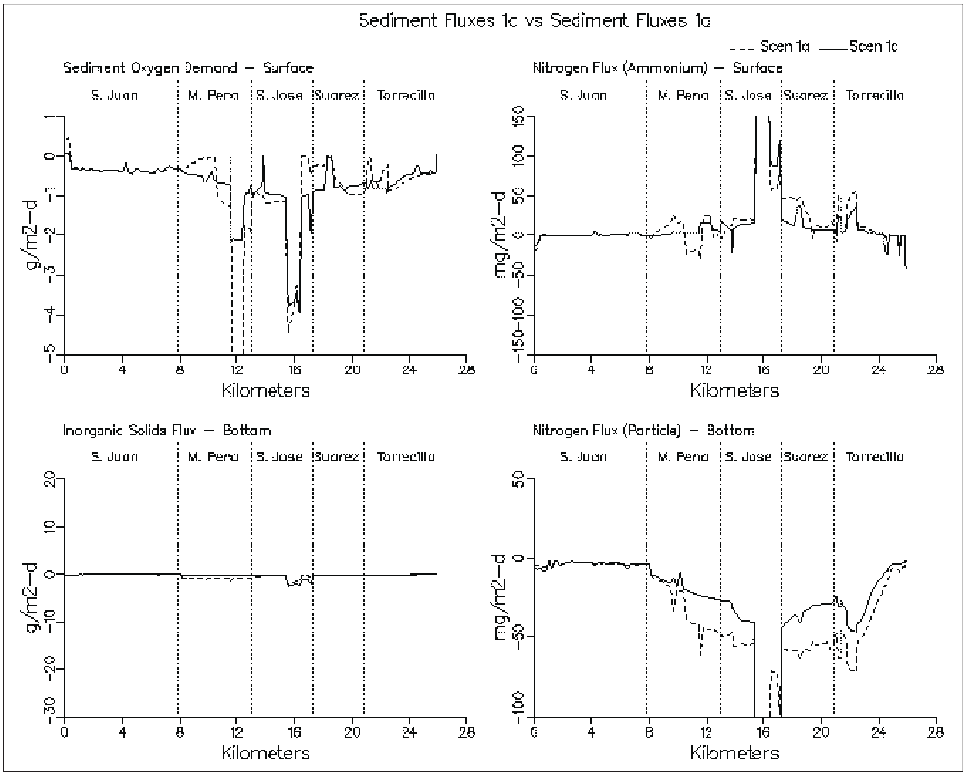

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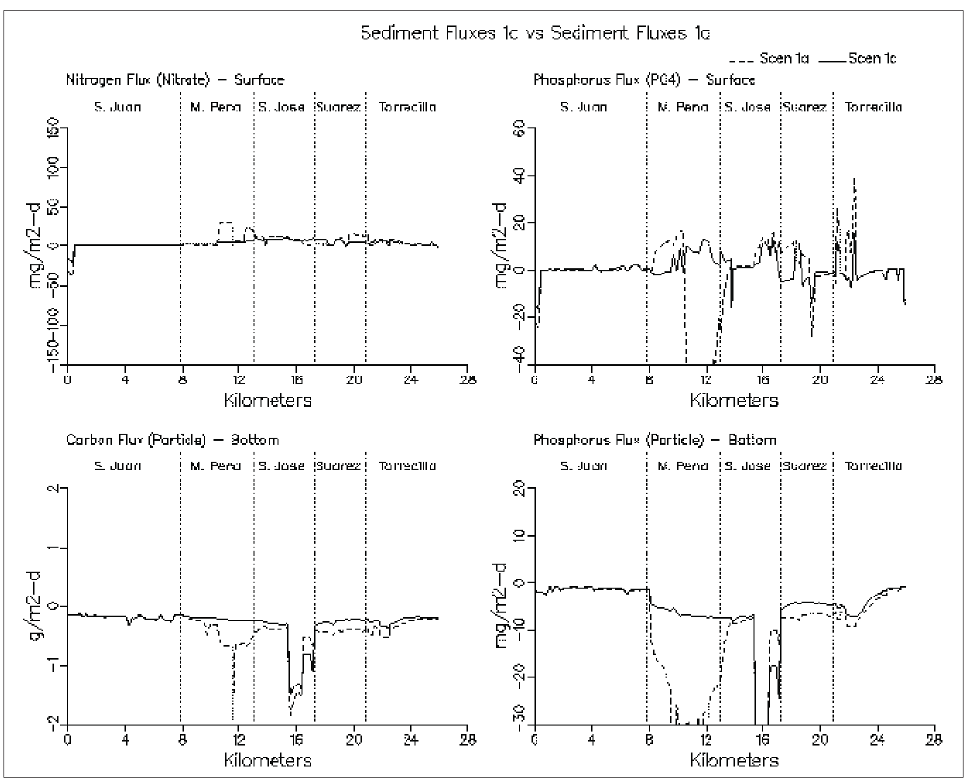

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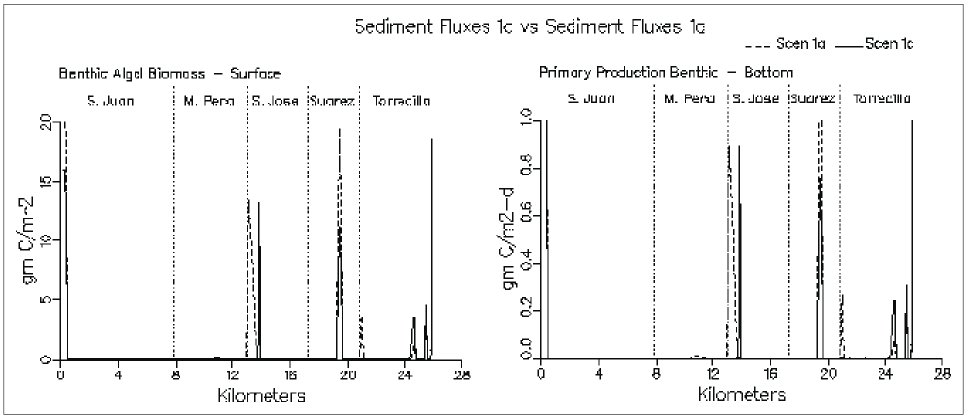


Figure 8-38. (Sheet 11 of 11)

Scenario 2

Scenario 2 was unique among scenarios in that nothing was done which would improve circulation and flushing of Laguna San José, Caño Martín Peña, or Canal Suárez. Neither would the features of Scenario 2 result in any decrease in tributary or runoff loads to the system. Instead, by filling the anoxic holes of Laguna San José, sediment nutrient fluxes and the oxygen demand arising from these holes should be decreased. The volume of Laguna San José in Scenario 1a was 12,781,933 m^3 which was decreased to 9,507,690 m^3 in Scenario 2. The distribution of flows leaving Laguna San José in Scenario 2 was identical to the flow distribution in 1a.

Results from Scenario 2 indicate that the surface temperatures in San Juan Bay are slightly cooler than 1a (Figure 8-39). Salinity transects show more differences. Filling in the holes resulted in there being no “nudging” of salinity. As a result, this internal salinity boundary condition was lost. The spin-up runs required to equilibrate the sediments effectively flushed the salt out of Laguna San José and Canal Suárez. As a result, the waters being flushed down Caño Martín Peña are too fresh and actually decrease the salinity of San Juan Bay.

Chlorophyll levels in Scenario 2 are much lower throughout the interior of the system. Tributary loads of chlorophyll are unchanged, thus the reason appears to be nutrient limitation. In Scenario 2, Laguna San José sediments take up 105.5 kg/day of ammonium and 28.9 kg/day of phosphate. In comparison, the sediments gave off 436 kg/day of ammonium and 20 kg/day of phosphate in Scenario 1a.

Dissolved organic carbon levels are decreased in Scenario 2 apparently as a result of the decrease in algae productivity. Carbon fluxes from Laguna San José to Caño Martín Peña were 329 kg/day. Fluxes from Laguna San José to Canal Suárez were 1060 kg/day.

Ammonium levels in Caño Martín Peña were unchanged in Scenario 2. Levels in Canal Suárez did drop to near 0 mg/l. Nitrate levels were unchanged throughout the system. Dissolved organic nitrogen levels decreased from the middle of Caño Martín Peña eastward in response to a decrease in algal levels. Total nitrogen levels indicated considerable decreases in Laguna San José and Canal Suárez when compared to Scenario 1a. Nitrogen fluxes from Laguna San José to Caño Martín Peña were 8.8 kg/day while fluxes from Laguna San José to Canal Suárez were 18.4 kg/day.

Dissolved inorganic phosphorus concentrations actually increased in Caño Martín Peña, Laguna San José, and Canal Suárez in Scenario 2. This is felt to be in response to the decreased levels of algae in Laguna San José. Also, the presence of phosphorus and the near absence of ammonium indicate that nitrogen in probably the limiting factor in algal growth. Dissolved organic phosphorus levels along the transect were relatively unchanged in Scenario 2. Total phosphorus levels were unchanged in Scenario 2 except for slight decreases in the eastern end of Canal Suárez. Phosphorus fluxes from Laguna San José to Caño Martín Peña in Scenario 2 were 2 kg/day. Phosphorus fluxes from Laguna San José to Canal Suárez were 12.9 kg/day.

Surface dissolved oxygen levels showed little change in Scenario 2. There were slight increases in DO in San Juan Bay but this is undoubtedly due to the decrease in salinity. Bottom dissolved oxygen levels increased significantly in Laguna San José as a result of the removal of the ammonium fluxes and sediment oxygen demand associated with the anoxic holes. Fecal coliform levels were unchanged. Total solids transect plots indicated a slight decrease in the interior system which is the result of decreased algal levels in these waters.

In summary, Scenario 2 improved water quality by removing internal nutrient sources which resulted in a decrease in algal concentrations. The extensive spin-up period resulted in the flushing of the salinity out of the interior of the system but does not appear to have influenced other water quality constituents significantly.

Scenario 3

Scenario 3 involved Scenario 1a plus removal of the bridge constriction on Canal Suárez. Net flow from Laguna San José to Canal Suárez increased from less than 2 m^3/s in Scenario 1a to over 2.5 m^3/s for Scenario 3. Flow from Laguna San José to Caño Martín Peña decreased from 0.5 m^3/s in 1a to less than 0.1 m^3/s in Scenario 3. In essence, all of Laguna San José's exchange with the ocean is via Canal Suárez in Scenario 3.

Results for Scenario 3 indicate that salinity increases in Caño Martín Peña, Laguna San José, and Canal Suárez when compared to 1a (Figure

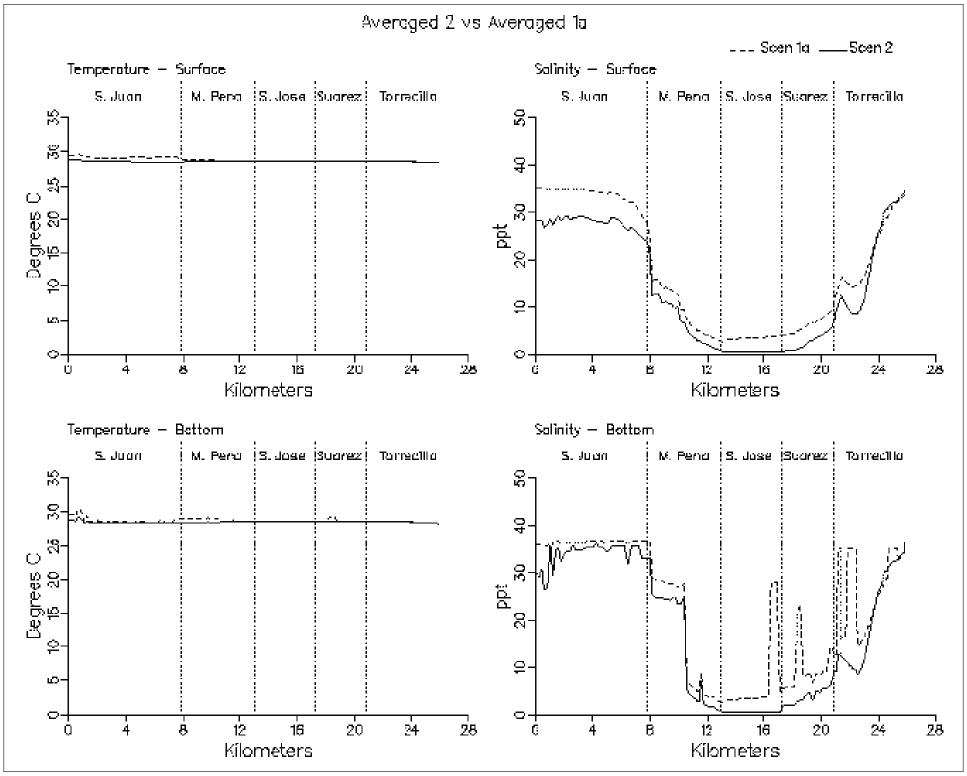


Figure 8-39. Simulation averaged transect plots comparing Scenario 2 with Scenario 1a (Sheet 1 of 11)

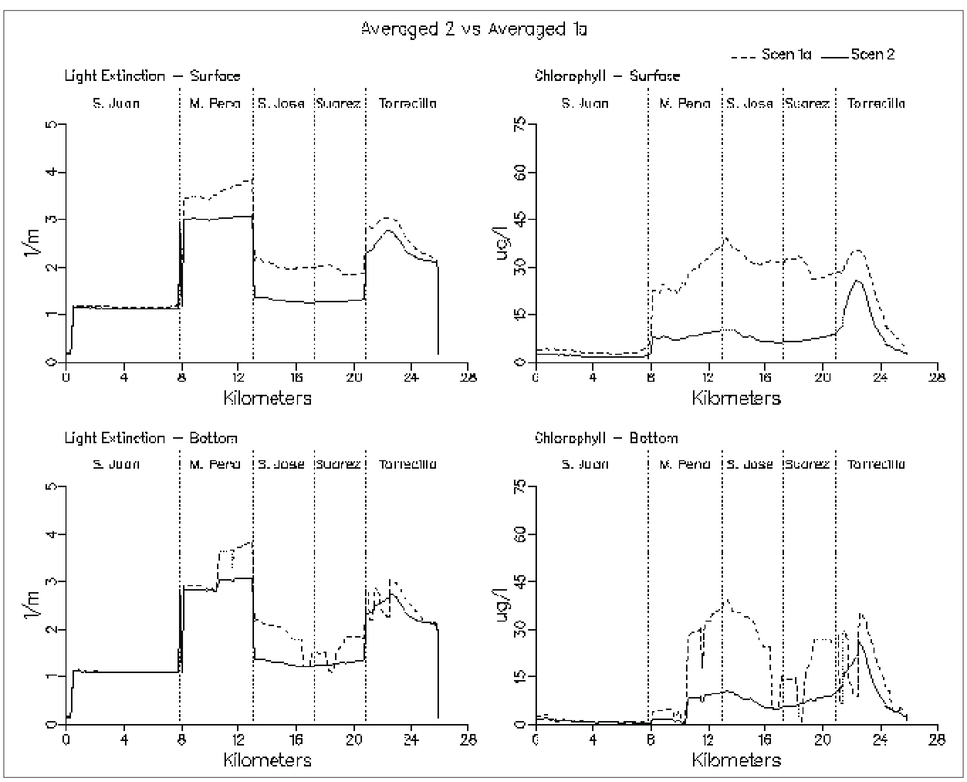


Figure 8-39. (Sheet 2 of 11)

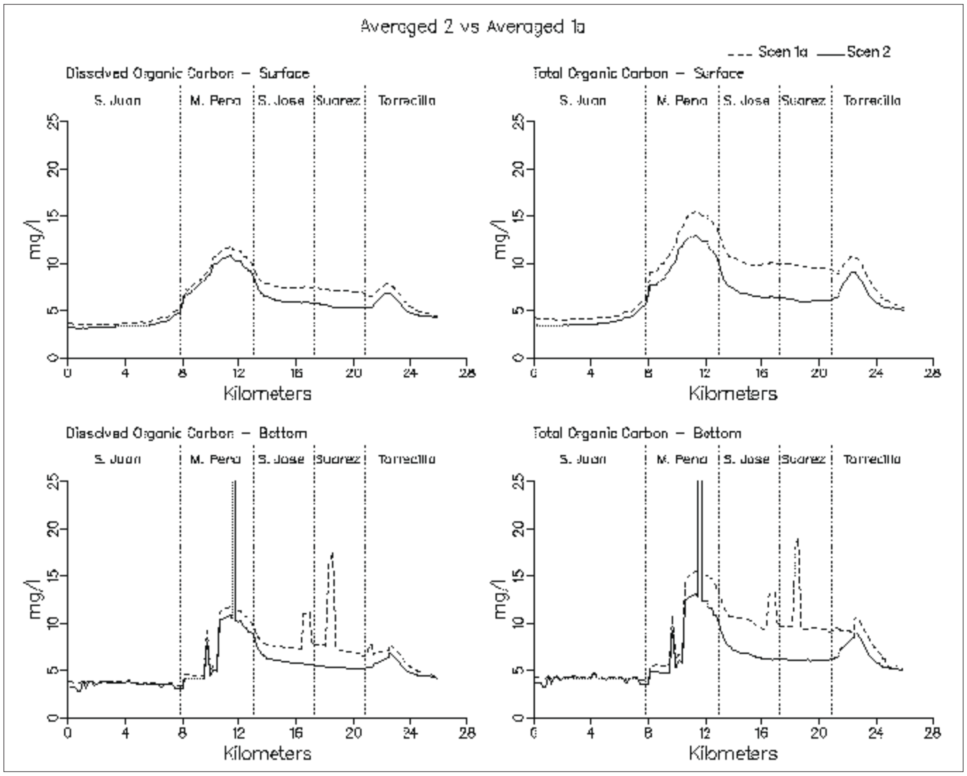
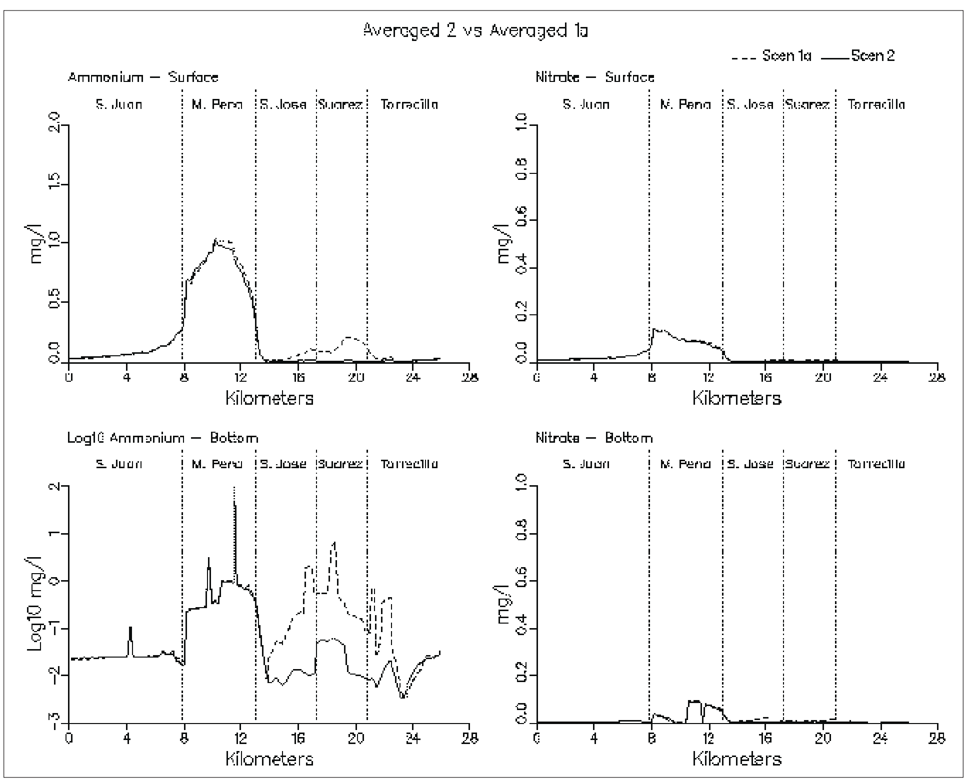


Figure 8-39. (Sheet 3 of 11)



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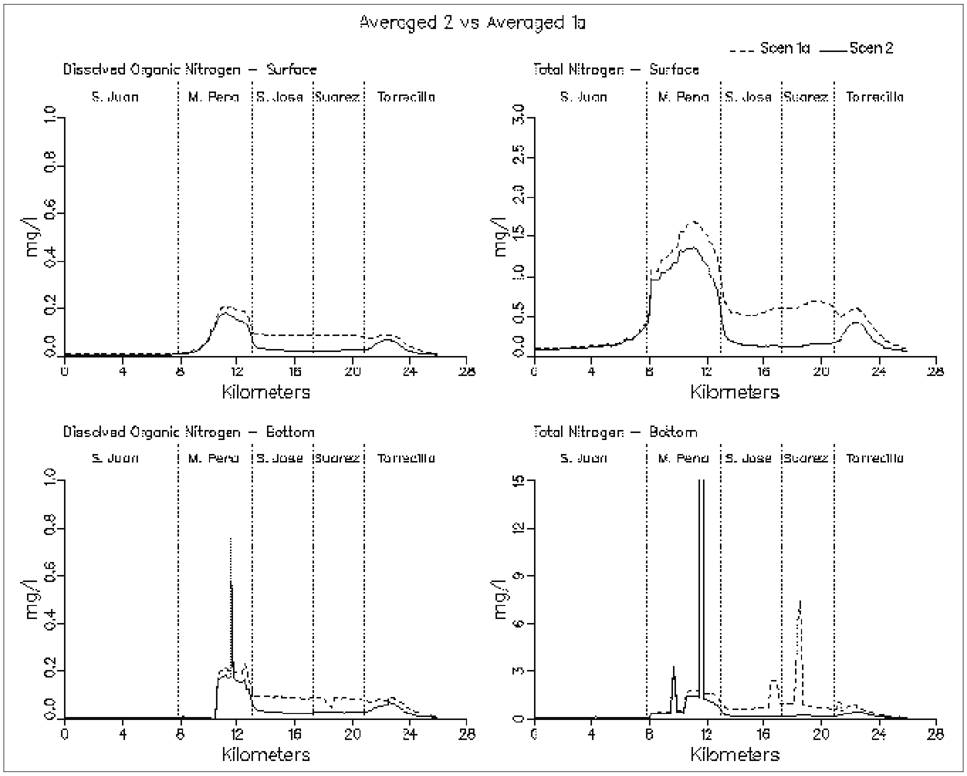

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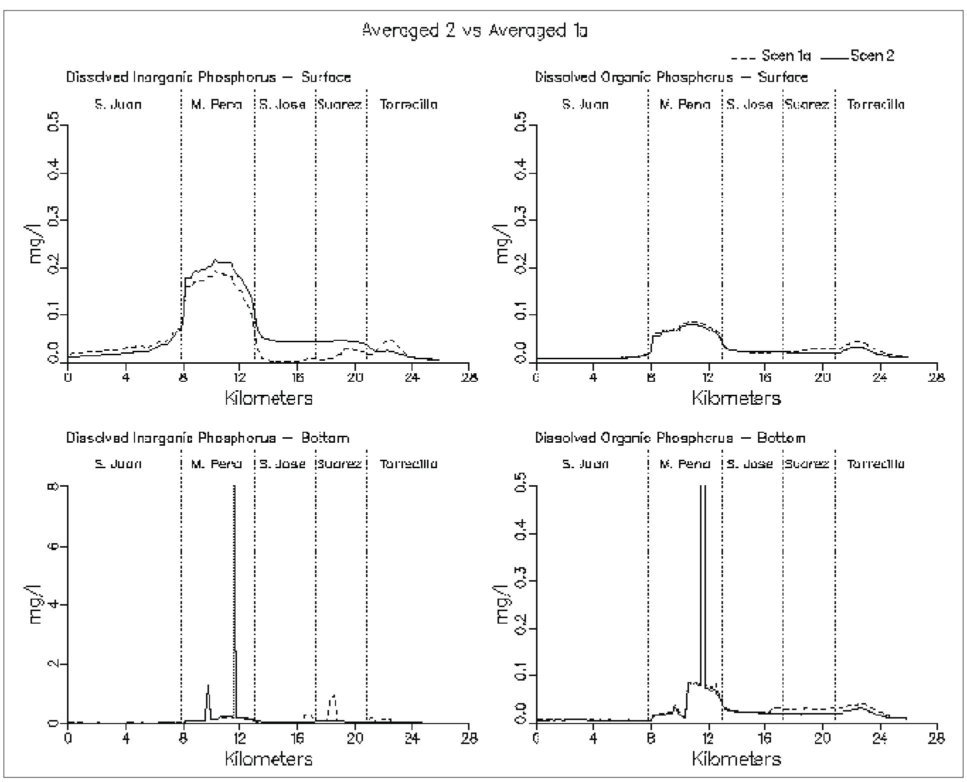

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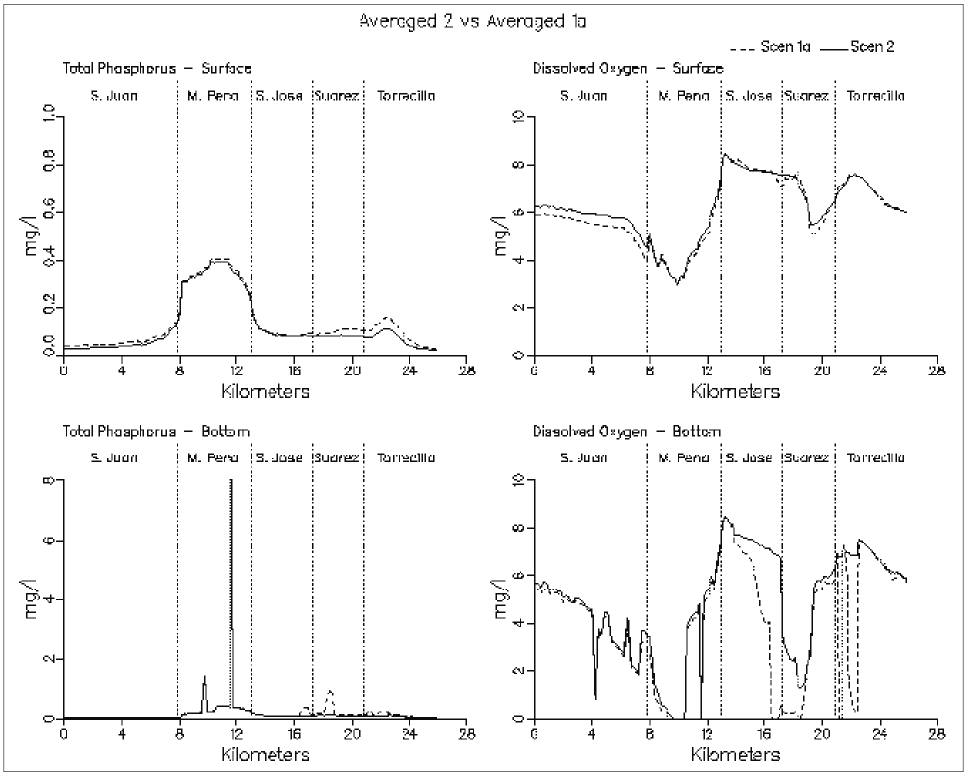

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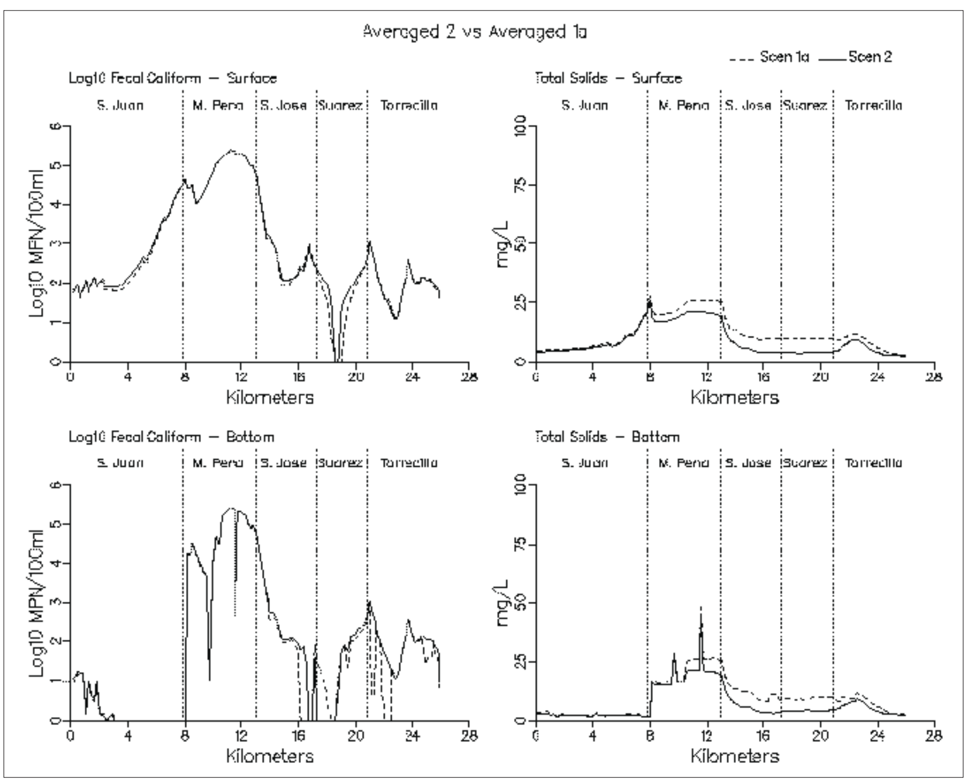

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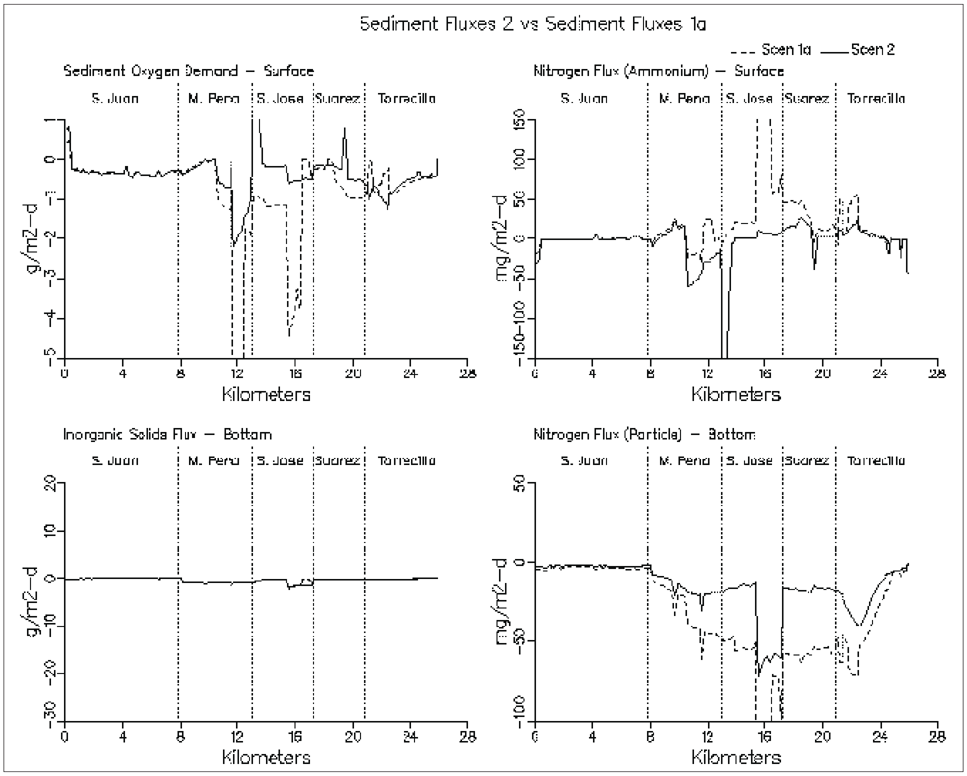
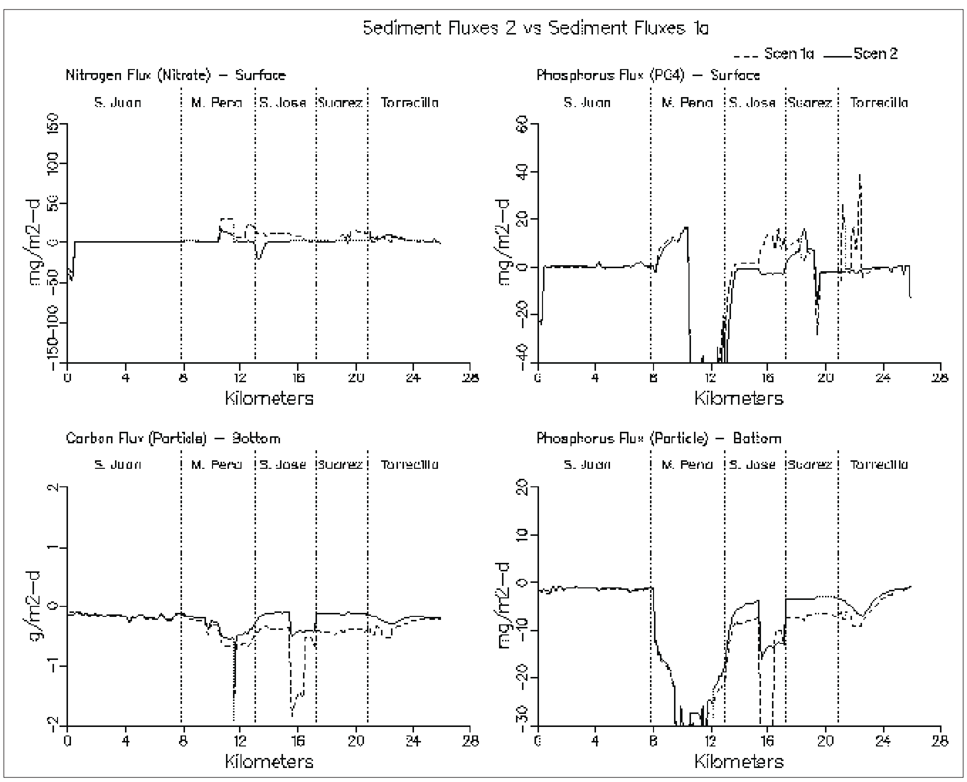


Figure 8-39. (Sheet 9 of 11)



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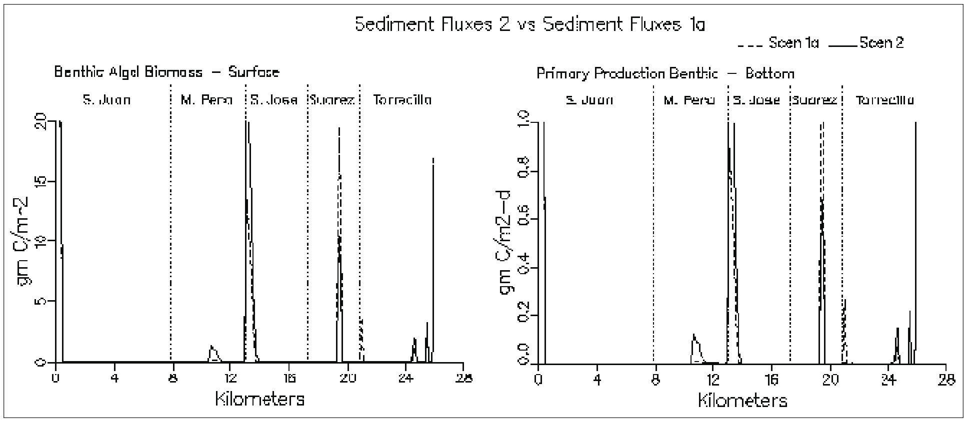


Figure 8-39. (Sheet 11 of 11)

8-40). Increases in Caño Martín Peña are probably the result of saltwater intrusion farther up the canal. Increases in Laguna San José and Canal Suárez result from more exchange with the ocean via Laguna La Torrecilla. Chlorophyll levels remained relatively unchanged in Laguna San José, Canal Suárez, and Laguna La Torrecilla in Scenario 3 compared to Scenario 1a, but decreased in western Caño Martín Peña by 10 µg/l due to bay water intrusion up the canal and less algae exchange with Laguna San José. Light extinction levels were unchanged except for Caño Martín Peña where there was a slight decrease due to a decrease in algal self-shading. Only slight changes were observed in organic carbon levels in Scenario 3. Surface dissolved organic carbon levels decreased slightly in western and increased slightly in the eastern portions of Caño Martín Peña. Although total organic carbon concentrations in Laguna San José in Scenario 3 are nearly identical to those in 1a, the flux of carbon from Laguna San José to Canal Suárez is 2261 kg/day versus 1631 kg/day in 1a. Caño Martín Peña actually exports a slight amount of carbon (35.5 kg/day) to Laguna San José in Scenario 3.

Surface water ammonium concentrations increased in the eastern undredged portion of Caño Martín Peña as a result of lower flushing from Laguna San José. Bottom water ammonium levels increased slightly in the undredged portion of Caño Martín Peña to 1 mg/l. Surface water ammonium levels in eastern Canal Suárez decreased from 0.2 mg/l to less than 0.1 mg/l. Bottom ammonia concentrations decreased the entire length of Canal Suárez in part due to a decrease in sediment ammonium fluxes in the western portion of the canal. Nitrate levels exhibited only the slightest change in Caño Martín Peña. Dissolved organic nitrogen levels were relatively unchanged in Scenario 3. Changes in transect plots for total nitrogen between 1a and Scenario 3 are attributable to the changes in ammonium concentrations in Caño Martín Peña and Canal Suárez. Laguna San José exported 178 kg/day of nitrogen though Canal Suárez in Scenario 3 versus 138 kg/day in Scenario 1a. Laguna San José also imported 38.2 kg/day from Caño Martín Peña in Scenario 3 where it had exported 7.5 kg/day in Scenario 1a.

Scenario 3 phosphorus results were similar to those of nitrogen. Increases occurred in dissolved inorganic phosphorus in the undredged eastern portion of Caño Martín Peña and decreases occurred in the eastern end of Canal Suárez. Bottom dissolved inorganic phosphorus levels decreased in the hole in Caño Martín Peña. Dissolved organic phosphorus levels increased slightly in eastern Caño Martín Peña. DIP and DOP levels elsewhere did not change. Laguna San José imported 9.4 kg/day of phosphorus from Caño Martín Peña and exported 23.4 kg/day through Canal Suárez.

Dissolved oxygen levels in Scenario 3 were similar to those in Scenario 1c. Dissolved oxygen decreased slightly in eastern Caño Martín Peña probably as a result of decreased photosynthesis. Surface dissolved oxygen levels did increase in the eastern portion of Canal Suárez. Anoxic conditions in the western end of Canal Suárez were relieved. Fecal coliform levels were unchanged throughout the system except for a slight increase in Canal Suárez. Little change in total solids transect plots occurred as a result of Scenario 3 modifications.

In summary, the modifications of Scenario 3 did little to improve overall water quality when compared to Scenario 1a. Salinity in Laguna San José was increased over 1a results. However, even though there was still a slight discharge from Laguna San José to Caño Martín Peña, Caño Martín Peña became a source of nutrients to Laguna San José. Nutrient concentrations increased in the undredged section of Caño Martín Peña with the diminished flushing from Laguna San José.

Scenario 4

Scenario 4 like Scenario 3 centered on modifications to Canal Suárez without any channel modifications elsewhere. In Scenario 4, a one-way tide gate was installed in the western section of Canal Suárez, along with the removal of the bridge constriction. The tide gate would allow flows in Canal Suárez to move in an east to west fashion but not west to east. This prevented Laguna San José from discharging via Canal Suárez and forced all flow leaving Laguna San José to exit via Caño Martín Peña. No additional channel modifications were made to Caño Martín Peña other than those performed for Scenario 1a.

Scenario 4 results indicated significant change in salinity when compared to results for Scenario 1a (see Figure 8-41). Salinity levels decreased in Caño Martín Peña in response to increased flow from Laguna San José. Average net flow from Laguna San José to Caño Martín Peña increased from 0.5 m^3/s in Scenario 1a to 2.55 m^3/s in Scenario 4. For comparisons' sake, the net discharge from Laguna San José to Caño Martín Peña in Scenario 1c where Caño Martín Peña had been widened and deepened was 3.05 m^3/s. A net inflow of water from Canal Suárez to Laguna San José of 0.2 m^3/s occurred in Scenario 4. Salinity levels on the ocean

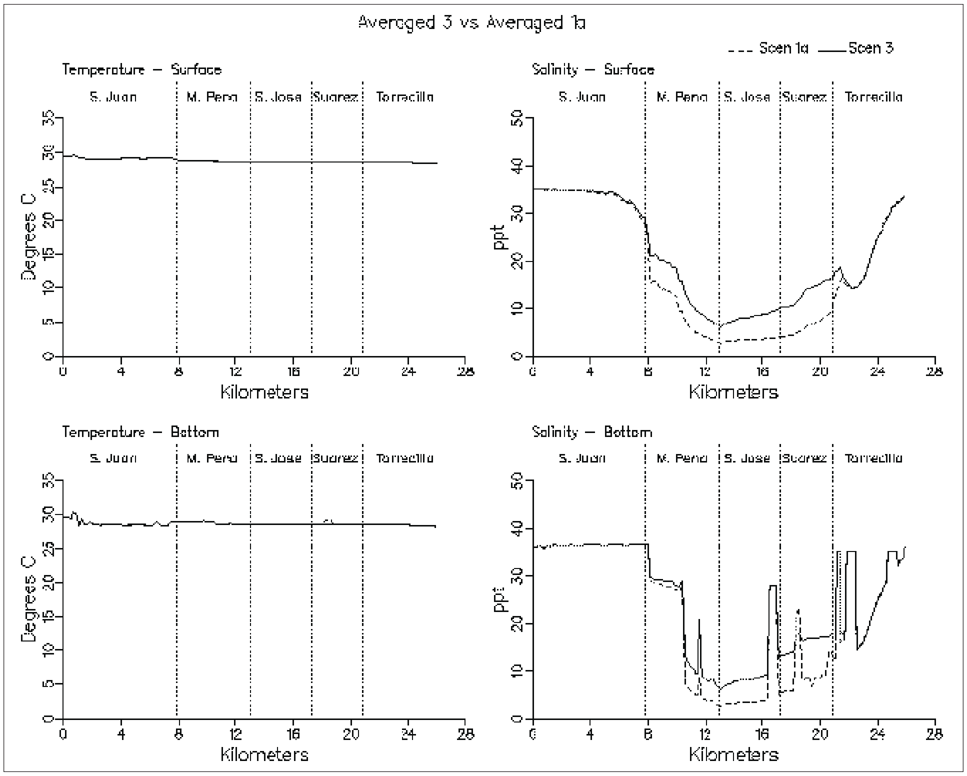


Figure 8-40. Simulation averaged transect plots comparing Scenario 3 with Scenario 1a (Sheet 1 of 11)

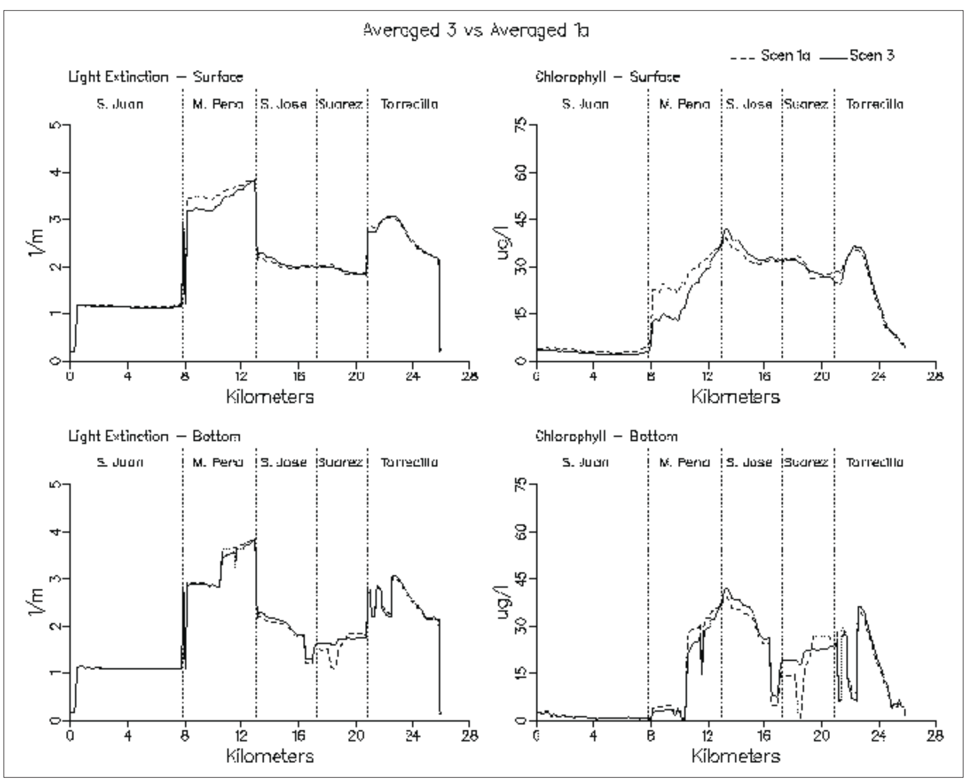


Figure 8-40. (Sheet 2 of 11)

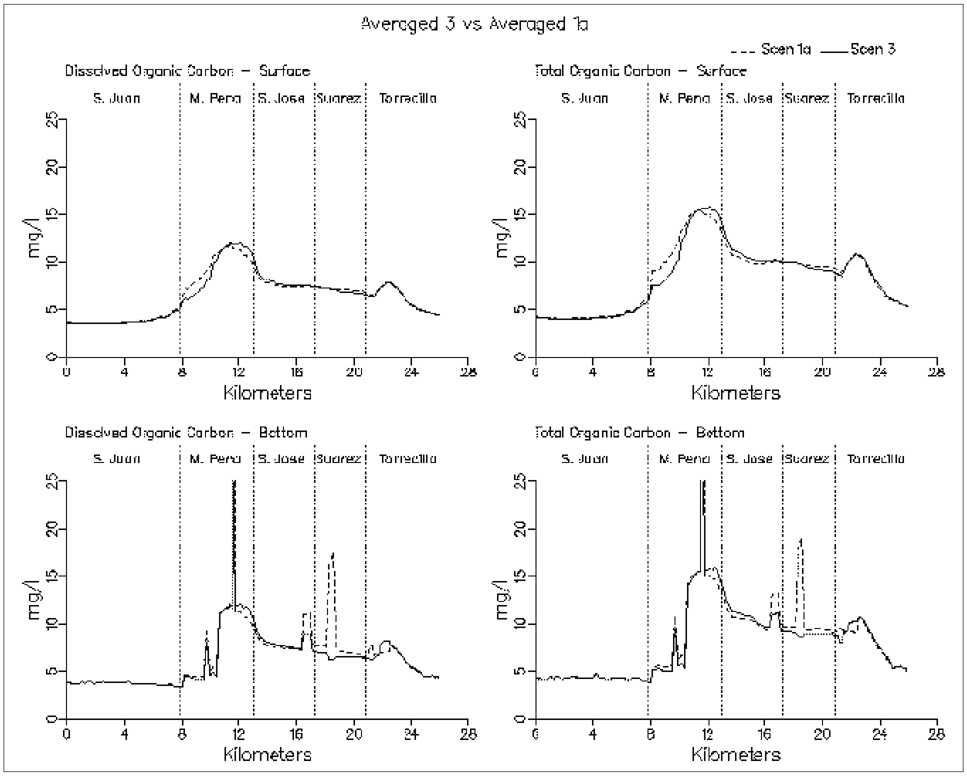


Figure 8-40. (Sheet 3 of 11)

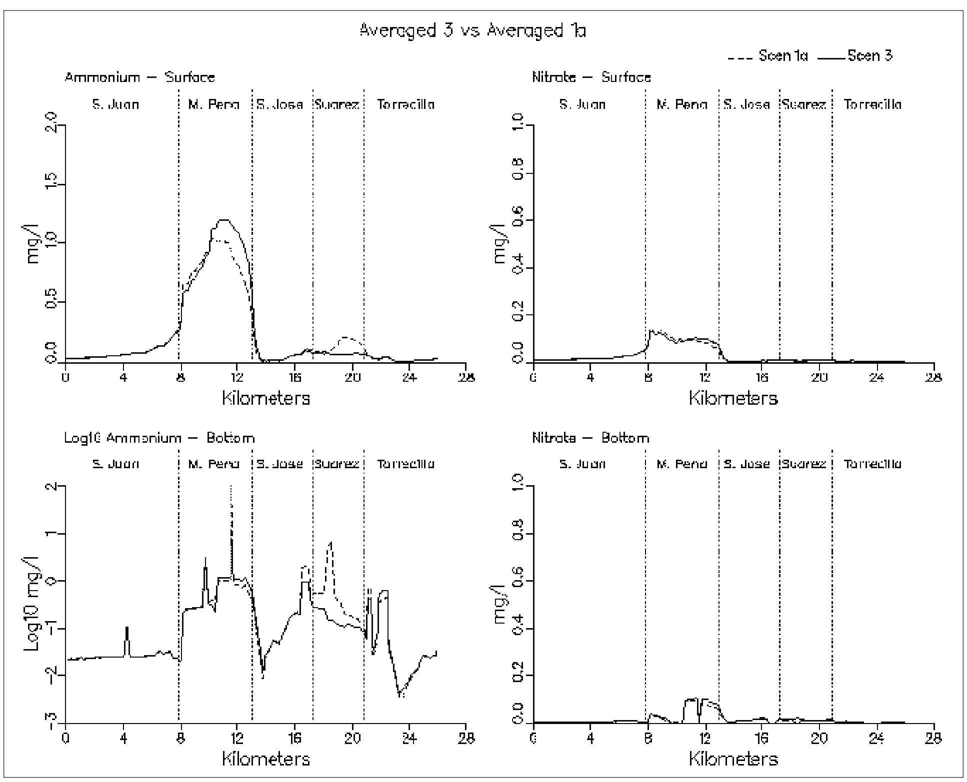


Figure 8-40. (Sheet 4 of 11)

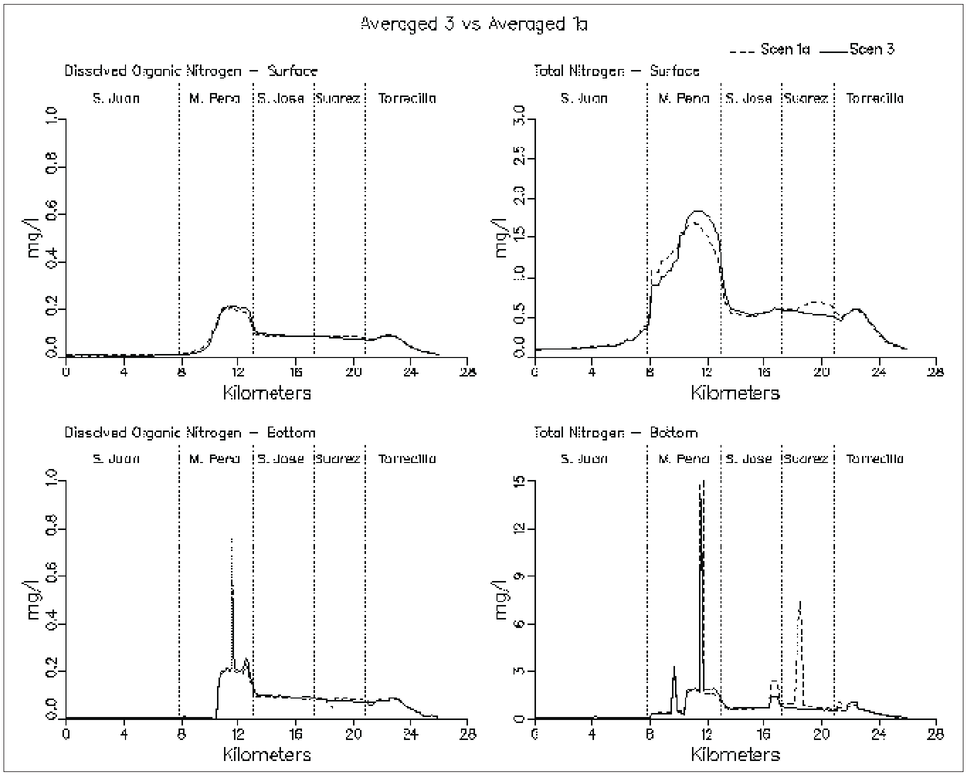


Figure 8-40. (Sheet 5 of 11)

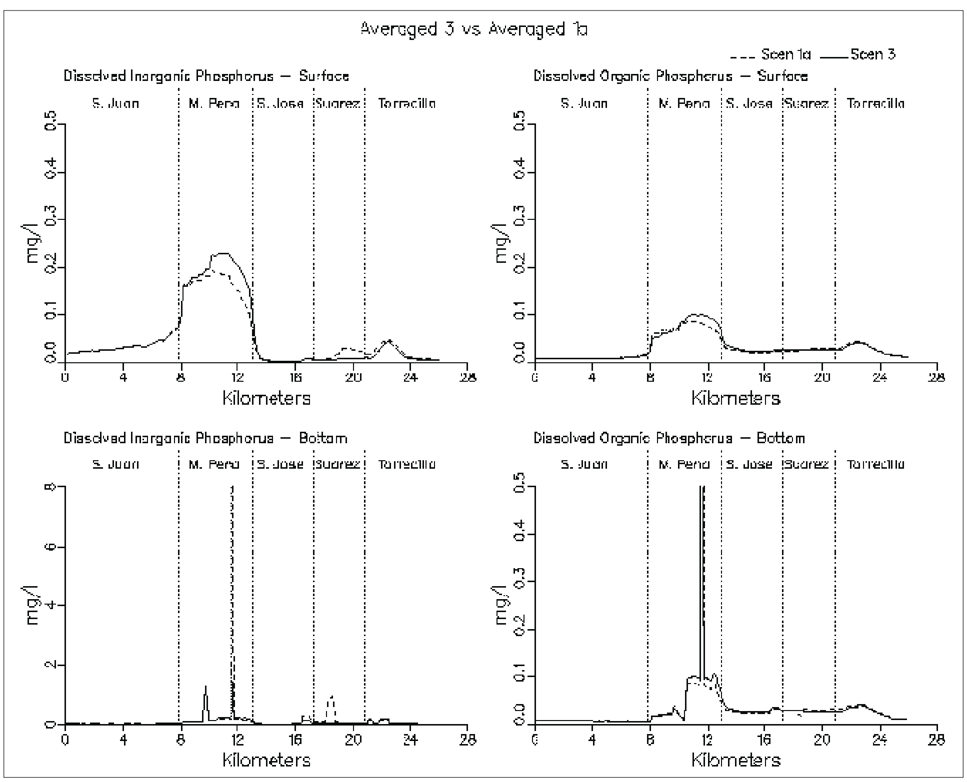
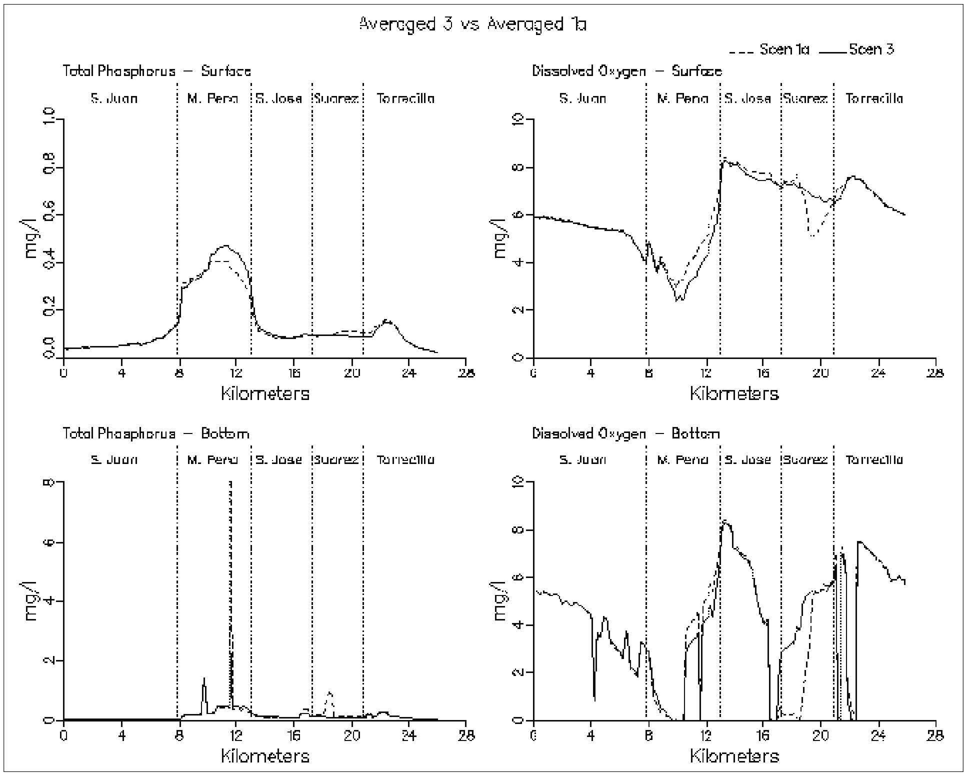


Figure 8-40. (Sheet 6 of 11)



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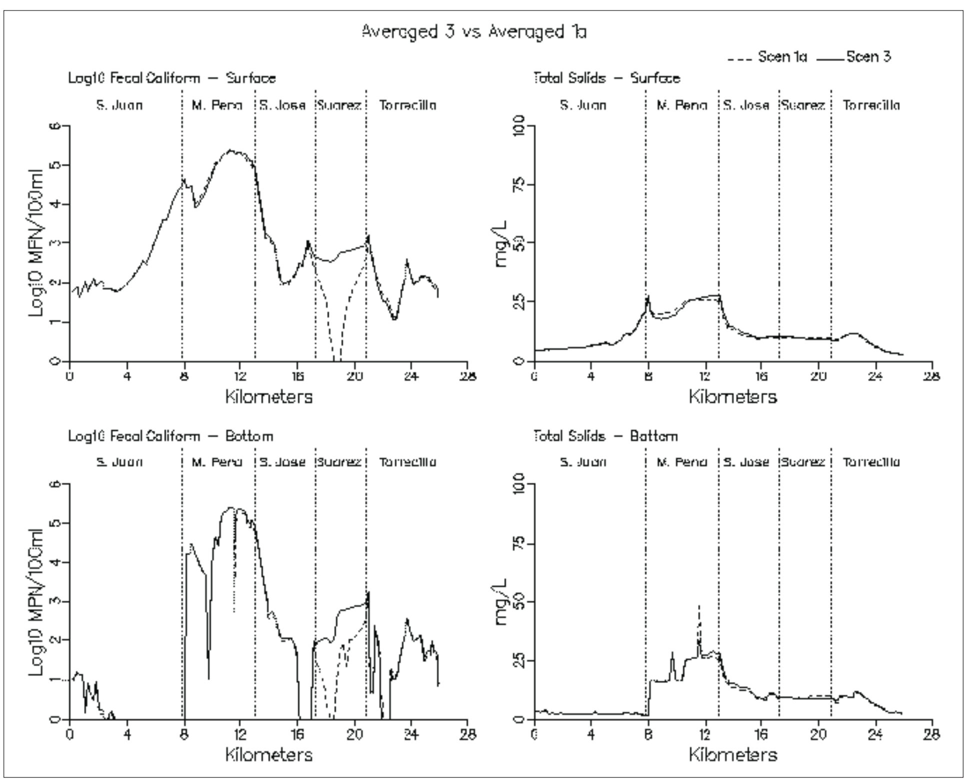
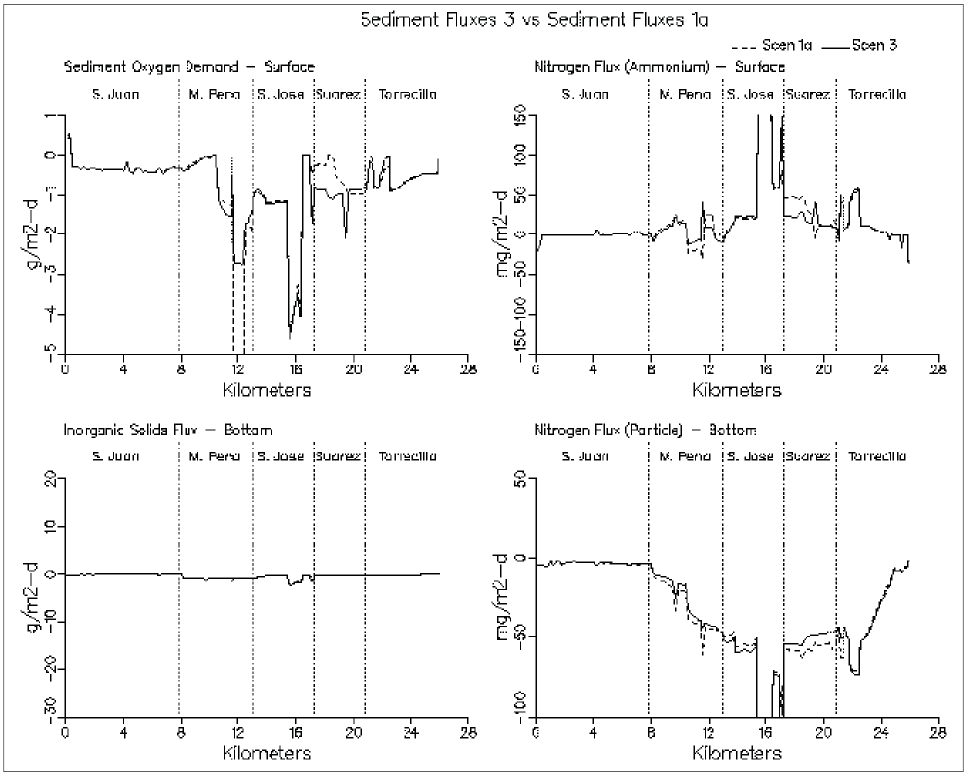


Figure 8-40. (Sheet 8 of 11)



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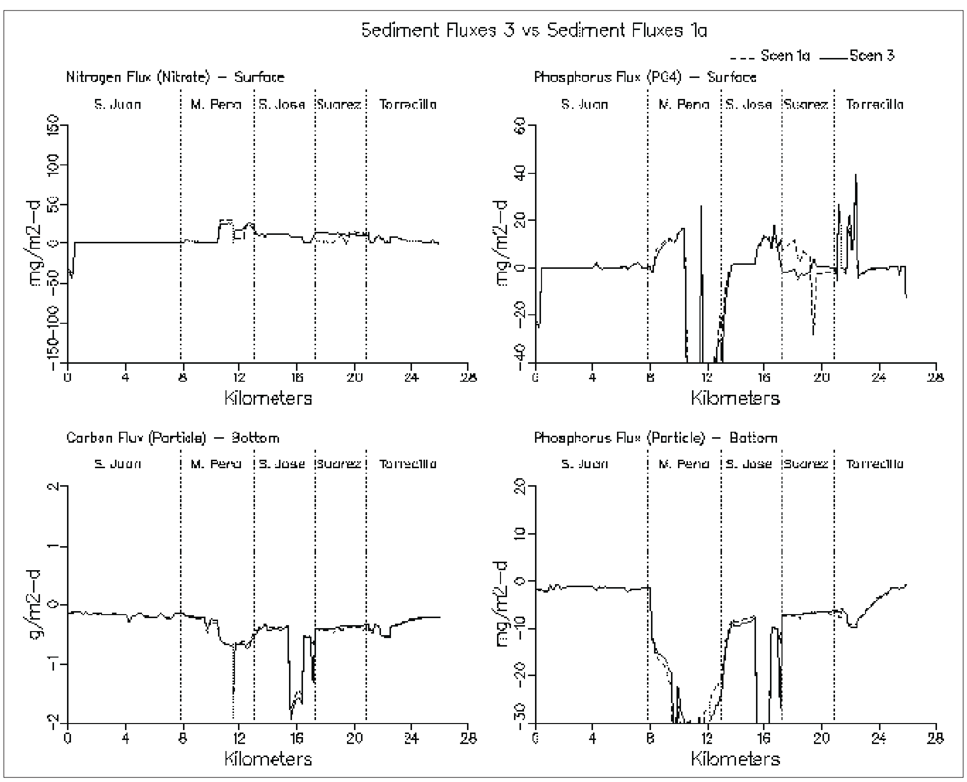

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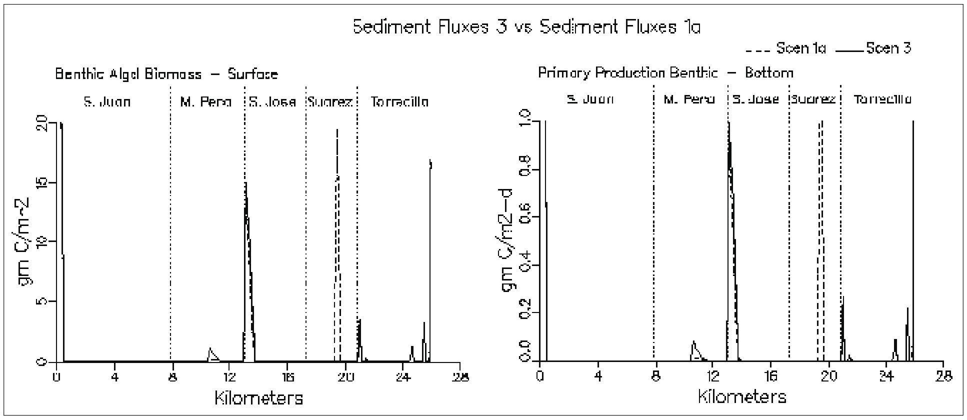


Figure 8-40. (Sheet 11 of 11)

side of the tide gate in Canal Suárez increased in response to the lack of flow from Laguna San José.

Chlorophyll results indicate that chlorophyll levels in Caño Martín Peña increased in Scenario 4. Laguna San José chlorophyll levels were relatively unchanged in comparison to 1a which indicates that the rise observed in Caño Martín Peña is due to the algae from Laguna San José being forced out through Caño Martín Peña. Addition of the tidal gate does not significantly decrease algae levels in Laguna San José. Chlorophyll levels do decrease on the ocean side of the tide gate in Canal Suárez once again because flows from Laguna San José are cut off.

Transect plots for carbon for Scenario 4 indicate patterns that are repeated in other water-quality constituents. The tide gate acts as a wall preventing waters from Laguna San José, which typically have higher concentrations of carbon, nitrogen, and phosphorus, from entering Canal Suárez. As a result, concentrations in Suarez decrease. Dissolved organic carbon concentrations on the ocean side of the tide gate decreased by 4 mg/l. Concentrations in eastern Caño Martín Peña also decreased but this decrease was in response to the increased flushing resulting from the higher flows. Total organic carbon profiles exhibited the same behavior as dissolved organic carbon. Carbon fluxes from Laguna San José to Caño Martín Peña were 2415 kg/day. Daily carbon imports from Canal Suárez to Laguna San José were 73 kg/day.

Surface ammonium concentrations decreased in Caño Martín Peña in response to the increased flushing and dilution through the canal. Surface ammonium concentrations on the ocean side of the tide gate decreased to nearly 0 mg/l. Bottom water ammonia concentrations at this location decreased to approximately 0.02 mg/l. This decrease is attributed to a decrease in particulate nitrogen deposition to the sediments and its subsequent decay and release as ammonium. Nitrate levels in the surface waters of Caño Martín Peña decreased by 0.05 mg/l. Dissolved organic nitrogen levels on the ocean side of the tide gate decreased to 0.05 mg/l while those in Laguna San José were unchanged. Dissolved organic nitrogen levels in eastern Caño Martín Peña decreased, but concentrations on the western end increased as a result of the higher flows redistributing the un-sewered organic nitrogen loads. Total nitrogen daily fluxes from Laguna San José to Caño Martín Peña were 141 kg/day. Total daily imports of nitrogen from Canal Suárez were 2 kg/day.

Dissolved inorganic phosphorus levels in Caño Martín Peña decreased in Scenario 4. Levels on the ocean side of the tide gate increased in Canal Suárez in response to lower levels of algae. Higher levels of algae and increased dilution are probably the reason for the dissolved inorganic phosphorus decrease in Caño Martín Peña. Dissolved organic phosphorus levels indicated decreases in Caño Martín Peña with slight increases on the eastern side of Laguna San José. Concentrations on the ocean side of the tide gate were relatively unaffected. Daily phosphorus flux from Laguna San José to Caño Martín Peña were 32 kg/day. An average of 1 kg/day was imported from Canal Suárez to Laguna San José.

Dissolved oxygen levels increased in Scenario 4 in Caño Martín Peña as a result of the increased flushing of high dissolved oxygen concentration water from Laguna San José. Anoxic conditions that occurred in the bottom waters of western Caño Martín Peña were unaffected by the additional flushing. Dissolved oxygen levels on the ocean side of the tide gate decreased slightly as a result of decreased algal photosynthesis. Fecal coliform levels throughout most of the system remained unchanged except for Canal Suárez which saw a slight decrease as a result of loading from Laguna San José being cut off. Total solids levels decreased slightly in Caño Martín Peña as a result of additional flushing. Solids concentrations on the ocean side of the tide gate decreased slightly again because the source of the solids in Laguna San José had been cut off.

In summary, Scenario 4 tended to improve water quality conditions in Canal Suárez since it prevented the more polluted water from Laguna San José from entering. Any improvements seen in Caño Martín Peña appear to be due to increased flow through the canal resulting in an increased volume of receiving water for runoff.

Scenario 5a

In Scenario 5a the un-sewered loads were removed from Caño Martín Peña. These loads were not redirected any place but were simply removed from the model. A total of 400 kg/day of carbon, 100 kg/day of nitrogen, and 20 kg/day of phosphorus were removed. An additional reduction was made to the fecal coliform loading for the Martín Peña sub-basin to approximate the effect of removal of fecal coliform loading associated with these loads would have.

Scenario 5a was run using Scenario 1a hydrodynamics. Scenario 5a temperature and salinity were identical to those of 1a (see Figure 8-42).

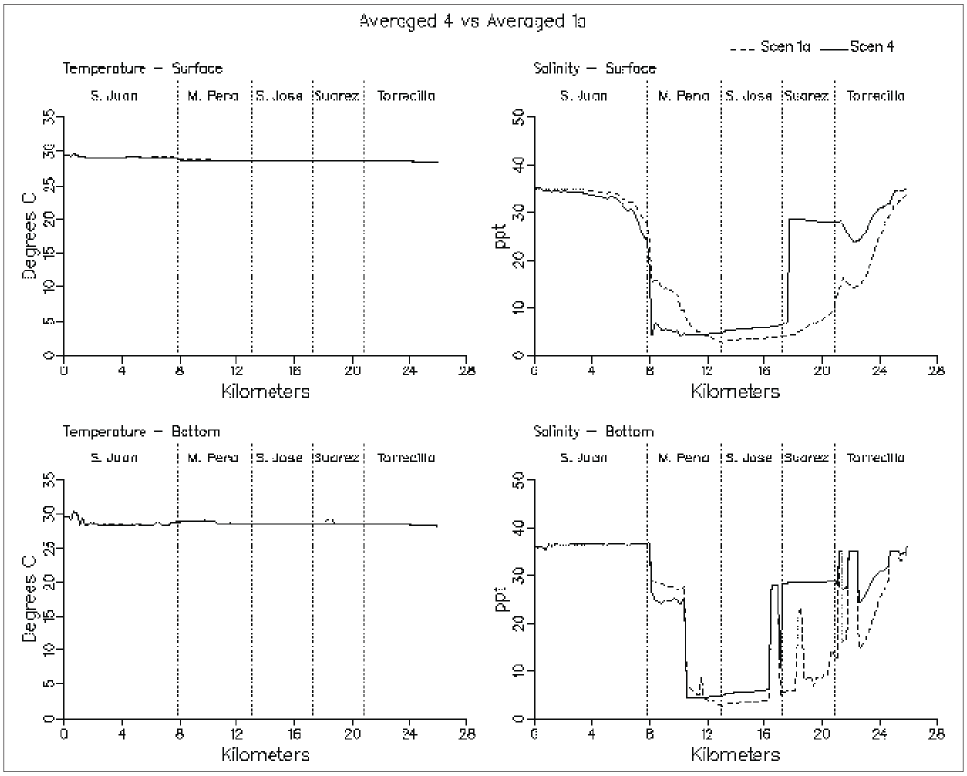


Figure 8-41. Simulation averaged transect plots comparing Scenario 4 with Scenario 1a (Sheet 1 of 11)

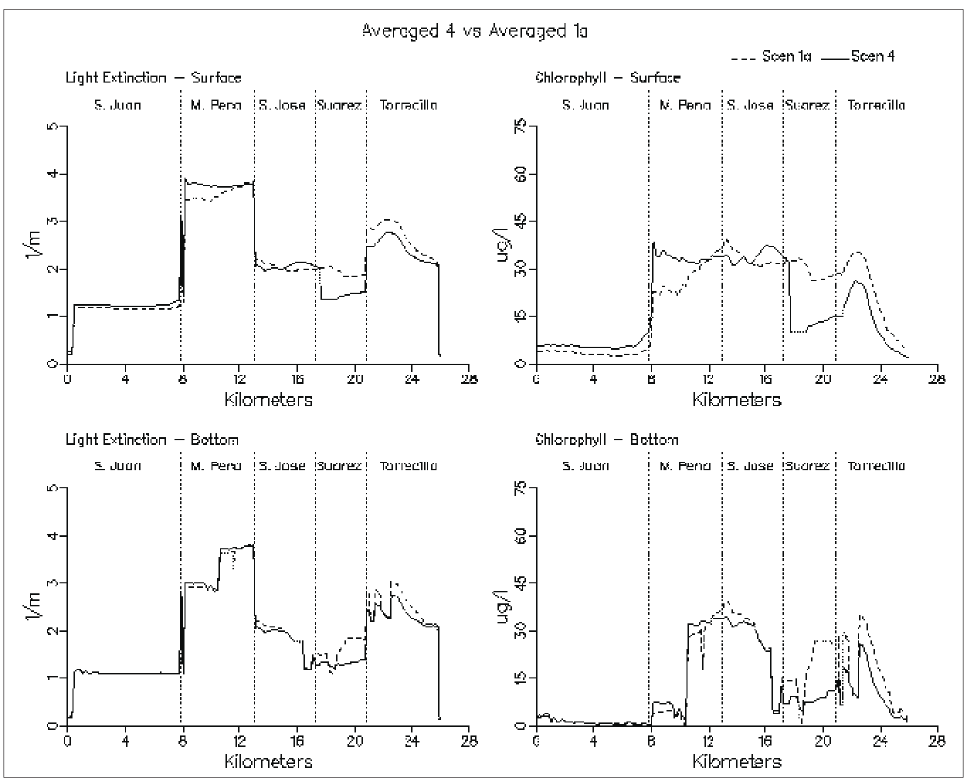
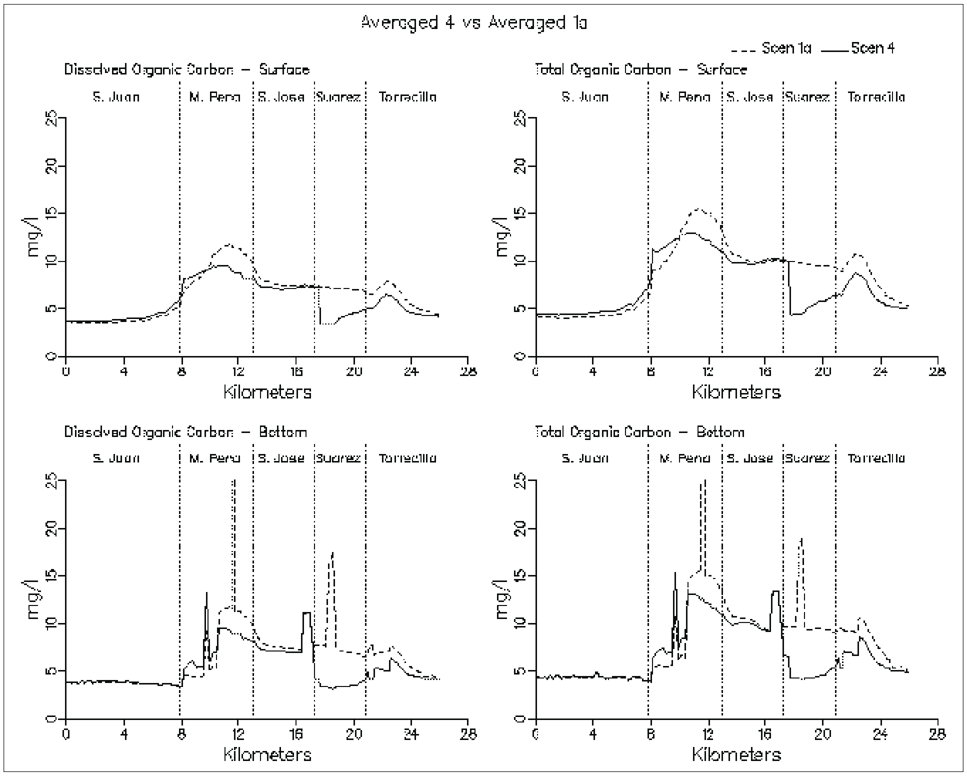


Figure 8-41. (Sheet 2 of 11)



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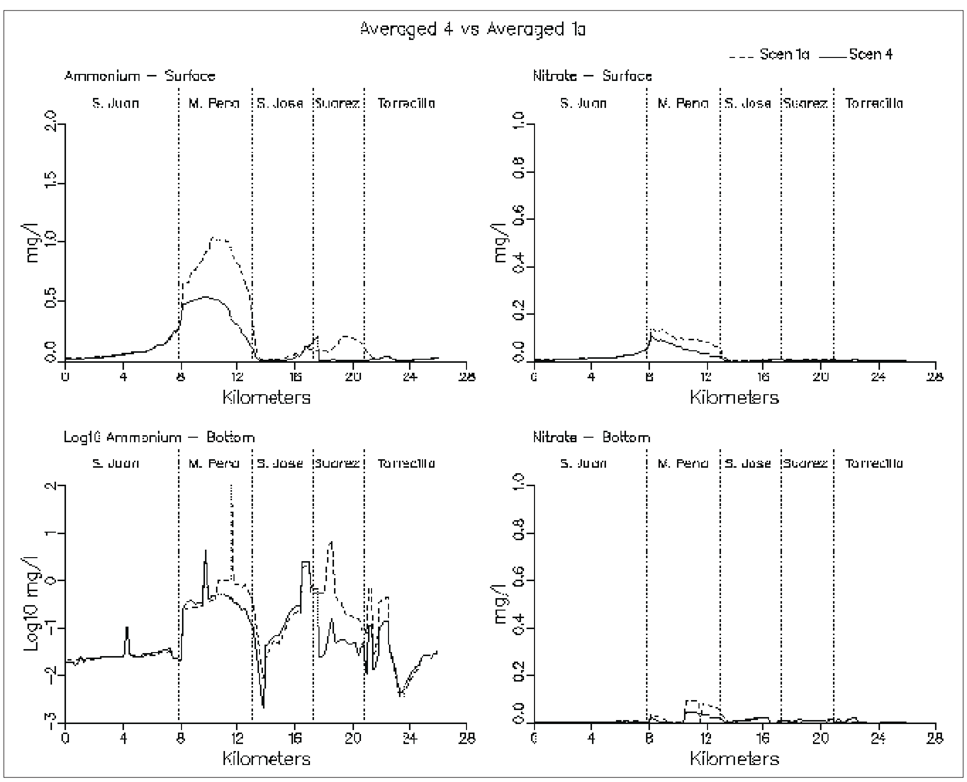

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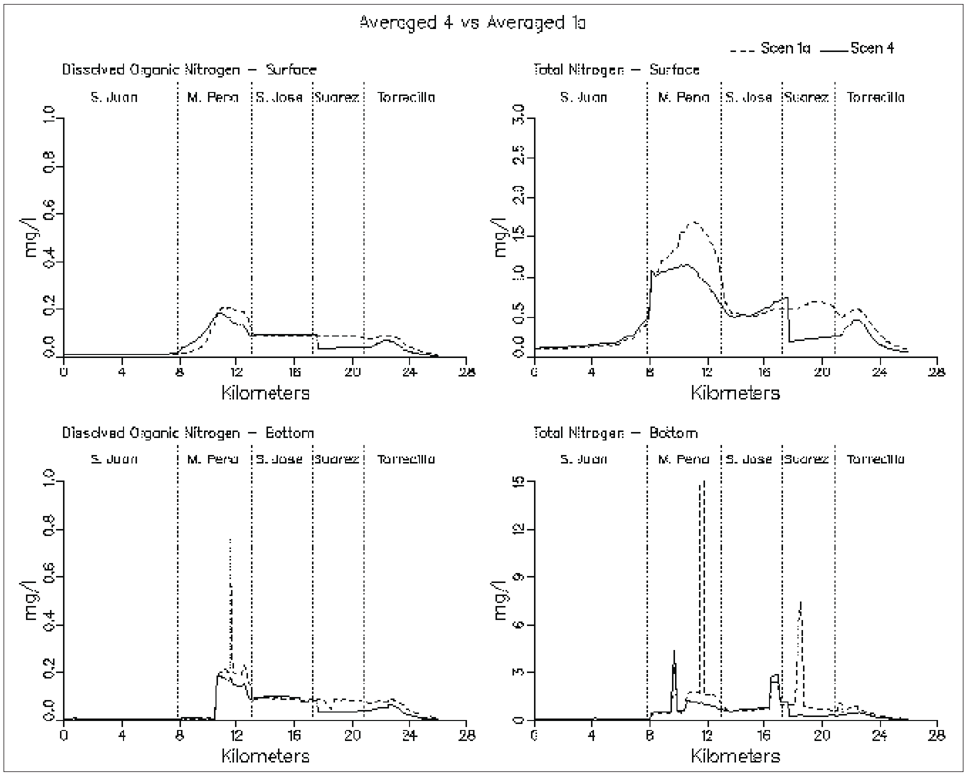

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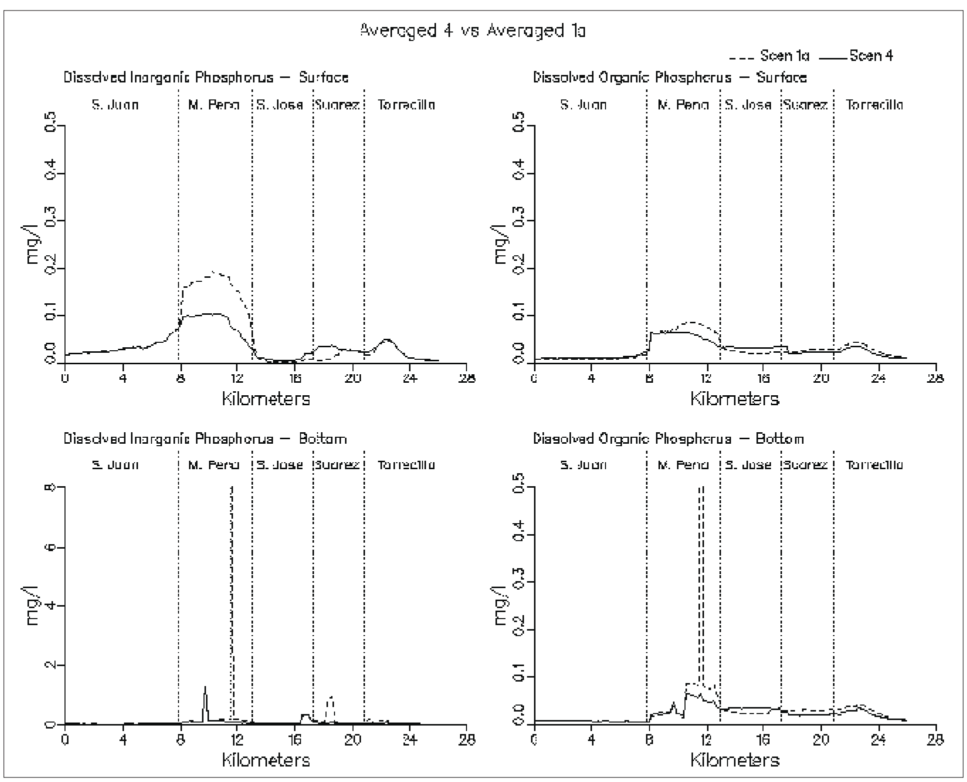

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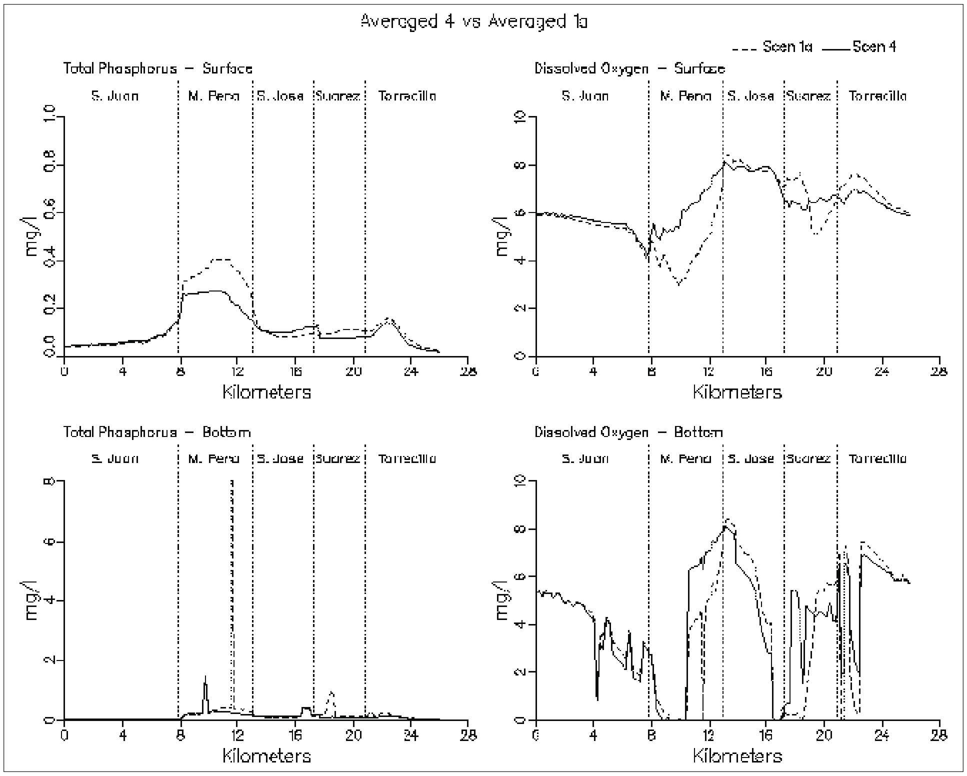


Figure 8-41. (Sheet 7 of 11)

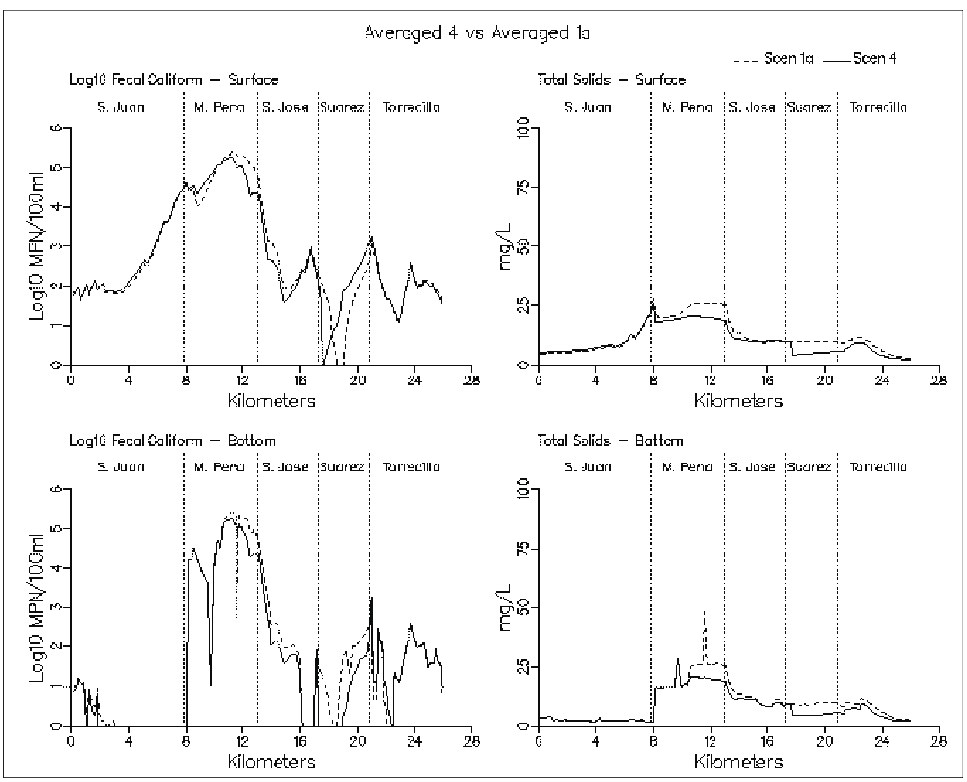
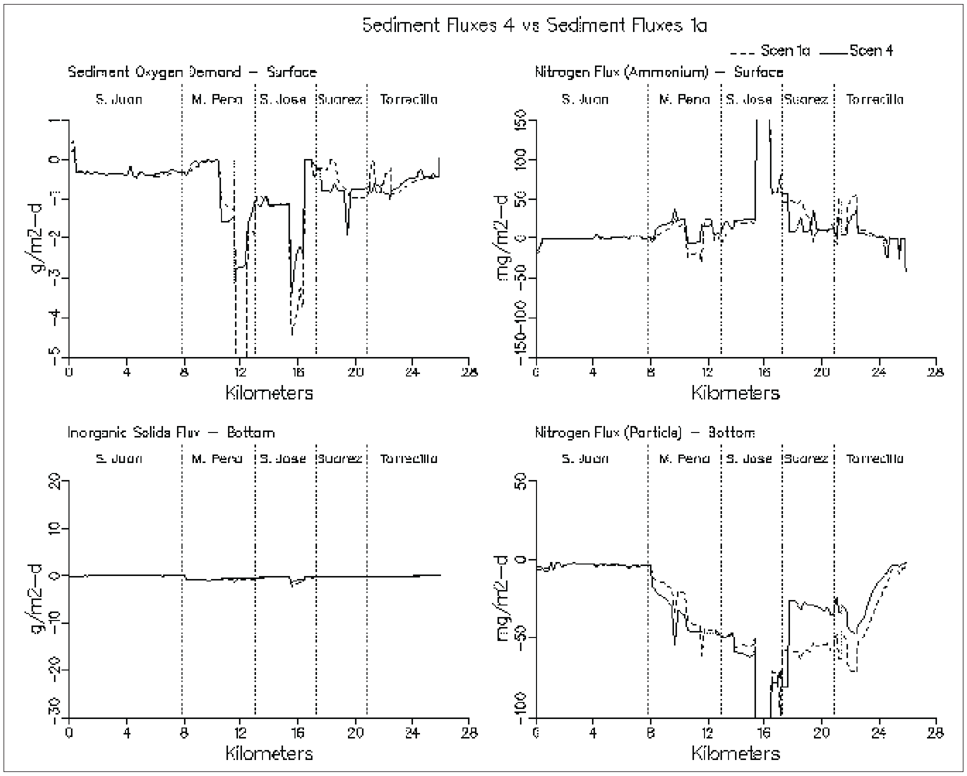


Figure 8-41. (Sheet 8 of 11)



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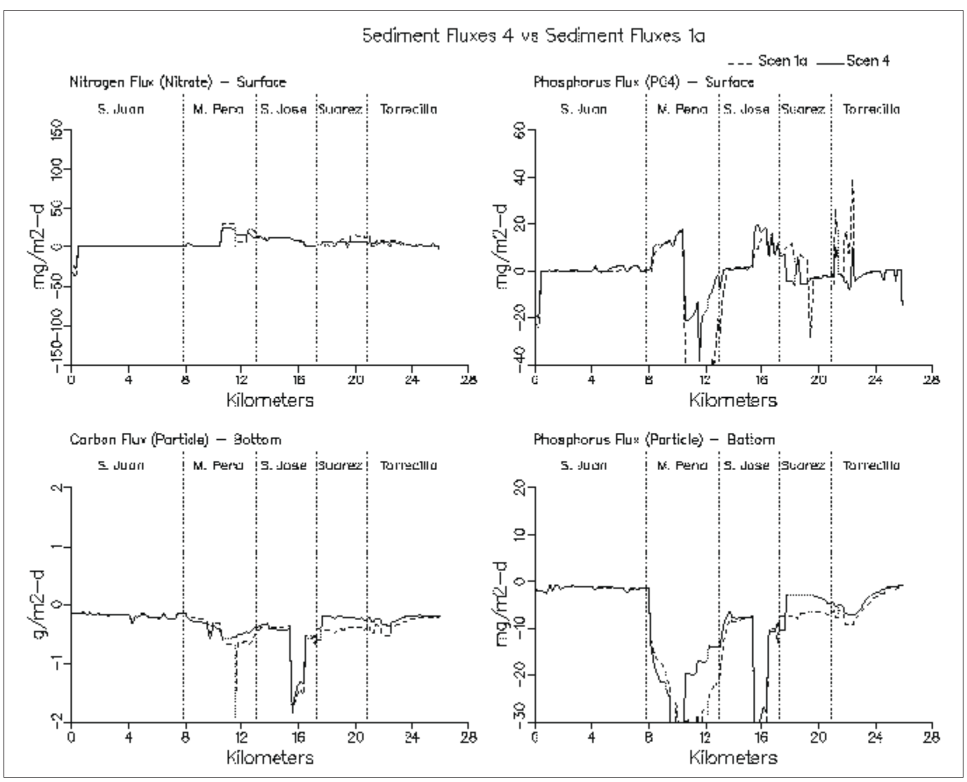

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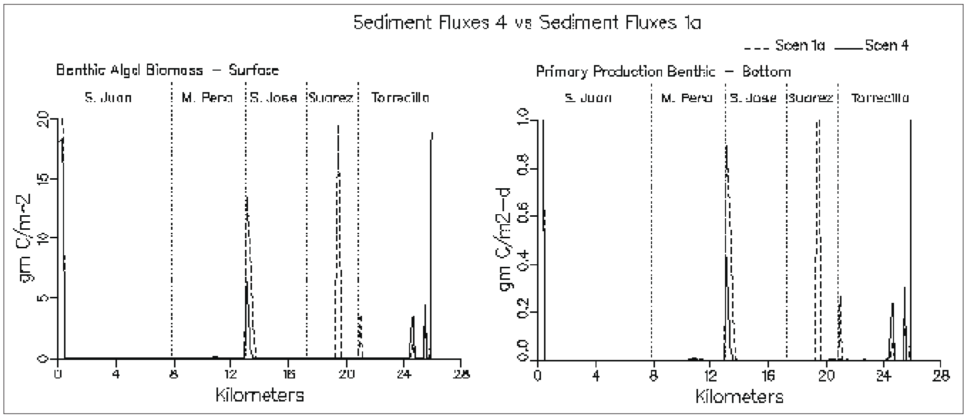


Figure 8-41. (Sheet 11 of 11)

Chlorophyll levels decreased slightly in Caño Martín Peña, Laguna San José, and Canal Suárez. The amount of the decrease was a maximum of 4 μg/l. Dissolved organic carbon levels decreased by 3 mg/l in Caño Martín Peña. Total carbon levels in Caño Martín Peña decreased by 4 mg/l. There was a slight decrease in DOC and TOC in Laguna San José and Canal Suárez.

Ammonium levels in Caño Martín Peña decreased from a maximum of 1.0 mg/l to 0.4 mg/l. No changes occurred elsewhere along the transect. Nitrate levels also decreased in Caño Martín Peña in response to the loading reduction. Dissolved organic nitrogen levels decreased significantly in Caño Martín Peña with the removal of the un-sewered loads. Surface total nitrogen levels decreased by nearly 1 mg/l in Caño Martín Peña. Concentrations at this location are still the highest along the transect.

Removal of the un-sewered loads resulted in a decrease in dissolved inorganic phosphorus levels in Caño Martín Peña of 0.1 mg/l, while dissolved organic phosphorus levels decreased to Laguna San José levels. No other significant change occurred in phosphorus concentrations elsewhere along the transect.

The DO transect indicates a slight improvement (0.3 mg/l) in Caño Martín Peña. No other changes were observed. Fecal coliform levels showed some decrease in Caño Martín Peña. Effects did not extend beyond the confluence of Caño Martín Peña and San Juan Bay. A slight increase in total solids resulting from a decrease in algae occurred in Caño Martín Peña.

In summary, impacts resulting from Scenario 5a conditions were confined for the most part to Caño Martín Peña. Other than in Caño Martín Peña, these effects were insignificant.

Scenario 5b

Scenario 5b like 5a involved a loading reduction. In this scenario, the loading reduction was the removal of loads originating from the Baldeorioty de Castro storm water pumping station. Upper Laguna San José serves as the receiving waters for this load. An average loading of 906 kg/day of carbon, 79.2 kg/day of nitrogen, and 27.2 kg/day of phosphorus was removed. All other conditions and loads were the same as those used in Scenario 1a. The pumping discharges remained without the loads.

Salinity and temperature were identical in Scenario 5b to those of 1a (see Figure 8-43). Chlorophyll levels decreased by a maximum of approximately 8 µg/l in Laguna San José and Canal Suárez. Smaller decreases were predicted in Caño Martín Peña.

Dissolved organic carbon levels decreased approximately 2 mg/l in Laguna San José and Canal Suárez. Total organic carbon levels indicated a similar decrease. Carbon fluxes from Laguna San José to Caño Martín Peña were 369 kg/day. Carbon fluxes from Laguna San José to Canal Suárez were 1240 kg/day.

Neither ammonium nor nitrate discharges indicated any change along the transect in Scenario 5b when compared with Scenario 1a. Any ammonium discharged by the pump station is rapidly taken up and doesn't remain in the system long enough to influence ammonium concentrations along the transect. Dissolved organic nitrogen levels decreased slightly in response to lower chlorophyll levels in Laguna San José and Canal Suárez. Nitrogen flux rates from Laguna San José to Caño Martín Peña averaged 10.2 kg/day. Nitrogen flux rates from Laguna San José to Canal Suárez averaged 109.9 kg/day.

The only change in phosphorus levels along the transect in Scenario 5b occurred as a result of decreased algae levels. Dissolved inorganic phosphorus levels in Scenario 5b were unchanged from 1a. Dissolved organic phosphorus levels showed only the slightest decrease in Laguna San José. Phosphorus flux rates from Laguna San José to Caño Martín Peña averaged 1 kg/day. Phosphorus flux rates from Laguna San José to Canal Suárez averaged 15.5 kg/day.

Dissolved oxygen, fecal coliform, and total solids levels along the transect were relatively unaffected by the loading reductions of Scenario 5b.

In summary, the effects of the loading reduction of Scenario 5b were limited to a great extent to Laguna San José. The reduction in nutrients resulted in a decrease in algae which did affect organic carbon levels in Caño Martín Peña and Canal Suárez. Nitrogen levels were affected slightly in Laguna San José and Canal Suárez. Substantial impacts in nutrients were not observed along the transect since this loading reduction

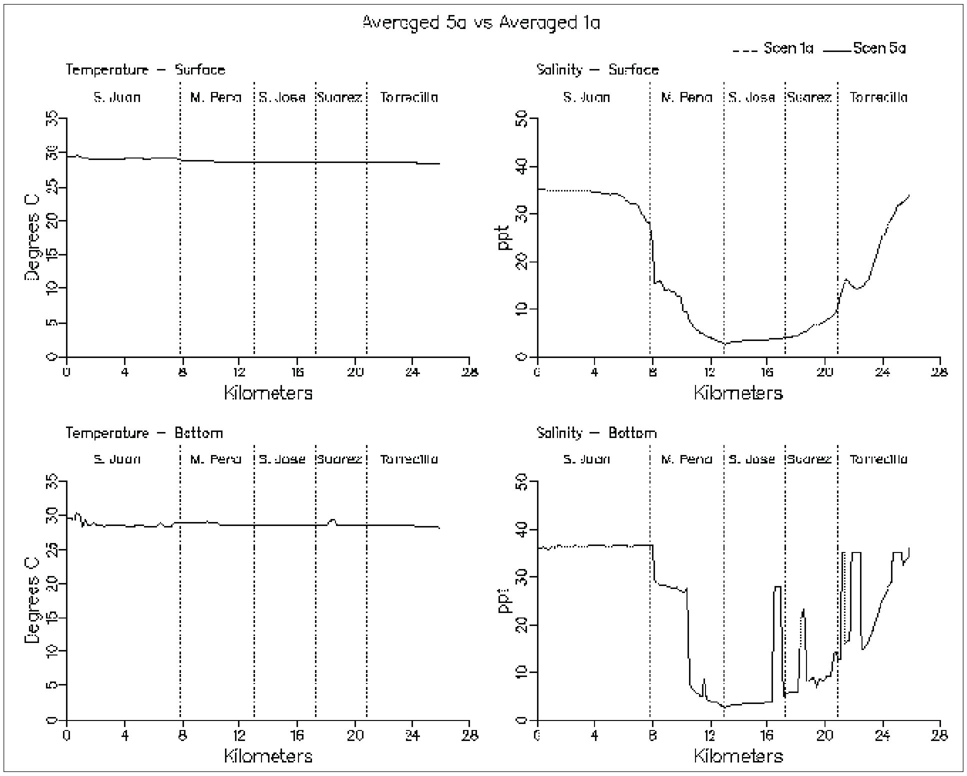


Figure 8-42. Simulation averaged transect plots comparing Scenario 5a with Scenario 1a (Sheet 1 of 11)

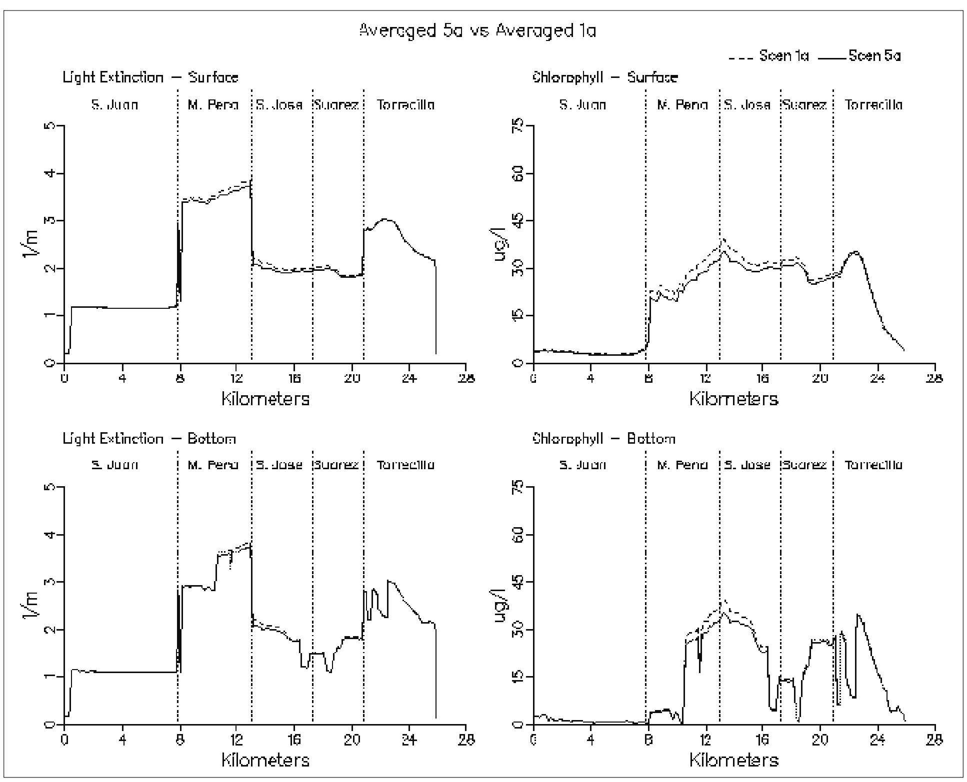


Figure 8-42. (Sheet 2 of 11)

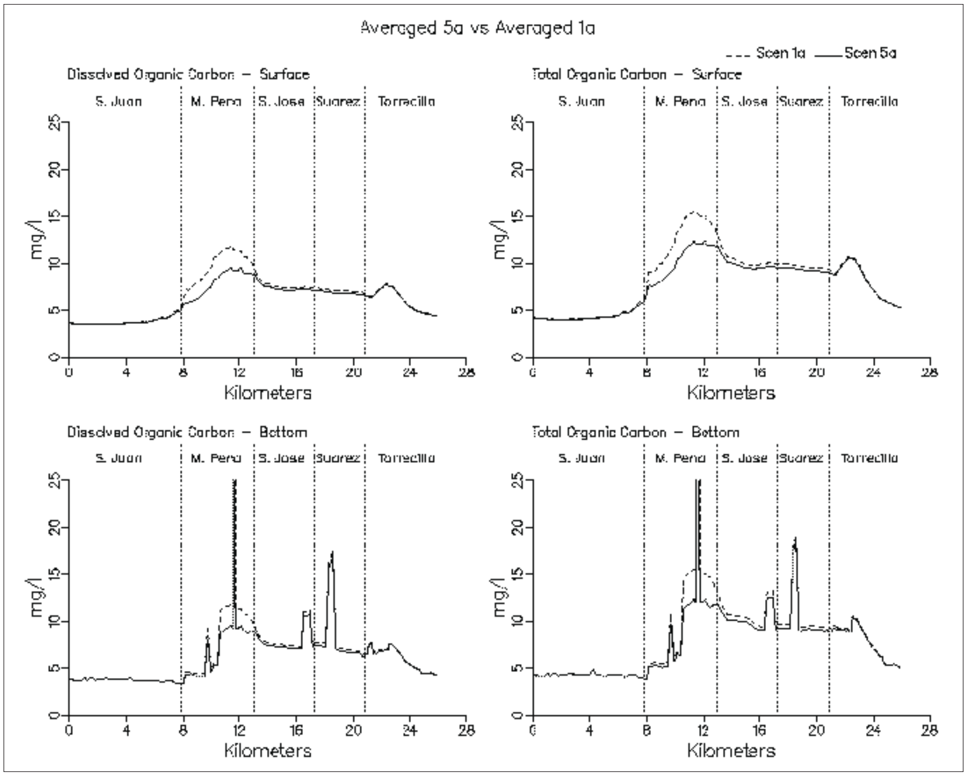
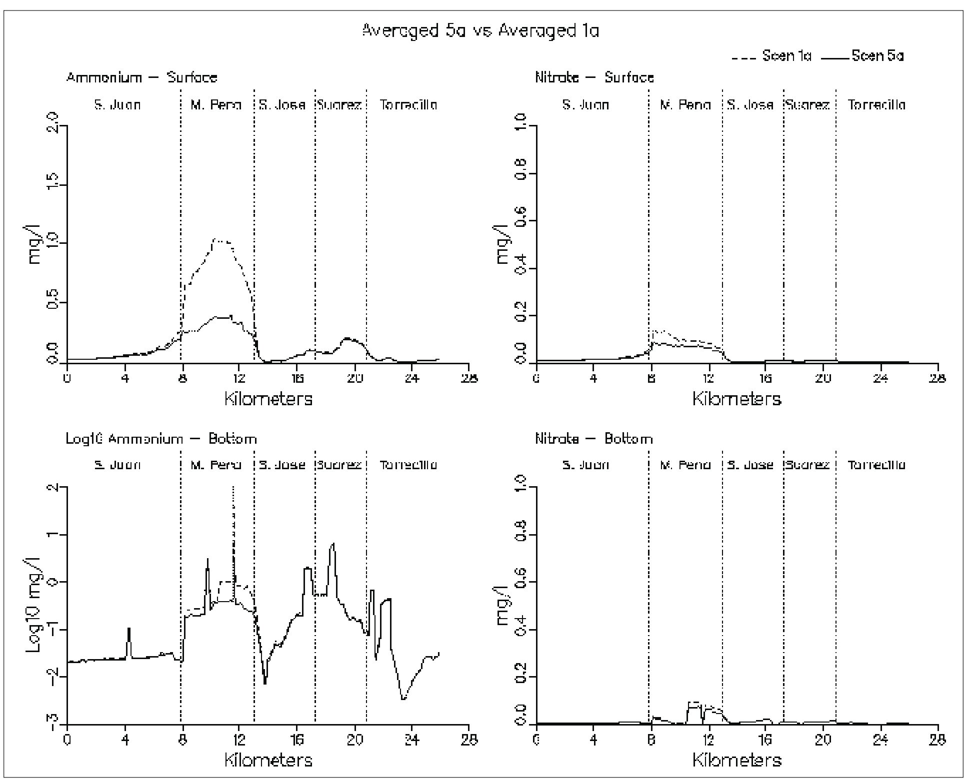


Figure 8-42. (Sheet 3 of 11)



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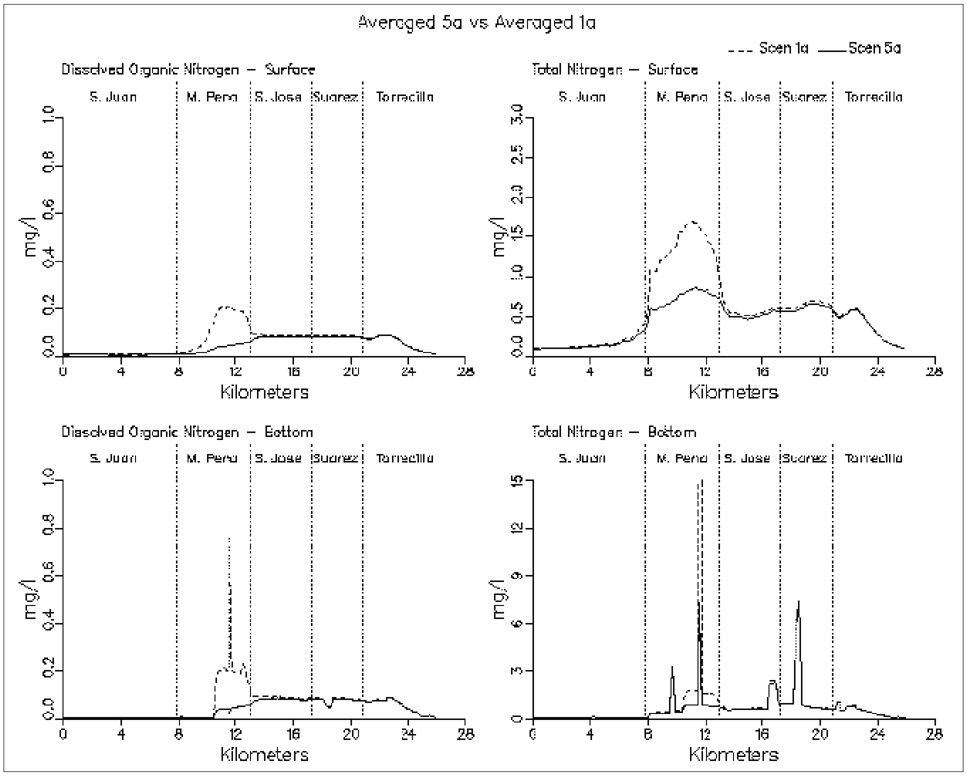
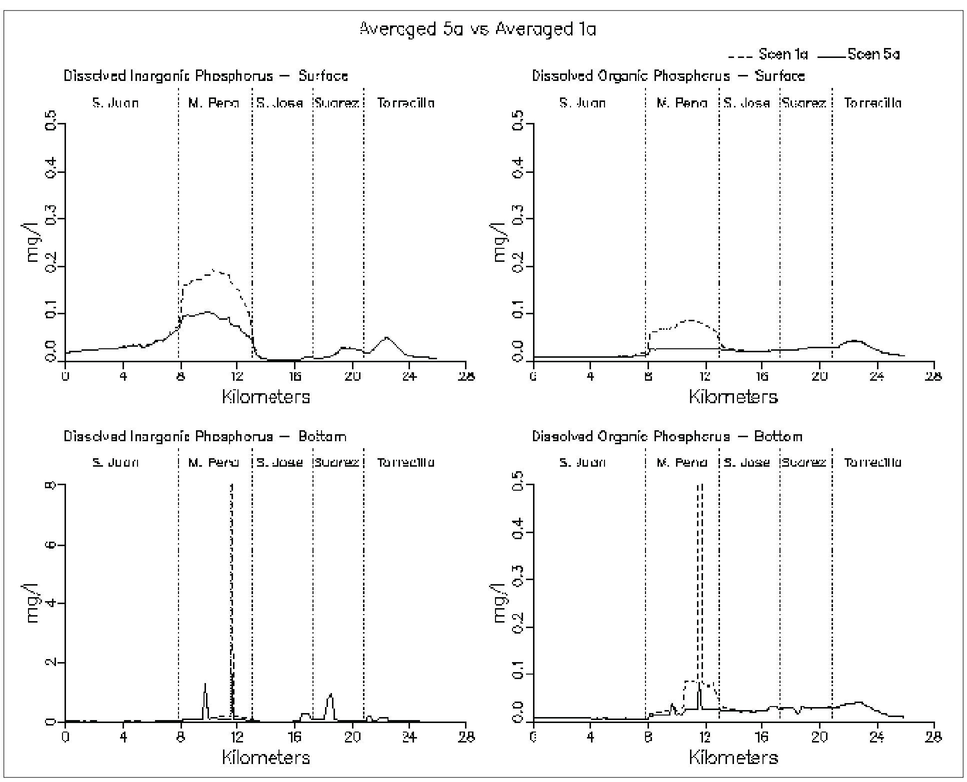


Figure 8-42. (Sheet 5 of 11)



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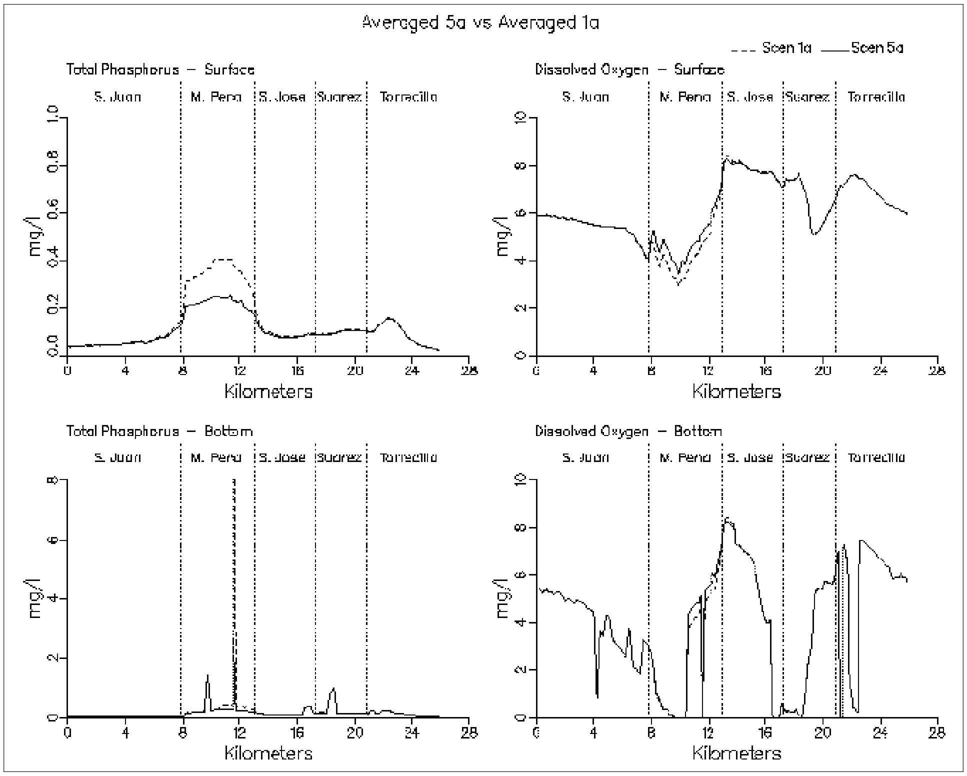

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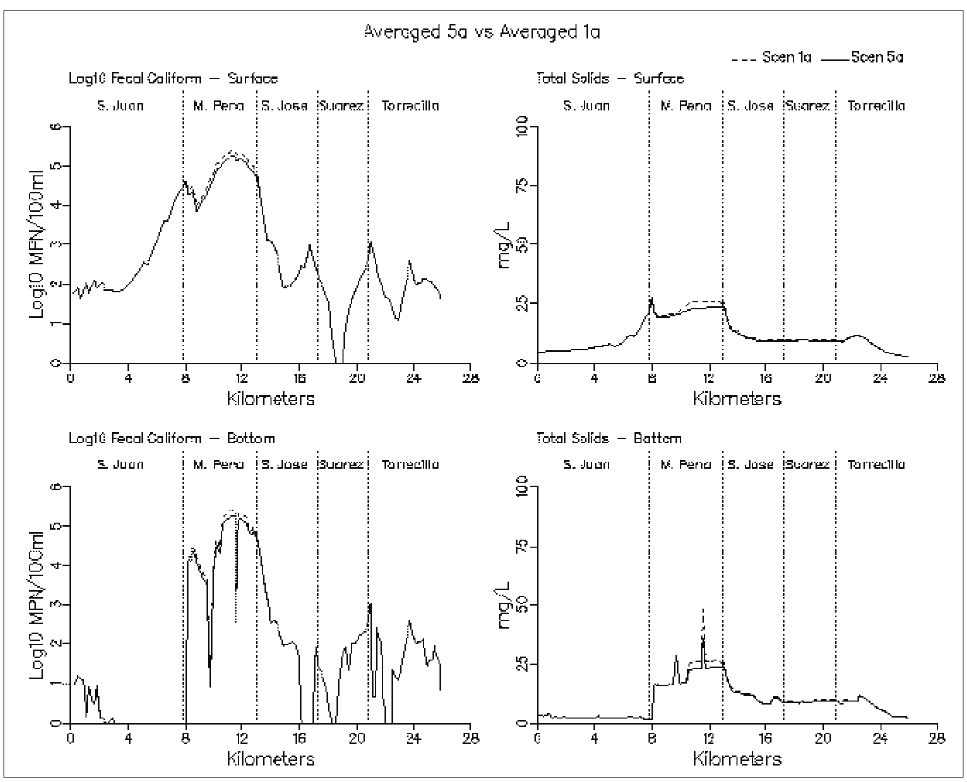

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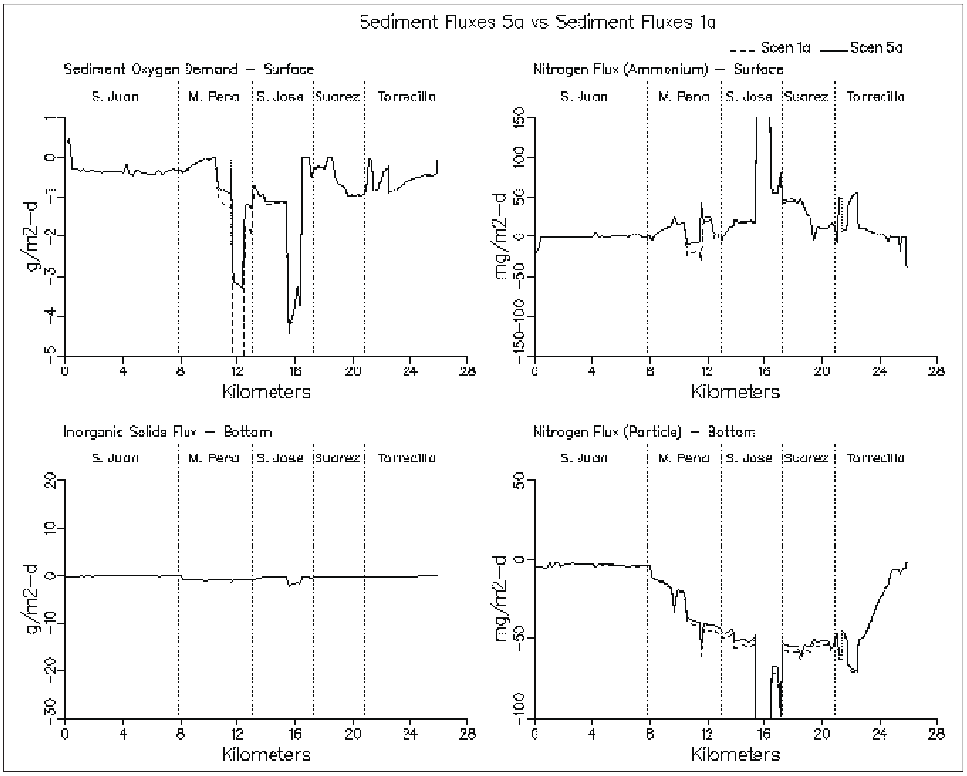
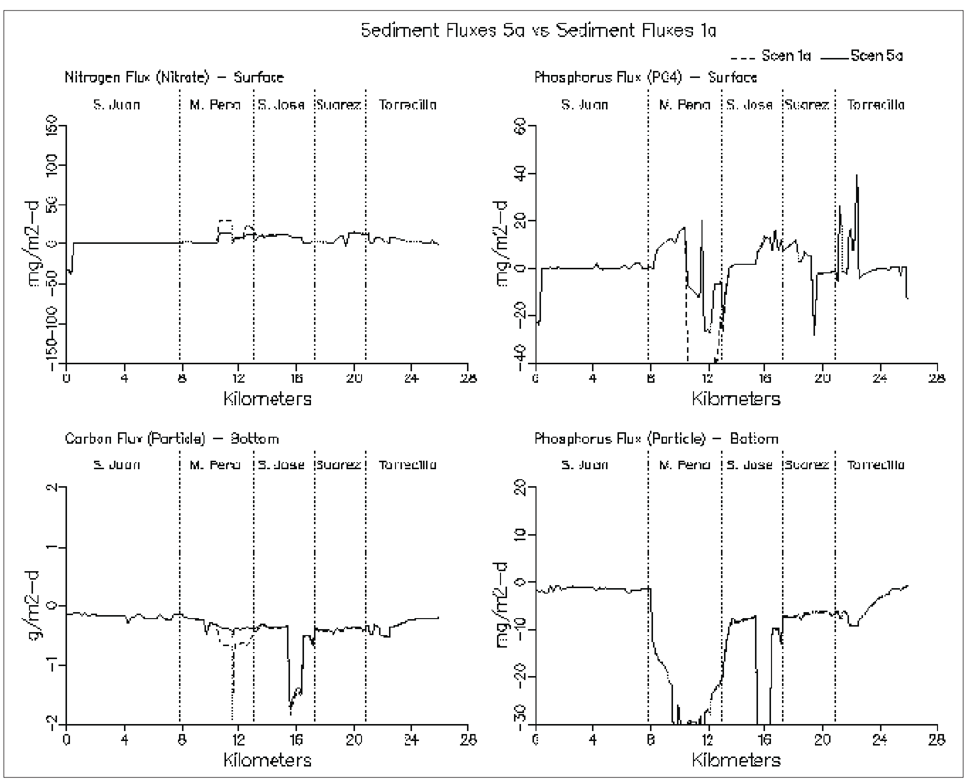


Figure 8-42. (Sheet 9 of 11)



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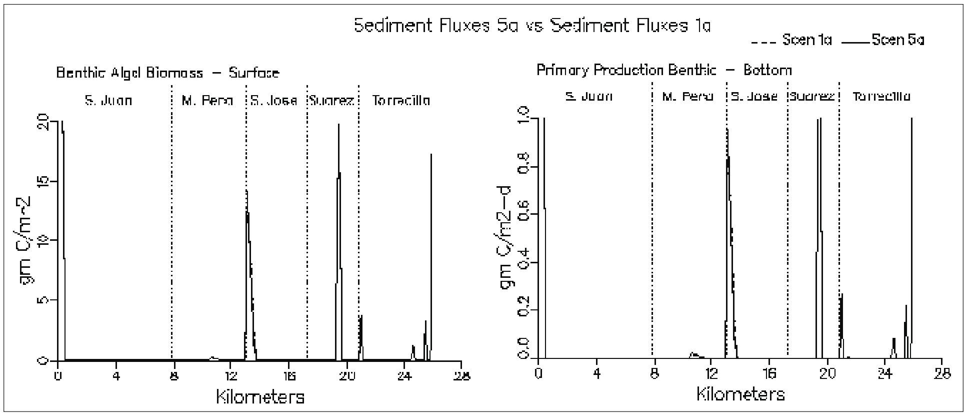


Figure 8-42. (Sheet 11 of 11)

is relatively far from the transect. Changes in nutrients loadings are rapidly compensated by algal uptake near the point of discharge.

Scenario 6a

Scenario 6a combined the loading reductions of Scenarios 5a and 5b with the channel modification to Caño Martín Peña of Scenario 1c. Since the loading reductions of 5a and 5b did not require the grid to be reconfigured, the grid and hydrodynamic data for Scenario 1c could be used for Scenario 6a. In essence, Scenario 6a is a repeat of Scenario 1c with loading reductions in Laguna San José and Caño Martín Peña.

As expected, temperature and salinity transects for Scenario 6a (see Figure 8-44) were identical to results for Scenario 1c. Chlorophyll levels for Scenario 6a are lower than those of Scenario 1a for all of the transect except San Juan Bay where levels increased by 3 µg/l. Chlorophyll levels in Laguna San José are typically 15 µg/l lower than those of Scenario 1a with the greatest decrease occurring at the confluence of Caño Martín Peña and Laguna San José. At this location, chlorophyll levels were approximately 23 µg/l lower in Scenario 6a than in Scenario 1a. Surface chlorophyll levels in Scenario 6a were lower than those predicted in Scenario 1c. The average surface chlorophyll level in Laguna San José was approximately 7 µg/l lower in Scenario 6a than that in Scenario 1c. Chlorophyll levels decreased in Caño Martín Peña by 2 µg/l on the western end and as much as 5 µg/l on the eastern end in Scenario 6a when compared to results from Scenario 1c. A decrease of 6 µg/l of chlorophyll occurred in western Canal Suárez in Scenario 6a when compared to Scenario 1c . The decreases in chlorophyll observed between Scenarios 6a and 1c result from the removal of the un-sewered loads for Caño Martín Peña and the loads for the Baldeoroity de Castro Pump Station. Since neither one of these sources input a chlorophyll load, the decrease in chlorophyll levels observed is the result of a decrease in nutrients.

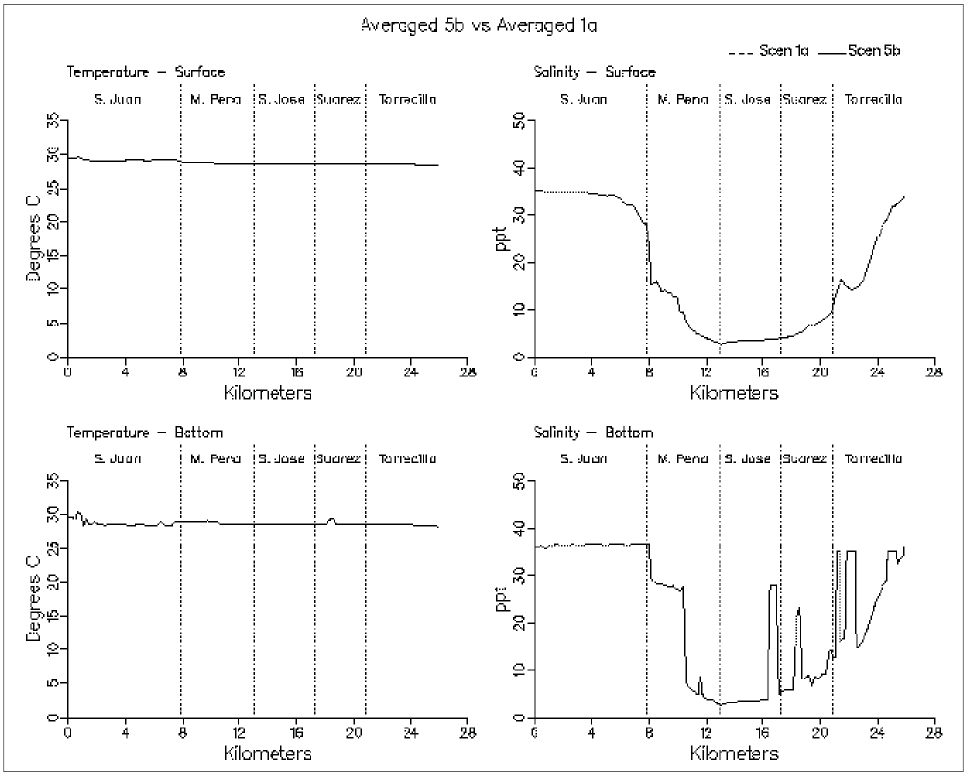
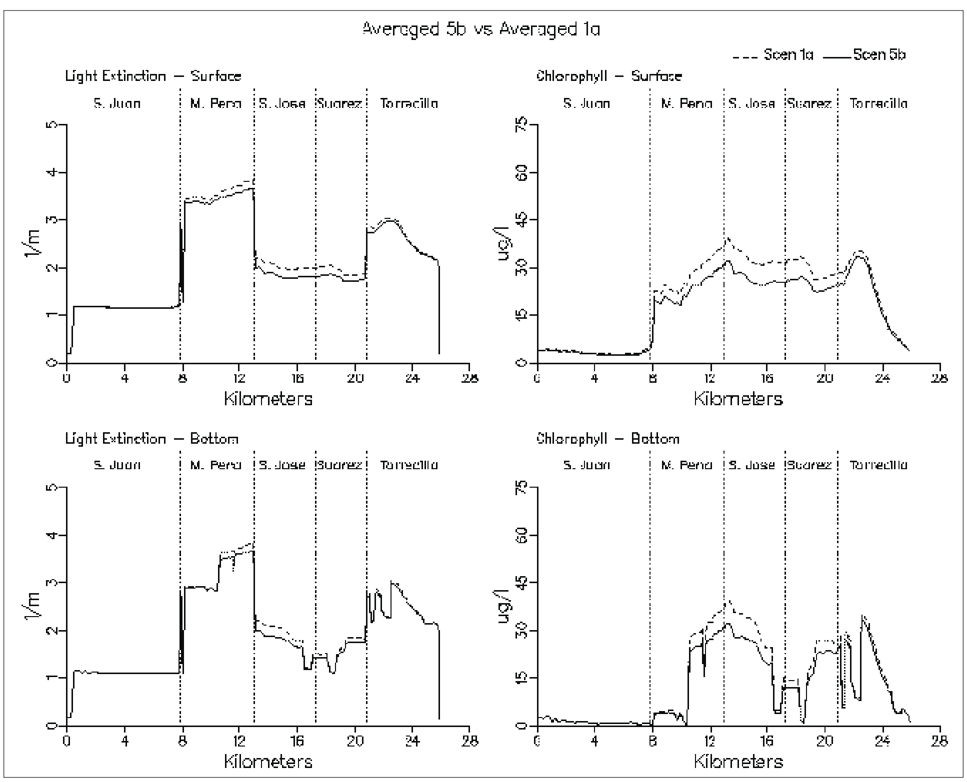


Figure 8-43. Simulation averaged transect plots comparing Scenario 5b with Scenario 1a (Sheet 1 of 11)



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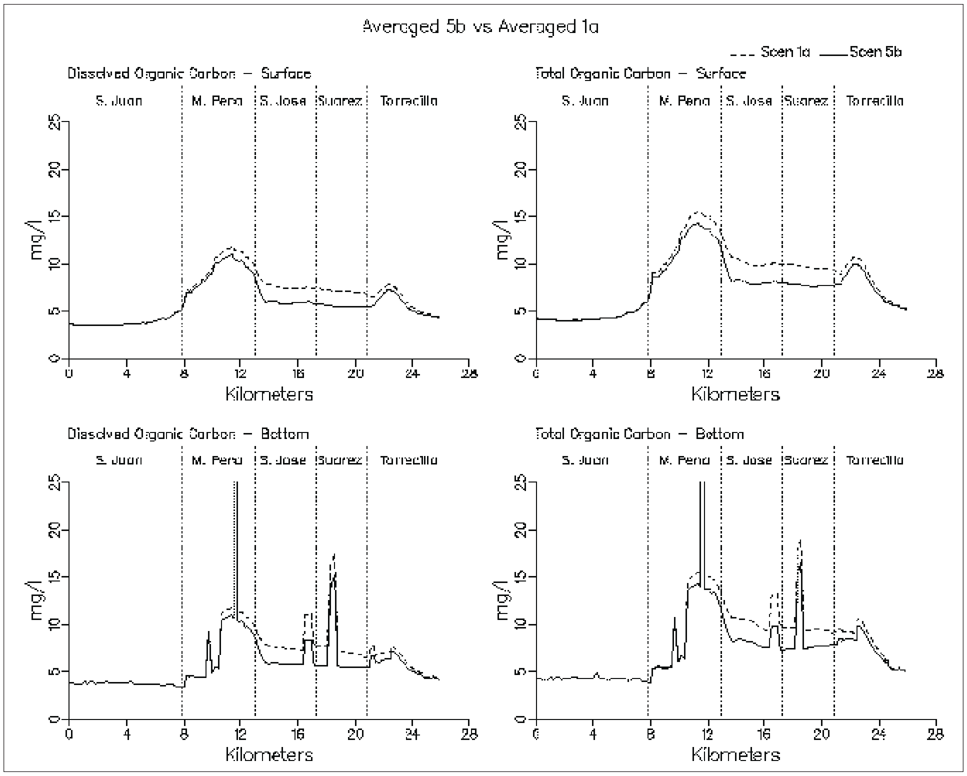

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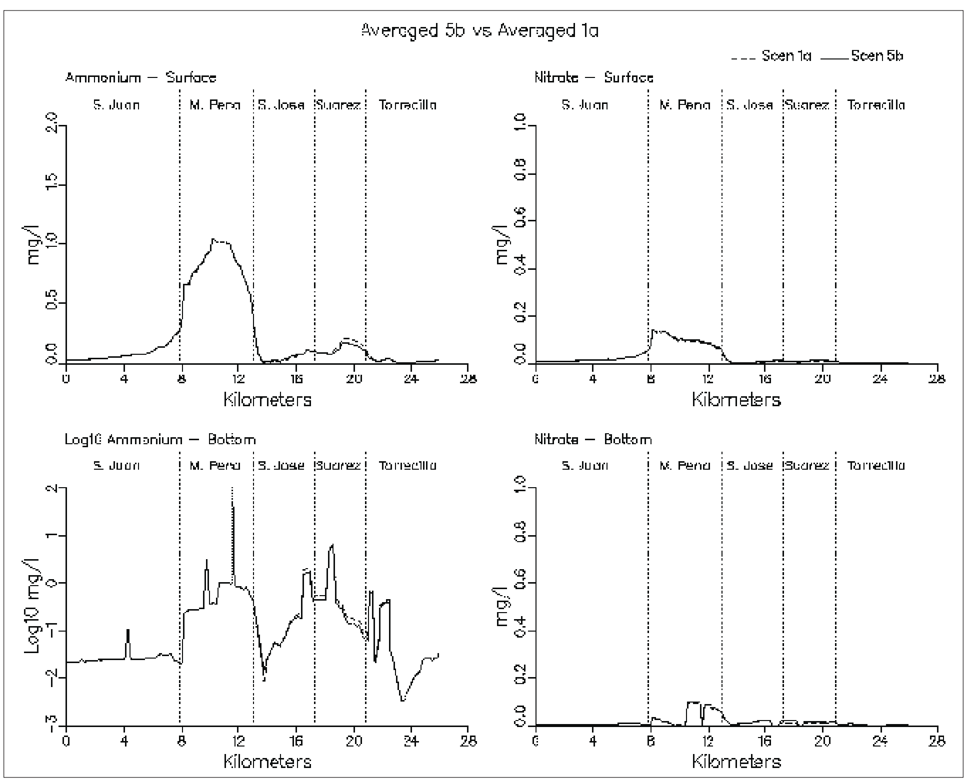


Figure 8-43. (Sheet 4 of 11)

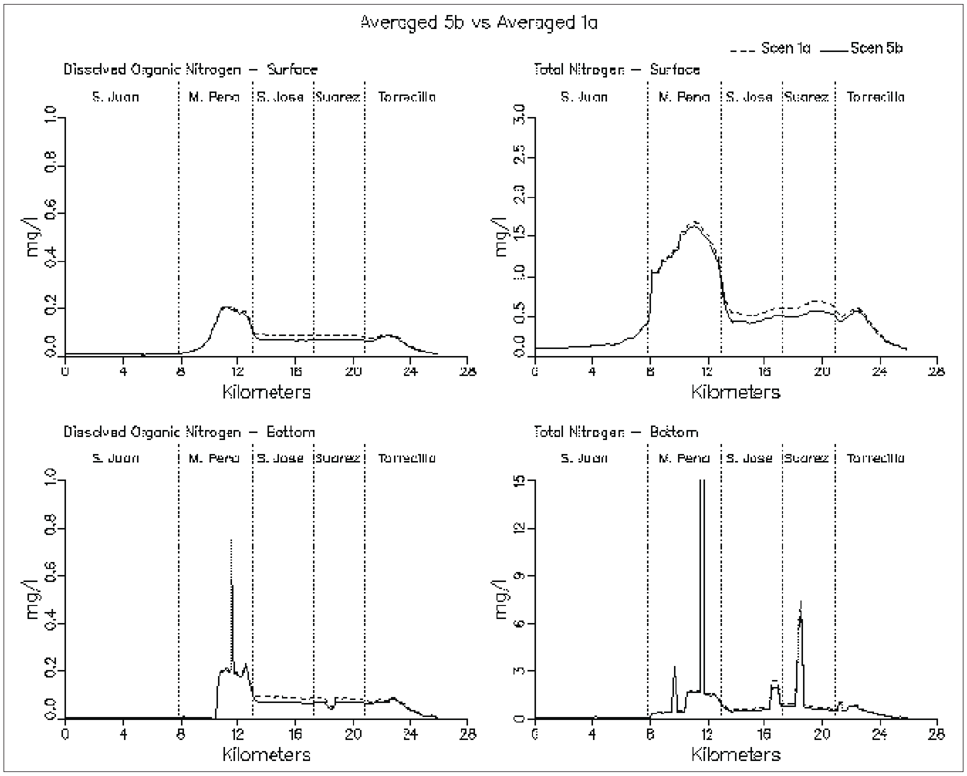
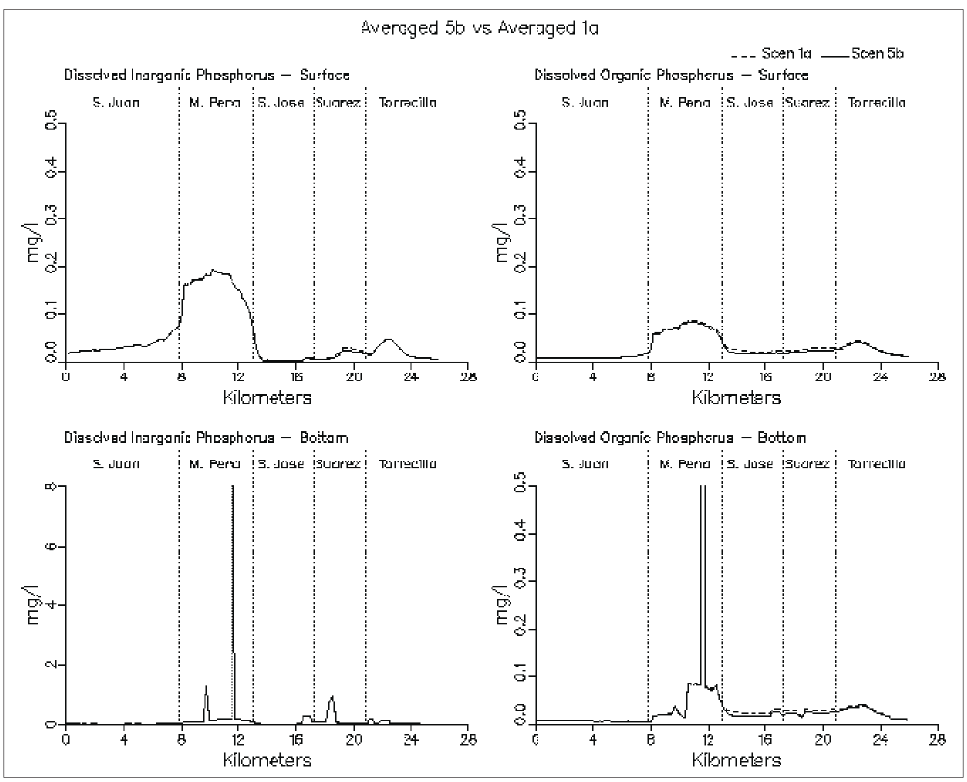


Figure 8-43. (Sheet 5 of 11)



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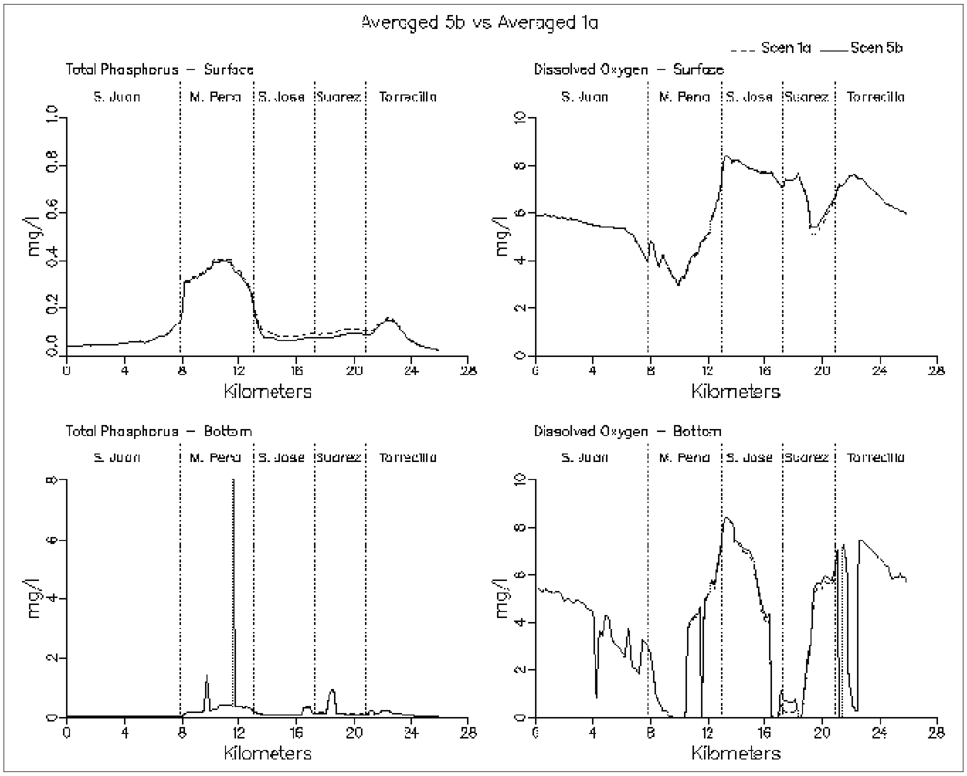

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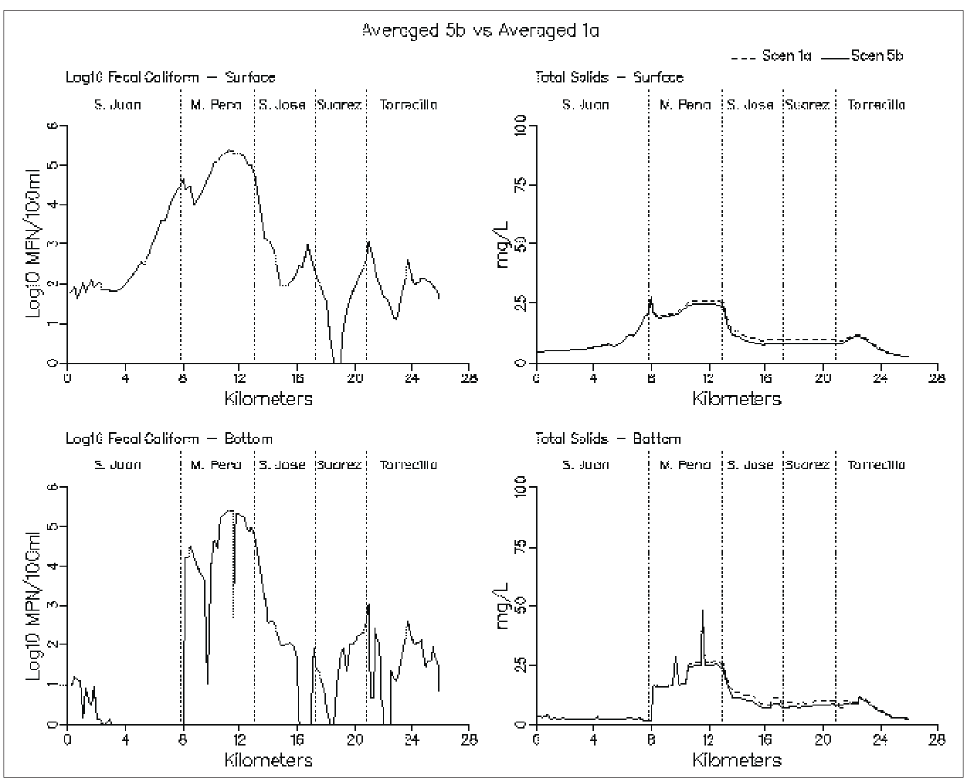

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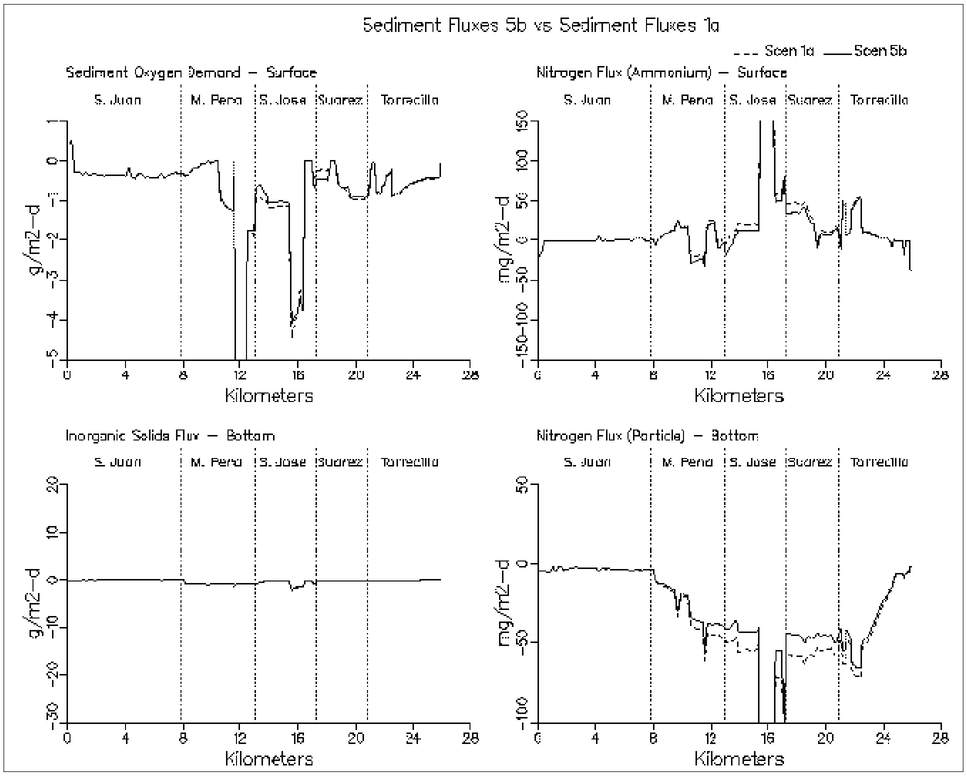

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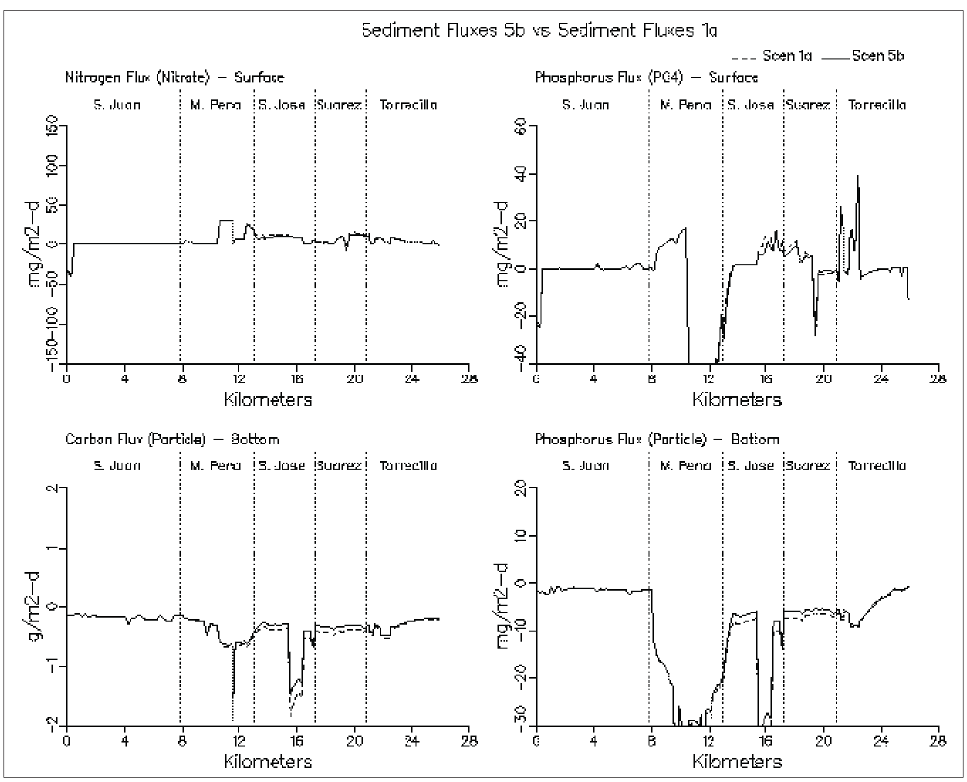

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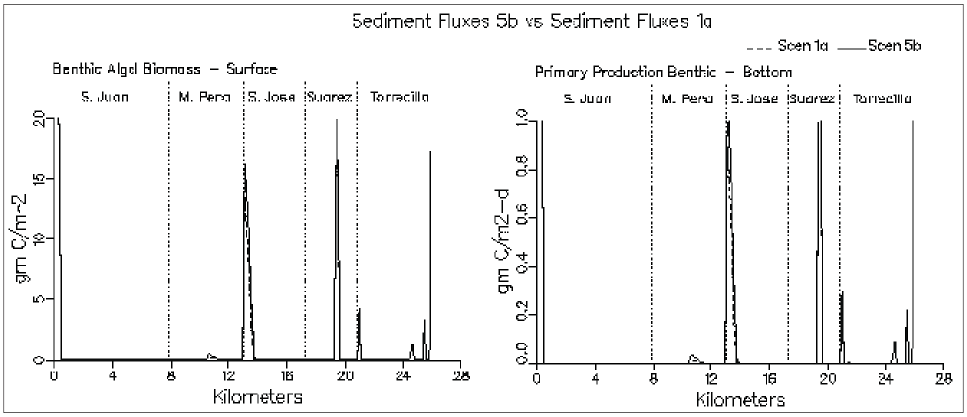


Figure 8-43. (Sheet 11 of 11)

Organic carbon concentrations decreased in Caño Martín Peña, Laguna San José, Canal Suárez, and Laguna La Torrecilla in Scenario 6a when compared to 1a. Dissolved organic carbon levels decreased by 8 mg/l in eastern Caño Martín Peña, 4 mg/l in Laguna San José, 3 mg/l in Canal Suárez, and 1 mg/l in upper Laguna La Torrecilla. Similar decreases in total organic carbon levels occurred in Scenario 6a. Comparison of Scenario 6a results with those of 1c indicates that dissolved organic carbon levels decreased by 1 mg/l in Caño Martín Peña and 1.5 mg/l in Laguna San José. In Scenario 6a, Laguna San José exported 2558 kg/day of carbon to Caño Martín Peña and imported 174 kg/day from Canal Suárez.

Caño Martín Peña surface ammonium levels in Scenario 6a were much lower than those of 1a and slightly lower than those of 1c as a result of the removal of the un-sewered loadings. In Scenario 6a, the maximum ammonium concentration in Caño Martín Peña occurs in the western end and is the result of Rio Piedras inflows. Caño Martín Peña nitrate concentrations decreased in Scenario 6a by 0.1 mg/l in comparison to Scenario 1a levels but were identical to Scenario 1c levels. Dissolved organic nitrogen decreased in Caño Martín Peña, Laguna San José, Canal Suárez, and Laguna La Torrecilla in Scenario 6a. The greatest decrease occurred in eastern Caño Martín Peña. When compared to 1a results, dissolved organic nitrogen concentrations decreased 0.18 mg/l at this location in Scenario 6a. However, when compared to Scenario 1c, it is evident that most of this decrease is the result of the channelization of Caño Martín Peña as the dissolved organic nitrogen levels in Scenario 1c are only 0.02 mg/l higher than those of 6a. In Scenario 6a, Laguna San José dissolved organic nitrogen levels were half of what they had been in Scenario 1a. These levels were also 0.03 mg/l lower than they had been in Scenario 1c. Total nitrogen levels in Scenario 6a were significantly lower in Scenario 6a than in 1a as a result of the decreases in ammonium, dissolved organic nitrogen, and particulate organic nitrogen. In Scenario 6a, Laguna San José discharged 161 kg/day of nitrogen to Caño Martín Peña and imported 7 kg/day from Canal Suárez.

Scenario 6a phosphorus levels indicated large decreases in Caño Martín Peña when compared to results for Scenario 1a. Dissolved inorganic phosphorus levels decreased from as much as 0.2 mg/l in Caño Martín Peña in 1a to 0.04 mg/l in 6a. However, comparison of results from 1c to those of 6a indicates that this decrease results from the channelization of Caño Martín Peña and not from the removal of the un-sewered loads as the concentrations for dissolved inorganic phosphorus in Caño Martín Peña in Scenarios 1c and 6a are identical. Scenario 6a dissolved organic phosphorus levels and total phosphorus levels in Caño Martín Peña and Laguna San José also indicate decreases when compared to Scenario 1a. The largest decreases occur in Caño Martín Peña and are a result of both the channelization and loading reductions as dissolved organic phosphorus and total phosphorus levels are lower in Scenario 6a than in Scenario 1c. In Scenario 6a, Laguna San José exports 14.6 kg/day of phosphorus to Caño Martín Peña and imports 2.5 kg/day from Canal Suárez.

Dissolved oxygen levels in Scenario 6a increased significantly in Caño Martín Peña when compared to Scenario 1a results. Dissolved oxygen levels decreased in Laguna San José, Canal Suárez, and Laguna La Torrecilla as a result of lower algal photosynthesis. Both surface and bottom dissolved oxygen results from Scenario 6a are nearly identical to the results for Scenario 1c which indicates that, at least along the transect, the removal of the un-sewered loads and the storm water loads had less of an effect than channelization of Caño Martín Peña. It must be remembered that surface dissolved oxygen levels in Scenario 1c and 6a are relatively high and cannot go any higher without algal photosynthesis. Dissolved oxygen levels along the bottom of Laguna San José in Scenario 6a did increase slightly when compared to Scenario 1c indicating that the loading removal did have some effect.

Fecal coliform levels in Scenario 6a exhibited the same behavior as those of 1a except for Caño Martín Peña where levels were one order of magnitude lower. Total solids transects for Scenario 6a were lower than the results for Scenario 1a. Scenario 6a results exhibited the same pattern as the results of Scenario 1c but were slightly lower. The decrease in total solids that occurs between Scenarios 1c and 6a results from a decrease in the solids load at Baldeorioty de Castro Pump Station and the decrease in algae brought upon by lower nutrient levels.

In summary, the conditions simulated in Scenario 6a improved water quality throughout the interior portions of the system. Opening Caño Martín Peña established a clockwise circulation through the interior system which promotes flushing. The most significant feature that the loading reductions added was a decrease in chlorophyll levels in Laguna San José in turn decreasing levels in Canal Suárez and Caño Martín Peña. Decreases in algae levels in these bodies translated into decreases in organic carbon, nitrogen, phosphorus, and total solids.

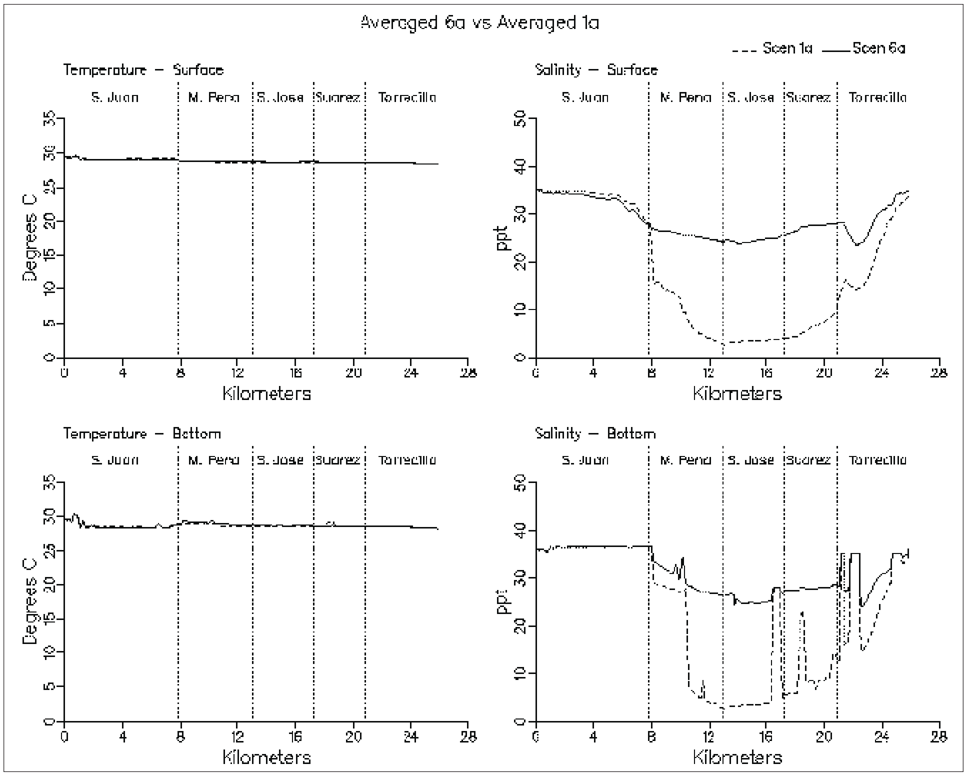


Figure 8-44. Simulation averaged transect plots comparing Scenario 6a with Scenario 1a (Sheet 1 of 11)

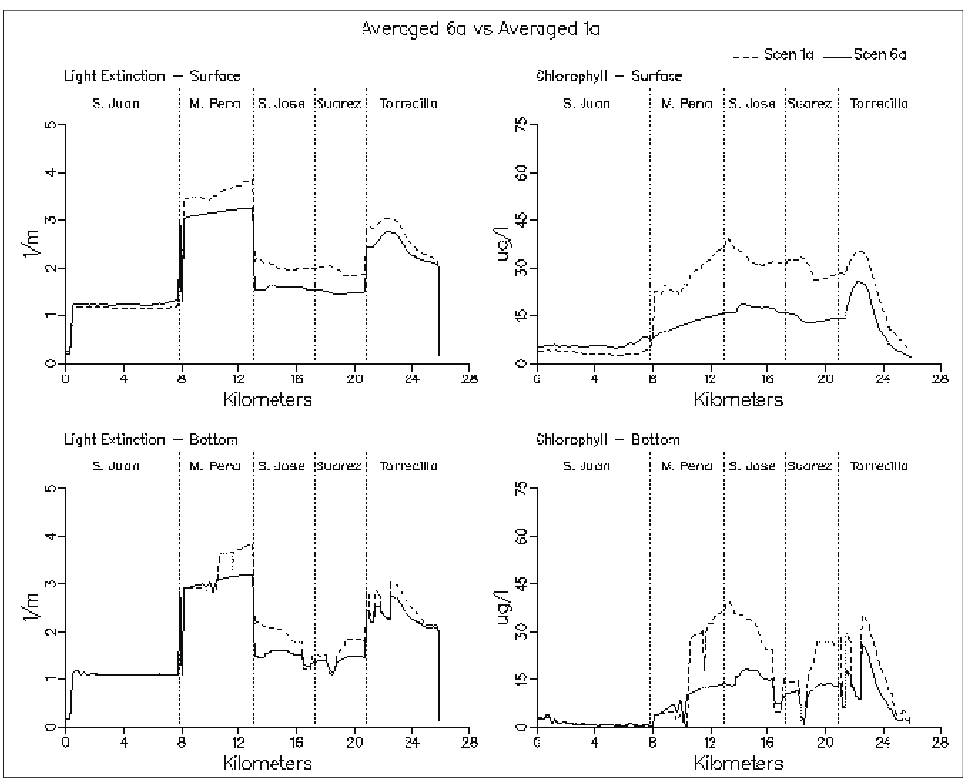
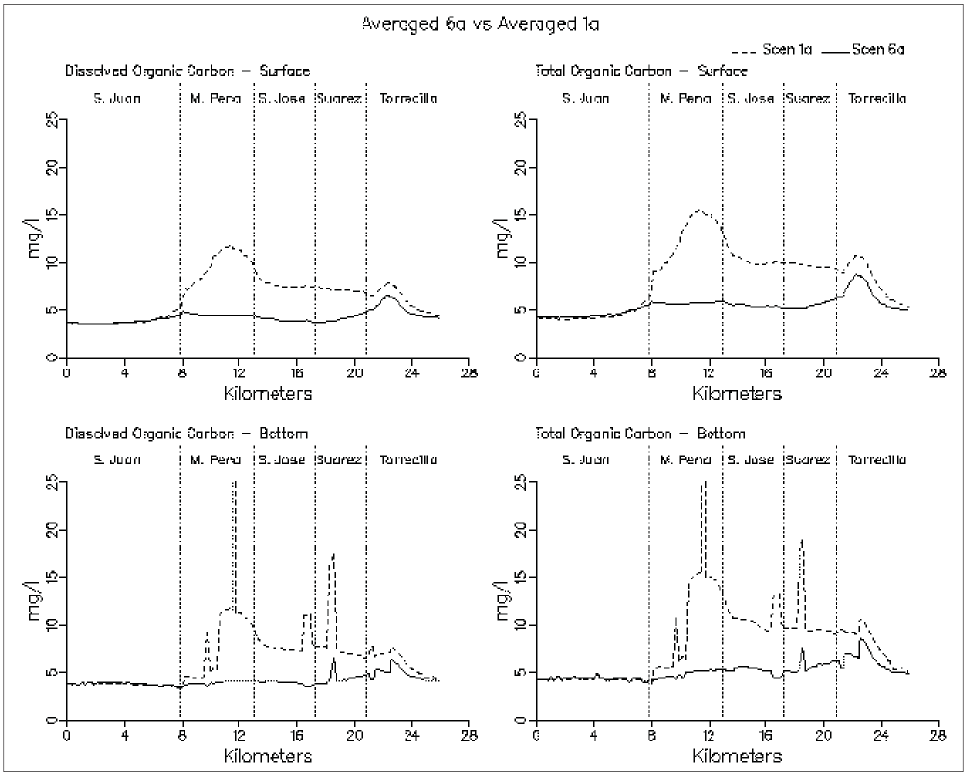


Figure 8-44. (Sheet 2 of 11)



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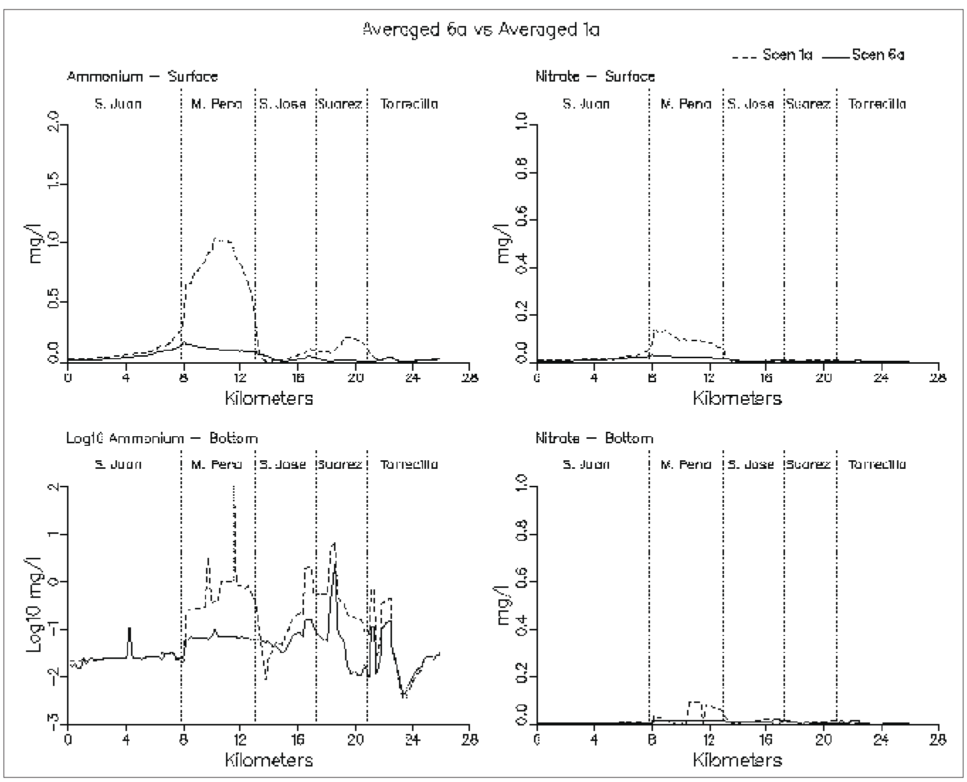

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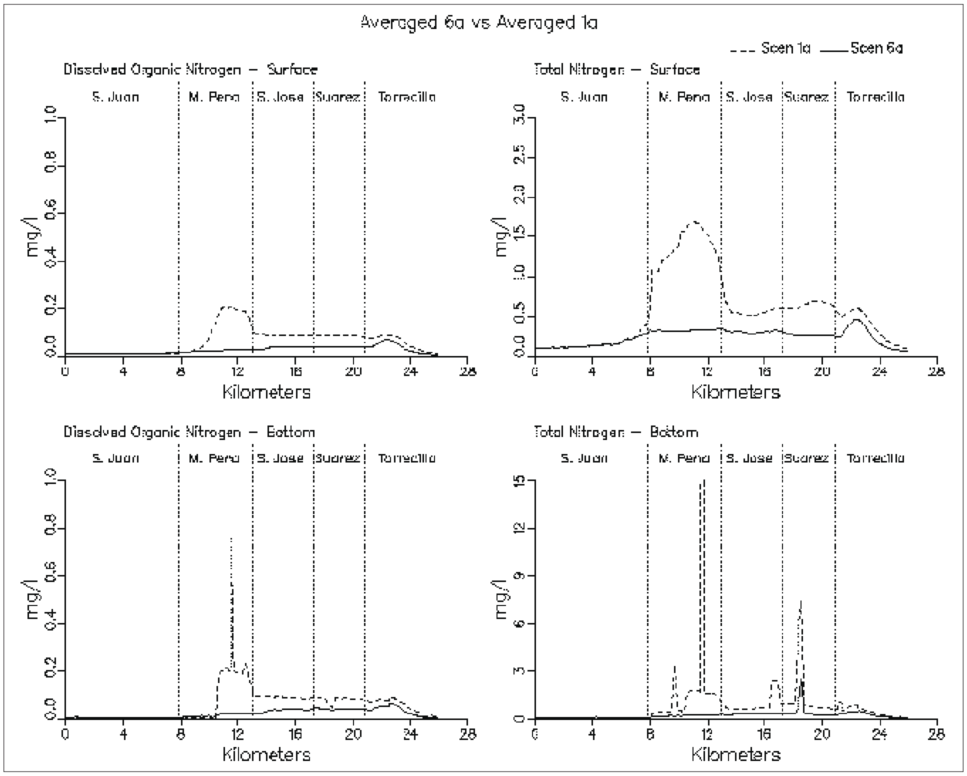

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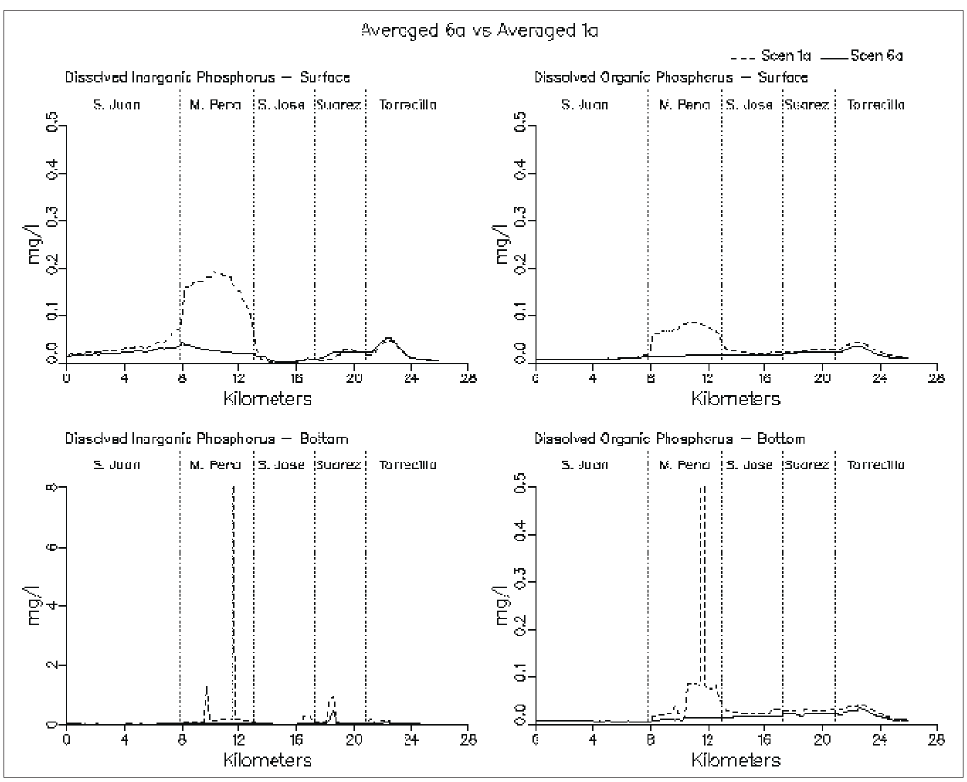

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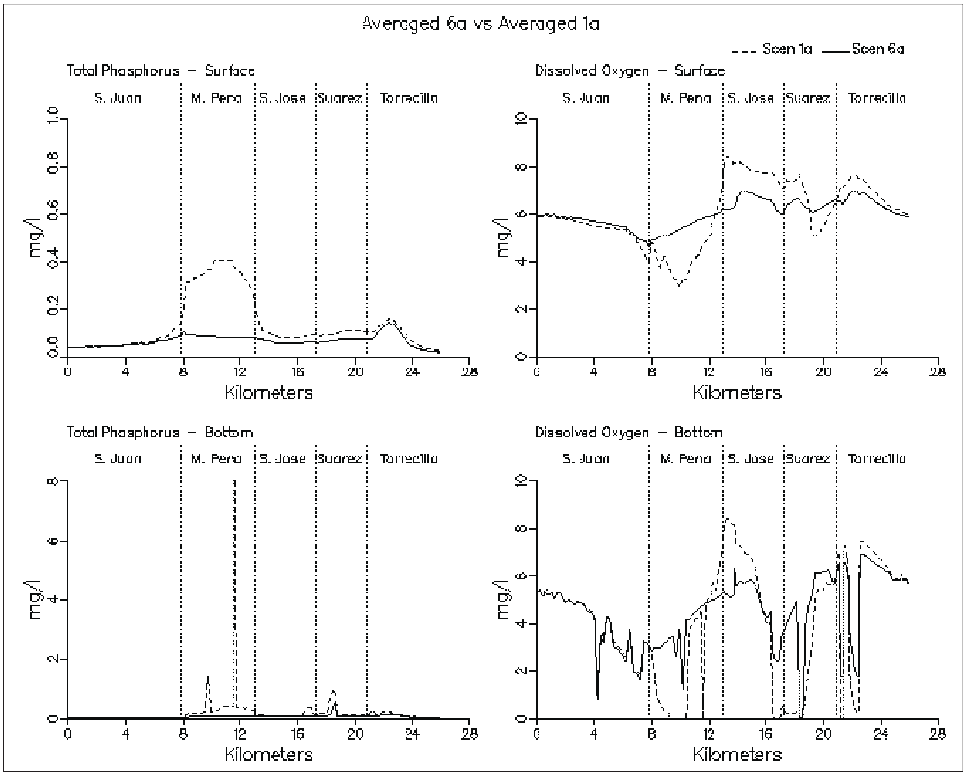

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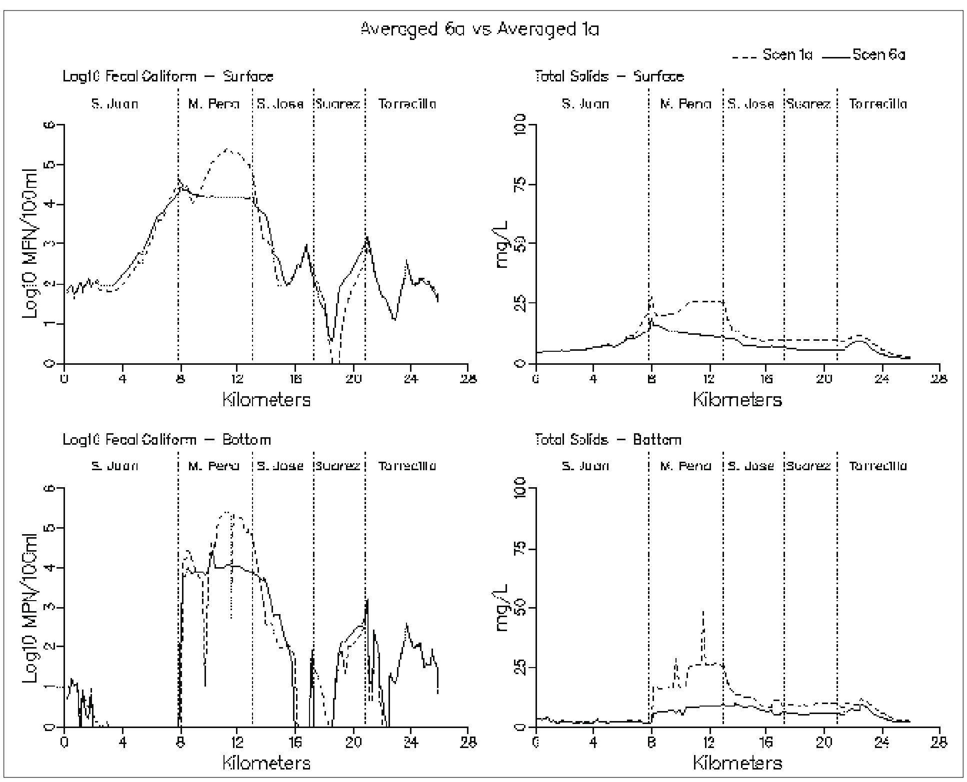

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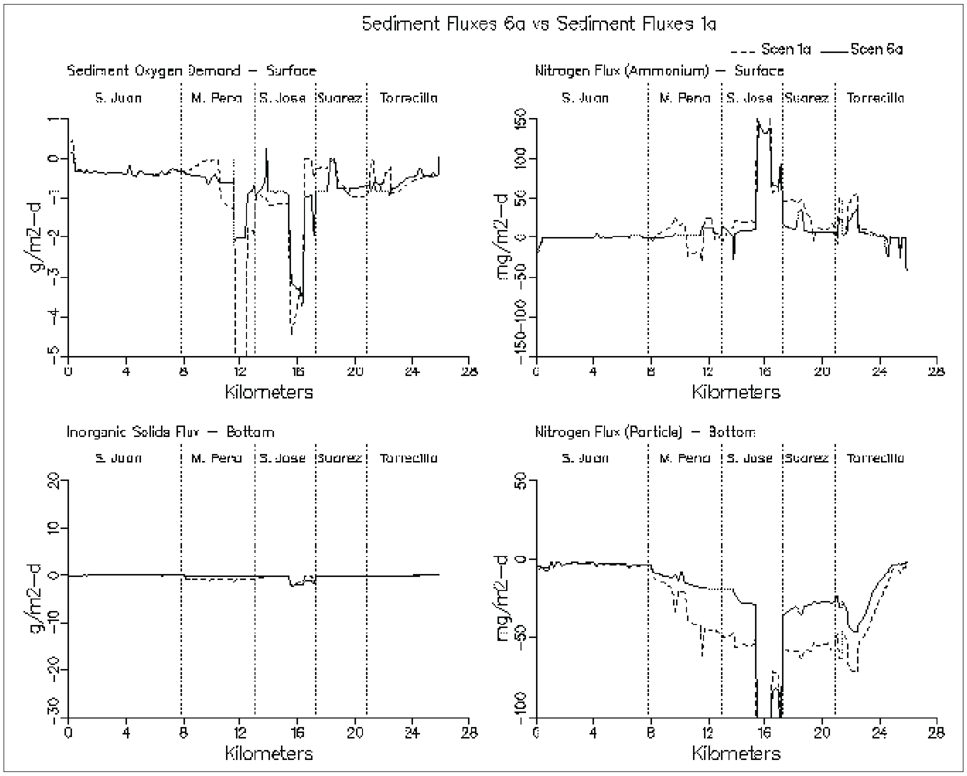

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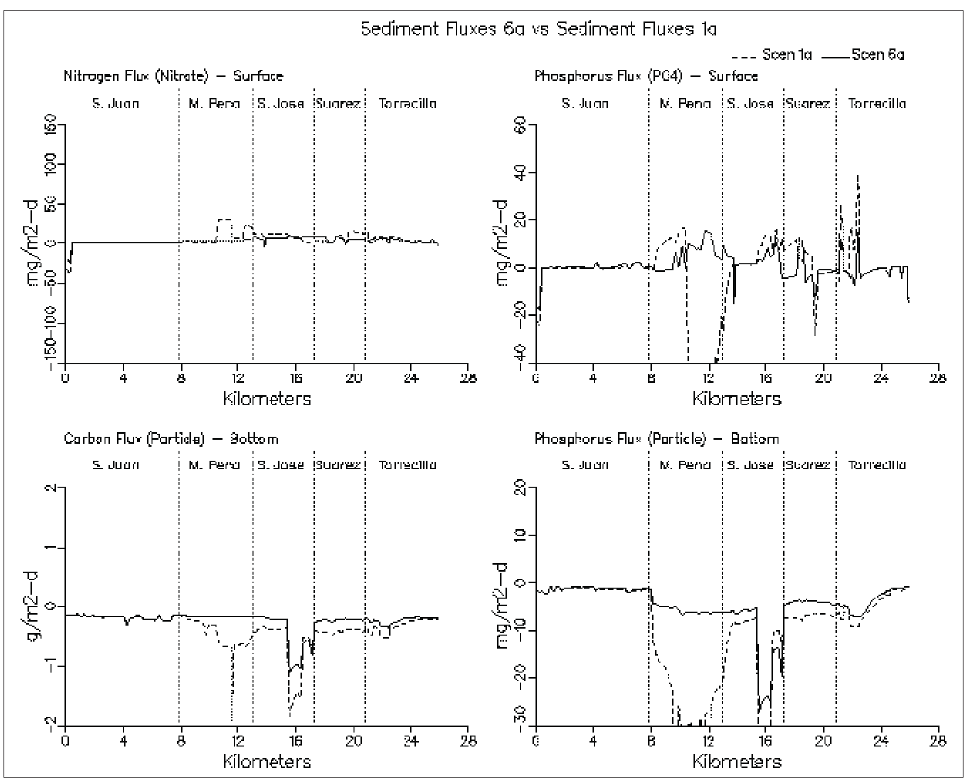

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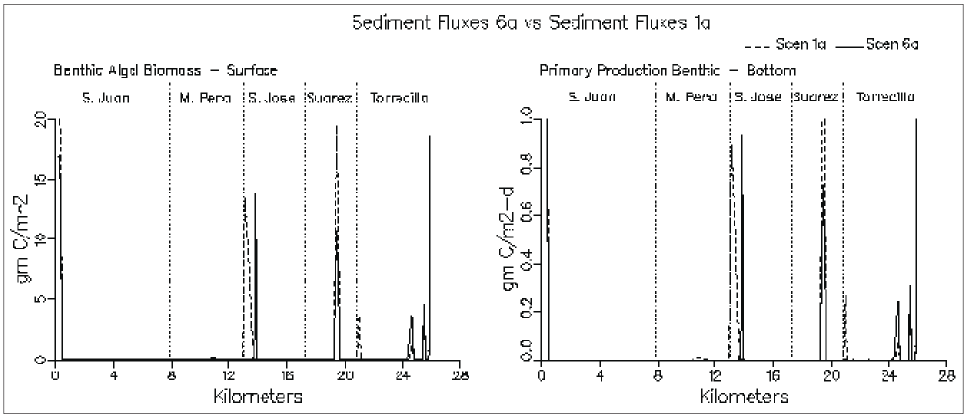


Figure 8-44. (Sheet 11 of 11)

Scenario 6b

Scenario 6b combines all of the loading reductions and channelization of Scenario 6a with the filling of anoxic dredge material borrow pits in Scenario 2. Flows from Laguna San José to Caño Martín Peña were 3.05 m^3 /s and flows from Canal Suárez into Laguna San José were 0.4 m^3 /s. Since Scenario 6b is a hybrid version of Scenario 6a, this discussion will focus more on the changes that occurred between Scenarios 6a and 6b, than between 6b and 1a.

Temperature results from Scenario 6b indicate that surface temperatures are slightly cooler in San Juan Bay (see Figure 8-45) compared with Scenario 1a. Salinity in Laguna San José increased in Scenario 6b over what it was in either Scenarios 1a or Scenario 2 but is still below what it was for Scenario 1c. The reason for the increase is obviously the channelization of Caño Martín Peña which is why the salinity is higher than it was in either Scenario 1a or 2. The reason that the salinity in Scenario 6b is lower than that of Scenario 1c appears to be the effects of spin-up runs without nudging on. As discussed earlier, nudging acts as a pseudo-salinity-boundary condition inside Laguna San José. Without nudging, the cells in the anoxic holes freshened up. While the opening of Caño Martín Peña allowed more saltwater intrusion into Laguna San José, the freshwater inflows diluted the waters of the lagoon which resulted in a decrease in the salinity of San Juan Bay.

Scenario 6b chlorophyll levels indicated the same behavior as observed in Scenario 6a. There was a slight decrease of 1 μg/l to 2 μg/l in surface chlorophyll levels in Caño Martín Peña and Laguna San José. This decrease resulted from the additional reduction in nutrient releases from the anoxic holes. When comparing Scenario 6b to 6a, sediment ammonium releases decreased in Laguna San José and dissolved inorganic phosphorus releases decreased in eastern Caño Martín Peña. Phytoplankton primary production in Laguna San José decreased in Scenario 6b to 3470 kg C /day from 3972 kg C/day in Scenario 6a. For comparison, Laguna San José phytoplankton primary production was 6093 kg C/day in Scenario 1a.

Dissolved and total organic carbon results for Scenario 6b are similar to those of 6a. Both dissolved and total organic carbon levels are slightly lower in San Juan Bay and slightly higher in Canal Suárez and upper Laguna La Torrecilla. Laguna San José organic carbon exports to Caño Martín Peña were 2650 kg/day and imports from Canal Suárez were 190 kg/day.

Scenario 6b surface ammonium results were very similar to those of 6a. Slight decreases in Laguna San José occurred as a result of decreases in sediment ammonium fluxes. There were also slight decreases in bottom ammonium levels mainly in eastern Laguna San José and in Canal Suárez. Nitrate levels were unchanged between Scenario 6a and 6b. Dissolved organic nitrogen and total nitrogen also exhibited no change. Nitrogen exports from Laguna San José via Caño Martín Peña in Scenario 6b were 167 kg/day and imports from Canal Suárez were 7.3 kg/day.

Dissolved inorganic phosphorus levels in Scenarios 6b were slightly lower than those of 6a. The largest decreases, 0.03 mg/l, occurred in Canal Suárez and Laguna La Torrecilla as a result of decreases in sediment fluxes in those regions. A slight decrease was observed in the surface waters of San Juan Bay and appears to be the result of decreased releases in Caño Martín Peña. Dissolved organic phosphorus transects for 6b and 6a were identical. Total phosphorus plots for 6a and 6b appear to be the same except for the differences due to dissolved inorganic phosphorus. Phosphorus exports in Scenario 6b from Laguna San José via Caño Martín Peña were 15.3 kg/day while imports from Canal Suárez were 1.6 kg/day.

Dissolved oxygen results for Scenario 6b were similar to those of 6a. Surface dissolved oxygen levels show increases over those of 6a but these are due to an increase in the saturation concentration of dissolved oxygen resulting from decreased salinity. Since the reason for the decreases in salinity are not fully understood at present, it is felt that the conditions of Scenario 6b did not improve the surface dissolved oxygen significantly. The conditions of Scenario 6b did improve the bottom dissolved oxygen in Laguna San José and Canal Suárez. Fecal coliform and total solids levels in Scenario 6b were not appreciably different from levels in 6a.

In summary, Scenario 6b indicated some improvements in water quality over Scenario 6a. Chlorophyll levels decreased slightly as did some nutrient releases. Significant effects were observed in dissolved oxygen levels in the locations where the anoxic holes in eastern Laguna San José and Canal Suárez were filled in.

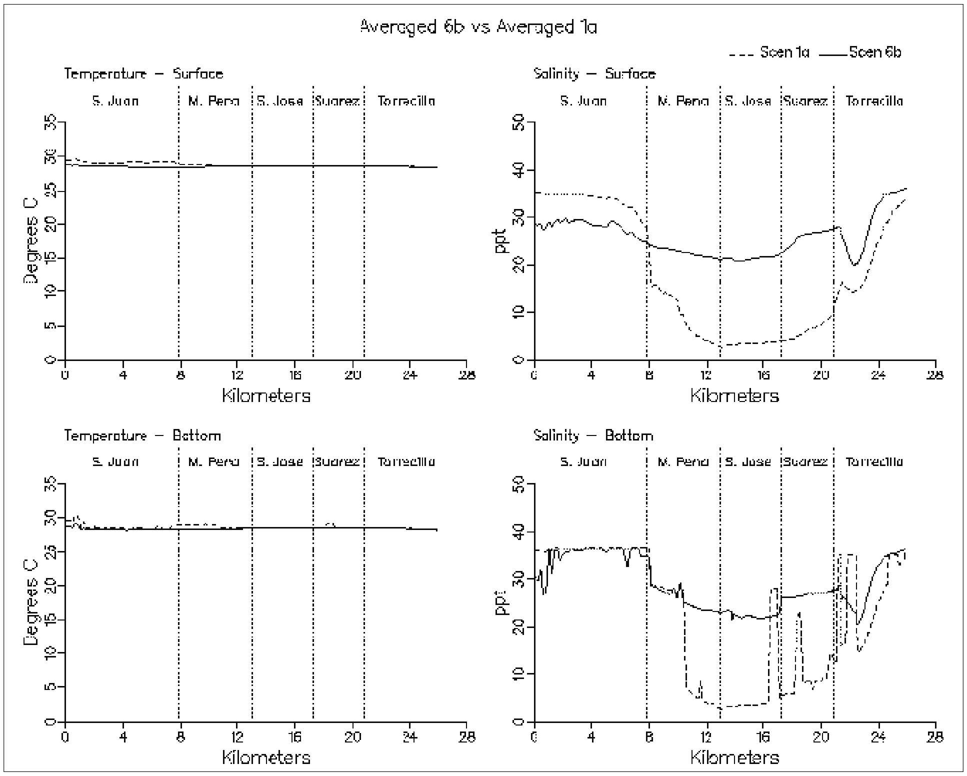


Figure 8-45. Simulation averaged transect plots comparing Scenario 6b with Scenario 1a (Sheet 1 of 11)

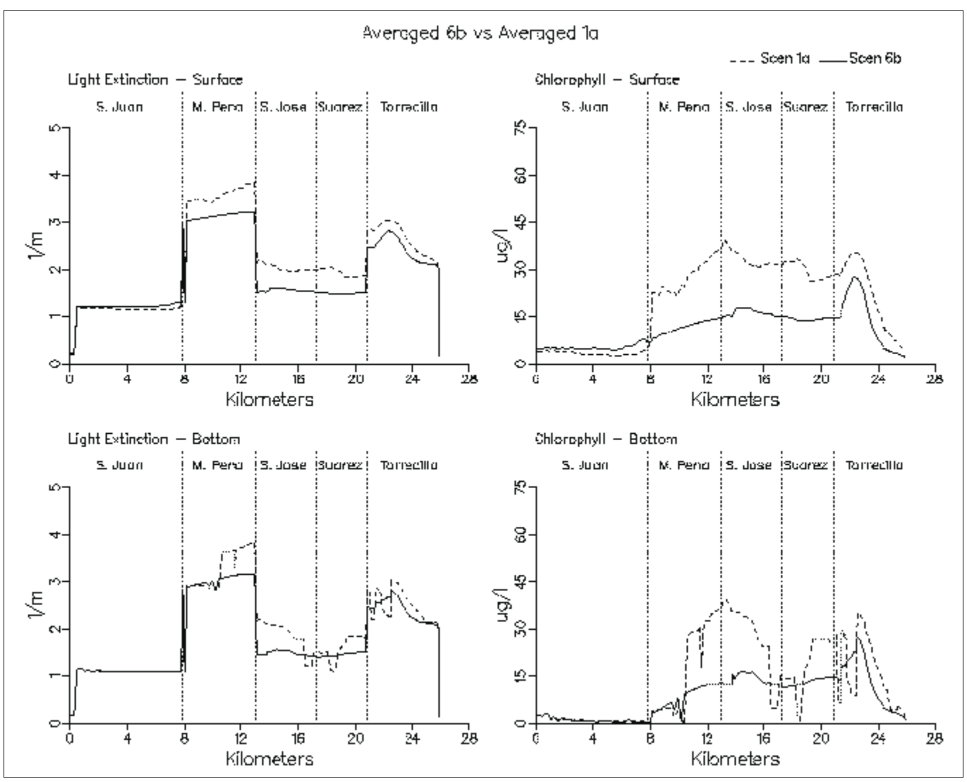


Figure 8-45. (Sheet 2 of 11)

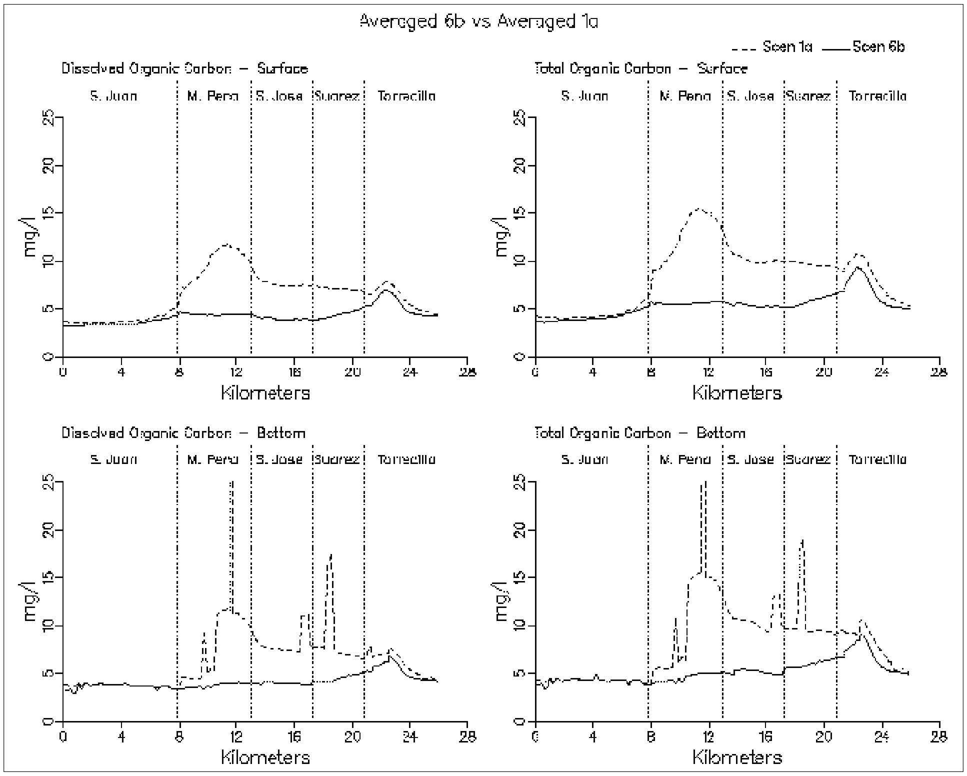
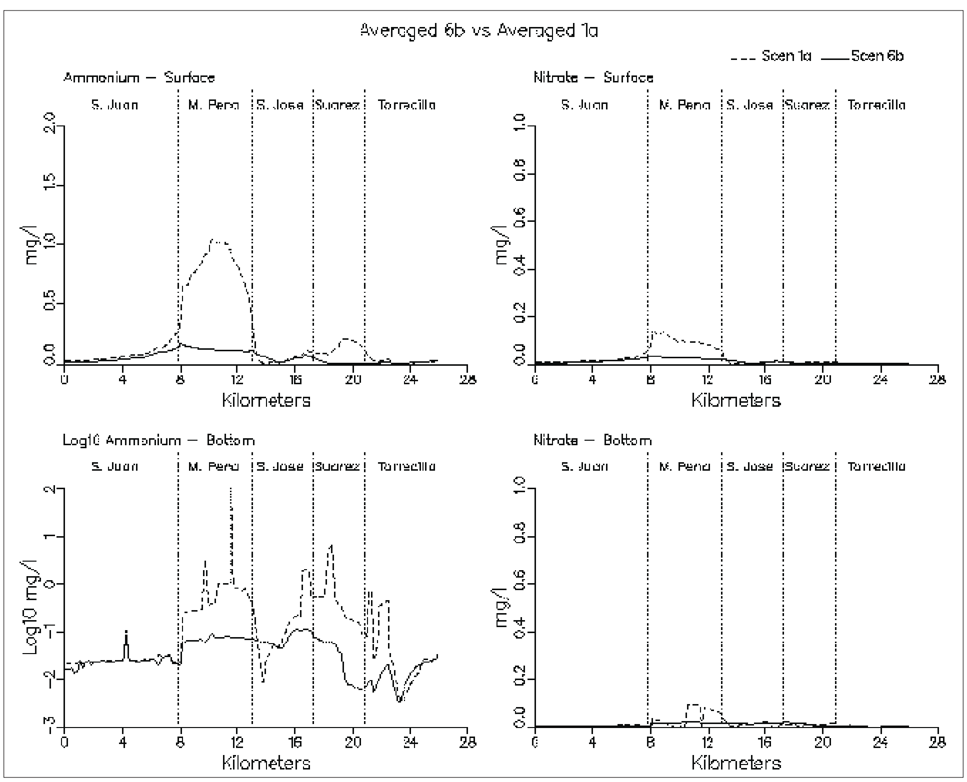


Figure 8-45.   (Sheet 3 of 11)



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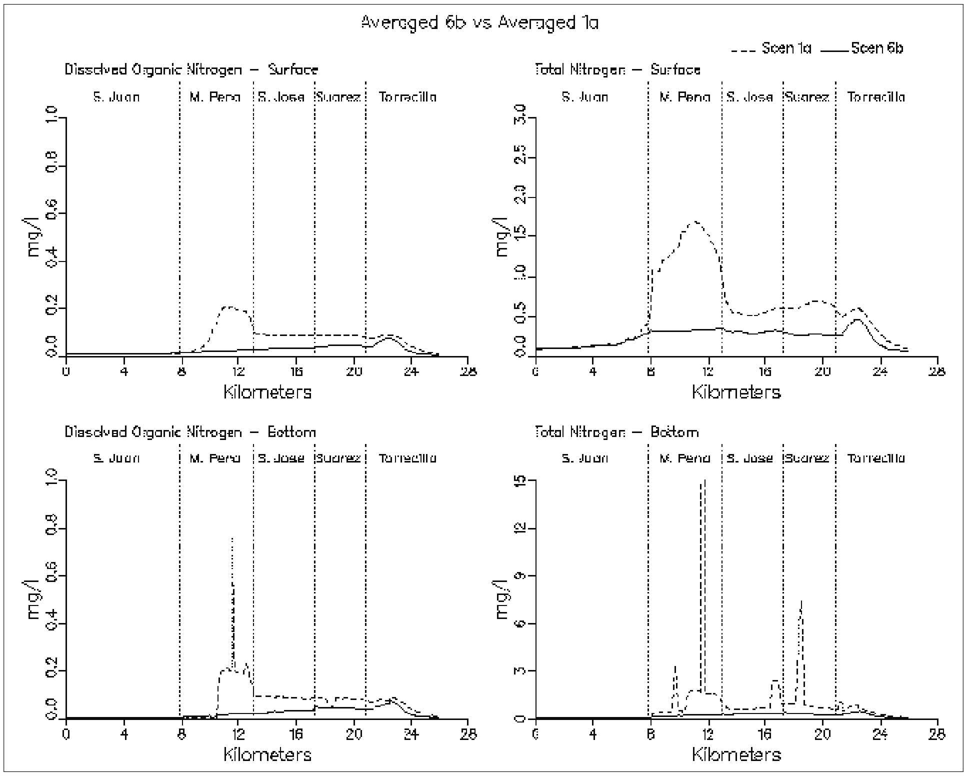

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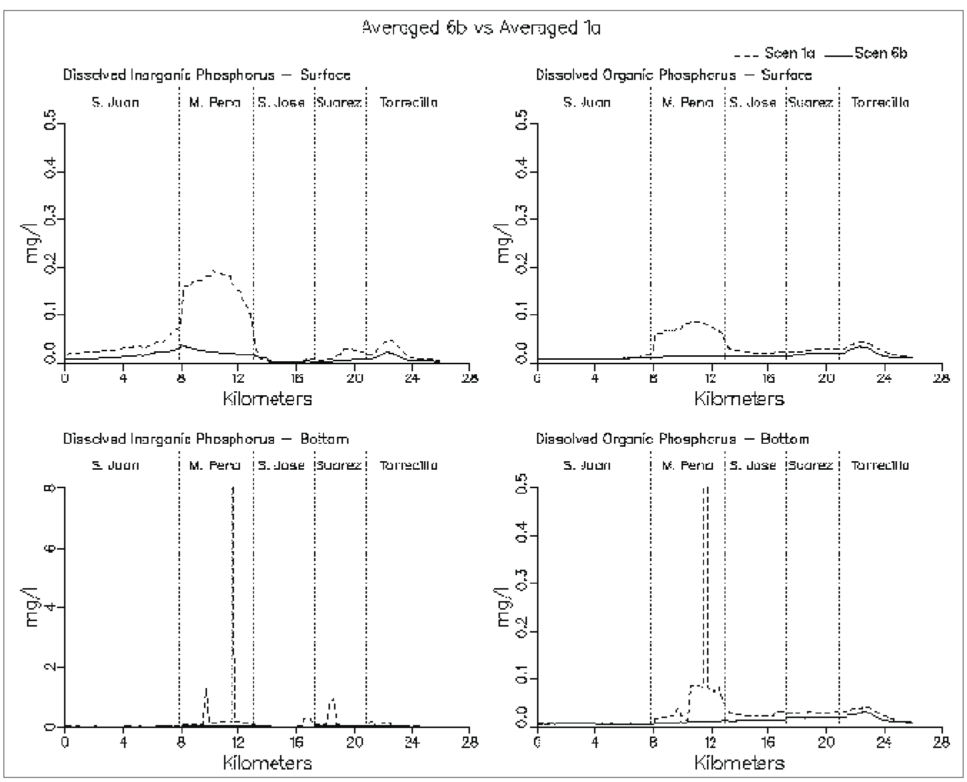

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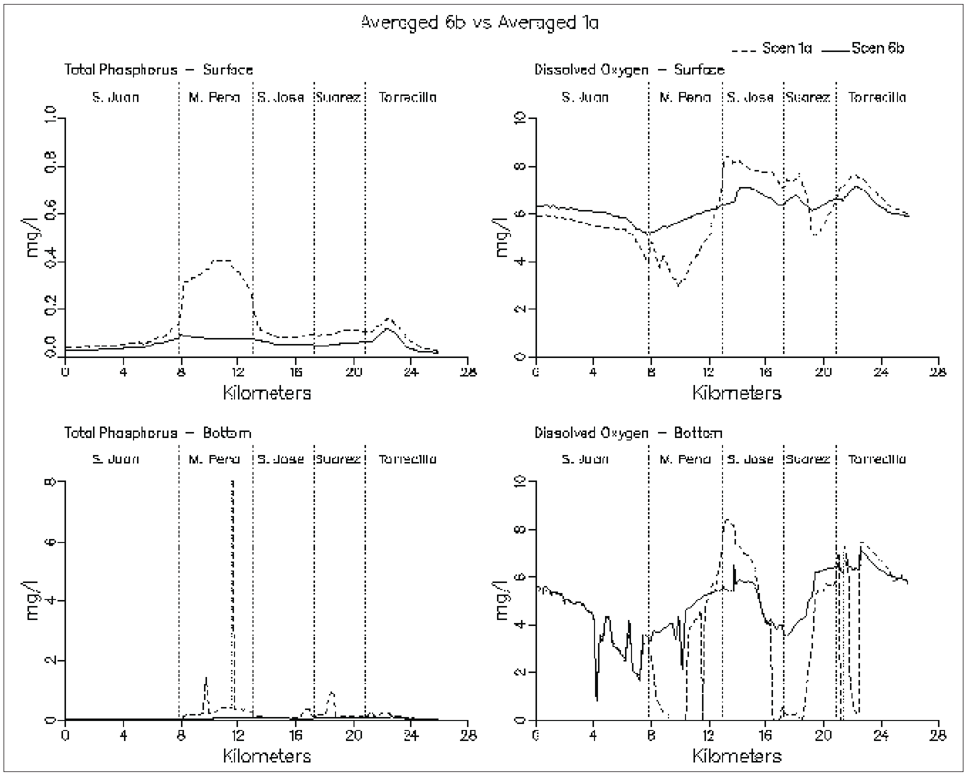

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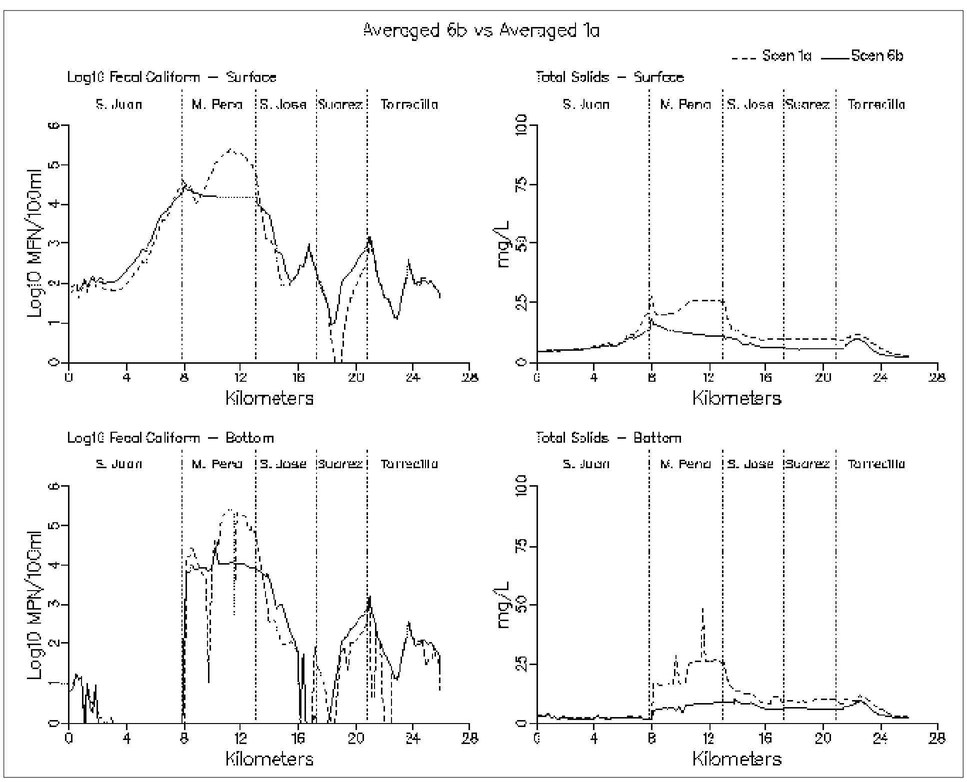

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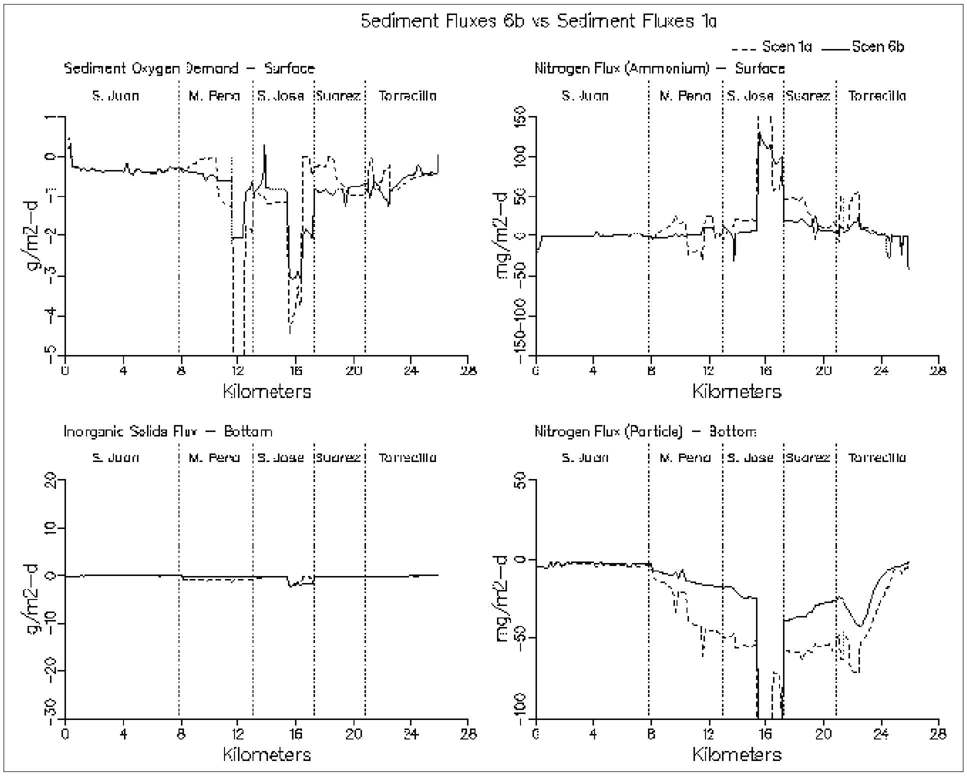

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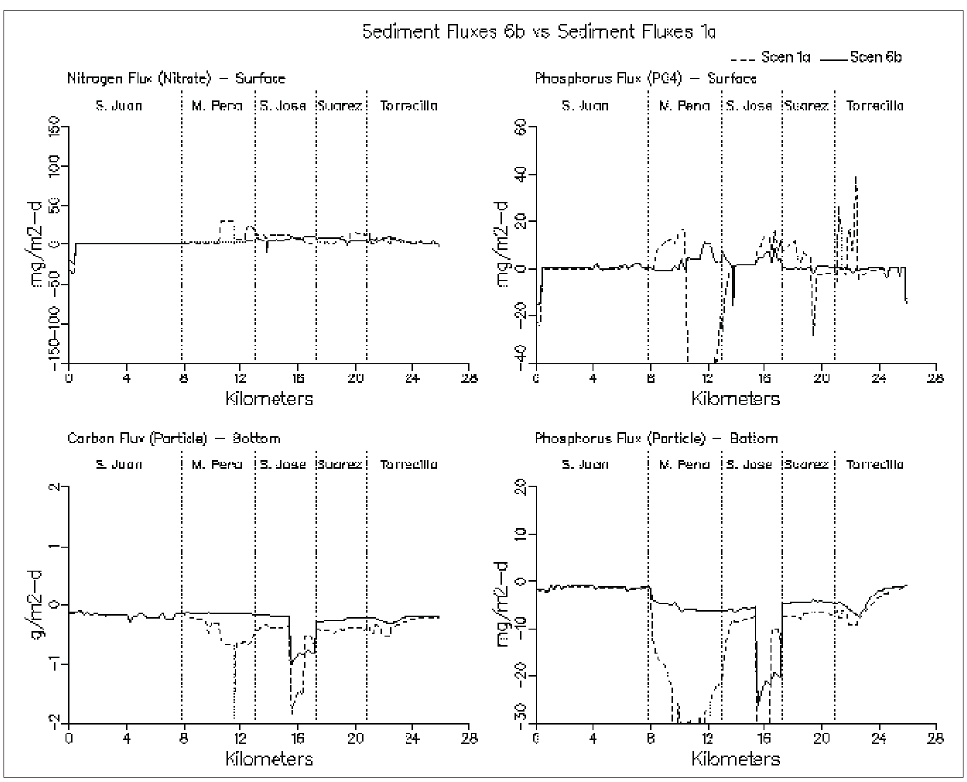

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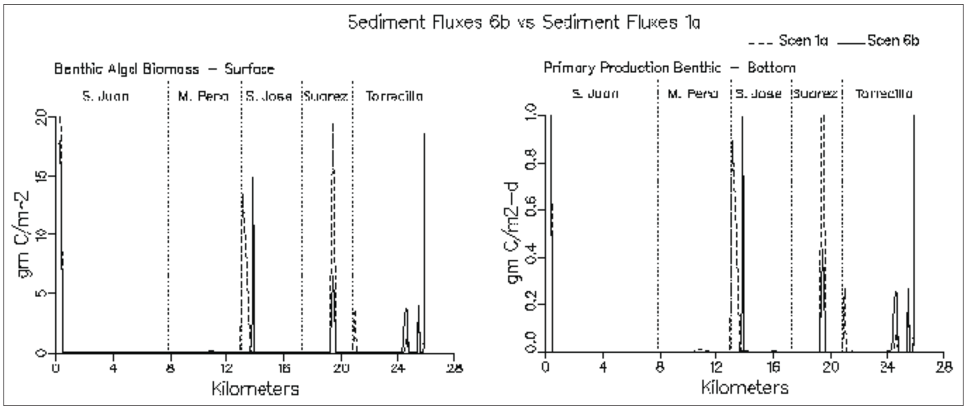

Figure 8-45. (Sheet 11 of 11)

9 Conclusions and Recommendations

A three-dimensional, coupled, hydrodynamic and water quality model of the SJBE system was calibrated using field observations for the summer of 1995. Overall, given the complexity of this system with the multiple ocean inlets, connecting channels, and lagoons, the calibrated model reproduces the observations reasonably well.

Following adjustments and calibration, the model was applied for scenarios to evaluate the effectiveness of various alternatives to increase flushing and reduce loadings for improving water quality. The impacts of each management alternative that was simulated are summarized in Table 9-1 in terms of fluxes of material from one region of the system to another over the scenario simulation duration. As an alternative for comparison, Appendix B contains a summary of the volume-weighted, scenario-average constituent concentrations and the percent change from the base (1a) concentration for all scenarios so that one can easily compare how each alternative affects water quality in an average sense.

All of the alternatives offer some benefits for improving water quality. However, improvements in some areas of the SJBE system can result in degradation to other areas. For example, Scenario 1c provides much improvement to Caño Martín Peña and Laguna San José, but at the expense of flushing more carbon, nitrogen, and phosphorus into San Juan Bay.

Clearly, alternatives were simulated that provide dramatic improvements to water quality. However, the improvements come with costs, including construction costs as well as changes in habitat. For example, it is possible to improve water quality through increased flushing (e.g., Scenarios 1b, 1c, and 3), but this will increase the salinity of Laguna San José and could result in loss of mangrove habitat. Stakeholders must first decide if altering the salinity of Laguna San José is acceptable in terms of habitat and how much mangrove loss is acceptable.

There is not an unequivocally best alternative for improving water quality since a *best* alternative will involve trade-offs, such as water-quality improvement in one area versus degradation in another, costs, habitat

Table 9-1.
Summary of Impacts for Each Management Scenario

Scenario	Flux from Laguna San José to Caño Martín Peña				Flux from Laguna San José to Canal Suárez				Laguna San José Primary Production	San Juan Bay Primary Production
	Flow, m^3/s	C, kg/d	N, kg/d	P, kg/d	Flow, m^3/s	C, kg/d	N, kg/d	P, kg/d	As C, kg/day	As C, kg/day
1a	0.5	454	8	2	1.98	1631	138	20	6093	3586
1b	1.45	1311	54	9	1.08	769	71	10	5825	4065
1c	3.05	3530	187	15	-0.4	-166	-5	-2	5860	5300
2	0.5	329	8.8	2	1.98	1060	18	13	1584	2264
3	0.1	-35	-38	-9	2.5	2261	178	23	6450	3060
4	2.55	2415	141	32	-0.2	-73	-2	-1	6675	4957
5a	0.5	513	27	6	1.98	1563	130	19	5741	3263
5b	0.5	369	10	1	1.98	1240	110	15	4541	3347
6a	3.05	2558	161	15	-0.4	-175	-7	-3	3973	4574
6b	3.05	2650	167	15	-0.4	-190	-7	-2	3470	3968

Note: C, N, and P fluxes are rounded off to near whole number

considerations, and other considerations. Even though trade-offs can be assessed to find the optimal solution, politics will eventually enter the decision process and can affect the final selection. However, if one studies the table in Appendix B and does not consider other factors, such as habitat considerations, it is clear that alternative 6b provides the best overall water quality, especially the best DO conditions.

In order to find the preferred alternative for water quality improvement, it is recommended that the stakeholders first specify the bounds of acceptable results in terms of water quality standards, construction/remediation costs, habitat, etc. For example, the stakeholders may decide that it is acceptable to degrade water quality slightly in San Juan Bay as long as water quality standards are satisfied. The stakeholders may decide that it is acceptable to increase the salinity of Laguna San José, thus favoring flushing alternatives involving enlargement of Caño Martín Peña. Conversely, the stakeholders may decide that the preference is to hold steady or even decrease the salinity of Laguna San José. In this case, alternative 4 (i.e., tide gate and removal of bridge constriction in Canal Suárez) may be preferred. Alternative 1c may result in more mangrove loss along Caño Martín Peña than alternative 1b, a consequence to consider.

Assuming that an increase in the salinity of Laguna San José is acceptable and ignoring mangrove losses, a combination of alternatives 1c, 2, and loading reductions seems intuitively appropriate. It is possible that material removed from Caño Martín Peña could be placed in the dredged borrow pits, thus solving two problems while providing added water quality benefits. Additionally, it seems logical that channel improvements in Caño Martín Peña would be accomplished concurrently with removal of un-sewered, untreated wastes in that area. The combination scenario, e.g., dredging of Caño Martín Peña, filling borrow pits, and removal of un-sewered loads (with the inclusion of the pumping station loads removed), was simulated with Scenario 6b which provided the most improvement in water quality. Based upon this logic and the degree of water-quality improvement, one would have to conclude that alternative 6b is preferred.

However, upon review of the results of Scenario 5b, the relatively minor benefits in water quality gained by removal of the Baldeorioty de Castro Pump Station loads may not warrant the cost of this additional waste treatment. Therefore, a preferred alternative may be 6b with the Baldeorioty de Castro Pump Station loads included.

10 References

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Appendix A
Transformed Horizontal Momentum Diffusion Terms

X - Horizontal Diffusion

$$= \frac{Y_\eta}{J^2}\left(\frac{A_h G_{22}}{J}\left[\left(X_\xi H\bar{u}\right)_\xi + \left(X_\eta H\bar{v}\right)_\xi\right]\right)_\xi$$

$$+ \frac{Y_\eta}{J^2}\left(\frac{A_h G_{11}}{J}\left[\left(X_\xi H\bar{u}\right)_\eta + \left(X_\eta H\bar{v}\right)_\eta\right]\right)_\eta$$

$$- \frac{X_n}{J^2}\left(\frac{A_h G_{11}}{J}\left[\left(Y_\xi H\bar{u}\right)_\eta + \left(Y_\eta H\bar{v}\right)_\eta\right]\right)_\eta$$

$$- \frac{Y_\eta}{J^2}\left(\frac{A_h G_{12}}{J}\left[\left(X_\xi H\bar{u}\right)_\eta + \left(X_\eta H\bar{v}\right)_\eta\right]\right)_\xi$$

$$- \frac{Y_\eta}{J^2}\left(\frac{A_h G_{12}}{J}\left[\left(X_\xi H\bar{u}\right)_\xi + \left(X_\eta H\bar{v}\right)_\xi\right]\right)_\eta$$

$$+ \frac{X_\eta}{J^2}\left(\frac{A_h G_{12}}{J}\left[\left(Y_\xi H\bar{u}\right)_\eta + \left(Y_\eta H\bar{v}\right)_\eta\right]\right)_\xi$$

$$+ \frac{X_\eta}{J^2}\left(\frac{A_h G_{12}}{J}\left[\left(Y_\xi H\bar{u}\right)_\xi + \left(Y_\eta H\bar{v}\right)_\xi\right]\right)_\eta$$

Y - Horizontal Diffusion

$$=\frac{X_\xi}{J^2}\left(\frac{A_h G_{11}}{J}\left[\left(Y_\eta H\bar{v}\right)_\eta+\left(Y_\xi H\bar{u}\right)_\eta\right]\right)_\eta$$

$$-\frac{Y_\xi}{J^2}\left(\frac{A_h G_{11}}{J}\left[\left(X_\eta H\bar{v}\right)_\eta+\left(X_\xi H\bar{u}\right)_\eta\right]\right)_\eta$$

$$+\frac{X_\xi}{J^2}\left(\frac{A_h G_{22}}{J}\left[\left(Y_\eta H\bar{v}\right)_\xi+\left(Y_\xi H\bar{u}\right)_\xi\right]\right)_\xi$$

$$-\frac{Y_\xi}{J^2}\left(\frac{A_h G_{22}}{J}\left[\left(X_\eta H\bar{v}\right)_\xi+\left(X_\xi H\bar{u}\right)_\xi\right]\right)_\xi$$

$$-\frac{X_\xi}{J^2}\left(\frac{A_h G_{12}}{J}\left[\left(Y_\eta H\bar{v}\right)_\eta+\left(Y_\xi H\bar{u}\right)_\eta\right]\right)_\xi$$

$$-\frac{X_\xi}{J^2}\left(\frac{A_h G_{12}}{J}\left[\left(Y_\eta H\bar{v}\right)_\xi+\left(Y_\xi H\bar{u}\right)_\xi\right]\right)_\eta$$

$$+\frac{Y_\xi}{J^2}\left(\frac{A_h G_{12}}{J}\left[\left(X_\eta H\bar{v}\right)_n+\left(X_\xi H\bar{u}\right)_\eta\right]\right)_\xi$$

$$+\frac{Y_\xi}{J^2}\left(\frac{A_h G_{12}}{J}\left[\left(X_\eta H\bar{v}\right)_\xi+\left(X_\xi H\bar{u}\right)_\xi\right]\right)_\eta$$

Replacing $H\bar{u}$ and $H\bar{v}$ with $\overline{U}$ and $\overline{V}$, respectively, the same expressions apply in the external mode equations.

Appendix B
Scenario Average Concentrations and Percent Change from Base Condition

Surface Salinity (PPT)

Region	SC 1a	SC 1b	%	SC 1c	%	SC 2	%	SC 3	%	SC 4	%
San Juan Bay	33.7	33.4	-1	33.0	-2	26.0	-23	33.9	1	32.8	-3
Cano Martin Pena	20.7	19.5	-6	27.5	33	18.2	-12	23.8	15	16.9	-19
Laguna San Jose	3.2	6.0	90	22.7	619	0.5	-86	7.7	144	5.2	65
Canal Suarez	5.5	10.0	81	27.3	396	1.8	-67	12.4	126	26.0	373
Laguna La Torrecilla	18.6	22.1	19	26.2	41	16.1	-14	19.5	5	26.2	41
Laguna de Pinones	13.8	17.5	26	22.1	59	6.6	-52	13.2	-5	22.4	61

Note: "SC" denotes Scenario.

Surface Salinity (PPT)

Region	SC 1a	SC 5a	%	SC 5b	%	SC 6a	%	SC 6b	%
San Juan Bay	33.7	33.7	0	33.7	0	33.0	-2	26.4	-22
Cano Martin Pena	20.7	20.7	0	20.7	0	27.5	33	24.9	20
Laguna San Jose	3.2	3.2	0	3.2	0	22.7	619	19.9	529
Canal Suarez	5.5	5.5	0	5.5	0	27.3	396	25.8	369
Laguna La Torrecilla	18.6	18.6	0	18.6	0	26.2	41	25.6	38
Laguna de Pinones	13.8	13.8	0	13.8	0	22.1	59	16.5	19

Surface
Chlorophyll (μg/L)

Region	SC 1a	SC 1b	%	SC 1c	%	SC 2	%	SC 3	%	SC 4	%
San Juan Bay	3.95	4.78	21	7.44	88	2.50	-37	3.27	-17	6.13	55
Cano Martin Pena	13.53	16.76	24	11.66	-14	4.44	-67	9.41	-30	18.80	39
Laguna San Jose	32.30	29.86	-8	25.26	-22	8.50	-74	33.99	5	34.00	5
Canal Suarez	31.31	27.51	-12	16.13	-48	6.82	-78	30.37	-3	13.53	-57
Laguna La Torrecilla	26.90	17.70	-34	18.22	-32	17.49	-35	26.18	-3	18.39	-32
Laguna de Pinones	38.26	19.78	-48	33.79	-12	32.62	-15	38.55	1	33.78	-12

Surface
Chlorophyll (μg/L)

Region	SC 1a	SC 5a	%	SC 5b	%	SC 6a	%	SC 6b	%
San Juan Bay	3.95	3.63	-8	3.67	-7	6.10	54	5.42	37
Cano Martin Pena	13.53	12.19	-10	11.31	-16	8.65	-36	8.06	-40
Laguna San Jose	32.30	30.28	-6	22.99	-29	15.74	-51	14.90	-54
Canal Suarez	31.31	29.86	-5	25.73	-18	13.76	-56	13.98	-55
Laguna La Torrecilla	26.90	26.34	-2	24.95	-7	18.15	-33	18.48	-31
Laguna de Pinones	38.26	37.98	-1	37.27	-3	33.75	-12	33.62	-12

Surface
Total Nitrogen (mg/L)

Region	SC 1a	SC 1b	%	SC 1c	%	SC 2	%	SC 3	%	SC 4	%
San Juan Bay	0.1443	0.1458	1	0.1640	14	0.1250	-13	0.1366	-5	0.1668	16
Cano Martin Pena	0.8100	0.6238	-23	0.3496	-57	0.6967	-14	0.7645	-6	0.6863	-15
Laguna San Jose	0.5809	0.5553	-4	0.4568	-21	0.1789	-69	0.6085	5	0.6019	4
Canal Suarez	0.6267	0.5238	-16	0.2985	-52	0.1268	-80	0.5607	-11	0.2694	-57
Laguna La Torrecilla	0.4828	0.3290	-32	0.3432	-29	0.3260	-32	0.4758	-1	0.3466	-28
Laguna de Pinones	0.6610	0.3585	-46	0.5881	-11	0.5854	-11	0.6680	1	0.5883	-11

Surface
Total Nitrogen (mg/L)

Region	SC 1a	SC 5a	%	SC 5b	%	SC 6a	%	SC 6b	%
San Juan Bay	0.1443	0.1321	-9	0.1393	-4	0.1445	0	0.1315	-9
Cano Martin Pena	0.8100	0.4756	-41	0.6800	-16	0.2883	-64	0.2863	-65
Laguna San Jose	0.5809	0.5453	-6	0.4296	-26	0.2945	-49	0.2947	-49
Canal Suarez	0.6267	0.5923	-5	0.5102	-19	0.2537	-60	0.2568	-59
Laguna La Torrecilla	0.4828	0.4731	-2	0.4487	-7	0.3420	-29	0.3420	-29
Laguna de Pinones	0.6610	0.6563	-1	0.6446	-2	0.5875	-11	0.5986	-9

Surface
Total Phosphorus (mg/L)

Region	SC 1a	SC 1b	%	SC 1c	%	SC 2	%	SC 3	%	SC 4	%
San Juan Bay	0.0594	0.0587	-1	0.0585	-1	0.0415	-30	0.0574	-3	0.0639	8
Cano Martin Pena	0.2270	0.1677	-26	0.0943	-58	0.2190	-4	0.2304	2	0.1778	-22
Laguna San Jose	0.0989	0.0918	-7	0.0919	-7	0.0998	1	0.1055	7	0.1140	15
Canal Suarez	0.0949	0.0798	-16	0.0748	-21	0.0790	-17	0.0884	-7	0.0804	-15
Laguna La Torrecilla	0.1239	0.0944	-24	0.1063	-14	0.0943	-24	0.1157	-7	0.1066	-14
Laguna de Pinones	0.1034	0.0728	-30	0.0934	-10	0.0788	-24	0.0974	-6	0.0929	-10

Surface
Total Phosphorus (mg/L)

Region	SC 1a	SC 5a	%	SC 5b	%	SC 6a	%	SC 6b	%
San Juan Bay	0.0594	0.0568	-4	0.0592	0	0.0546	-8	0.0382	-36
Cano Martin Pena	0.2270	0.1610	-29	0.2232	-2	0.0830	-63	0.0765	-66
Laguna San Jose	0.0989	0.0939	-5	0.0696	-30	0.0601	-39	0.0541	-45
Canal Suarez	0.0949	0.0907	-4	0.0770	-19	0.0674	-29	0.0496	-48
Laguna La Torrecilla	0.1239	0.1227	-1	0.1184	-4	0.1061	-14	0.0916	-26
Laguna de Pinones	0.1034	0.1029	0	0.1009	-2	0.0932	-10	0.0811	-22

Surface
Fecal Coliform (MPN/ml)

Region	SC 1a	SC 1b	%	SC 1c	%	SC 2	%	SC 3	%	SC 4	%
San Juan Bay	1748.2	1784.4	2	1810.6	4	1903.2	9	1732.3	-1	1830.9	5
Cano Martin Pena	62863.0	54475.0	-13	32547.0	-48	64263.0	2	61782.0	-2	61210.0	-3
Laguna San Jose	6534.3	6762.1	3	6981.6	7	6471.7	-1	7025.5	8	5170.6	-21
Canal Suarez	41.4	59.5	44	114.3	176	74.4	80	457.8	1005	130.8	216
Laguna La Torrecilla	2235.9	2235.8	0	2243.0	0	2229.0	0	2093.5	-6	2259.2	1
Laguna de Pinones	745.9	747.2	0	749.6	0	743.8	0	743.8	0	750.0	1

Surface
Fecal Coliform (MPN/ml)

Region	SC 1a	SC 5a	%	SC 5b	%	SC 6a	%	SC 6b	%
San Juan Bay	1748.2	1730.9	-1	1748.2	0	1718.4	-2	1839.3	5
Cano Martin Pena	62863.0	53056.0	-16	62862.0	0	30888.0	-51	31832.0	-49
Laguna San Jose	6534.3	6478.3	-1	4088.6	-37	4196.6	-36	4287.9	-34
Canal Suarez	41.4	41.4	0	41.4	0	114.0	175	129.5	213
Laguna La Torrecilla	2235.9	2235.9	0	2235.9	0	2243.0	0	2243.1	0
Laguna de Pinones	745.9	745.9	0	745.9	0	749.6	0	748.4	0

Water Column
Dissolved Oxygen (mg/L)

Region	SC 1a	SC 1b	%	SC 1c	%	SC 2	%	SC 3	%	SC 4	%
San Juan Bay	4.2	4.2	-1	4.1	-2	4.8	15	4.2	1	4.1	-3
Cano Martin Pena	2.8	3.0	8	4.0	42	3.2	14	2.9	3	3.0	7
Laguna San Jose	5.3	5.3	1	5.4	1	7.6	44	5.3	1	5.1	-5
Canal Suarez	2.8	3.3	21	4.3	55	5.1	86	4.8	75	4.8	74
Laguna La Torrecilla	4.4	4.6	5	4.5	2	6.7	50	4.3	-3	4.5	3
Laguna de Pinones	7.3	7.2	-2	6.9	-5	7.6	4	7.3	0	6.9	-5

Water Column
Dissolved Oxygen (mg/L)

Region	SC 1a	SC 5a	%	SC 5b	%	SC 6a	%	SC 6b	%
San Juan Bay	4.2	4.2	0	4.2	0	4.1	-2	4.7	12
Cano Martin Pena	2.8	2.8	2	2.8	0	4.0	43	4.4	59
Laguna San Jose	5.3	5.3	0	5.4	2	5.4	2	6.1	15
Canal Suarez	2.8	2.8	1	3.0	10	4.3	57	5.8	109
Laguna La Torrecilla	4.4	4.4	0	4.5	1	4.5	2	6.2	41
Laguna de Pinones	7.3	7.3	0	7.3	0	6.9	-5	7.1	-2

Water Column
Bottom Dissolved Oxygen (mg/L)

Region	SC 1a	SC 1b	%	SC 1c	%	SC 2	%	SC 3	%	SC 4	%
San Juan Bay	4.0	3.9	-2	3.9	-3	4.4	12	4.0	1	3.8	-4
Cano Martin Pena	2.3	2.5	8	3.7	62	2.6	13	2.3	1	2.5	8
Laguna San Jose	5.0	5.1	0	5.0	0	7.5	48	5.0	0	4.7	-7
Canal Suarez	1.4	1.8	23	2.5	76	2.6	83	3.9	171	3.0	109
Laguna La Torrecilla	5.2	5.3	2	5.1	-2	6.4	22	5.1	-2	5.1	-2
Laguna de Pinones	7.3	7.2	-2	6.9	-5	7.6	4	7.3	0	6.9	-5

Water Column
Bottom Dissolved Oxygen (mg/L)

Region	SC 1a	SC 5a	%	SC 5b	%	SC 6a	%	SC 6b	%
San Juan Bay	4.0	3.9	0	3.9	0	3.9	-3	4.3	9
Cano Martin Pena	2.3	2.4	2	2.3	0	3.8	63	4.2	83
Laguna San Jose	5.0	5.1	0	5.1	2	5.1	1	5.4	8
Canal Suarez	1.4	1.5	1	1.6	11	2.6	79	4.6	224
Laguna La Torrecilla	5.2	5.2	0	5.3	0	5.1	-2	5.9	13
Laguna de Pinones	7.3	7.3	0	7.3	0	6.9	-5	7.1	-2

Water Column Salinity (PPT)

Region	SC 1a	SC 1b	%	SC 1c	%	SC 2	%	SC 3	%	SC 4	%
San Juan Bay	35.9	35.9	0	35.7	-1	29.9	-17	35.9	0	35.7	0
Cano Martin Pena	30.2	29.7	-2	31.5	4	27.0	-11	31.0	3	28.1	-7
Laguna San Jose	7.2	9.6	34	24.1	235	0.5	-93	11.2	55	9.0	25
Canal Suarez	9.6	13.6	42	27.6	188	2.1	-78	14.9	55	27.6	188
Laguna La Torrecilla	23.7	26.1	10	29.0	23	15.3	-35	24.2	2	29.1	23
Laguna de Pinones	13.8	17.5	26	22.1	59	6.6	-52	13.2	-5	22.4	61

Water Column Salinity (PPT)

Region	SC 1a	SC 5a	%	SC 5b	%	SC 6a	%	SC 6b	%
San Juan Bay	35.9	35.9	0	35.9	0	35.7	-1	30.6	-15
Cano Martin Pena	30.2	30.2	0	30.2	0	31.5	4	28.6	-5
Laguna San Jose	7.2	7.2	0	7.2	0	24.1	235	20.4	184
Canal Suarez	9.6	9.6	0	9.6	0	27.6	188	26.0	171
Laguna La Torrecilla	23.7	23.7	0	23.7	0	29.0	23	24.8	5
Laguna de Pinones	13.8	13.8	0	13.8	0	22.1	59	16.5	19

Water Column Chlorophyll (μg/L)

Region	SC 1a	SC 1b	%	SC 1c	%	SC 2	%	SC 3	%	SC 4	%
San Juan Bay	3.95	4.78	21	7.44	88	2.50	-37	3.27	-17	6.13	55
Cano Martin Pena	13.53	16.76	24	11.66	-14	4.44	-67	9.41	-30	18.80	39
Laguna San Jose	32.30	29.86	-8	25.26	-22	8.50	-74	33.99	5	34.00	5
Canal Suarez	31.31	27.51	-12	16.13	-48	6.82	-78	30.37	-3	13.53	-57
Laguna La Torrecilla	26.90	17.70	-34	18.22	-32	17.49	-35	26.18	-3	18.39	-32
Laguna de Pinones	38.26	19.78	-48	33.79	-12	32.62	-15	38.55	1	33.78	-12

Water Column Chlorophyll (μg/L)

Region	SC 1a	SC 5a	%	SC 5b	%	SC 6a	%	SC 6b	%
San Juan Bay	3.95	3.63	-8	3.67	-7	6.10	54	5.42	37
Cano Martin Pena	13.53	12.19	-10	11.31	-16	8.65	-36	8.06	-40
Laguna San Jose	32.30	30.28	-6	22.99	-29	15.74	-51	14.90	-54
Canal Suarez	31.31	29.86	-5	25.73	-18	13.76	-56	13.98	-55
Laguna La Torrecilla	26.90	26.34	-2	24.95	-7	18.15	-33	18.48	-31
Laguna de Pinones	38.26	37.98	-1	37.27	-3	33.75	-12	33.62	-12

Water Column
Total Nitrogen (mg/L)

Region	SC 1a	SC 1b	%	SC 1c	%	SC 2	%	SC 3	%	SC 4	%
San Juan Bay	0.0753	0.0728	-3	0.0843	12	0.0591	-21	0.0727	-3	0.0815	8
Cano Martin Pena	0.6112	0.3230	-47	0.2262	-63	0.5754	-6	0.3382	-45	0.3875	-37
Laguna San Jose	0.9073	0.7942	-12	0.5038	-44	0.1964	-78	0.8004	-12	1.0316	14
Canal Suarez	2.0877	1.7914	-14	0.7041	-66	0.1433	-93	0.5963	-71	0.2971	-86
Laguna La Torrecilla	0.6469	0.3869	-40	0.4045	-37	0.3787	-41	0.6861	6	0.4076	-37
Laguna de Pinones	0.6610	0.3585	-46	0.5881	-11	0.5854	-11	0.6680	1	0.5883	-11

Water Column
Total Nitrogen (mg/L)

Region	SC 1a	SC 5a	%	SC 5b	%	SC 6a	%	SC 6b	%
San Juan Bay	0.0753	0.0709	-6	0.0731	-3	0.0763	1	0.0634	-16
Cano Martin Pena	0.6112	0.2822	-54	0.4977	-19	0.1879	-69	0.1828	-70
Laguna San Jose	0.9073	0.8577	-5	0.6790	-25	0.3250	-64	0.2985	-67
Canal Suarez	2.0877	2.0222	-3	1.8416	-12	0.6421	-69	0.2791	-87
Laguna La Torrecilla	0.6469	0.6340	-2	0.6009	-7	0.4028	-38	0.3991	-38
Laguna de Pinones	0.6610	0.6563	-1	0.6446	-2	0.5875	-11	0.5986	-9

Water Column
Total Phosphorus (mg/L)

Region	SC 1a	SC 1b	%	SC 1c	%	SC 2	%	SC 3	%	SC 4	%
San Juan Bay	0.0383	0.0370	-3	0.0375	-2	0.0241	-37	0.0375	-2	0.0396	3
Cano Martin Pena	0.1609	0.1154	-28	0.0677	-58	0.1501	-7	0.1324	-18	0.1320	-18
Laguna San Jose	0.1396	0.1219	-13	0.0936	-33	0.1001	-28	0.1271	-9	0.1654	18
Canal Suarez	0.2856	0.2551	-11	0.1481	-48	0.0841	-71	0.0955	-67	0.0892	-69
Laguna La Torrecilla	0.1690	0.1119	-34	0.1205	-29	0.1051	-38	0.1759	4	0.1194	-29
Laguna de Pinones	0.1034	0.0728	-30	0.0934	-10	0.0788	-24	0.0974	-6	0.0929	-10

Water Column
Total Phosphorus (mg/L)

Region	SC 1a	SC 5a	%	SC 5b	%	SC 6a	%	SC 6b	%
San Juan Bay	0.0383	0.0373	-2	0.0381	0	0.0361	-6	0.0230	-40
Cano Martin Pena	0.1609	0.1203	-25	0.1598	-1	0.0606	-62	0.0528	-67
Laguna San Jose	0.1396	0.1341	-4	0.1057	-24	0.0625	-55	0.0538	-61
Canal Suarez	0.2856	0.2806	-2	0.2622	-8	0.1407	-51	0.0513	-82
Laguna La Torrecilla	0.1690	0.1675	-1	0.1622	-4	0.1202	-29	0.1046	-38
Laguna de Pinones	0.1034	0.1029	0	0.1009	-2	0.0932	-10	0.0811	-22

Water Column
Fecal Coliform (MPN/ml)

Region	SC 1a	SC 1b	%	SC 1c	%	SC 2	%	SC 3	%	SC 4	%
San Juan Bay	265.4	270.4	2	335.4	26	292.1	10	264.9	0	272.5	3
Cano Martin Pena	25974.0	25409.0	-2	19081.0	-27	26954.0	4	25689.0	-1	26534.0	2
Laguna San Jose	2994.6	3086.6	3	3488.0	16	4061.0	36	3281.5	10	2562.1	-14
Canal Suarez	3.6	13.8	281	47.7	1219	31.7	775	283.1	7723	28.9	700
Laguna La Torrecilla	1071.0	1071.4	0	1080.3	1	1781.6	66	1011.0	-6	1086.1	1
Laguna de Pinones	745.9	747.2	0	749.6	0	743.8	0	743.8	0	750.0	1

Water Column
Fecal Coliform (MPN/ml)

Region	SC 1a	SC 5a	%	SC 5b	%	SC 6a	%	SC 6b	%
San Juan Bay	265.4	264.4	0	265.4	0	319.8	21	345.6	30
Cano Martin Pena	25974.0	22905.0	-12	25974.0	0	17729.0	-32	18320.0	-29
Laguna San Jose	2994.6	2969.6	-1	1808.7	-40	2065.2	-31	2827.9	-6
Canal Suarez	3.6	3.6	0	3.6	0	47.6	1214	79.1	2084
Laguna La Torrecilla	1071.0	1071.0	0	1071.0	0	1080.3	1	1792.2	67
Laguna de Pinones	745.9	745.9	0	745.9	0	749.6	0	748.4	0

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13. ABSTRACT ***(Maximum 200 words)***

This report describes a three-dimensional hydrodynamic and water quality model study of the San Juan Bay and Estuaries system conducted to evaluate the effectiveness of various management alternatives for improving water quality. Alternatives included methods to increase flushing, reduce pollutant loadings, and combinations of the two. The CH3D-WES hydrodynamic model and the CE-QUAL-ICM water quality model were employed in the study. The models were indirectly coupled and were adjusted and calibrated against data collected during the summer of 1995. Analysis of various management scenarios revealed that a combination of widening and deepening of Cano Martìn Peña, filling of dredged submerged borrow pits, and removal of un-sewered loads in Cano Martìn Peña provided the greatest water quality benefits.

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Appendix A3

Development of the Benthic Index for the San Juan Bay Estuary System (PBS&J 2009a)

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1.0 Background

The San Juan Bay estuarine complex (SJBE) includes San Juan Bay, Condado Lagoon, San José Lagoon, Los Corozos Lagoon, La Torrecilla Lagoon, and Piñones Lagoon. Also included are the Martin Peña Canal, which connects San Juan Bay and San José Lagoon, the San Antonio Canal, which connects San Juan Bay and Condado Lagoon, and the Suárez Canal, which connects San José Lagoon and Torrecilla Lagoon (see figure 1).

Figure 1
Location of Major Features in the San Juan Bay Estuary Program Study Area (from SJBEP 2000)

Impacts to water and sediment quality include not only the high population density in some portions of the watershed, but also the very high density of automobiles used by the population. The density (vehicles per mile of paved road) in the San Juan Bay Estuary watershed is nearly three times the US mainland average (SJBEP 2000). Population densities were lowest in the region surrounding Piñones Lagoon, and highest in the regions surrounding Condado Lagoon (SJBEP 2000).The high level of automobile use in the watershed suggests that contaminants associated with such use (i.e., greases, PAHs, etc.) would also be elevated in the bay's sediments.

Water quality, and the quality of bottom sediments in the San Juan Bay system are impacted by point and non-point pollution, impacts to circulation from channel dredging and filling (especially adjacent to the Martín Peña Canal), erosion from upland areas of the watershed, and resuspension of bottom sediments (SJBEP 2000).

In recognition of these and other threats to the health of the SJBE, the Governor of Puerto Rico nominated the SJBE system for the U.S. Environmental Protection Agency's National Estuary Program in 1992. The goals of the SJBEP are the following:

- Establish a comprehensive water quality policy.
- Develop an administrative and regulatory framework for the SJBEP.
- Optimize the social, economic and recreational benefits of the estuary.
- Prevent further degradation, and improve water quality to ensure healthy terrestrial and aquatic systems and social well-being.
- Minimize health risks associated with bodily contact and the consumption of fish and shellfish.

These goals are to be accomplished via undertaking a series of actions meant to allow the SJBEP to meet specific measurable objectives:

- Identification of the major stressors to the system, and their relative importance.
- Develop action plans to remediate these stressors.
- Conserve and enhance the natural resources of the SJBEP system.
- Promote public awareness and address major concerns of various stakeholders.
- Develop a hydrologic model sufficient to determine appropriate mechanisms to improve circulation and guide future development.

In its early stages, the SJBEP completed a series of studies designed to collect baseline information, establish appropriate indicators of ecosystem health, and enable the analysis of such information to be used to assess progress toward achievement of program goals (Otero 2002).

This project was designed to provide the SJBEP with a regionally-appropriate benthic index for the SJBE. This index can then be used as an indicator of the environmental condition of the estuary. This indicator can be used to compare and contrast segments of the San Juan Bay Estuary system against each other, and also to track the health of the benthic communities over time both on a localized level (e.g., Torrecilla Lagoon) or a regional level (e.g., San Juan Bay Estuary as a whole).

A benthic index can be useful for summarizing complex information in a way that allows for review and assessment by technical staff without specific technical expertise in benthic ecology, and can also be a valuable tool for public education. According to EPA (2008) "Indicators can be a cost-effective, accurate alternative to monitoring the individual components of a system."

The EPA (2008) suggests that a suite of different indicators, such as the following, can be useful: 1) a water quality index, 2) a sediment quality index, 3) a benthic index, 4) a coastal habitat index, and 5) a fish tissue contaminants index. For a benthic index, the topic of this effort, EPA (2008) recommends it contain information on benthic community diversity, the presence or absence of pollution-tolerant taxa, and the presence or absence of pollution-sensitive taxa.

Benthic communities, and benthic indexes, can be a useful tool to track degradation and/or improvements in watershed-level pollutant loading, as they "integrate" water and sediment quality conditions on a longer timescale than a single point in time sample in a collection bottle.

With this information as background, we have developed a benthic index for the San Juan Bay Estuary, using the below-described approach.

2.0 Methods

2.1. Data Management

Benthic sampling data were provided by SJBEP in the form of Appendices C-E from Rivera (2005). These data were arranged into a single data table and data describing the family classification for each taxon were added based on a review of data via the Integrated Taxonomic Information System (ITIS, www.itis.gov). Location data for GIS maps were provided in Appendix J from Rivera (2005). These data were reviewed, and when the stated location (i.e. San Juan Bay, Condado Lagoon, etc.) did not agree with the provided coordinates these samples were removed from the maps. However some samples were still used in calculating descriptive statistics. The described location of a sample rather than provided coordinates was used to assign the station location for those stations where such a discrepancy occurred (Table 1).

Table 1
Benthic Stations at Which There Were Location Issues

STATION	COMMENT
BA-401	Is identified as being in a channel, however it's GIS position puts it squarely in San Juan Bay, index score of 1.78 seems to be more representative of the channels than San Juan Bay, use data for analysis of channels
JM-M001	Station is identified as being in a channel, it is located near the mouth of a drainage channel to SJL , this sample is within SJL proper and will be used in the SJL analyses
S1	Station is identified as being in SJB, however the GPS coordinates place it on land, the data from this station will be used for SJB analyses
S19	Station is identified as being in San José Lagoon (SJL), however the GPS coordinates place it in SJB, the Index Score would be the highest score in SJL, and would fit in very well in SJB, because of the uncertainty associated with the sample location it will not be included in the analyses
S29C	Station is identified as being in SJL, however the GPS coordinates place it on the Atlantic shoreline near CL, data from this sample will be included in the analyses for SJL
S4	Station is identified as "Atlantic", GPS coordinates place the sample in Torrecilla Lagoon (TL), there were no other TL samples from the Coastal 2000 study, so it is very likely that this sample actually occurred in TL, data from this sample will be included in the analyses
S43	Station is identified as being in Condado Lagoon (CL), however the GPS coordinates place it in SJB proper the Index Score of 2.85 appears to fit with either CL or SJB, because of the uncertainty associated with the sample location it will not be included in the analyses
S5	Station is identified as being in SJB, however the GPS coordinates place it in SJL, the index score of 3.33 does not fit in with the SJL samples surrounding it, because of the uncertainty associated with the location of this sample it will not be used in the analyses
SF-M001	Station is identified as being in a channel, it is located at the mouth of a small bay within SJB (see sample SJB_B004), this sample is within SJB proper and will be used in the SJB analyses
SJB_B004	Sample is in a small bay within SJB that is not representative of the general condition of SJB, Index score of 0.0 will be used in SJB calculations, but the site difference needed to be described

2.2. Calculating the Index

All calculations were performed using Statistical Analysis Software (SAS). For all analyses the family taxonomic level was utilized. The total abundance of each family of organisms was calculated for each sample. The initial component of the index is Shannon Diversity scores. These scores integrate taxonomic richness, abundance, and evenness of distribution into a single calculated number. The equation for Shannon Diversity is:

$$\overset{S}{\underset{i=1}{H}} = - \sum (Pi * LnP_i)$$

Where:

H= Shannon Diversity Index Score

P_i= Proportion of sample comprised of family i

S = Number of families in the sample

Based on recommendations found in the literature additional components were added to create the benthic index score. Adjustments were made so that the score would increase due to the presence of members of the families Aoridae and Ampeliscidae, which are generally pollution-sensitive organisms (Lee et al 2005, Weston 1996, Traunspurger and Drews 1996). The score also decreases due to the presence of members of the families Capitellidae and Tubificidae, which are regarded as pollution-tolerant, or indicative of disturbed benthic habitat (Paul et al 2001, Pinto et al. 2009). These components were added to the index equation in an iterative manner until the results matched a scale deemed appropriate. The resultant San Juan Bay benthic index equation is as follows:

$$B = H - {P_{Cap}}^2 - {P_{Tub}}^2 + {P_{Aor}}^{0.5} + {P_{Amp}}^{0.5} + 1$$

Where:

B = Benthic Index Score

H = Shannon Diversity Score

P_{cap} = Proportion of the sample in the family Capitellidae

P_{Tub} = Proportion of the sample in the family Tubificidae

P_{Aor} = Proportion of the sample in the family Aoridae

P_{Amp} = Proportion of the sample in the family Ampeliscidae

This equation was then applied to the provided benthic data and scores were generated based on those data. The results were reviewed with the ArcGIS software utilizing data for substrate type and depth to further explain the benthic index scores.

2.3. GIS Data

The SAV and bathymetry data were geo-referenced from the San Juan Bay Estuary Program Management Plan. The SAV data were then converted from raster data to vector features. All features corresponding to Non-Dredge SAV were selected and quantified. Bathymetry data was digitized and quantified.

In addition the shortest feasible non-landward route from each sample point to the Atlantic Ocean was measured in ArcGIS. An identity function was performed on the benthic stations, bathymetry, and habitat data for each station used in the Benthic Index.

3.0 Results

3.1. Benthic Index Scores

Mean benthic index scores ranged from 0 in the Suarez Canal to 2.74 in Torrecilla Lagoon. Torrecilla Lagoon, Condado Lagoon, and San Juan Bay were found to have higher mean benthic habitat scores than San José Lagoon and Piñones Lagoon (Table 2). Individual sample scores ranged from a minimum of 0.00 (in all waterbodies except Condado Lagoon and Torrecilla Lagoon) to a maximum of 4.13 in San Juan Bay.

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Table 2
Benthic Index Scores for Individual Waterbodies

Waterbody	Mean	Standard Deviation	Maximum	Median	Minimum	Number of Observations
San Juan Bay	2.74	0.80	4.13	2.86	1.45	15
Condado Lagoon	2.62	1.09	4.01	3.04	1.00	7
San José Lagoon	1.14	1.03	2.24	1.63	0.00	12
Torrecilla Lagoon	3.07	0.42	3.41	3.21	2.35	5
Piñones Lagoon	1.01	0.88	2.14	0.95	0.00	4
San Antonio Canal	3.09		3.09	3.09	3.09	1
Martín Peña Canal	1.00		1.00	1.00	1.00	1
Suárez Canal	0.00	0.00	0.00	0.00	0.00	2
Other Channel Sites	1.48	0.20	1.63	1.56	1.26	3

These data were tested for differences, if any, between waterbodies for those systems with at least four samples. Benthic Index Scores were found to be normally distributed and homoscedastic for each waterbody, therefore ANOVA and Fischer's Least Significant Difference (LSD) multiple comparison test were used to compare scores for waterbodies with at least four samples. ANOVA indicated that significant ($p < 0.01$) differences existed for scores. Fischer's LSD test indicated that two groups existed, concerning Benthic Index scores; Piñones Lagoon and San José Lagoon were not different from each other, but they were different from San Juan Bay, Condado Lagoon, and Torrecilla Lagoon (which were also not different from each other).

Figures 2 to 9 illustrate the spatial distribution of benthic index scores for San Juan Bay, Condado Lagoon, San José Lagoon, Torrecilla Lagoon, Piñones Lagoon, San Antonio Canal, Martín Peña Canal, and Suárez Canal, respectively.

Figure 2
Locations and Benthic Index Scores for Stations Located in San Juan Bay
Values are Color-Coded as to their Benthic Index Scores

Figure 3
Locations and Benthic Index Scores for Stations Located in Condado Lagoon
Values are Color-coded as to their Benthic Index Scores

Figure 4
Locations and Benthic Index Scores for Stations located in San José Lagoon
Values are Color-coded as to their Benthic Index Scores

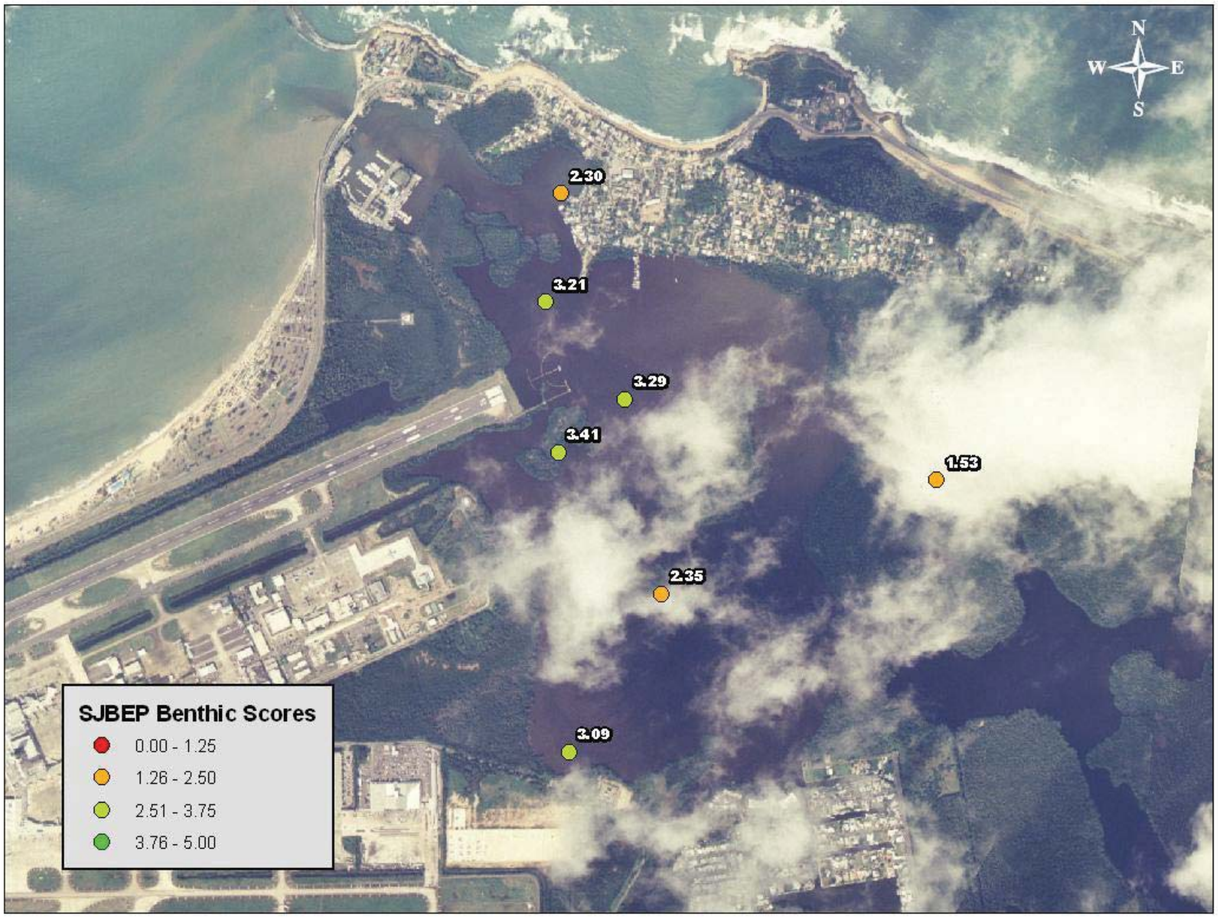

Figure 5
Locations and Benthic Index Scores for Stations located in Torrecilla Lagoon Values are Color-coded as to their Benthic Index Scores

Figure 6
Locations and Benthic Index Scores for Stations located in Piñones Lagoon
Values are Color-coded as to their Benthic Index Scores

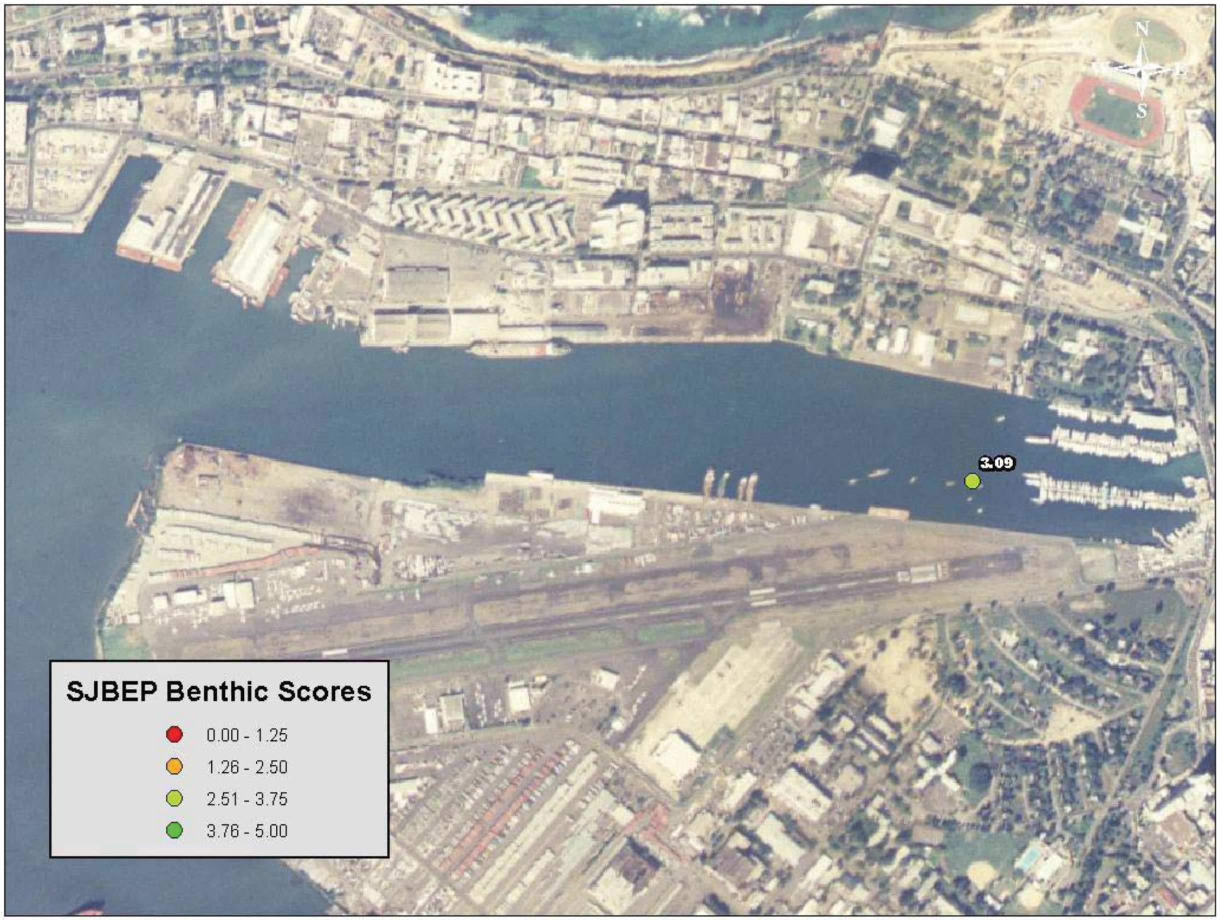

Figure 7
Locations and Benthic Index Scores for stations located in San Antonio Canal. Values are color-coded as to their benthic Index Scores.

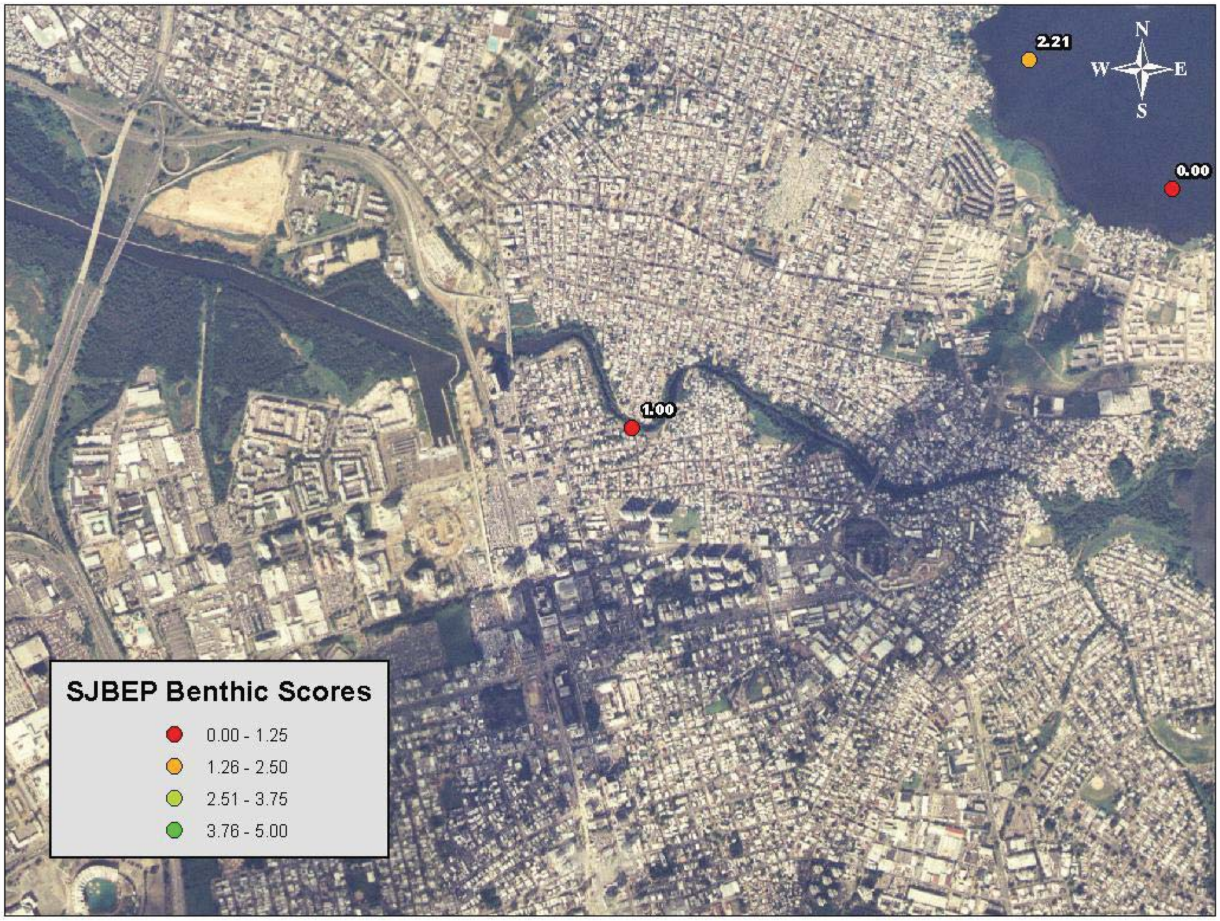

Figure 8
Locations and Benthic Index Scores for stations located in Martín Peña Canal. Values are color-coded as to their benthic Index Scores.

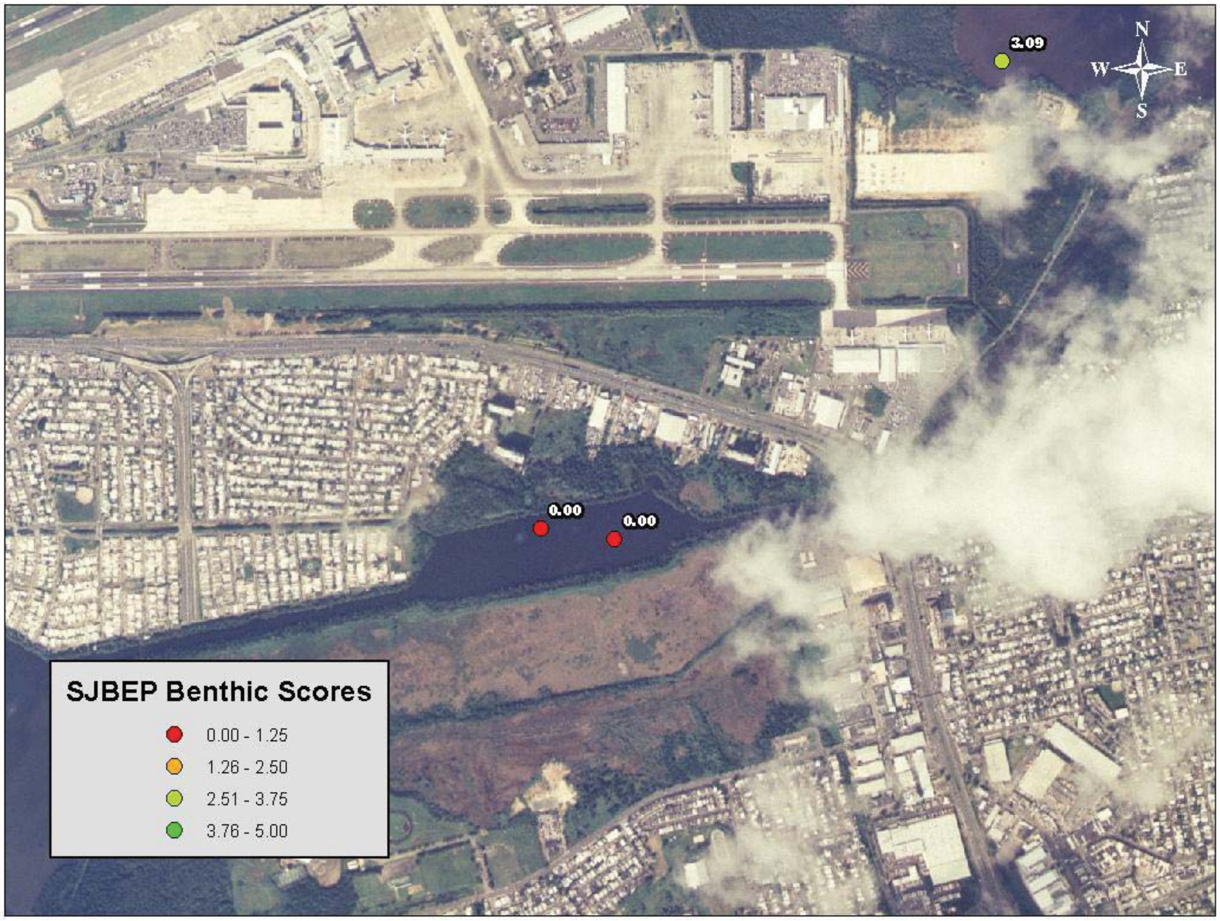

Figure 9
Locations and Benthic Index Scores for stations located in Suárez Canal. Values are color-coded as to their benthic Index Scores.

Additional data sets were analyzed to aid in the interpretation of the Benthic Index Scores. Using a bathymetry layer derived from the bathymetry map shown in SJBEP (2000), station locations were displayed on top the bathymetric contours derived from the map (Figure 10).

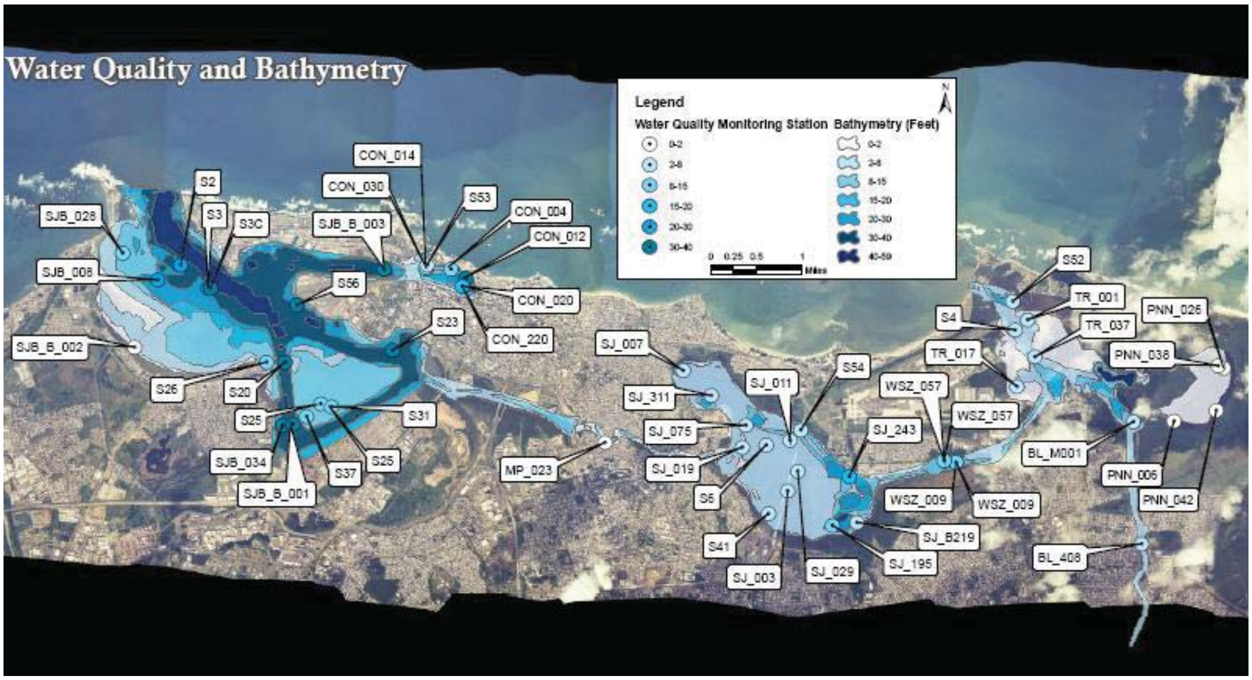

Figure 10
Locations of Benthic sampling Stations and Bathymetry
Bathymetry Data from SJBEP [2000)

Bathymetry within San Juan Bay itself is deeper along the northern boundary of the bay, especially near the opening to the Atlantic Ocean. There is a well-defined shipping channel in the southeastern portion of the bay, forming a triangle with a shallow shelf interior to the dredged channels. Within San Juan Bay, benthic sampling stations were located in both shallow water (0 to 2 feet), deep water (30 to 40 feet) and in all depth categories between these two extremes.

In Condado Lagoon, some of the sampling sites in the eastern part of the lagoon are located in dredged areas more than 20 feet in depth. Benthic sampling sites in the western part of Condado Lagoon are in shallower, non-dredged areas.

The bathymetry in San José Lagoon shows deeper dredged areas in the far eastern portions, with a mostly natural and shallow (2 to 8 feet) bottom. Two of the three benthic sampling sites in the easternmost part of San José Lagoon appear to be located in areas that have been dredged in the past.

In Torrecilla Lagoon, the irregular and angular boundaries of some of the bathymetry layer boundaries suggest significant dredging activities. Most of the benthic sampling sites in Torrecilla Lagoon appear to be located in areas that might be influenced by prior dredging.

The bathymetry data for Piñones Lagoon indicates no significant dredging activity, as the entirety of the lagoon appears to be uniformly shallow, with depths no deeper than 8 feet. Based on bathymetry data, Piñones Lagoon appears to have the least impact from dredging of any portion of the San Juan Bay system.

In addition to the existing bathymetry data, GIS was used to calculate the distance between benthic sampling sites and the nearest connection to the Atlantic Ocean. For each location, GIS was used to estimate the shortest practical distance between that location and the Atlantic; all routes were restricted to open water only, without crossing any land features. Flushing of San José Lagoon occurs almost entirely via the Suárez Canal, rather than the Martín Peña Canal. Therefore locations in San José Lagoon were measured based on an eastward connection to the Atlantic Ocean via Suárez canal.

Table 3 summarizes data for each station for Benthic Index Scores, water depth, and distance from that station to the Atlantic Ocean. These data were used for further analyses, described below.

Table 3
Summary of Benthic Index Scores, Water Depth (feet) and Distance to the Atlantic Ocean (m) for each Benthic Sampling Station

STATION	CODE	LONGITUDE	LATITUDE	BENTHIC INDEX SCORE	BATHYMETRY (ft)	Distance to Atlantic Ocean (m)
BL_M001	Channel	-65.96714	18.43283	1.26	8-Feb	4,097
BL_408	Channel	-65.96613	18.41338	1.56	8-Feb	6,248
S6	Channel	-66.02825	18.43009	1.63	8-Feb	8,097
S53	Condado Lagoon	-66.08413	18.45953	4.01	8-Feb	414
CON_030	Condado Lagoon	-66.08436	18.45916	3.04	15-Aug	452
CON_014	Condado Lagoon	-66.08436	18.45887	2.95	15-Aug	489
CON_004	Condado Lagoon	-66.08021	18.45889	1	15-Aug	690
CON_220	Condado Lagoon	-66.07837	18.4561	3.05	15-20	1,000
CON_012	Condado Lagoon	-66.07771	18.45734	1.24	30-40	1,014
CON_020	Condado Lagoon	-66.07814	18.45602	3.05	15-20	1,015
MP_023	Martin Pena Canal	-66.05505	18.43089	1	0-2	9,260
PNN_006	Pinones Lagoon	-65.96048	18.43277	2.14	0-2	4,906
PNN_042	Pinones Lagoon	-65.95335	18.43439	0.9	0-2	5,553
PNN_038	Pinones Lagoon	-65.95292	18.44151	0	0-2	5,948
PNN_026	Pinones Lagoon	-65.95203	18.44107	1	0-2	5,982
SJB_B_003	San Antonio Canal	-66.09133	18.45902	3.09	30-40	1,070
SJ_243	San Jose Lagoon	-66.0146	18.42487	0	15-20	6,364
SJ_B219	San Jose Lagoon	-66.01338	18.41753	0	8-Feb	7,064
SJ_195	San Jose Lagoon	-66.01749	18.41716	0	15-Aug	7,223
SJ_029	San Jose Lagoon	-66.02305	18.42589	2.24	8-Feb	7,522
SJ_003	San Jose Lagoon	-66.02484	18.42278	0	8-Feb	7,652
S54	San Jose Lagoon	-66.02249	18.43233	1.68	8-Feb	7,760
SJ_011	San Jose Lagoon	-66.02423	18.43075	2.13	8-Feb	7,780
S41	San Jose Lagoon	-66.02804	18.41918	1.69	8-Feb	8,026
SJ_019	San Jose Lagoon	-66.03222	18.42975	2.12	8-Feb	8,561
SJ_075	San Jose Lagoon	-66.03161	18.43332	1.58	8-Feb	8,679
SJ_311	San Jose Lagoon	-66.03724	18.43807	0	8-Feb	9,359
SJ_007	San Jose Lagoon	-66.04186	18.44217	2.21	8-Feb	10,127
SJB_028	San Juan Bay	-66.13472	18.46227	2.93	15-Aug	1,112
S2	San Juan Bay	-66.12514	18.46016	3	20-30	1,230
SJB_008	San Juan Bay	-66.12894	18.45788	2.27	20-30	1,420
S3	San Juan Bay	-66.12065	18.45645	2.86	20-30	1,802

S3C	San Juan Bay	-66.12025	18.45645	4.13	30-40	1,808
SJB_B_002	San Juan Bay	-66.13293	18.44726	3.04	0-2	2,922
S56	San Juan Bay	-66.10585	18.45357	2.25	30-40	3,115
S26	San Juan Bay	-66.11105	18.44456	4.1	15-Aug	3,445
S20	San Juan Bay	-66.10799	18.44453	2.68	30-40	3,631
S25	San Juan Bay	-66.10218	18.4378	2.5	15-Aug	4,584
SJB_034	San Juan Bay	-66.1086	18.43446	1.69	30-40	4,644
S37	San Juan Bay	-66.10463	18.4358	3.43	15-Aug	4,647
SJB_B_001	San Juan Bay	-66.10691	18.4346	3.03	30-40	4,664
S31	San Juan Bay	-66.10042	18.43726	1.45	15-Aug	4,743
S23	San Juan Bay	-66.09015	18.4461	1.69	30-40	5,102
WSZ_009	Suarez Canal	-65.9968	18.42689	0	20-30	4,642
WSZ_057	Suarez Canal	-65.99873	18.42719	0	20-30	4,936
S52	Torrecilla Bay	-65.98691	18.45223	3.21	8-Feb	887
TR_001	Torrecilla Bay	-65.98446	18.44926	3.29	8-Feb	1,323
S4	Torrecilla Bay	-65.98658	18.4477	3.41	8-Feb	1,475
TR_037	Torrecilla Bay	-65.98341	18.44341	2.35	8-Feb	2,004
TR_017	Torrecilla Bay	-65.9864	18.43869	3.09	8-Feb	2,587

These data were then used to test for the effects, if any, of water depth and distance from the Atlantic Ocean as potential influences on Benthic Index scores for the entire SJBE system combined (Figures 11 and 12, respectively).

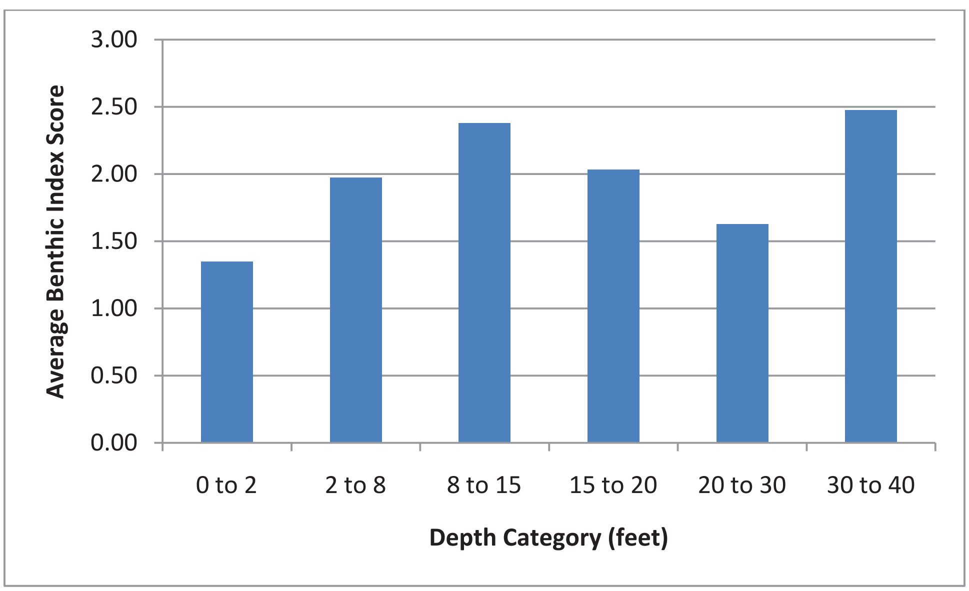

Figure 11
Benthic Index Scores across Different Depth Categories

When categorized for depth, Benthic Index scores were normally distributed and homoscedastic. ANOVA found no significant difference in Benthic Index scores between different depth categories ($p = 0.514$). As an additional assessment, the non-parametric Kruskal-Wallis test was employed, and it also found no affect of depth on Benthic Index scores ($p = 0.482$).

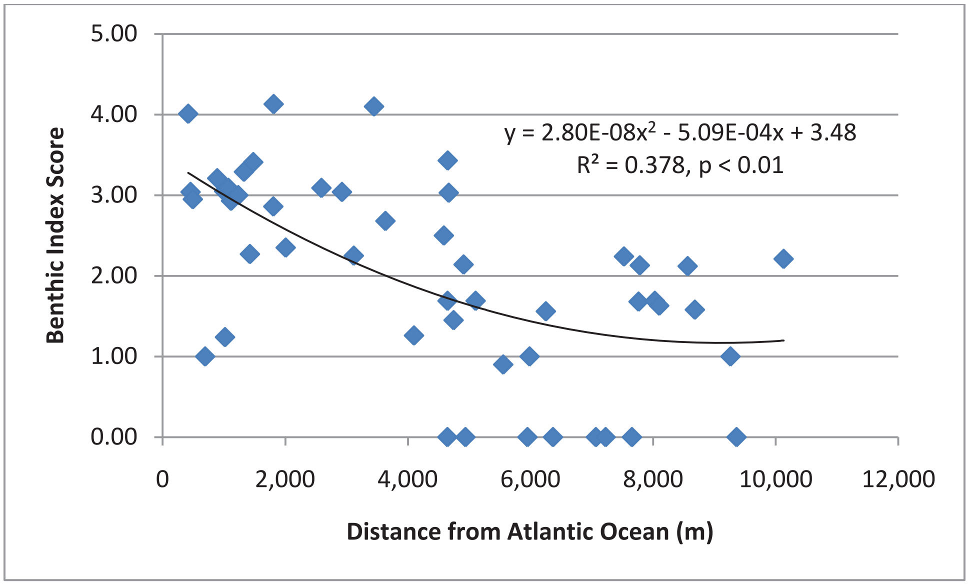

Figure 12
Benthic Index Scores vs. Distance from the Atlantic Ocean

Results shown in Figure 12 show a relationship wherein increasing distance from the Atlantic Ocean, an inverse proxy for the rate of flushing, is associated with a general pattern of decreasing Benthic Index scores. These data were found to be normally distributed and homoscedastic, and the polynomial equation relating Benthic Index scores to distance from the Atlantic was significant at $p < 0.01$. As an additional assessment, the non-parametric Spearman's Rho test was employed, which also found a statistically significant relationship between the ranked values of these two factors ($p < 0.01$).

When examining the distance vs. Benthic Index scores plot, it appeared as if the data more or less represented two groups of data, scores for stations less than 5,000 meters from the Atlantic Ocean, and scores for stations at greater distances. Figure 13 shows the results when data are segregated into these two groups.

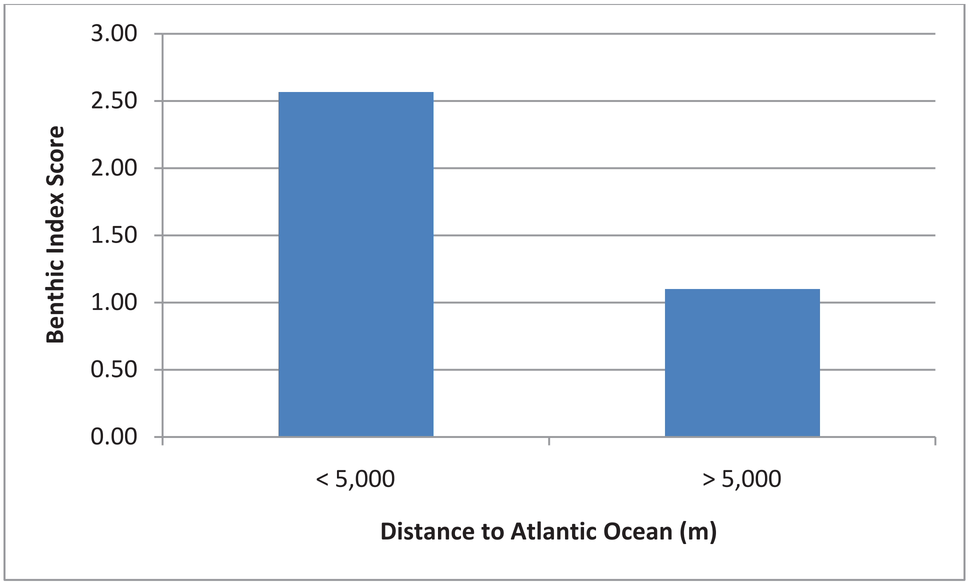

Figure 13
Benthic Index Scores for Stations Less Than and Greater Than 5,000 meters from the Atlantic Ocean

When grouped in this manner, the data are not normally distributed. The non-parametric Mann-Whitney U-test indicated that Benthic Index scores for stations less than 5,000 meters from the Atlantic Ocean were significantly higher ($p<0.05$) than for stations greater than 5,000 meters from the Atlantic. However, waterbodies such as San José Lagoon and Piñones Lagoon may have underlying features such as toxicity of sediments, frequency of disturbance, etc., that could be equally if not more important influences on Benthic Index scores than flushing rates. Caution is required when interpreting these results as suggesting distance from the Atlantic Ocean (with distance acting as an inverse surrogate for flushing) is the dominant influence on the health of benthic communities.

4.0 Discussion

4.1. Prior Characterization Efforts

The sediments within the San Juan Bay Estuary System have been previously characterized by Webb and Gomez-Gomez (1998) and Webb et al. (1998). These reports summarized results of sediment contamination levels and sedimentation rates from six sites throughout the SJBEP study area. Sediment dating techniques were used to compare contamination levels between the time periods of 1925 to 1949, 1950 to 1974, and 1975 to 1995.

For the earliest (deepest) sediments analyzed, levels of lead, mercury, and arsenic in sediment were similar to values from streams in undisturbed portions of the watershed. These results indicate contamination was minimal in the time period prior to 1950 (Webb and Gomez-Gomez, 1998; Webb et al., 1998).

After 1950, levels of PCBs (used in electrical transformers, etc.), lead (from leaded gasoline and paints) and mercury increased in the sediments. Agricultural chemicals such as dieldrin and DDT also increased post-1950. Results also indicate recent declines in levels of dieldrin and DDT, as well as a decline in levels of arsenic throughout the San Juan Bay Estuary (Webb and Gomez-Gomez, 1998; Webb et al., 1998). Declines in lead and DDT are expected to occur as a result of relatively recent (mid-1980s) phase-out of leaded gasoline and bans on DDT, but sediments do not yet show such a pattern.

Sedimentation rates appear to be nearly two orders of magnitude higher in the Martín Peña Canal than in other locations, suggesting that location is a probable "hot spot" for the accumulation of toxins in bottom sediments, a finding not at all in conflict with expectations (SJBEP 2000).

In addition to the potential impacts to benthic communities from toxins in sediments, benthic communities can also be stressed via fluctuations in salinity regimes (Montague and Ley, 1993, Fleischer and Zettler, 2008) and depressed levels of dissolved oxygen and other stressors (Dauer et al. 2000, Llanso et al. 2002).

In the San Juan Bay Estuary, Webb and Gomez-Gomez (1998) and Webb et al. (1998) showed evidence of declining levels of phosphorus within the waters of the bay itself, possibly related to upgrades in levels of wastewater treatment. As a whole, trends in sediment contaminant levels and water quality are suggestive of a situation where the San Juan Bay system may be degraded, but it also may be improving over time – albeit perhaps not at an equal rate in all locations.

4.2. Benthic Index Scores

The Benthic Index created for San Juan Bay can be used to compare the waterbodies of the SJBE against each other, as well as tracking waterbodies over time. Comparing waterbodies against each other, San Juan Bay, Condado Lagoon and the Torrecilla Lagoon all had median Benthic Index scores close to (San Juan Bay) or higher than (Condado Lagoon and Torrecilla Lagoon) a value of three. As a whole, these three systems appear to have the healthiest benthic communities, with greater species diversity, a lower percentage of pollution tolerant species, and a higher percentage of pollution intolerant species than other locations.

San José Lagoon and the various Channel locations (including the Martín Peña Canal) had median Benthic Index scores of 1.69 and 1.35, respectively. These data show that overall species diversity and the percentages of pollution intolerant organisms are lower in San José Lagoon and the various Channel locations than in San Juan Bay, and much lower than Condado Lagoon and Torrecilla Lagoon.

Based on median values, the lowest Benthic Index score of any waterbody was found in Piñones Lagoon (1.00). However, when comparing mean values, the Channel locations had slightly worse Benthic Index scores than Piñones Lagoon (1.18 and 1.21, respectively). The difference in order found when using mean vs. median values suggests that an appropriate classification scheme might be constructed as follows:

- Healthiest benthic communities: Torrecilla Lagoon and Condado Lagoon
- Healthy benthic communities: San Juan Bay
- Moderately healthy to stressed benthic communities: San José Lagoon
- Stressed benthic communities: Canal locations and Piñones Lagoon

The low scores in Piñones Lagoon should be interpreted considering the possibility that such a condition might be somewhat or entirely appropriate for that particular location. While Benthic Index scores were much higher in Condado Lagoon than in Piñones Lagoon, population density within the watershed of Condado Lagoon is much higher than in the region surrounding Piñones Lagoon (SJBEP 2000).

When comparing these Benthic Index scores to a previously constructed Water Quality Index (as summarized in the "Tarjeta de Calificaciónes" produced by the SJBEP) both similarities and differences in the "health" of various components of the San Juan Bay Estuary were found. The Water Quality Index was based on the parameters of dissolved oxygen, turbidity, fecal coliform bacteria, and pH, and was developed in consideration of the number of contaminants that exceeded appropriate water quality standards, the frequency at which contaminants exceeded those standards, and the amount by which exceedances were above relevant standards. The index was developed using data from fourteen water quality stations in total. In San Juan Bay proper, there were three open water stations. San José Lagoon had two stations, Torrecilla Lagoon had two stations, Piñones Lagoon had one station, and no stations were located within Condado Lagoon. In comparison, there is a larger number and wider geographical spread of sampling locations for the Benthic Index scores.

The Water Quality Index ranked San Juan Bay and Piñones Lagoon as having a score of "B", with San José Lagoon and Torrecilla Lagoon with ranks of "C". The Suárez Canal was given a grade of "D" and the Martin Peña Canal was ranked as an "F". To allow a comparison of findings between these two indices, median Benthic Index scores between 3.76 and 5 were given a rank of "A", values between 2.51 and 3.75 were given a rank of "B", 1.26 to 2.50 was given a "C", and scores below 1.26 were given a score of "D/F". Table 4 compares the relative scores for each main waterbody using the Water Quality Index and the Benthic Index.

Table 4
Comparison of Scores Produced using Water Quality Index and Benthic Index Techniques

Waterbody	Water Quality Index Classification	Benthic Index Classification
San Juan Bay	B	B
Condado Lagoon	N/A	B
San José Lagoon	C	C
Torrecilla Lagoon	C	B
Piñones Lagoon	B	D/F
Suárez Canal	D	D/F
Martín Peña Canal	F	D/F

Both the Water Quality Index and the Benthic Index characterized San Juan Bay as a “B”. While individual sample locations had higher or lower scores, typical conditions indicate this waterbody has better than average water quality and benthic health, compared to the San Juan Bay Estuary system as a whole. While Condado Lagoon was not graded by the Water Quality Index, its Benthic Index score of a “B” was the same as in San Juan Bay. San José Lagoon was ranked as a “C” for both indices, indicating concurrence on this system’s reduced ecological health. For Torrecilla Lagoon, the Benthic Index score of “B” was higher than its Water Quality Index score of “C”.

The Suárez Canal was graded as a “D” for water quality, which matches its grade of “D/F” on the Benthic Index score. And the Martín Peña Canal’s Water Quality Index score of “F” was matched with a Benthic Index score of “D/F”.

The greatest discrepancy between Water Quality Index scores and Benthic Index scores was found in Piñones Lagoon; the Water Quality Index score of “B” is matched with a Benthic Index score of “D/F”.

The Water Quality and Benthic Index scores both indicate that the least healthy waterbodies in the San Juan Bay Estuary are the Martín Peña and Suárez Canals. Both systems had the lowest possible scores for both indicators of ecosystem health.

In contrast, Piñones Lagoon had a relatively good Water Quality Index score, but a much lower Benthic Index score. Rather than suggesting Piñones Lagoon is “polluted”, the benthic community in this system might be that of a natural condition that makes it inappropriate to compare it to other portions of the San Juan Bay Estuary. If water quality in Piñones Lagoon does in fact represent a healthy ecosystem (as would be expected based on its low population density) then a depauperate benthic community might be representative of a natural condition. Conversely, it could be that factors other than population density alone could be stressing the benthic communities in Piñones Lagoon without being manifested in those parameters used to construct the Water Quality Index.

5.0 Value and Use of the Benthic Index and Other Findings

The Benthic Index developed here is a tool that can be used to report on the status and trends (if any) of the health of the San Juan Bay Estuary and its individual component waterbodies. The technique is consistent with the wider body of literature on how such indices should be constructed, and it is consistent with guidance provided by EPA (2008) on the requirements of a benthic index.

This index can be used to grade portions of the San Juan Bay Estuary in a way that is technically sound, yet also able to be interpreted by non-technical stakeholders and the public and policy makers as well.

While researching topics related to water and sediment quality in San Juan Bay, we discovered a discrepancy in seagrass acreage estimates that may be of interest to the San Juan Bay Estuary Program. If the San Juan Bay Estuary system is improving over the past few years, as is indicated by results from Webb and Gomez-Gomez (1998) and Webb et al. (1998), then one of the bio-indicators that might be useful to track is the acreage of seagrass meadows throughout the system. Seagrass coverage has been previously found to correlate with spatial and temporal trends in water quality in Sarasota Bay, Florida (Tomasko et al. 1996), Lemon Bay, Florida (Tomasko et al. 2001), and Tampa Bay, Florida (Johansson 1995). Due to their proven relationships with water quality, seagrass coverage has been monitored as an indicator of ecosystem health in various locations in Southwest Florida for many years (Tomasko et al. 2005).

In the San Juan Bay Estuary, there does not appear to be a consistent approach to seagrass mapping and/or monitoring, even though one of the earliest papers relating seagrass distribution to water quality was conducted in Puerto Rico (Vicente and Riviera 1982). Also, some of the highest Benthic Index scores found in the San Juan Bay Estuary system were found in areas that appear to be associated with seagrass meadows.

Perhaps due to the differing techniques used, seagrass acreage estimates for the entirety of the San Juan Bay estuary range from 65 acres (listed as 26.5 hectares in SJBEP 2000) to 92 acres (derived from GIS data created by NOAA's Biogeography Program) to 375 acres (Rivera 2005). As seagrass coverage was previously shown to be sensitive to water quality in Puerto Rico (Vicente and Rivera 1982), and as seagrass coverage has been used a bio-indicator of system health in many locations, the finding that the San Juan Bay Estuary system may be recovering due to actions taken to reduce past pollutant impacts (Webb and Gomez-Gomez 1998, and Webb et al. 1998) highlights the need to have a consistent and repeatable program in place to track seagrass acreage over time. These results, in combination with the Water Quality Index and this Benthic Index, could be useful tools for determining the status and trends of overall ecological health throughout the San Juan Bay Estuary.

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Appendix A4

Mapped Habitat and Caño Martín Peña Channel Configurations

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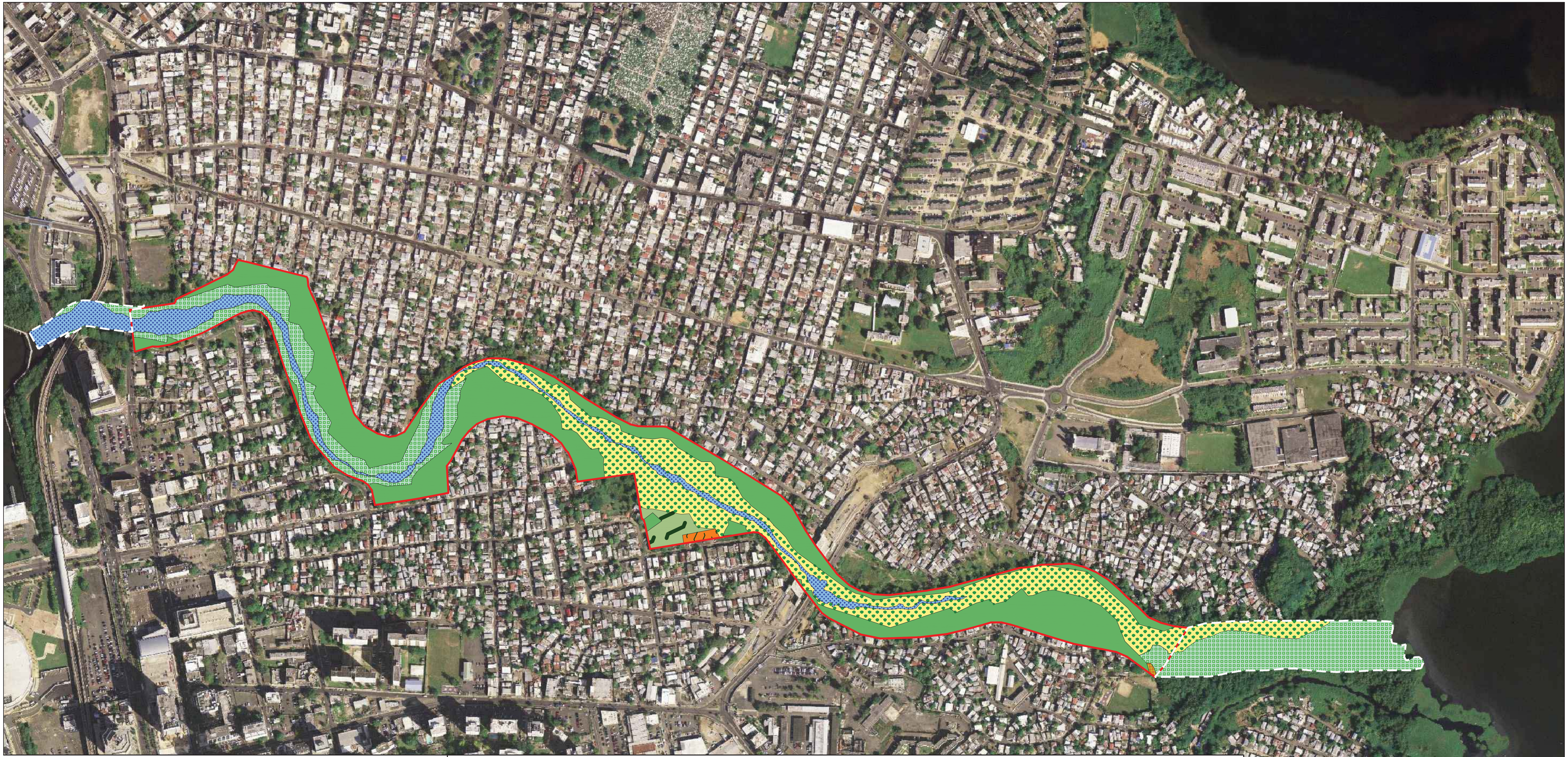
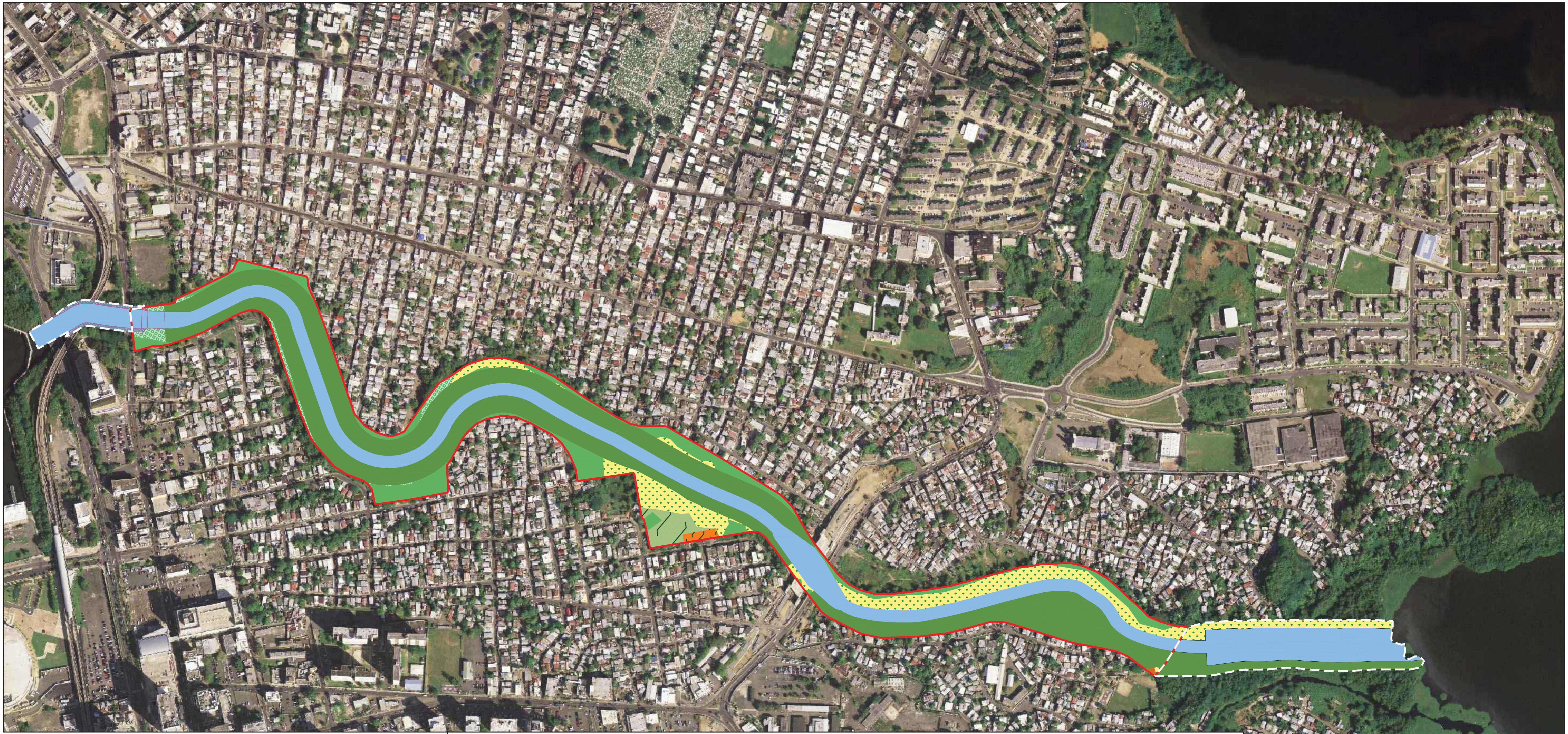


LEGEND

- EASTERN CMP PROJECT BOUNDARY
- EXTENDED PROJECT BOUNDARY
- ESTUARINE FORESTED WETLANDS–MANGROVE
- ESTUARINE OPEN WATER
- MANAGED GREEN AREA
- PALUSTRINE EMERGENT WETLANDS
- PALUSTRINE FORESTED WETLANDS–MANGROVE
- SECONDARY FOREST
- UPLAND

EXISTING WETLAND AREAS

DESCRIPTION	WESTERN END CMP (ACRES)	LIMIT OF PUBLIC DOMAIN CMP (ACRES)	EASTERN END CMP (ACRES)	TOTAL (ACRES)
ESTUARINE FORESTED WETLANDS–MANGROVE	0.35	7.39	7.79	15.53
ESTUARINE OPEN WATER	1.71	5.69	0	7.40
MANAGED GREEN AREA	0	0.31	0	0.31
PALUSTRINE EMERGENT WETLANDS	0	0.06	0	0.06
PALUSTRINE FORESTED WETLANDS–MANGROVE	0	16.22	1.65	17.87
SECONDARY FOREST	0	1.17	0	1.17
UPLAND	0	26.13	0	26.13
TOTAL	2.06	56.97	9.44	68.47



LEGEND

- EASTERN CMP PROJECT BOUNDARY
- EXTENDED PROJECT BOUNDARY
- ESTUARINE FORESTED WETLANDS—MANGROVE
- ESTUARINE OPEN WATER
- MANAGED GREEN AREA
- PALUSTRINE EMERGENT WETLANDS
- PALUSTRINE FORESTED WETLANDS—MANGROVE
- SECONDARY FOREST
- UPLAND
- PROPOSED 75' CHANNEL
- PROPOSED WETLANDS

PROPOSED 75' CHANNEL AREAS

DESCRIPTION	WESTERN END CMP (ACRES)	LIMIT OF PUBLIC DOMAIN CMP (ACRES)	EASTERN END CMP (ACRES)	TOTAL (ACRES)
ESTUARINE FORESTED WETLANDS—MANGROVE	0	0.82	0	0.82
MANAGED GREEN AREA	0	0.30	0	0.30
PALUSTRINE EMERGENT WETLANDS	0	0.03	0	0.03
PALUSTRINE FORESTED WETLANDS—MANGROVE	0	6.28	1.51	7.79
SECONDARY FOREST	0	1.17	0	1.17
UPLAND	0	6.96	0	6.96
PROPOSED CHANNEL	2.06	14.29	5.61	21.96
PROPOSED WETLAND	0	27.12	2.32	29.44
TOTAL	2.06	56.97	9.44	68.47

LEGEND

- EASTERN CMP PROJECT BOUNDARY
- EXTENDED PROJECT BOUNDARY
- ESTUARINE FORESTED WETLANDS—MANGROVE
- MANAGED GREEN AREA
- PALUSTRINE EMERGENT WETLANDS
- PALUSTRINE FORESTED WETLANDS—MANGROVE
- SECONDARY FOREST
- UPLAND
- PROPOSED 100' CHANNEL
- PROPOSED WETLANDS

PROPOSED 100' CHANNEL AREAS

DESCRIPTION	WESTERN END CMP (ACRES)	LIMIT OF PUBLIC DOMAIN CMP (ACRES)	EASTERN END CMP (ACRES)	TOTAL (ACRES)
ESTUARINE FORESTED WETLANDS—MANGROVE	0	0.82	0	0.82
MANAGED GREEN AREA	0	0.30	0	0.30
PALUSTRINE EMERGENT WETLANDS	0	0.03	0	0.03
PALUSTRINE FORESTED WETLANDS—MANGROVE	0	5.64	1.03	6.67
SECONDARY FOREST	0	1.17	0	1.17
UPLAND	0	6.95	0	6.95
PROPOSED CHANNEL	2.06	18.22	6.68	26.96
PROPOSED WETLAND	0	23.84	1.73	25.57
TOTAL	2.06	56.97	9.44	68.47

LEGEND

- EASTERN CMP PROJECT BOUNDARY
- EXTENDED PROJECT BOUNDARY
- ESTUARINE FORESTED WETLANDS—MANGROVE
- MANAGED GREEN AREA
- PALUSTRINE EMERGENT WETLANDS
- PALUSTRINE FORESTED WETLANDS—MANGROVE
- SECONDARY FOREST
- UPLAND
- PROPOSED 75' CHANNEL
- PROPOSED WETLANDS

PROPOSED 125' CHANNEL AREAS

DESCRIPTION	WESTERN END CMP (ACRES)	LIMIT OF PUBLIC DOMAIN CMP (ACRES)	EASTERN END CMP (ACRES)	TOTAL (ACRES)
ESTUARINE FORESTED WETLANDS—MANGROVE	0	0.82	0	0.82
MANAGED GREEN AREA	0	0.30	0	0.30
PALUSTRINE EMERGENT WETLANDS	0	0.03	0	0.03
PALUSTRINE FORESTED WETLANDS—MANGROVE	0	5.01	0.18	5.19
SECONDARY FOREST	0	1.17	0	1.17
UPLAND	0	6.95	0	6.95
PROPOSED CHANNEL	2.06	22.17	8.56	32.79
PROPOSED WETLAND	0	20.52	0.70	21.22
TOTAL	2.06	56.97	9.44	68.47

Appendix B

Real Estate Plan

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DRAFT
REAL ESTATE PLAN
CAÑO MARTÍN PEÑA
ECOSYSTEM RESTORATION PROJECT
SAN JUAN, PUERTO RICO

Prepared for:

Corporación del Proyecto ENLACE del Caño Martín Peña
Apartado Postal 41308
San Juan, Puerto Rico 00940-1308

September 2015

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Contents

List of Exhibits

List of Figures (Exhibit A)

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Acronyms and Abbreviations

CAD	Contained Aquatic Disposal
CDRC	Ciudad Deportiva Roberto Clemente
CMP	Caño Martín Peña
CMP-ERP	Caño Martín Peña Ecosystem Restoration Project
CMP-CLT	Caño Martín Peña Community Land Trust
DNER	Puerto Rico Department of Natural and Environmental Resources
DSS	Decent, Safe and Sanitary
EIS	Environmental Impact Statement
ENLACE	Corporación del Proyecto ENLACE del Caño Martín Peña
G-8	Group of the Eight Communities bordering the Caño Martín Peña
HTRW	Hazardous, Toxic and Radioactive Waste
MCACES	Micro-Computer Aided Cost Engineering System
MTZ	Maritime-Terrestrial Zone
NEP	USEPA's National Estuary Program
OMRR&R	Operations, Maintenance, Repair, Rehabilitation & Replacement
PL	Public Law
PPA	Project Partnership Agreement
PR	Puerto Rico
PREPA	Puerto Rico Electric Power Authority
REP	Real Estate Plan
SJL	San José Lagoon
TSP	Tentatively Selected Plan
URA	Uniform Relocation Assistance and Real Estate Acquisition Act
U.S.	United States of America
USACE	U.S. Corps of Engineers
USEPA	U.S. Environmental Protection Agency
WRDA	Water Resources Development Act of 2007

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1. STATEMENT OF PURPOSE

The purpose of this Real Estate Plan (REP) is to present the overall plan describing the minimum real estate requirements for the construction, operation, maintenance, repair and rehabilitation of the proposed Project. It is Appendix B to the *Caño Martín Peña Ecosystem Restoration Project* (CMP-ERP) *Feasibility Report* dated September 2015.

2. PROJECT AUTHORIZATION

The Water Resources Development Act of 2007 (WRDA 2007, United States Public Law 110-114, 121 Stat. 1048) was enacted and provided for the conservation and development of water and related resources, and authorized the Secretary of the Army to carry out various projects for improvements to rivers and harbors of the United States and for other purposes. In particular, Section 5127 of WRDA 2007 states the following:

> Section 5127. Cano Martin Pena, San Juan, Puerto Rico.
> *The Secretary shall review a report prepared by the non-Federal interest concerning flood protection and environmental restoration for Caño Martín Peña, San Juan, Puerto Rico, and, if the Secretary determines that the report meets the evaluation and design standards of the Corps of Engineers and that the project is feasible, the Secretary may carry out the project at a total cost of $150,000,000.*

On October 27, 2008, the Director of Civil Works issued an implementation guidance memorandum for Section 5127 of the WRDA 2007, which established that the feasibility report "will follow the requirements set forth in Appendix H of ER 1105-2-100 for projects authorized without a report and be submitted for approval by the Assistant Secretary of the Army (Civil Works)." This Feasibility Report is submitted in accordance with the guidance memorandum, and the Memorandum of Agreement executed on June 26, 2012, between the United States Corps of Engineers (USACE) and the Caño Martín Peña ENLACE Project Corporation (ENLACE), the non-Federal sponsor for report revision.

3. PROJECT LOCATION

The location of the CMP-ERP is within the Municipalities of San Juan and Carolina, PR (see **Figure A-1**). More specifically, the CMP-ERP will be located in the eastern part of the Caño Martín Peña (CMP). In addition, it will extend to the *Ciudad Deportiva Roberto Clemente* (CDRC) in Carolina, P.R. Most of the CMP-ERP lies within the flood zone AE and the Public Domain Lands associated with the Maritime-Terrestrial Zone (MTZ) of the CMP District (see **Figure A-1**), with the exception of the Humacao Regional Landfill and CDRC staging area. The Public Domain Lands of the CMP District (encompassing the CMP and its associated conservation strip) were established by Puerto Rico Law No. 489 of 2004, known as the *Comprehensive Development of the Cano Martin Pena Special Planning District Act*, as amended (hereinafter, PR Law 489); are property of the people of Puerto Rico and administered by the Department of Natural and Environmental Resources (DNER).

The CMP-ERP is located within a residential area that has the highest population density on the Island, having over twenty six thousand (26,000) persons per square mile. The urban environment in which the CMP-ERP is being developed is in the heart of the city of San Juan, which highly increases the real estate costs associated with the plan.

4. PROJECT DESCRIPTION

The purpose of the CMP-ERP is to re-establish the tidal connection between the San José Lagoon (SJL) and the San Juan Bay, and thus, the eastern and western sections of the San Juan Bay Estuary, the only tropical estuary that is included in the United States Environmental Protection Agency (USEPA) National Estuary Program (NEP). The CMP-ERP consists of the dredging of approximately 2.2 miles of the eastern half of the CMP, starting from the SJL towards the west, in the vicinity of the Luis Muñoz Rivera Avenue Bridge. The CMP-ERP would improve dissolved oxygen levels and salinity stratification, increase biodiversity by restoring or enhancing, among others, fish habitat and benthic conditions, and overall health of the San Juan Bay Estuary System. The CMP-ERP is also critical for the revitalization of eight impoverished communities settled along the Martín Peña tidal channel, and restoration of this system will significantly improve human health and safety in the area. Recreational navigation will also be reestablished in the area, allowing for increased public and commercial use of the entire estuary.

The Tentatively Selected Plan (TSP) consists of dredging approximately 2.2 miles of the eastern half of the CMP to a width of 100 feet and a depth of 10 feet, with slight variations in channel width and depth at the four (4) bridges to the west, the Barbosa Bridge to the east, and at the terminus of the CMP with the SLJ. The walls of the CMP-ERP Channel would be constructed with vertical concrete-capped steel sheet piles with hydrologic connections to the surrounding lands. The sill depth of the window would be set at mean low water so that tidal exchanges are facilitated to the mangrove beds. Rip rap would be placed at the four bridges. At the terminus of the CMP-ERP Channel with the SJL, an extended channel would be dredged east into the SJL (over a distance of approximately 4,300 feet) as a hydraulic transition from the CMP. This extended channel would transition from the 10-foot-deep CMP-ERP Channel to the 6-foot-deep areas of SJL. The extended channel would maintain the CMP-ERP Channel's 100-foot width but replace its steel sheet pile walls with a trapezoidal configuration with 5-foot to 1-foot earthen side slopes. The TSP includes the following management measures:

a. One-hundred-foot-wide, ten-foot-deep rectangular channel with concrete-capped steel sheet pile walls (with the variations in channel width and depth for the Barbosa Avenue Bridge and terminus of the CMP with the SJL as described in Section 5.2.1.1 of this report);

b. Solid waste debris would be transported by barge to a staging area for subsequent landfill disposal. Sediments would be transported by barge for disposal at the SJ1 and SJ2 Contained Aquatic Disposal (CAD) in the SJL pits;

c. A weir at the western end of the project area for mitigating water flows into the adjacent waterways and to protect the structural integrity of the four bridges; and

d. Restoration of the disturbed mangrove by grading the site and planting with native vegetation. After dredging and construction of mangrove planting beds, the CMP would consist of 25.57 acres of open water and 34.48 acres of mangrove wetland

5. REAL ESTATE REQUIREMENTS

Lands will be required for the CMP-ERP as follows:

a. **Channel** – The CMP-ERP consists of dredging approximately 2.2 miles of the eastern part of the CMP. This area falls within the Public Domain Lands associated with the MTZ of the CMP, therefore land acquisition will not be part of the Project (see **Figure A-2**), with exception of the landowners who acquired land titles through Puerto Rico's Housing Department or the Municipality of San Juan, and whose titles were recognized in Opinion Number 11-131-A, emitted by the Secretary of the Department of Justice of Puerto Rico.

b. **Project Area** (Public Domain limit) – 56.97 acres + 9.44 acres transition area into SJL.

c. **Extended Channel into SJL** – 9.44 acres.

d. **Solid Waste Disposal Areas** – Solid waste debris resulting from housing and construction would be transported from Project's site to the CDRC staging area. Subsequently, the solid waste debris would be transported from the CDRC staging area to the Humacao Regional Landfill, which is owned by the Local government and is located at approximately 32 miles from the project site. A total of 6 acres of the CDRC staging area are included in addition to the Project Footprint within the CMP, on the southeast shore of the SJL (see **Figure A-2**). Of these 6 acres, 5 acres are upland habitat and 1 acre is mangrove fringe. The CDRC staging area includes a dock for loading/unloading the dredged material to be transported to the landfill. The 5 upland acres are within a previously disturbed 35-acre parcel. After all solid waste has been disposed in the upland landfill, the 5 acre CDRC staging area would be restored with native upland vegetation, and the 1 acre of mangrove fringe would be restored with mangroves. The CMP-ERP would use a local landfill going to the transfer station of the Municipality of San Juan, as such; no additional permits are required (see **Figure A-3**). Slurry from the dredged channel would be pumped into dump scows, which would be transported to and deposited in the SJL Pits 1 and 2, which will be used as CAD sites. This route and the SJL are property of the Commonwealth of Puerto Rico; therefore no lands need to be acquired (see **Figure A-4**). In addition, the non-Federal sponsor has identified at least three other potential landfills located in: Yauco, Peñuelas and Ponce (see **Figure A-4**).

e. **Mangrove Restoration** (34.48 acres within the Project Channel footprint) – The width of the mangrove planting area would extend from the channel wall to the limit of the Public Domain Lands associated with the MTZ of the CMP. Since these are property of the Commonwealth of Puerto Rico, the non-Federal sponsor would not be responsible for any land acquisitions (see **Figure A-5**).

f. **Temporary Work Area** (6 acres) – A staging area would be located at the CDRC. This land belongs to CDRC; however, no lands need to be acquired by the non-Federal sponsor (see **Figure A-6**). ENLACE has already initiated the dialogue with the CDRC's Board of Directors to request the right to use the area and incorporate the Project in their future development plans' timeline.

g. **Recreation Areas** (5 acres) – There are no formal areas where CMP District and Cantera Peninsula residents may access the Project Channel for fishing, bird watching, or other activities except at the three bridges which cross the channel. Fishing and navigation for recreational purposes are highly impaired and unsafe. The linear nature of the Project allows for the placement of recreational features along the length of the CMP. There will be three types of recreation access areas: (a) recreation access parks, (b) recreation parks with a trail to the CMP, (c) and recreation parks without a trail. In addition, there will be a linear park extension along the southern bank of the Project Channel. There is no land acquisitions associated with the development of these recreation areas (see **Figure A-7**).

h. **Road Access** – Road access would be over public roads and highways. No lands would need to be acquired by the non-Federal sponsor.

i. **Operation and Management** – After construction is completed, operation and management of the channel would be done within the Public Domain Lands associated with the MTZ of the CMP. At this time, it appears that no additional lands would need to be acquired by the non-Federal sponsor.

6. ESTATES TO BE ACQUIRED

a. Standard Estates

No Standard Estates would be acquired for this project.

b. Non-Standard Estates

No Non-Standard Estates would be acquired for this project.

Temporary Work Area Easement – A staging area would be located at the CDRC. This land belongs to the CDRC and would be provided by the non-Federal sponsor. A temporary easement and right-of-way in, on, over and across (the land described in Schedule A) (Tracts Nos. 063-000-005-07); for a period not to exceed five years would be acquired by the Commonwealth of Puerto Rico for this Project. The Commonwealth of Puerto Rico has the means to acquire the permits needed to use CDRC. As a governmental entity, ENLACE would be able to use the same permits for CDRC during project construction. ENLACE would share the right to use permit with the USACE for and during project construction.

7. NAVIGATIONAL SERVITUDE

Although the lands required for the project will not be provided through an exercise of the navigation servitude, they remain subject to the navigation servitude

8. FEDERALLY OWNED LAND

There are no federally owned lands within the Project limits.

9. NON-FEDERALLY OWNED LAND

PR Law 489 creates a new delimitation establishing the Public Domain Lands associated with the MTZ of the CMP, which are property of the people of Puerto Rico and administered by the DNER. The Project Channel lies only within the limits of these Public Domain Lands associated with the MTZ of the CMP. Consistent with PR Law 489, ENLACE does not own any lands within the Public Domain Limits where the Project Footprint is located.

As per the dispositions of PR Law 489 and the regulations for the Public Domain Lands, ENLACE would have access to the lands within the Project Footprint for construction and will provide said access to the USACE.

10. NON-FEDERAL OPERATION/MAINTENANCE RESPONSIBILITIES

Operations, Maintenance, Repair, Rehabilitation & Replacement (OMRR&R) will be the responsibility of the DNER. The non-Federal sponsor shall provide, if necessary, all lands, easements, and rights-of-way. The USACE will develop an O&M manual detailing expected OMRR&R requirements and periodically inspect the Project to ensure that DNER is implementing the identified procedures. In addition, the Government of Puerto Rico is and will be conducting all the necessary alterations and/or relocations of facilities and utilities located within the Project's Footprint, the cost of these alterations and relocations are included in the

Project's costs and are disaggregated in the Micro-Computer Aided Cost Engineering System (MCACES).

11. NON-FEDERAL AUTHORITY TO PARTICIPATE IN THE PROJECT

The non-Federal sponsor, ENLACE, derived its authority to participate in the CMP-ERP from PR Law 489.

12. ATTITUDE OF OWNERS

Many residents affected by the present conditions of the CMP support the proposed restoration of the CMP since it represents an improvement in the quality of urban life. Hundreds of meetings have been held with local residents to gather data necessary for the investigation, assessment, and evaluation of alternatives to ensure that the CMP-ERP counts with the active participation and approval of the CMP bordering communities. A "no action" alternative would not be acceptable to many residents of the Project area, the environmental community, or to the government of Puerto Rico. All landowners impacted by the proposed project have been involved in the planning process and have indicated strong support for the Project. In addition, the G-8, Inc., a nonprofit organization that represents leaders of twelve grassroots organizations based in the eight communities that border the CMP, have expressed their support to the CMP-ERP and has established as their mission to promote the interest and involvement of residents in the decision-making process and in the implementation of the CMP Comprehensive Development Plan, in order to ensure the permanence of their communities.

ENLACE is also incorporating a new replacement housing alternative under the Caño Martín Peña Community Land Trust (CMP-CLT). The CMP-CLT is a pioneering entity in Puerto Rico, created to guarantee affordable housing, resolve land tenure issues, and reinvest any future increase in land value in the community. The CMP-CLT is a critical instrument for the implementation of the CMP Comprehensive Development District Plan, as it prevents gentrification and ensures that the current residents benefit directly from investment in infrastructure, urban reform, and environmental restoration.

The ultimate implementation and operation of the CMP-CLT is expected to provide an additional source of affordable housing for relocation purposes. This mechanism enacted by ENLACE have eliminated the displacement of residents as an alternative to conduct the Project and have been essential to ensure the willing support of the community members.

13. MINERALS

All minerals discovered in Puerto Rico are the property of the people of Puerto Rico and the Government of Puerto Rico is their steward. The right to mine and exploit mineral deposits and all laws and regulations regarding this industry are overseen by DNER and the Mining Commission, assigned to the Governor's Office.

There are no known minerals of value in the Project Area.

14. HAZARDOUS, TOXIC AND RADIOACTIVE WASTES (HTRW)

Materials within the Cano Martin Pena include various types of solid waste, debris and other materials. Such materials will require further testing prior to and/or during project construction, as appropriate in accordance with an agreed sampling plan. If the testing determines that any materials contain hazardous substances at levels that are not suitable for unregulated disposal, they will be managed in accordance with the applicable laws and regulations of the relevant regulatory agencies.

15. INDUCED FLOODING

Tidal amplitude within the CMP and the San José Lagoon would increase as a result of construction of the channel. The Lagoon's tide range is expected to increase 1.28 feet after construction, which would equate to a 0.64-foot increase in average monthly water levels. The water surface rise may affect extremely low-lying structures around the SJL. In addition, storm sewers from the airport, at the north of the Suarez Canal, outfall into the SJL. The airport has been present for decades and presumably operating prior to the filling of the CMP. The airport is higher than its outfalls and thus may be able to build up a hydraulic head in its conduit to offset these monthly events. The proposed Project Channel, along with its sheet pile walls and adjoining mangrove beds, are intended to form the floodway to contain the frequent storm events. Flood control measures, such as the construction of suitable protective structures between the channel waters and the adjoining low areas, will be incorporated to mitigate water backflow effect. Other alternatives may include the installation of a temporary sheet pile wall with local select backfill to buttress the structure. These temporary flood protection solutions would remain in place until the proposed sheet pile channel wall and upland embankment of the mangrove bed are installed. Proper construction (e.g., elevation) of the Paseo and related structures would provide additional, ancillary community flood protection.

Additional hydraulic and hydrologic (H&H) modeling and analyses are needed to confirm the potential for induced flooding as a result of the implementation of the CMP-ERP. This additional technical investigation would be completed before the conclusion of preconstruction engineering and design (PED).

16. RELOCATIONS ASSISTANCE (PL 91-646)

Approximately, 435 total acquisitiones and relocations will occur as part of the federal project. Of these, 99 have already been carried out and an estimated 336 structures with 229 eligible resident owners and 106 tenants remain to be relocated as a consequence of the CMP-ERP. Currently there is no estimate for the number of businesses within the project footprint. In accordance with the Uniform Relocation Assistance and Real Property Acquisition Policies Act of 1970 (URA), as amended (42 U.S.C. 9601 et seq.), relocation assistance will be provided to persons and businesses, if any, displaced as a result of the project. In order to qualify as a "displaced person" under the URA, the person must be a lawful occupant. The non-Federal sponsor will determine on a case by case basis whether an occupant of the Project Area is a lawful occupant, as per the criteria established under applicable Puerto Rico State law. The nature and amount of assistance provided to displaced persons will be determined in accordance with the URA and the lead agency implementing regulations at 49 CFR Part 24.

The non-Federal sponsor understands that relocations carried out prior to the execution of a Project Partnership Agreement (PPA) may not be creditable for the CMP-ERP.

ENLACE has been advised about and acknowledges the risk of proceeding with acquisitions in advance of Project Authorization and a PPA.

17. RELOCATIONS, ALTERATIONS, VACATIONS AND ABANDONMENTS (UTILITIES, STRUCTURES AND FACILITIES, CEMETERIES AND TOWNS)

The entire known infrastructure affected by the CMP-ERP falls within the Public Domain Lands associated with the MTZ of the CMP. Alterations and relocations will be responsibility of the non-Federal sponsor, following the detailed list of infrastructure affected by the CMP-ERP (see **Figure A-8**):

- Rexach Trunk Sewer Siphon Project
- Borinquen Water Transmission Line
- An existing 115-kV overhead transmission line that runs from a substation near the Tren Urbano guiderail on the western end of the Project Channel, east via Rexach Avenue and then south to the canal and SJL will be raised and then its alignment changed to the northern side of the Project.
- Construction of the CMP-ERP requires demolition of tertiary roadways adjacent to the canal
- Construction of the CMP-ERP requires the capping of several tertiary drinking water lines
- Demolition of 336 structures and associated infrastructure

These structures would be demolished and their utility services rerouted or terminated; debris and existing surface streets within the Project's limits would be removed, as listed above. Any existing raw sewage discharges and/or uncontrolled storm water runoff from the area will be stopped prior to commencing dredging activities. No bridge relocations or alterations are being considered as part of the CMP-ERP. No towns or cemeteries would be relocated as result of the CMP-ERP.

18. STANDING TIMBER AND VEGETATIVE COVER

Currently the CMP is mostly covered by approximately 33 acres of mangrove wetland. As a result of the CMP-ERP, both the north and south sides of the Project Channel would be graded to allow the creation of 34 acres of habitat for mangrove planting and a future forested wetland. The planting bed would be graded from the channel margin to, in most cases, the upland side of the Project limit.

Initial control of invasive species would be provided during construction of the mangrove planting beds. Visual surveys would be conducted and removal of identified invasive vegetation would be accomplished by physical removal or through the use of herbicide, as applicable. Over the life of the CMP-ERP, monitoring for invasive species establishments would be included as part of the monitoring plan, and additional physical removal or herbicide application would be utilized, as necessary. The CMP-ERP would be designed to provide optimal conditions for native vegetation, reducing the probability for establishment and spread of invasive species. As such, no costs have been estimated for future control efforts.

19. RECREATION RESOURCES

The CMP-ERP would include nine recreation access parks, six recreation parks with a trail to the CMP, six recreation parks without a trail, and a linear park extension along the southern bank in the Project Channel that would terminate in the Parada 27 community (see **Figure A-6**). The recreational features fall within the Public Domain Lands associated with the MTZ of the CMP, therefore no land acquisition is required.

20. CULTURAL RESOURCES

At present, no previously recorded sub-aquatic prehistoric cultural resources have been identified in the area, and there is no historic evidence of smaller marine vessels encountered in the CMP; however, the investigations conducted in the area have been limited due to restricted access and pollution in the CMP Channel. The possibility of encountering submerged cultural remains still exists and is considered to be high. There is also a probability of encountering cultural remains from the old bridges constructed in the area, as well as remains from fishing corrals and middens resulting from the first squatter settlements in the early Twentieth Century.

The Martín Peña Bridge is located above the CMP in the 8 km of the Ponce de Leon Avenue and is regarded as one of the most important historic structures in the CMP District. Built in 1939, the Martín Peña Bridge is the last of several bridges which were located in the same area and that constituted the main crossing between Hato Rey and Santurce since the 1500s. This location is also the site of one of the key battles that led to the defeat of the British invasion of San Juan of 1797, led by Admiral Ralph Abercromby. Community efforts to preserve the Martín Peña Bridge led to the enactment of Puerto Rico Law No. 110 of 2007, which declares the Martín Peña Bridge as a Historical Monument of Puerto Rico. In 2008, the Martín Peña Bridge was listed on the United States National Register of Historic Places. The Martín Peña Bridge will be photo-documented as part of the Project.

A Field Archeologist will be employed full-time to monitor construction activities conducted near the Martín Peña Bridge, as well as the dredged materials during the dredging process. The Field Archeologist will be aided by a Supervising Archeologist who will be employed part-time. The Field Archeologist will be present on the materials barge where the screening of the dredged materials will be conducted; if multiple dredges are operating simultaneously, at least one Archaeologist per dredge will be required. Cultural resources monitoring would be conducted as each clamshell bucket of material is laid onto the barge. Additional information on *Cultural Resources* can be found in Section 3.15 of the EIS.

21. OUTSTANDING RIGHTS

There are no known outstanding rights in the Project Area.

22. MITIGATION

Construction mitigation entails noise and vibration mitigation efforts. Temporary noise curtains would be installed to the north and south of the dredging operations. Dredging and construction operations would be limited to 12 hours a day, no dredging or construction activities will be conducted on Sundays. Noise levels in areas adjoining construction sites will be monitored with appropriate portable and/or stationary equipment to ensure the levels are under the maximum allowed. If the maximum allowed is exceeded, the response will be to stop work; conduct noise producing operations during daylight hours; and/or review procedures to determine means and methods that are more effective to reduce noise levels.

Four stationary vibration monitoring devices will be installed along the border between the working area and the adjoining structures, both north and south of the CMP. In addition, a photo-survey of the exterior of existing structures facing and adjoining the work would be prepared to document pre-construction condition. Visual observation of existing structures in areas adjoining construction sites would be conducted for visible damage. If excessive levels of vibration occur, the response would be to stop work; avoid using equipment near adjoining structures that produces heavy vibrations; and/or review procedures to determine means and methods that are more effective to reduce vibration levels. Alternative sheet pile installation methods such as "press-in" pile drivers or other drivers that produce less vibration may be used, if available and feasible. Potential temporary relocations are incorporated as part of the Cost Risk Analysis that determined the 23 percent contingency for Relocations.

23. ACQUISITION/ADMINISTRATIVE COSTS

The estimate of the Federal real estate acquisition/administrative cost is $1,878,500.00. This figure includes Project REP, review, monitoring, land acquisition, and transportation costs. The non-Federal sponsor will receive credit towards its share of real estate acquisition/ administrative project cost incurred for certification. Non-Federal acquisition/administrative costs are estimated to be $1,939,520.00.

24. SUMMARY OF PROJECT REAL ESTATE COSTS

The following cost figures are subject to change prior to construction:

Federal:	
-Labor (DS-RE) (146 hrs.)	$14,000.00
-Labor (Appraisal) ($1,750 x 371 app. Reports)	$588,000.00
-Labor (RE-A) ($2,500 x 375 crdt pckgs)	$850,000.00
-Transportation	$3,000.00
Total	$1,455,000.00
Non-Federal Sponsor:	
Lands and Damages	
-Real Estate Acquisition (Staging Area)	$126,000
-Real Estate Adm. Costs (Staging Area)	$50,000
Relocations	
PL 91-646 Real Estate Payments	
-Structure Relocations Assistance Pmts (Rent Moving Pmts, etc.)	$34,660,000
-Relocation benefits for tenants	$907,572.00
-Adm. Costs (Appraisal, Attny Costs, Mapping)	$1,939,520
PL 91-646 Assistance (Labor) The non-Federal sponsor understands that labor may not be creditable for the Project.	$0.00
Contingencies (estimated at 23.06%)	$9,025,244.02
Total Estimated Real Estate Cost with contingency:	$48,163,336.02

25. REAL ESTATE ACQUISITION SCHEDULE

The acquisition process will be an aggressive one that will encompass 336 structures with 229 eligible resident owners and 106 tenants to be relocated utilizing PL 91-646 criteria. ENLACE will carry out 100 relocations in the first year, 100 in the second year and 135 in the third year, prior to start of construction. The non-Federal sponsor will acquire the necessary permits and rights for the establishment of the temporary work area.

26. REAL ESTATE CHART OF ACCOUNTS

LANDS & DAMAGES

RELOCATION AND CONDEMNATION EXPENSES – FEDERAL	
Relocation and Moving Cost – By Federal Government	**Cost ($)**
Relocation and Moving Cost (Federal) for Administrative Expenses	
Administrative Cost for Relocation and Moving – Appraisal Review by USACE	588,000.00
Administrative Cost for Relocation and Moving – Relocation Review by USACE	850,000.00
Transportation (Per USACE)	3,000.00
Real Estate Administrative Labor Expense (Per ENLACE)	14,000.00
RELOCATION AND CONDEMNATION EXPENSES – LOCAL	
Relocation and Moving Cost – By Local Sponsor	
Relocation and Moving Cost (By Local Sponsor) Paid to Eligible Occupying Owner	
Relocation and Moving Expense, Per Occupying Owner	34,660,000.00
Relocation and Moving Expense, Per Occupying Tenant	907,572.00
Relocation and Moving Cost (By Local Sponsor) for Administrative Expenses	
Administrative Cost for Relocation and Moving – Appraisal Expense	527,520.00
Administrative Cost for Relocation and Moving – Relocation Expense	1,190,000.00
Administrative Cost for Relocation and Moving – Condemnation Expense	222,000.00
REAL ESTATE ACQUISITION AND ADMINISTRATIVE COST	
Real Estate Temporary Operation Cost	
Temporary Operations and Land Use Cost	
Parking Area Land Use Fee	126,000.00
Project Planning (from real Estate Division Operations)	50,000.00

RELOCATIONS

UTILITY RELOCATIONS	
Utility Relocations Rexach Sewer Line	**Cost ($)**
Rexach Sewer Line Replacement & Relocation	8,500,000.00
Borinquen Water Main	
Borinquen Water Main Relocation	5,400,000.00
115-kV Transmission Line	
Power Line Relocation, 115 kV	263,163.00

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Exhibit A

Figures

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EXHIBIT A – FIGURES

Figure A-1. Caño Martín Peña Ecosystem Restoration Project Area Map & San José Lagoon Pits 1 and 2

Figure A-2. Caño Martín Peña Ecosystem Restoration Project Demolition Areas Map

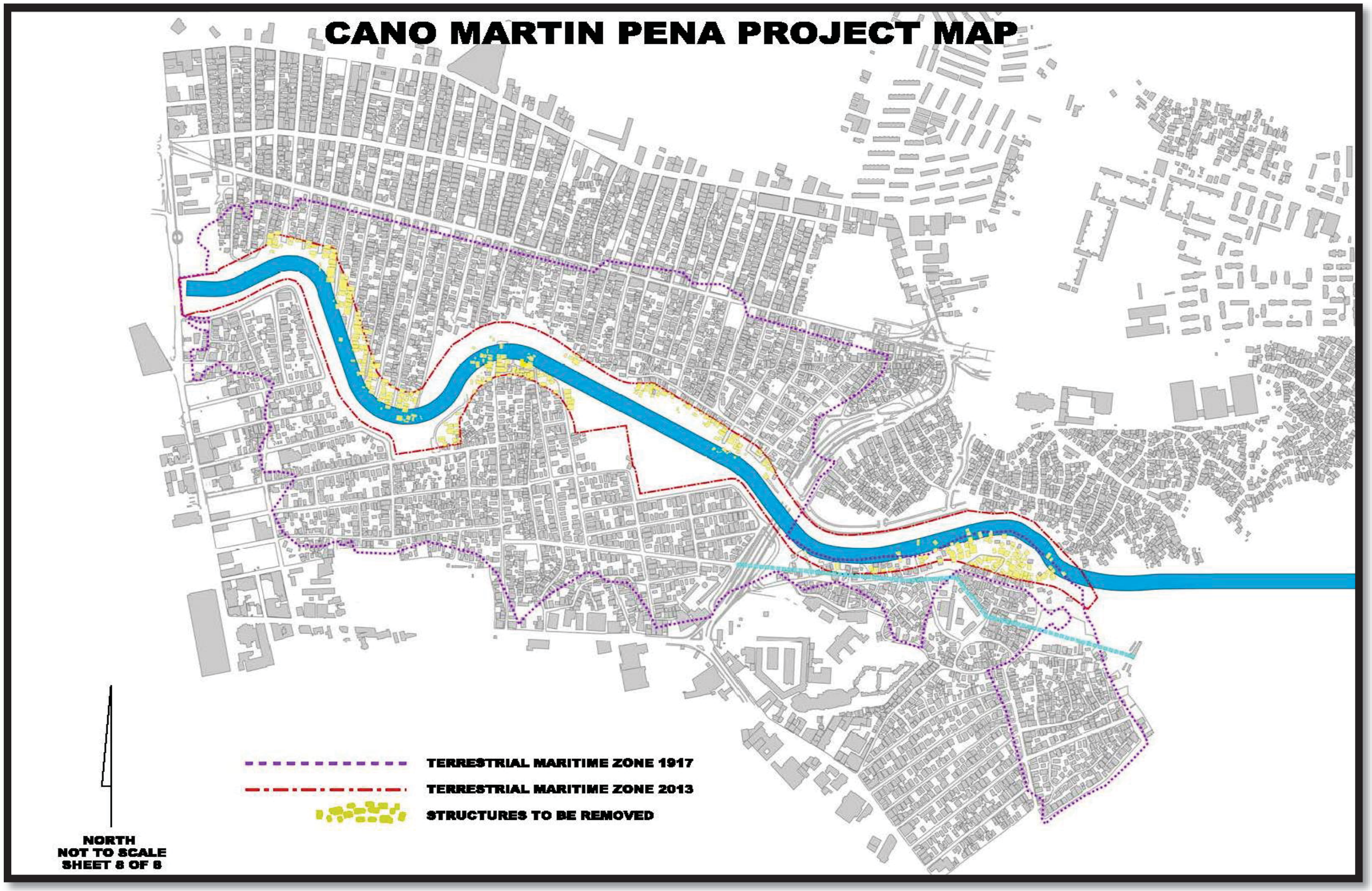

Figure A-3. Caño Martín Peña Ecosystem Restoration Project Humacao Regional Landfill Map & Potential Sediment Disposal Yauco, Peñuelas and Ponce Landfills Map

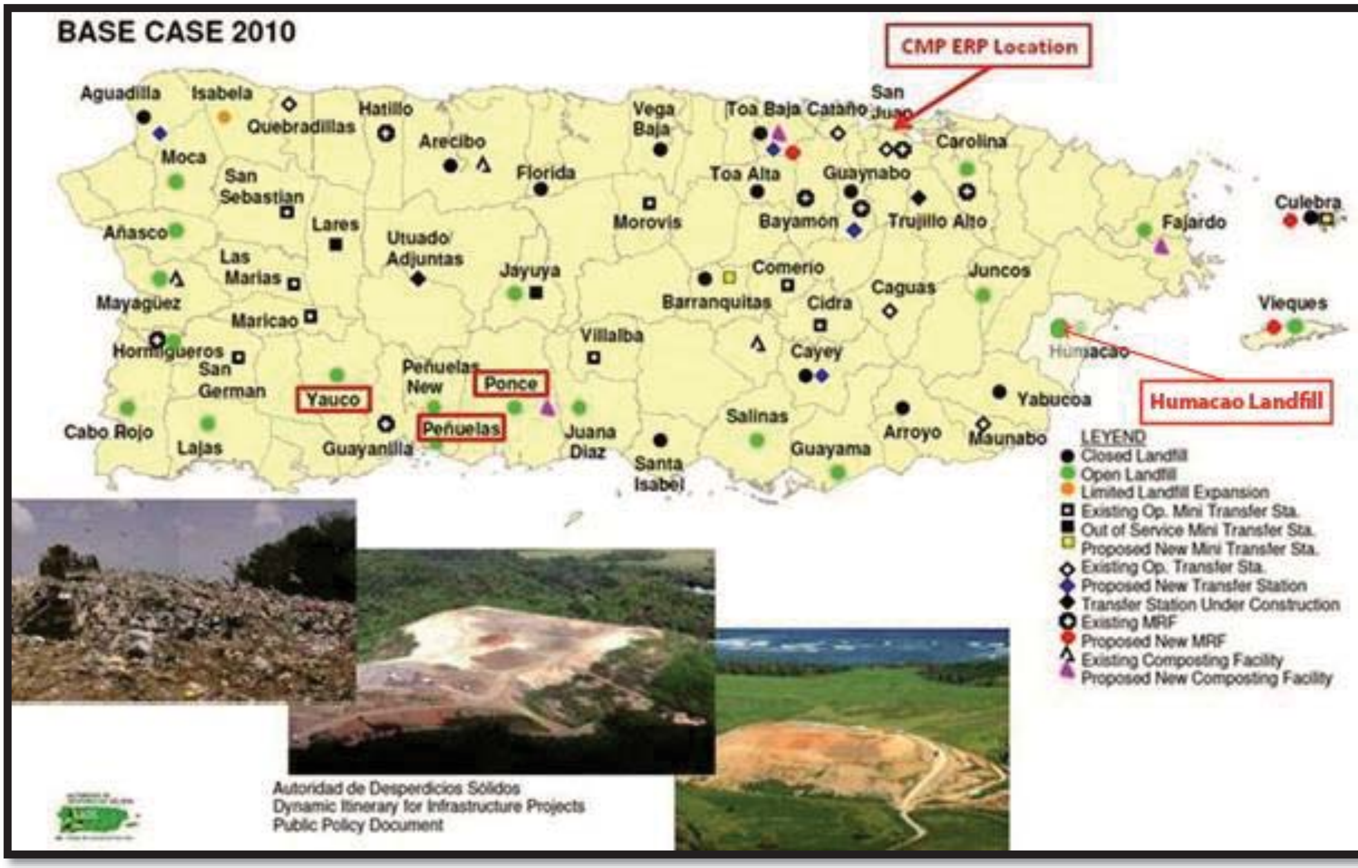

Figure A-4. Mangrove Restoration Area Map

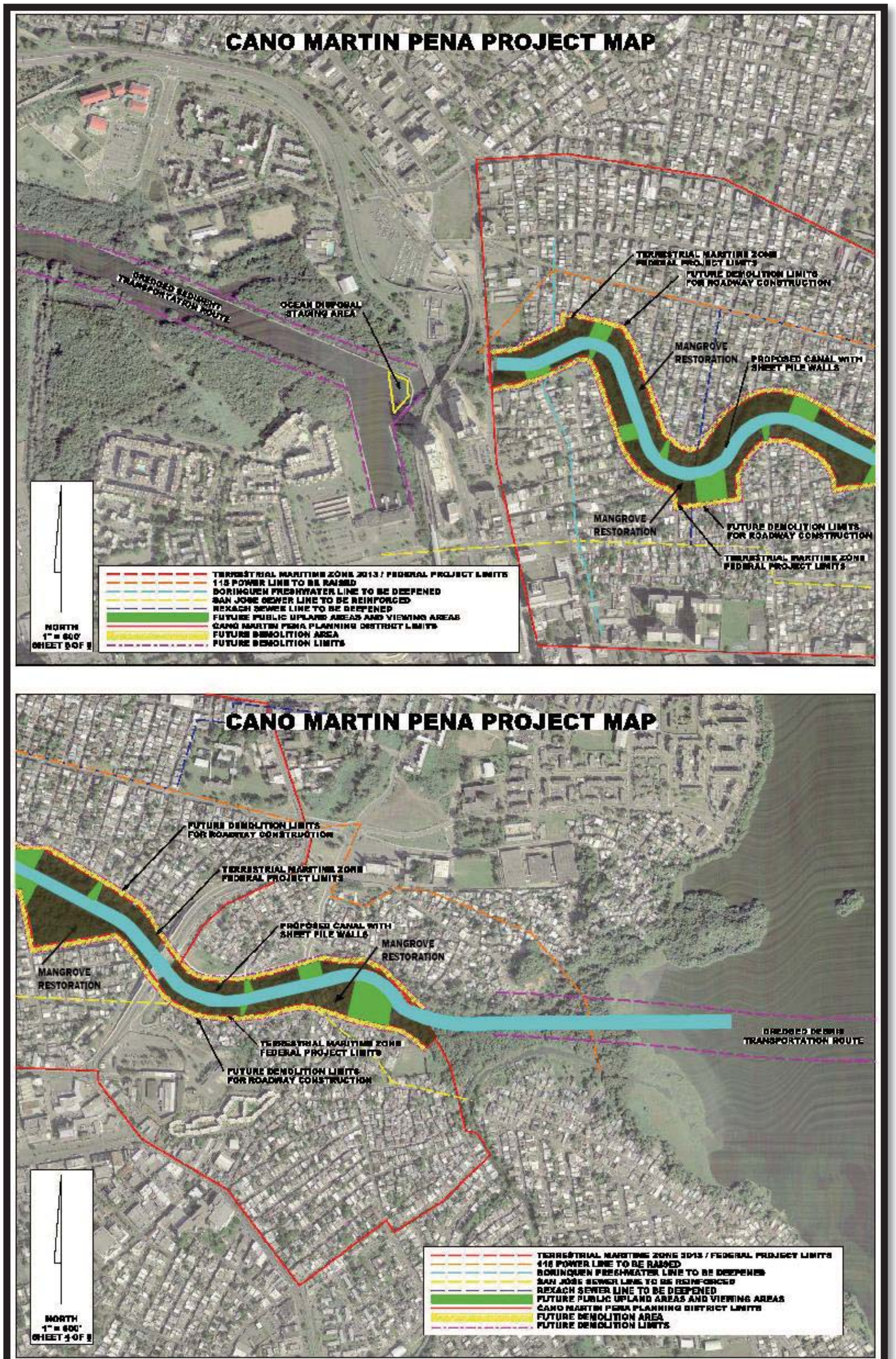

Figure A-5. *Ciudad Deportiva Roberto Clemente* Staging Area Map

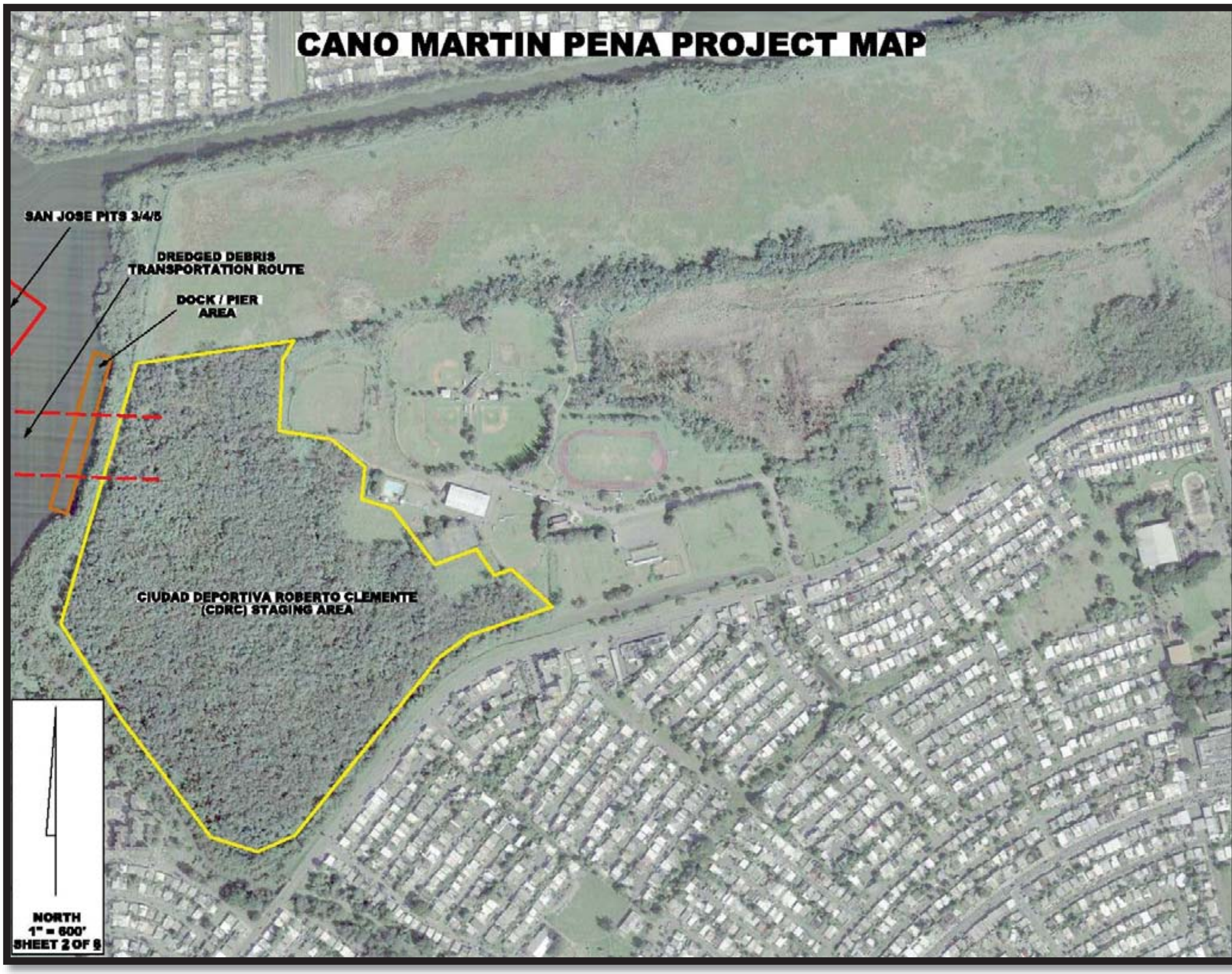

Figure A-6. Recreation Access Parks Map

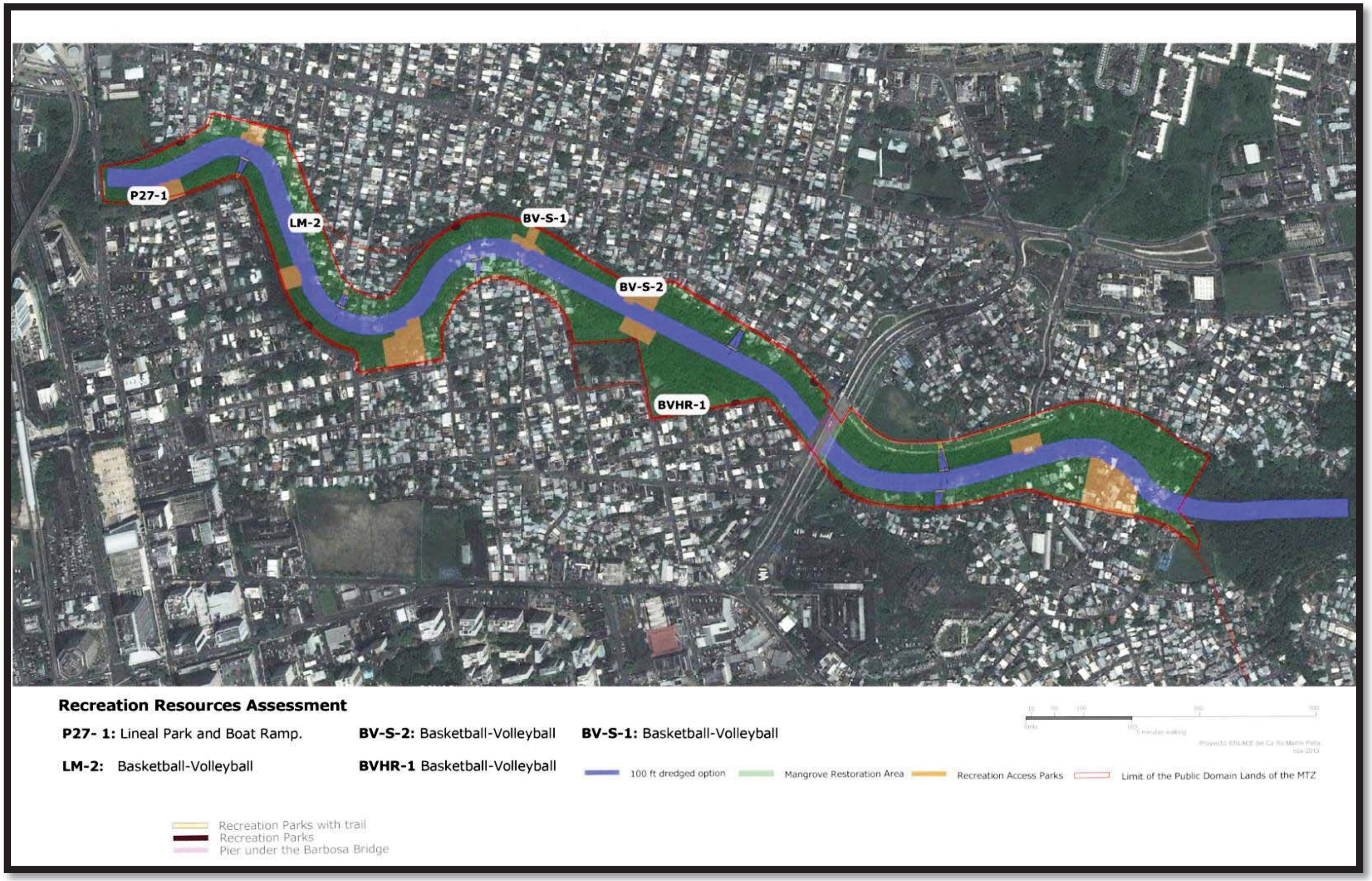

Figure A-7. Caño Martín Peña Aerial Photo (1936)

Figure A-8. Relocations, Alterations, Vacations and Abandonments Areas Map (utilities, structures and facilities, cemeteries and towns)

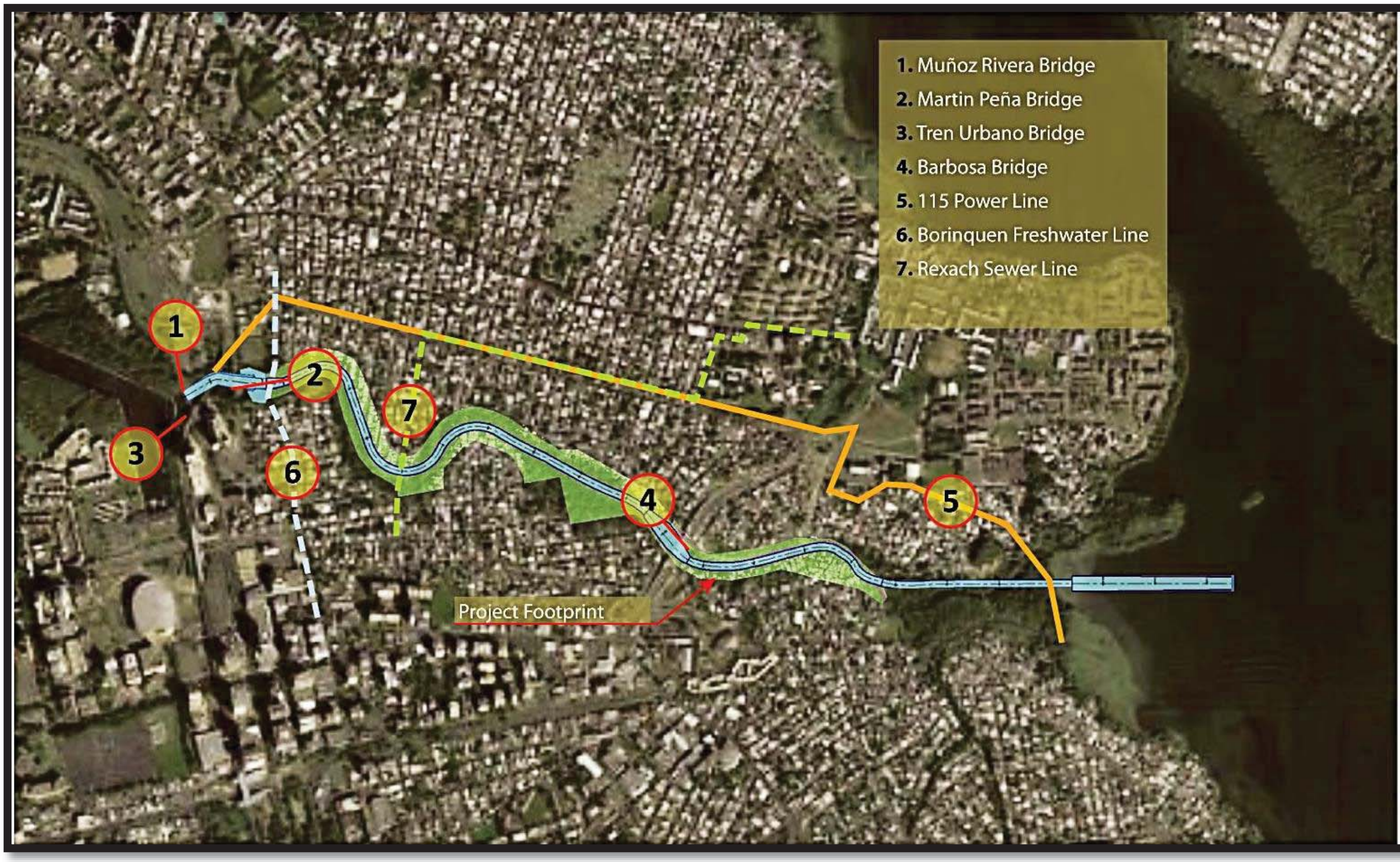

Exhibit B

Draft Assessment of Non-Federal Sponsor's
Real Estate Acquisition Capability
Corporación del Proyecto ENLACE del Caño Martín Peña

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EXHIBIT B – Draft Assessment of Non-Federal Sponsor's Real Estate Acquisition Capability Corporación del Proyecto ENLACE del Caño Martín Peña

PROJECT:
Caño Martín Peña Ecosystem Restoration Project

I. **LEGAL AUTHORITY**:

a. Does the sponsor have legal authority to acquire and hold title of real property for project purposes? **YES**

b. Does the sponsor have the power of eminent domain for this project? **YES**

c. Does the sponsor have "quick-take" authority for this project? **YES**

d. Are any of the lands/interests in land required for the Project located outside the non-Federal sponsor's political boundary? **NO**

e. Are any of the lands/interests in land required for the project owned by an entity whose property the sponsor cannot condemn? **NO**

II. **HUMAN RESOURCE REQUIREMENTS**:

a. Will the sponsor's in-house staff require technical training to become familiar with the real estate requirements of Federal projects including U.S. Public Law 91-646, as amended? **NO**

b. If the answer to IIa. is "yes," has a reasonable plan been developed to provide such training? **N/A**

c. Does the sponsor's in-house staff have sufficient real estate acquisition experience to meet its responsibilities for the project? **YES**

d. Is the sponsor's projected in-house staffing level sufficient considering its other work load, if any, and the project schedule? **YES**

e. Can the sponsor obtain contractor support, if required in a timely fashion? **YES**

f. Will the sponsor likely request United States Corps of Engineers (USACE) assistance in acquiring real estate? **NO**

III. **OTHER PROJECT VARIABLES**:

a. Will the sponsor's staff be located within reasonable proximity to the project site? **YES**

b. Has the non-Federal sponsor approved the project/real estate schedule/milestones? **YES**

IV. **OVERALL ASSESSMENT**:

a. Has the sponsor performed satisfactorily on other USACE projects? **N/A**

b. With regard to the project, the sponsor is anticipated to be: **HIGHLY CAPABLE**

V. COORDINATION:

a. Has this assessment been coordinated with the sponsor? **YES**

b. Does the sponsor concur with this assessment? **YES**

Date: ______________________

Prepared by:

____
Realty Specialist
Real Estate Division
Jacksonville District

Reviewed by:

____
Hansler A. Bealyer
Chief
Acquisition Branch
Real Estate Division
Jacksonville District

Reviewed and approved by:

____
Audrey C. Ormerod
Chief
Real Estate Division
Jacksonville District

Exhibit C

Memorandum of Agreement
Between ENLACE and USACE

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MEMORANDUM OF AGREEMENT
BETWEEN
THE DEPARTMENT OF THE ARMY
AND
CORPORACIÓN DEL PROYECTO ENLACE DEL CAÑO MARTÍN PEÑA
FOR THE REVIEW OF THE
FEASIBILITY REPORT AND ENVIRONMENTAL IMPACT STATEMENT
FOR THE
CAÑO MARTÍN PEÑA, ECOSYSTEM RESTORATION PROJECT

This MEMORANDUM OF AGREEMENT (hereinafter the "MOA") is entered into this 26th day of June, 2012, by and between the Department of the Army (hereinafter the "Government"), represented by the U.S. Army Engineer, Jacksonville District (hereinafter the "District Engineer"), and the Corporación del Proyecto ENLACE del Caño Martín Peña (hereinafter the "Contributor"), represented by its Executive Director.

WITNESSETH, THAT:

WHEREAS, Section 5127 of the Water Resources Development Act of 2007, Public Law 110-114, directs the Secretary of the Army to review a report prepared by the non-Federal interest concerning flood protection and environmental restoration for Caño Martín Peña, San Juan, Puerto Rico (hereinafter "report"), and, if the Secretary of the Army determines that the report meets the evaluation and design standards of the Corps of Engineers and that the project is feasible, the Secretary may carry out the project at a total cost of $150,000,000;

WHEREAS, the Contributor considers it to be in its own interest to contribute funds voluntarily (hereinafter the "Contributed Funds") to be used by the Government for the review of the report, entitled "Feasibility Report and Environmental Impact Statement for the Caño Martín Peña Ecosystem Restoration Project," to be completed by the Contributor in July 2012 (hereinafter "Review"); and

WHEREAS, the Government is authorized pursuant to 33 U.S.C. 701h to accept Contributed Funds to be used for the Review.

NOW, THEREFORE, the Government and Contributor agree as follows:

1. The Contributor shall provide to the Government Contributed Funds for all costs associated with the Review. While the Government will endeavor to limit costs associated with the Review under this MOA to the current estimate of $300,000, the Contributor understands that the actual costs for the Review may exceed the amount of the estimate due to claims or other unforeseen circumstances.

2. Within seven (7) calendar days of execution of this MOA, the Contributor shall provide to the Government the sum of $300,000, which is the current estimated cost of the

Review. Within thirty (30) calendar days of written notification by the Government that additional funds are needed to fund costs of the Review, the Contributor shall provide such additional funds.

3. The Contributor currently has $300,000 allocated and available to fund the Review, as well as an additional $50,000 in reserve to fund potential cost overages.

a. Nothing in this MOA shall constitute, nor be deemed to constitute, an obligation of future appropriations by the Government of the Commonwealth of Puerto Rico, where creating such obligation would be inconsistent with Law 230 of July 23, 1974, known as the Accounting Law of the Government of Puerto Rico (3 L.P.R.A. § 283, et seq., as amended).

b. The Contributor intends to fulfill its obligation under this MOA. In the event that the costs of the Review will exceed $350,000, the Government will notify the Contributor of the additional funds needed to fund costs of the Review. The Contributor shall include in its budget request or otherwise propose appropriations of these funds and shall use all reasonable and lawful means to secure these funds. The Contributor reasonably believes that funds in amounts sufficient to fulfill these obligations lawfully can and will be appropriated and made available for this purpose. In the event funds are not appropriated in amounts sufficient to fulfill these obligations, the Contributor shall use its best efforts to satisfy any requirements for Contributed Funds under this MOA from any other source of funds legally available for this purpose.

4. The Contributor shall provide the Contributed Funds to the Government by delivering a check payable to "FAO, USAED Jacksonville" to the District Engineer; or verifying to the satisfaction of the Government that such funds have been deposited in an escrow or other account acceptable to the Government, with interest accruing to the Contributor; or presenting the Government with an irrevocable letter of credit acceptable to the Government for such funds; or providing an Electronic Funds Transfer of such funds in accordance with procedures established by the Government.

5. The Government shall provide the Contributor with quarterly accountings of obligations of the Contributed Funds for the Review. The first such accounting shall be provided within thirty (30) calendar days after the final day of the first complete Government fiscal year quarter following receipt of the Contributed Funds, and subsequent accountings shall be provided within thirty (30) calendar days after the final day of each succeeding quarter until the Government concludes the Review. Upon conclusion of the Review and resolution of all relevant claims and appeals, the Government shall conduct a final accounting of the costs of such work and furnish the Contributor with written notice of the results of such final accounting. Such final accounting shall in no way limit the Contributor's responsibility to pay for all costs associated with the Review, including contract claims or any other liability that may become known after the final accounting.

6. Should the final accounting show that the costs of the Review exceed the amount provided by the Contributor, the Contributor shall provide the additional required funding in

accordance with paragraph 4 of this MOA within sixty (60) calendar days of written notice of the final accounting. Should the final accounting show that the costs of the Review is less than the amount provided by the Contributor, the Government shall refund the excess to the Contributor within sixty (60) calendar days of the written notice of the final accounting.

7. No credit or repayment is authorized, nor shall be provided, for any Contributed Funds obligated by the Government.

8. Nothing herein shall constitute, represent, or imply any commitment to budget or appropriate funds for the Project in the future; and nothing herein shall represent, or give rise to, obligations of the United States.

9. Before any party to this MOA may bring suit in any court concerning an issue relating to this MOA, such party must first seek in good faith to resolve the issue through negotiation or other forms of nonbinding alternative dispute resolution mutually acceptable to the parties.

10. In the exercise of their respective rights and obligations under this MOA, the Contributor and the Government agree to comply with all applicable Federal and State laws and regulations, including, but not limited to, Section 601 of the Civil Rights Act of 1964, Public Law 88-352 (42 U.S.C. 2000d), and Department of Defense Directive 5500.11 issued pursuant thereto, as well as Army Regulation 600-7, entitled "Nondiscrimination on the Basis of Handicap in Programs and Activities Assisted or Conducted by the Department of the Army."

11. In the exercise of their respective rights and obligations under this MOA, the Government and the Contributor each act in an independent capacity, and neither is to be considered the officer, agent, or employee of the other.

12. Notices.

a. Any notice, request, demand, or other communication required or permitted to be given under this MOA shall be deemed to have been duly given if in writing and either delivered personally or mailed by first-class, registered, or certified mail, as follows:

If to the Contributor:

Executive Director
Corporación del Proyecto
ENLACE del Caño Martín Peña
PO Box 41308
San Juan, PR 00940-1308

If to the Government:

District Engineer
Jacksonville District
U.S. Army Corps of Engineers
P.O. Box 4970
Jacksonville, Florida 32232-0019

b. A party may change the address to which such communications are to be directed by giving written notice to the other party in the manner provided in this paragraph.

c. Any notice, request, demand, or other communication made pursuant to this paragraph shall be deemed to have been received by the addressee at the earlier of such time as it is actually received or seven (7) calendar days after it is mailed.

13. To the extent permitted by the laws governing each party, the parties agree to maintain the confidentiality of exchanged information when requested to do so by the providing party.

14. This MOA may be modified or amended only by written, mutual agreement of the parties.

IN WITNESS WHEREOF, the parties have executed this MOA as of the day, month, and year first above written.

THE DEPARTMENT OF THE ARMY

BY:
Alfred A. Pantano, Jr.
Colonel, U.S. Army
District Commander

DATE: 26 June 2012

CORPORACIÓN DEL PROYECTO ENLACE DEL CAÑO MARTÍN PEÑA

BY:
Lyvia N. Rodríguez del Valle
Executive Director

DATE: June 25, 2012

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CERTIFICATE OF AUTHORITY

I, Myriam González Torres, do hereby certify that I am the legal officer for this agreement for the CORPORACIÓN DEL PROYECTO ENLACE DEL CAÑO MARTÍN PEÑA, that the CORPORACIÓN DEL PROYECTO ENLACE DEL CAÑO MARTÍN PEÑA is a legally constituted public body with full authority and legal capability to perform the terms of the Agreement between the Department of the Army and the CORPORACIÓN DEL PROYECTO ENLACE DEL CAÑO MARTÍN PEÑA, and to pay damages in accordance with the terms of this Agreement, if necessary, in the event of the failure to perform and that the persons who have executed this Agreement on behalf of the CORPORACIÓN DEL PROYECTO ENLACE DEL CAÑO MARTÍN PEÑA have acted within their statutory authority.

IN WITNESS WHEREOF, I have made and executed this certification this 25th day of June 2012.

Myriam González Torre

Myriam González Torres, Attorney for
Corporación del Proyecto ENLACE del Caño Martín Peña

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CERTIFICATION REGARDING LOBBYING

The undersigned certifies, to the best of his or her knowledge and belief that:

(1) No Federal appropriated funds have been paid or will be paid, by or on behalf of the undersigned, to any person for influencing or attempting to influence an officer or employee of any agency, a Member of Congress, an officer or employee of Congress, or an employee of a Member of Congress in connection with the awarding of any Federal contract, the making of any Federal grant, the making of any Federal loan, the entering into of any cooperative agreement, and the extension, continuation, renewal, amendment, or modification of any Federal contract, grant, loan, or cooperative agreement.

(2) If any funds other than Federal appropriated funds have been paid or will be paid to any person for influencing or attempting to influence an officer or employee of any agency, a Member of Congress, an officer or employee of Congress, or an employee of a Member of Congress in connection with this Federal contract, grant, loan, or cooperative agreement, the undersigned shall complete and submit Standard Form-LLL, "Disclosure Form to Report Lobbying," in accordance with its instructions.

(3) The undersigned shall require that the language of this certification be included in the award documents for all sub-awards at all tiers (including subcontracts, sub-grants, and contracts under grants, loans, and cooperative agreements) and that all sub-recipients shall certify and disclose accordingly.

This certification is a material representation of fact upon which reliance was placed when this transaction was made or entered into. Submission of this certification is a prerequisite for making or entering into this transaction imposed by 31 U.S.C. 1352. Any person who fails to file the required certification shall be subject to a civil penalty of not less than $10,000 and not more than $100,000 for each such failure.

Lyvia N. Rodríguez del Valle
Executive Director

DATE: June 25, 2012

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Appendix C

Recreation Resources Assessment and Recreation Plan

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DRAFT
FEDERAL RECREATION PLAN AND RECREATION RESOURCE ASSESSMENT CAÑO MARTÍN PEÑA ECOSYSTEM RESTORATION PROJECT SAN JUAN, PUERTO RICO

Prepared for:

Corporación del Proyecto ENLACE del Caño Martín Peña
Apartado Postal 41308
San Juan, Puerto Rico 00940-1308

September 2015

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Contents

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List of Tables

Acronyms and Abbreviations

CDLUP	Comprehensive Development and Land Use Plan
CDRC	Ciudad Deportiva Roberto Clemente
CM	Construction Management
CMP	Caño Martín Peña
CMP-ERP	Caño Martín Peña Ecosystem Restoration Project
CPI	Consumer Price Index
CVM	Contingent valuation method
EGM	USACE Economic Guidance Memorandum
ER	Engineering Regulation
FRP	Federal Recreation Plan
FY	Fiscal year
NED	National Economic Development
PED	Preconstruction Engineering and Design
PR SCORP	Puerto Rico State Comprehensive Outdoor Recreation Plan
SJBE	San Juan Bay Estuary
TCM	Travel cost method
UDV	Unit day value
USEPA	U.S. Environmental Protection Agency

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1.0 INTRODUCTION

The Caño Martín Peña (CMP) is an approximately 4-mile-long waterway, which connects the San Juan Bay and San José Lagoon, in metropolitan San Juan, Puerto Rico. It is part of the San Juan Bay Estuary (SJBE), the only tropical estuary that is included in the U.S. Environmental Protection Agency (EPA) National Estuary Program. The total drainage area of the CMP is about 4 square miles (2,500 acres). The eastern 2.2-mile-long segment of the CMP (Project Channel) and its adjacent areas, including the San José Lagoon, are the focus of this restoration project.

Historically, the CMP waterway had an average width of at least 200 feet and 6 to 8 feet in depth. The CMP provided tidal exchange between the San Juan Bay and San José Lagoon; however, since the 1920s, the channel and its wetlands began to be modified as a result of development in the area. The wetlands adjacent to the San Juan Bay and along the CMP were used as a disposal site for material dredged from the San Juan Harbor Project, affecting or eliminating more than 80 percent of the original mangrove acreage found in this area of the SJBE. In addition, as a result of the decay of the sugar cane industry, among other factors, massive migration from rural Puerto Rico to San Juan led to squatter settlements in areas along the CMP. Today, there are eight communities located to the north and south of the eastern segment of the CMP. The population is estimated to total 26,000 inhabitants. Approximately 350 families still live within the construction footprint.

1.1 ECOSYSTEM RESTORATION PROJECT STUDY AUTHORITY

The 110th Congress enacted Public Law 110-114, known as the Water Resources Development Act of 2007 in which Section 5127 directed that:

> *The Secretary shall review a report prepared by the non-Federal interest concerning flood protection and environmental restoration for Cano Martin Pena, San Juan, Puerto Rico, and, if the Secretary determines that the report meets the evaluation and design standards of the Corps of Engineers and that the project is feasible, the Secretary may carry out the project at a total cost of $150,000,000.*

1.2 ECOSYSTEM RESTORATION PROJECT DESCRIPTION

The CMP's ability to convey flows has been almost completely blocked as a result of siltation, accumulation of sediment and solid waste and the encroachment of housing and other structures. The CMP ecosystem restoration project (CMP-ERP) proposes to dredge the eastern segment of the canal to restore the CMP and its adjacent areas and to increase tidal flushing of the San José Lagoon in order to achieve environmental restoration and, as ancillary benefits, reduce flooding. In addition, the CMP-ERP will promote recreation and tourism with minimal negative impact on the ecosystem and the adjacent communities. The "Project Area," which mostly lays out the construction footprint, has been defined as the Project Channel, where dredging would take place, the adjacent delimitation of the public domain lands within the MTZ-CMP where relocations are scheduled to occur. Also included in the Project Area is the 6-acre dredged material staging area within the 35-acre Ciudad Deportiva Roberto Clemente (CDRC) site, the boating routes from the eastern limit of the CMP to the CDRC and the nearby San José Lagoon pits, and the five pits in San José Lagoon (Figure 1).

1.3 LOCAL COOPERATION

The Caño Martín Peña ENLACE Project Corporation, hereinafter referred to as ENLACE, is the non-Federal sponsor for the ecosystem restoration project. The Caño Martín Peña Special Planning District (Planning District) is interested in the completion of the project to improve environmental conditions along the CMP and provide opportunities for recreation to assist with the completion of the Comprehensive Development and Land Use Plan (CDLUP). The Planning District has requested that the Corps pursue recreation development opportunities in conjunction with the ecosystem restoration project. The local sponsor understands and accepts the following constraints:

- The total recreation plan cost cannot exceed 10 percent of the Federal cost for the ecosystem recreation project.
- The recreation plan cannot reduce the environmental benefits of the ecosystem restoration project.
- Any additional recreation features not authorized for 50/50 cost share will be 100 percent non-Federal cost.
- The cost of any betterments to the proposed Federal Recreation Plan will be 100 percent non-Federal cost.
- The cost of operation and maintenance of the Federal Recreation Plan will be 100 percent non-Federal cost.
- The proposed recreation plan will not require purchase of additional project lands.

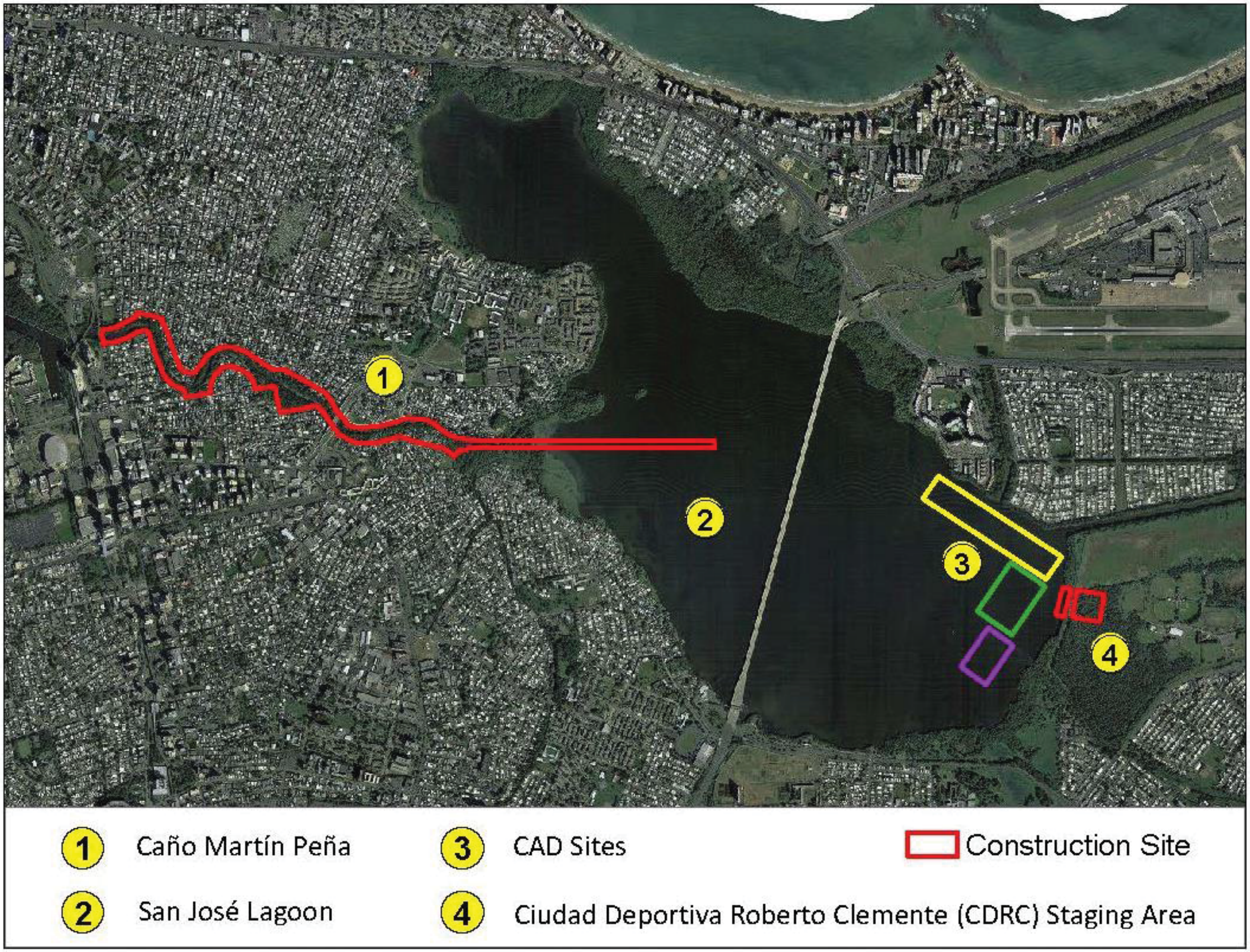

Figure 1. Caño Martín Peña Ecosystem Restoration Project Area Map

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2.0 FEDERAL RECREATION PLAN DEVELOPMENT

The design of the Federal Recreation Plan is largely influenced by the CDLUP for the Planning District and the Commonwealth of Puerto Rico State Comprehensive Outdoor Recreation Plan (PR SCORP). After reviewing the CDLUP, PR SCORP, existing data, and other related documentation, the project team developed a list of recreational features and identified potential areas for recreational use. The proposed Federal Recreation Plan is directed by the importance of balancing the needs of the community with protecting the restored areas and the function of the CMP. Based on existing studies, gap analysis, community input, and project constraints, a recreation resource assessment was completed to support the justification of the proposed Federal Recreation Plan.

2.1 RECREATION PLAN CONSTRAINTS

The following constraints were identified for the development of the Federal Recreation Plan.

1. No proposed recreational features will increase flooding in the CMP project area.
2. Recreational uses and facilities shall be compatible with the purpose of the ecosystem restoration project.
3. Proposed recreational features shall be compliant with the Corps and Federal Government regulations and design standards.

2.2 RECREATION PLAN PURPOSE

The recreational plan is considered an important component of the ecosystem restoration plan as it helps serve to alleviate the historic primary cause of ecosystem degradation in the area. The linear nature of the project area provides for water related recreational use. The goal of the Federal Recreation Plan would be to provide access, connectivity, and additional recreational facilities within the project limits.

2.3 RECREATION PLAN FEATURES

The CDLUP and State Comprehensive Recreational Opportunity Plan are the foundation of recreational features selected for the project. The recreation features and final recreation measures that are identified in the Federal Recreation Plan were developed and selected through an intensive public participation and feedback process from the population in the surrounding communities. Over 700 public activities were conducted to promote effective participatory planning, decision making, and implementation over a 2-year period leading up to the initiation of the Feasibility Report.

Recreational features have been refined to ensure that they are in compliance with Exhibit E-3 of ER 1105-2-100, and thus allowable for use in the Federal Recreation Plan (FRP). The following is a list of the recreational features identified as acceptable for the FRP.

- Trails
- Walks
- Steps/ramps
- Footbridges
- Picnic tables
- Trash receptacles
- Benches
- Entrance/Directional Marker
- Instructional signs
- Interpretive markers
- Gates
- Guardrails
- Lighting
- Handrails
- Walls

2.4 RECREATION PLAN ACCESS AREAS

The linear nature of the project allows for the placement of recreational features along the length of the CMP to maximize the benefit of the local community and reduce the impacts to the restored ecosystem. The project team, using the list of potential recreational features listed in Exhibit E-3 of ER 1105-2-100, identified 3 types of recreation access areas. The 3 types allow for major recreational use in some areas and median use in others. Two types would be adjacent to the proposed “Paseo” (a roadway that would parallel the CMP), whose construction is not a part of this federal ecosystem restoration project. This approach allows for large uninterrupted areas of restoration with major recreation areas that have access to the water, and median use areas along the smaller neighborhoods while connecting to the Paseo along the CMP (Figure 2). Recreation areas are designed to discourage improper use and facilitate educational programs to increase environmental stewardship of the restored ecosystem.

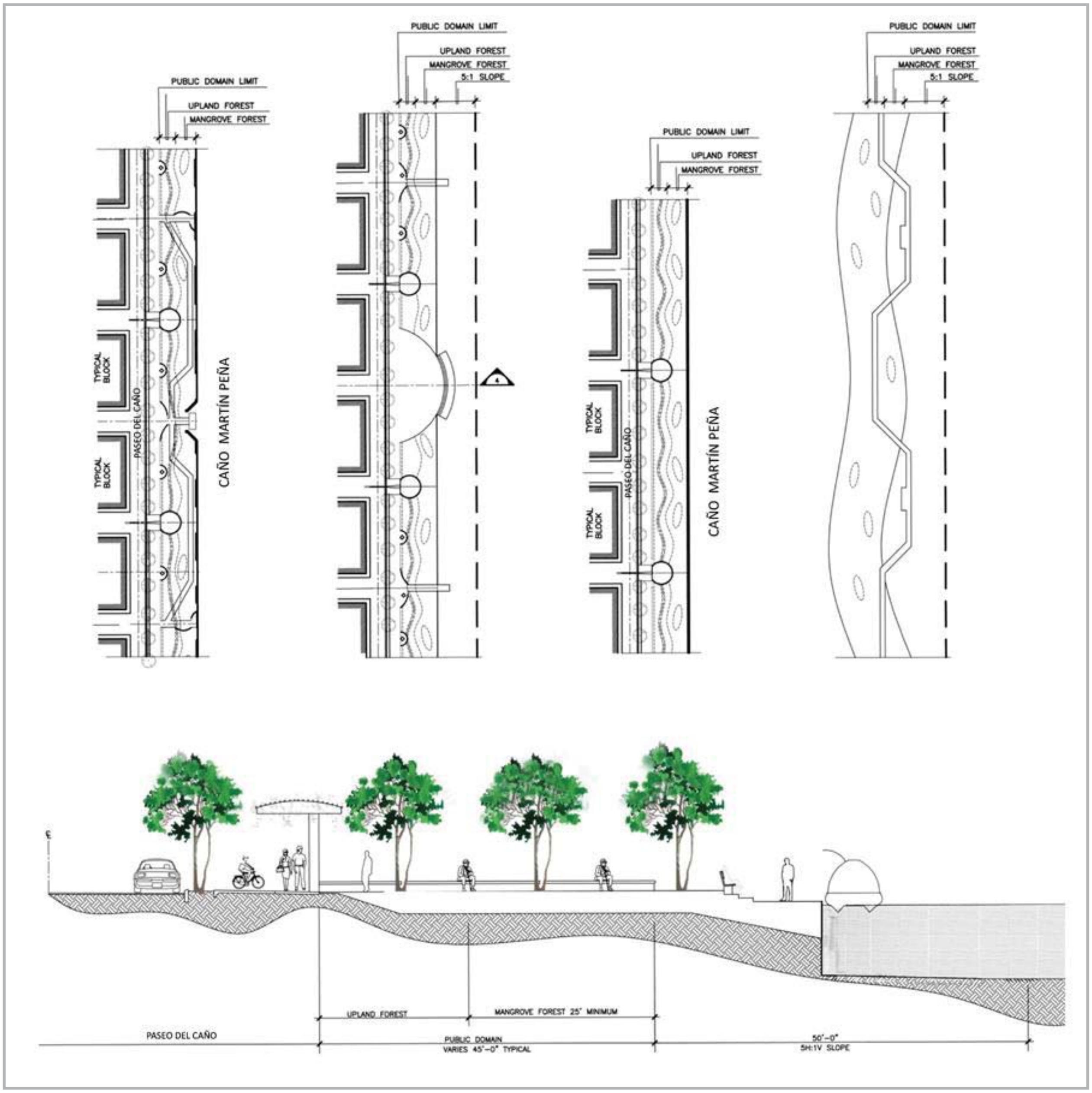

Figure 2. Sample designs for recreational access areas

2.4.1 Linear Park

This recreation area would consist of a trail, walk, and/or footbridge that extends the existing linear park located to the west of the Project Channel. The extended linear park trail would be constructed over the sheet pile bulk head in the channel (with the mangrove fringe between the linear park trail and the Paseo), and would be located on the southern side of the CMP, extending past the four western bridges in the project area and terminating at the first recreation access area in the Parada 27 community. In the vicinity of the western bridges, where the sheet pile wall is replaced with a riprap edge, the trail would be constructed on piles. If possible, benches may be placed in strategic locations to provide rest and or observation areas. The area would have entrance, instructional, and interpretive signs to educate the public on the CMP-ERP, proper use of the recreational area, and informative facts about the restored ecosystem. A gate and fence, or wall, would be placed along the CMP for safety and to discourage the disposal of materials into the CMP. Guardrails, handrails, steps, ramps, and lighting would be used as appropriate to maintain a safe and accessible recreation area. The linear park would fall within the navigational servitude.

2.4.2 Recreation Access Park

This type of recreational area would have open access to the restored CMP and would be scaled to accommodate more than 100 persons for passive recreation (Figure 3). The nine recreation access parks would provide visual openings through mangrove forest to the CMP, providing a strong community connection at these strategic locations. Each would be located strategically at the intersection of the Paseo del Cano walkway and an important community transportation artery. They would include picnic tables and benches to encourage educational gatherings and nature enthusiasts to enjoy the restored ecosystem. Each recreation access park would have an entrance sign, instructional signs and interpretive signs to educate the public on the CMP-ERP, proper use of the recreational area, and educational facts about the restored ecosystem. A gate and fence, or wall, would be placed along the CMP for safety and to discourage the disposal of materials into the CMP. Guardrails, handrails, steps, ramps, and lighting would be used, as appropriate, to maintain a safe and accessible recreation area. The recreation access parks would provide for navigation access to the CMP.

2.4.3 Recreation Park

This type of recreational area would be smaller in scale than the proposed recreational access park, and would be scaled to accommodate less than 100 persons for passive recreation. With the natural mangrove forest serving as a backdrop, the twelve recreation parks would be strategically located along the Paseo del Cano walkway corridor to serve immediately adjacent blocks. In six of the recreation parks, a trail would be built through the forest to allow access to the CMP (Figure 4). The recreation parks would include benches to create an outdoor classroom and be strategically positioned to enhance nature watching. They would have an entrance sign, instructional signs and interpretive signs to educate the public on the CMP-ERP, proper use of the recreational area, and educational facts about the restored ecosystem. A gate and fence, or wall, would be placed along the recreation parks and CMP where applicable for safety and to discourage the disposal of materials into the CMP. Guardrails, handrails, steps, ramps, and lighting would be used as appropriate to maintain a safe and accessible recreation area.

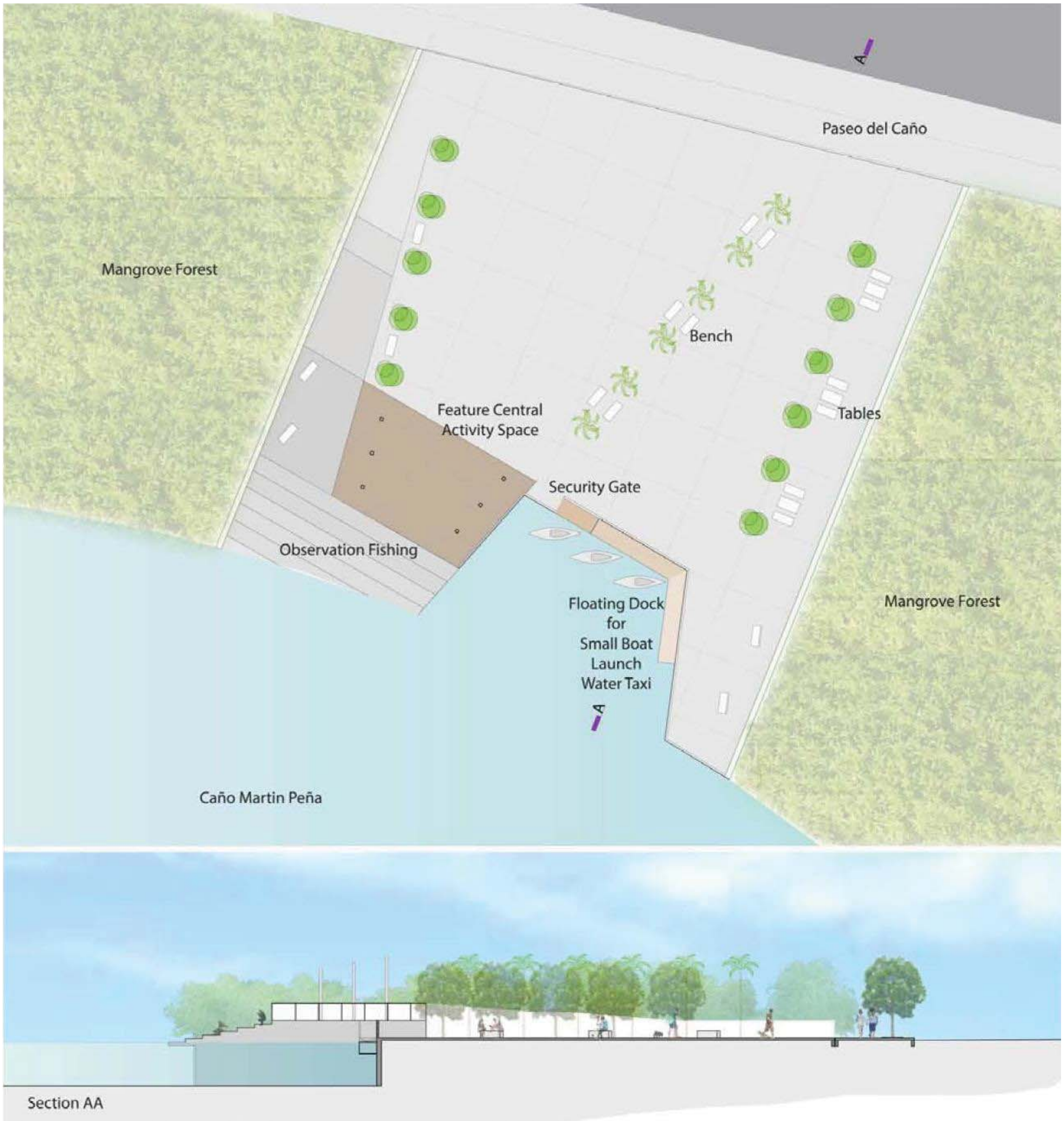

Figure 3. Sample design of recreation access park

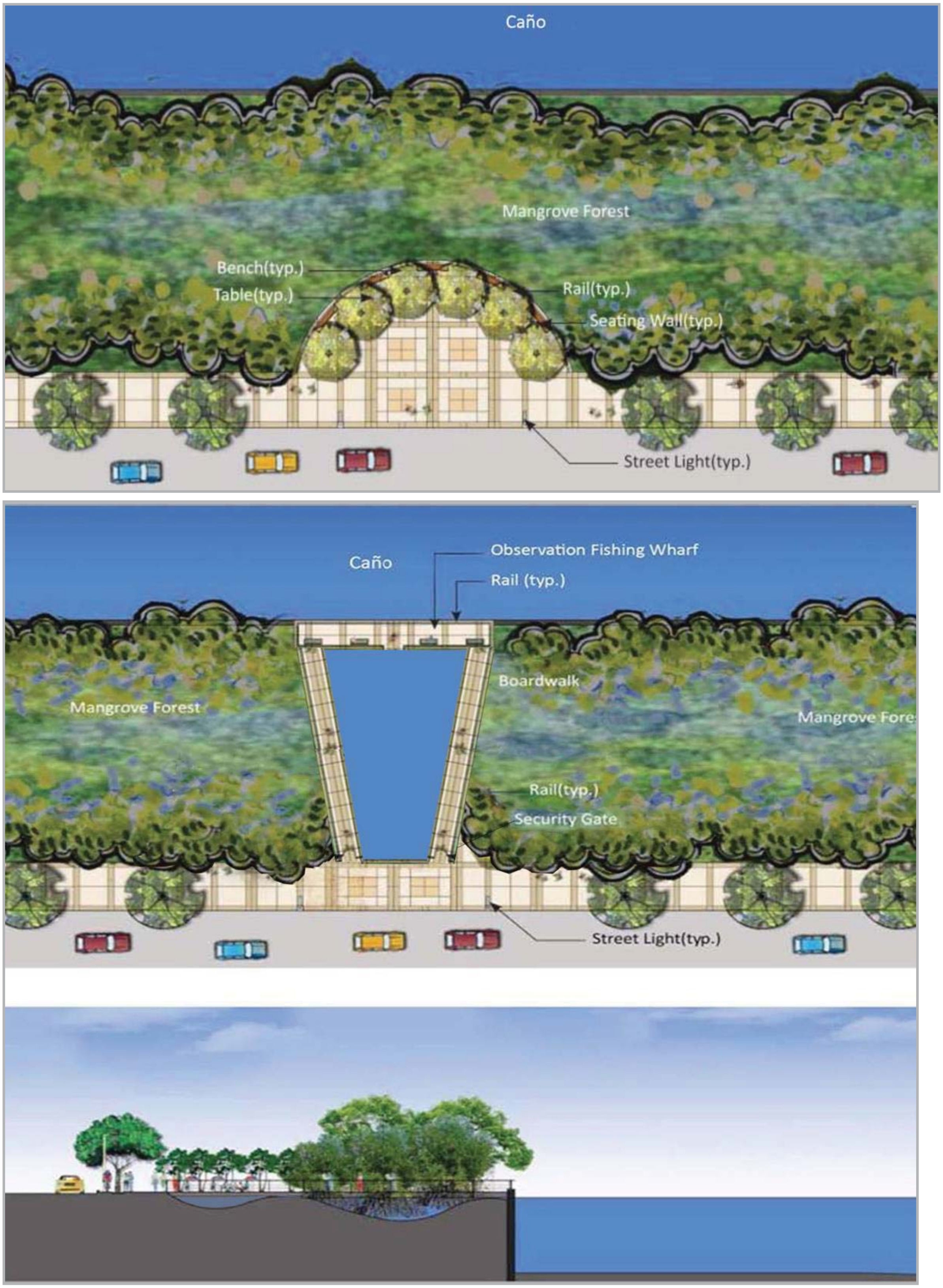

Figure 4. Sample design of recreation parks (with and without trail).

2.4.4 Proposed Non-Federal Recreation Features

The non-Federal sponsor, ENLACE, will continue to work with the local community to implement the CDLUP. As part of the CDLUP, ENLACE proposes to include improvements to the aesthetic appearance and include additional opportunities in the Federal Recreation Plan areas. ENLACE will continue to refine the improvements and additional opportunities with the community in a timely manner to incorporate them into the construction of the Federal Recreation Plan at 100 percent non-Federal cost. ENLACE is currently considering the addition of betterments to the lights, including figures or statues, and incorporating exercise stations, fishing, and kayak or canoeing opportunities. Navigation access would be provided through the Federal recreation access parks.

2.5 POTENTIAL LOCATION OF RECREATIONAL AREAS

The locations of the recreational areas were strategically identified along the CMP to serve the local communities and minimize impact on the restored ecosystem. In Figure 5, twenty-two potential areas have been identified for recreational use within the project limits. The three types of recreational areas would be interspersed to provide a variety of opportunities for each of the local communities.

2.6 PROPOSED FEDERAL RECREATION PLAN

The proposed Federal Recreation Plan consists of a combination of the recreation features outlined in Section 2.3 on approximately 5 acres. The recreation features would be organized in each of the three types of recreation areas, as outlined in Section 2.4, to maximize recreational opportunities. The Federal Recreation Plan would include nine recreation access parks, six recreation parks with a trail to the CMP, six recreation parks without a trail, and a linear park extension along the southern bank in the Project Channel that terminates in the Parada 27 community (Figure 6). The major and minor viewsheds that are associated with the CMP and their relation to the proposed Federal Recreation Plan are illustrated in Figure 7. The Cano Martin Pena recreation measure as presented is only one scale. Other measures/plans/scales were identified and considered in 700 plus public meeting activities to promote effective participatory planning, decision making, and implementation during the 2-year period leading up to the Feasibility Report.

Figure 5. Potential Federal Recreation Plan Access Areas (yellow dots).

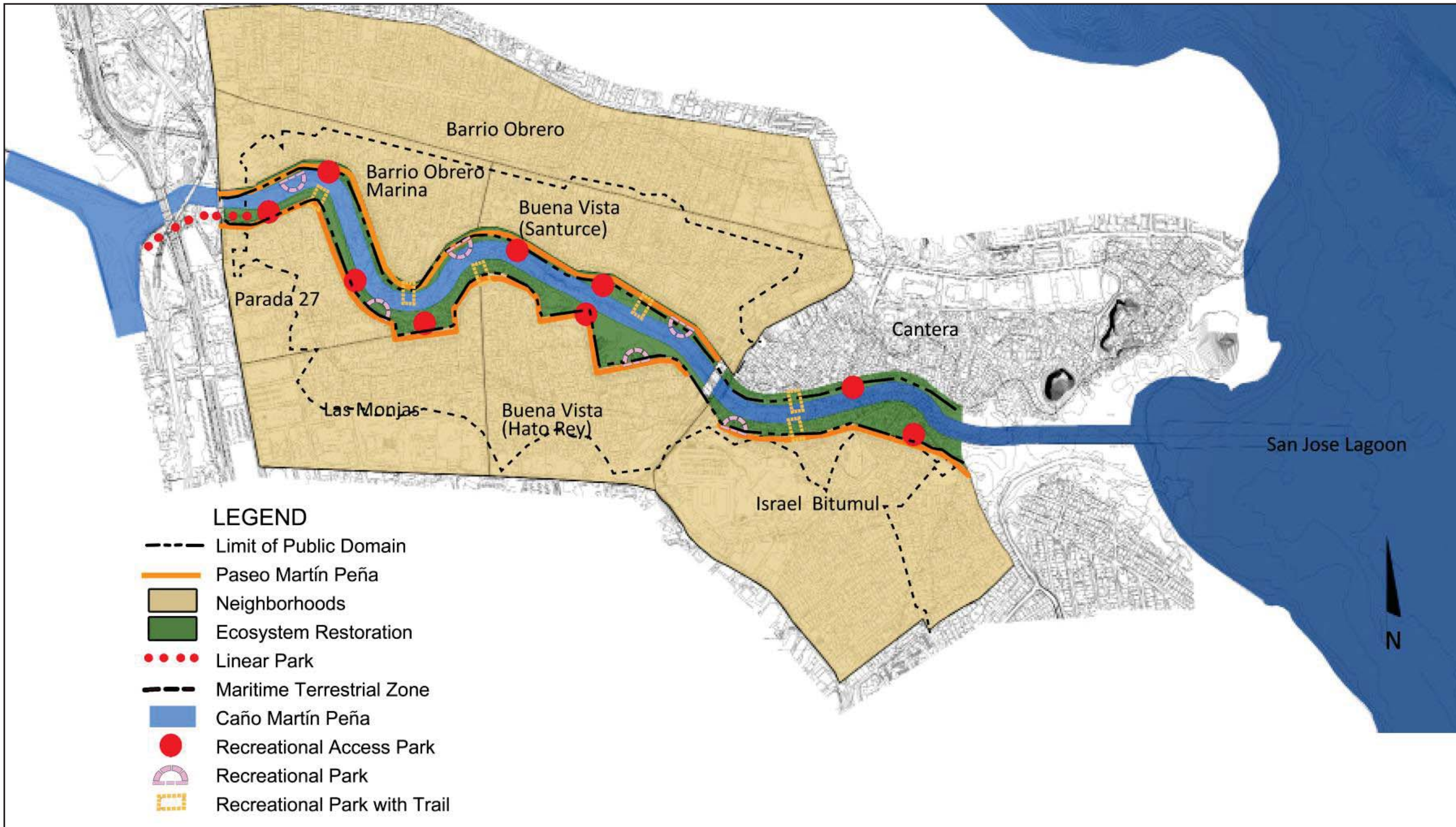

Figure 6. Proposed Federal Recreation Plan

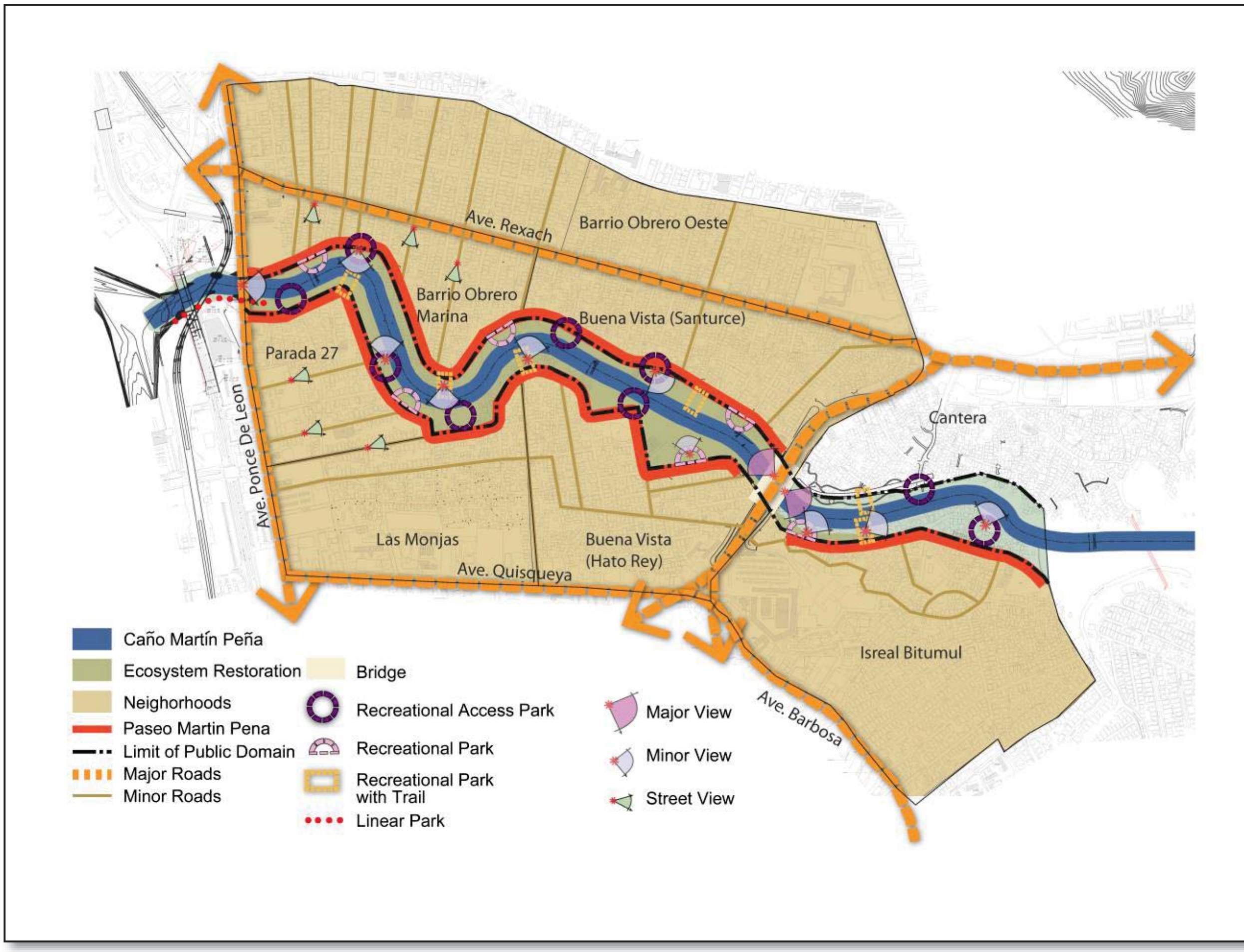

Figure 7. Proposed Federal Recreation Plan and Viewsheds.

3.0 RECREATION RESOURCE ASSESSMENT

The recreation resource assessment will analyze existing recreational data, costs, and anticipated National Economic Development (NED) benefits to determine whether the proposed Federal Recreation Plan is justified as a component of the ecosystem restoration plan.

3.1 EXISTING CONDITIONS

The most recent recreational data was gathered to establish the current state and need for additional recreational opportunities in the ecosystem restoration project area.

3.1.1 Recreational Opportunities

An inventory of existing recreation facilities is summarized in Table 1 and shown on Figure 8. Of these existing recreation facilities, four basketball/volleyball courts and a small impromptu dock are located within the project footprint.

There are no water-related recreation features currently within the Project Area, and as a result, there is no current or historic visitation information available for the types of proposed water-related recreational facilities. The existing land-related basketball/volleyball courts within the Project Area would be removed under the No-Action Alternative because they are in the public domain boundary. They will be replaced on a one-to-one usage basis and located outside the public domain using 100 percent non-Federal funds, and undertaken as part of the CDLUP. Their relocation is not associated with the CMP-ERP.

3.1.2 Population Projections

The population density of Puerto Rico and the San Juan Metropolitan Area demands an increase in urban recreational spaces. Population projections are presented in Table 2, which shows the projected study area population and United States population growth through 2025.

Table 1. Existing Recreation Facilities

NEIGHBORHOOD	KEY	TYPE OF FACILITY	LOCATION
NORTH AREA			
BARRIO OBRERO SAN CIPRIAN	BO-1	BASKETBALL-VOLLEYBALL	ALBERT EINSTEIN SCHOOL
BARRIO OBRERO MARINA	BOM-1	BASKETBALL-VOLLEYBALL	SANTIAGO IGLESIAS PANTIN ELEMENTARY SCHOOL
	BOM-2	BASKETBALL-VOLLEYBALL	CALLE 10 SUR
BUENA VISTA SANTURCE	BVS-1	BASKETBALL-VOLLEYBALL	CALLE EL FARO
	BVS-2	BASKETBALL-VOLLEYBALL	CALLE WILLIAM
CANTERA	CS-1	BASKETBALL-VOLLEYBALL	AVE BARBOSA & CALLE SAN MIGUEL
	CS-2	BASEBALL	COLEGIO SAN JUAN BOSCO
	CS-3	SPORT CENTER	COLEGIO SAN JUAN BOSCO
	CS-4	SPORT CENTER	CALLE CONSTITUCION
	CS-5	BASKETBALL-VOLLEYBALL	CALLE LOS PADRES
	CS-6	FOOTBALL	COLEGIO SAN JUAN BOSCO
	CS-7	RECREATION ASSOCIATION	CALLE SANTA ELENA
	CS-8	MAKESHIFT DOCK	
	CS-9	LAGUNERA ASSOCIATION	AVE A
SOUTH AREA			
PARADA 27	P27-1	LINEAR PARK AND BOAT RAMP	CALLE SAN JOSE
	P27-2	BASKETBALL-VOLLEYBALL	CALLE SAN JOSE esq BUENOS AIRES
	P27-3	MULTI-USE COURT	CALLE SANTIAGO IGLESIAS
LAS MONJAS	LM-1	BASKETBALL-VOLLEYBALL	EMILIO del TORO SCHOOL CALLE CHILE, CALLE URUGUAY
	LM-2	BASKETBALL-VOLLEYBALL	LAS GLADIOLAS CONDOMINIUM CALLE QUISQUEYA, CALLE CHILE
	LM-3	BASKETBALL-VOLLEYBALL	CALLE QUISQUEYA
	LM-4	BASEBALL	CALLE DOLORES
BUENA VISTA			
HATO REY	BVHR-1	BASKETBALL-VOLLEYBALL	CALLE 3 esq CALLE G
ISRAEL-BITUMUL	IB-1	BASKETBALL-VOLLEYBALL	JUANITA GARCIA PERAZA SCHOOL AVE GAUTIER, CALLE ROBLEDO
	IB-2	BASKETBALL-VOLLEYBALL	CALLE ALCANIZ
	IB-3	BASEBALL	CALLE ALCANIZ

Table 1, cont'd

SUMMARY		
NORTH AREA	**TYPE OF FACILITY**	**QUANTITY**
	BASKETBALL-VOLLEYBALL	7
	HALF COURT BASKETBALL	
	BASEBALL	1
	SPORT CENTER	2
	FOOTBALL	1
	RECREATION ASSOCIATION	11
	MAKESHIFT DOCK	1
	LAGUNERA ASSOCIATION	1
	MULTI-USE COURT	
	LINEAR PARK	
SOUTH AREA		
	BASKETBALL-VOLLEYBALL	8
	HALF COURT BASKETBALL	
	BASEBALL	2
	SPORT CENTER	
	FOOTBALL	
	RECREATION ASSOCIATION	
	MAKESHIFT DOCK	
	LAGUNERA ASSOCIATION	
	MULTI-USE COURT	1
	LINEAR PARK	1

Recreation Facilities Inventory, Corporación del Proyecto ENLACE del Caño Martín Peña and field validation.

Table 2. Study Area Population through 2025 (1,000)

	2010	2015	2020	2025
San Juan Totals	428	423	416	412
Puerto Rico	4,022	4,096	4,149	4,177
San Juan percent of Puerto Rico Population	10.6%	10.3%	10.0%	9.9%
United States	308,936	322,371	335,805	349,694
San Juan percent of United States Population	0.14%	0.13%	0.12%	0.12%
Puerto Rico growth rate		1.02%	1.02%	0.67%
U.S. growth rate		1.04%	1.04%	1.04%

Source: Puerto Rico Planning Board, Economic and Social Planning Program, Census Bureau.
Prepared December 2005, BEBR Projections for United States.

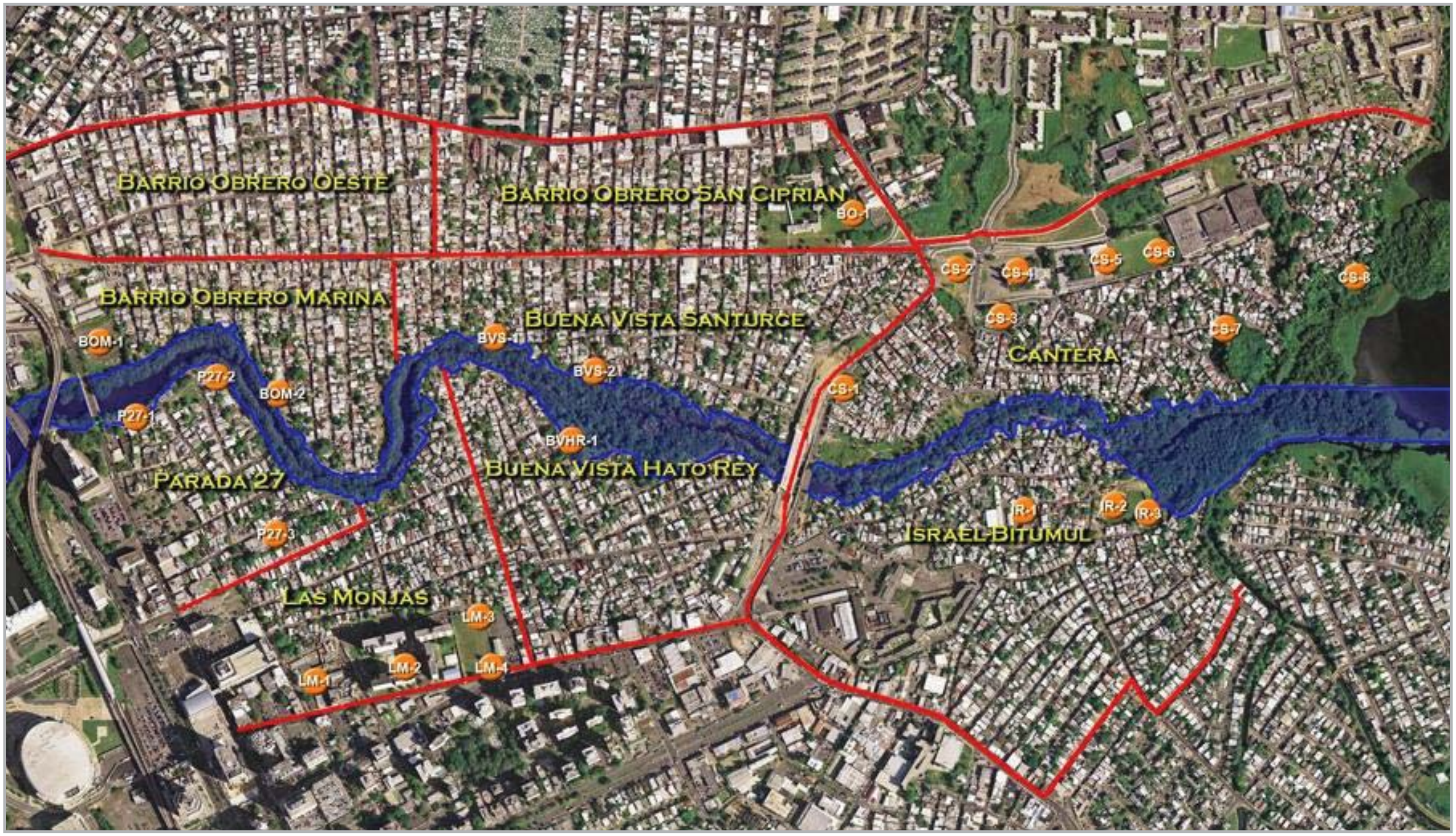

Figure 8. Existing Recreation

3.1.3 Recreational Needs Identified by SCORP

One of the key elements in the SCORP was the identification of population needs and preferences related to outdoor recreation. Those needs, which determine the demand for outdoor recreational services, were found through a general population survey complemented by focus groups. The participants in the SCORP were asked about outdoor recreation facilities that they thought are needed in Puerto Rico. Among those mentioned were facilities associated with the enjoyment of nature and the enhancement of physical and emotional health. This coincided with the opinions of the general population, as captured by the survey. Among the facilities most frequently mentioned were: walking trails, bike trails and parks with trees and vegetation. Also, participants frequently mentioned their desire for restored and revitalized urban centers. Recreation trends show increased usage of existing facilities and a latent need for new facilities. With ensuing development in the project area, and the high population density in the San Juan Metropolitan Area, there would be extensive use of the proposed recreation facilities.

3.2 RECREATION BENEFIT

3.2.1 National Economic Development Benefit

The National Economic Development (NED) benefit evaluation procedures contained in ER 1105-2-100 (April 22, 2000), Appendix E, Section VII, include three methods of evaluating the beneficial and adverse NED effects of project recreation: travel cost method (TCM), contingent valuation method (CVM), and unit day value (UDV) method.

The basic premise of the travel cost method (TCM) is that per capita use of a recreation site will decrease as out-of-pocket and time costs of traveling to the site increase, other variables being constant. TCM consists of deriving a demand curve by using the variable costs of travel and the value of time as proxies for price. The TCM was not used because a large portion of the recreation users live in the surrounding areas and the poverty rate in the surrounding areas is over 50 percent.

The contingent valuation method (CVM) estimates NED benefits by directly asking individual households their willingness to pay for changes in recreation opportunities at a given site. The CVM was not used due to the impoverished nature of the surrounding communities expected to heavily use the recreation facilities. It is not perceived the subject population would be able to accurately define their willingness to pay or a willingness to pay that reflects the value of the recreation opportunities.

The arguments for employing the user day approach is based on two foundations: (1) Infeasibility for the technical reasons mentioned above; and, (2) formulation or plan selection was not materially affected by willingness to pay value or by expected visitation. (ER 1105-2-100 22 Apr 2000 E-50. NED Benefit Evaluation Procedure, Paragraph (4) (a)) Plan selection was based on feedback received from the population in the surrounding communities in over 700 public meetings conducted to promote effective participatory planning, decision making, and implementation over a 2-year period leading up to the Feasibility Report.

The unit day value method was selected for estimating recreation benefits associated with the creation of the CMP-ERP. When the unit day value method is used for economic evaluations, planners select a specific value from the range of values provided annually. Application of the selected value to estimate annual use over the project life, in the context of the with- and without-project framework of analysis, provides the estimate of recreation benefits.

As per ER 1105-2-100 Appendix E, Paragraph E-50 b.(4), when the Unit Day Approach is to be used annual usage cannot exceed 750,000 users. Therefore, even though expected usage was estimated at more than 750,000, the number of users used in the calculation of recreation benefits was held at 750,000.

The without-project condition analysis has no recreation value because, without the CMP-ERP, there would be no public access to the CMP. The with-project condition is the expected value of the recreational activity based on the unit day value method.

3.2.2 Assigning Points for General Recreation

The value of a day of general recreation at the restored CMP was determined using the guidelines for General Recreation in USACE Economic Guidance Memorandum (EGM) 13-03 (Table 3). EGM 13-03 provides judgment factor evaluations to assign points to the five criteria that determine the value of the expected general recreation experience. Point values for the general recreation experience provided by the proposed recreation features were determined after conducting site visits and coordinating with local agencies. Point values for the judgment were selected for each of the five criteria of: (1) recreation experience; (2) availability of opportunity; (3) carrying capacity; (4) accessibility; and (5) environmental quality based on the degree that the CMP-ERP would fulfill the judgment factor requirements.

- A point value rating of 14 out of a maximum of 30 was selected for the general recreation criteria. The point value of 14 was selected because the proposed facilities would provide several general activities and one high quality value activity in the densely populated Planning District and the San Juan metropolitan area. The CMP-ERP's proposed recreation resources would provide an area specific, unique recreation opportunity afforded by the project setting and the CMP. The site offers solitude and panoramic views in a growing metropolitan area, and would provide specific recreation amenities for densely populated District. The linear nature of the project provides recreational uses for each of the eight communities in the Planning District and for many users from outside the Planning District. The multi-use recreational areas provide panoramic view sheds at the recreational access parks and recreation parks. One high quality value activity would be the visual openings through the Mangrove Forest to the CMP that currently are nonexistent. The high quality value activity would be further enhanced if a trail were built through the forest to allow access to the CMP.

- The score for the availability of opportunity criteria is low at 6 out of 18 possible because of the current local recreation facilities near the project area within the proposed recreation resource location. At the high end of the scale are those recreational facilities that are a geographical rarity; these are sites for which there is no close substitute within two hours. There is insufficient access to water-oriented activities in the San Juan metropolitan area but limited access to mangrove forests. With the exception of visual contact with mangrove forests, alternative facilities exist that provide availability of opportunity for all other recreation activity classifications; however, the proposed recreation facilities would provide availability of opportunity to meet Puerto Rico SCORP-identified needs associated with the enjoyment of nature and the enhancement of physical and emotional health. In addition, the walking trails, bike trails, and parks with trees and vegetation offered by the proposed recreation facilities would provide opportunities to meet other needs frequently mentioned in the Puerto Rico SCORP.
- The CMP-ERP's recreation resources carrying capacity criteria point value is relatively high at 10 out of a maximum of 14 because the proposed recreation facilities provide optimum amenities to conduct general recreation activity at site potential. The general recreation values are based on the optimum use of the site potential, without overuse of the proposed recreation resources. Good water resources, and access to them for environmental observation purposes comprise a large part of the projected recreation resources use. According to the Puerto Rico SCORP, most of the people were engaged in outdoor recreational activities throughout the 12 months of the year due to a climate that is tropical marine and mild with little seasonal temperature variations. Therefore, use of the recreation facilities is projected to occur throughout the 12 months of the calendar year.
- The accessibility criteria point value is 16 out a possible 18 because there is good access, high standard roads to site, including public transportation. In addition, the proposed facilities would provide good access within site, compliant upon the availability of local highways, roads and streets in good condition that would provide access to these amenities.
- The environmental quality criteria rating is 13 out of a maximum of 20 based on the existing aesthetic values of the CMP-ERP recreation resource facilities and the ease of correcting any limiting aesthetic factors. The limiting aesthetic factors that currently exist would be eliminated by the CMP-ERP. The proposed site would possess panoramic views with no factors lowering environmental quality. The views through the Mangrove Forest to the CMP provided by the proposed recreation access parks, recreation parks, and the linear park that connects them merit the criteria rating of 13.

The points for the five criteria used for assigning points for general recreation total to 59 points.

Table 3. Guidelines for Assigning Points for General Recreation

Criteria	Judgment factors				
Recreation experience[1] Total Points: 30	Two general activities[2]	Several general activities	Several general activities: one high quality value activity[3]	Several general activities; more than one high quality high activity	Numerous high quality value activities; some general activities
Point Value: 14	0–4	5–10	11–16	17–23	24–30
Availability of opportunity[4] Total Points: 18	Several within 1-hour travel time; a few within 30 minutes travel time	Several within 1-hour travel time; none within 30 minutes travel time	One or two within 1-hour travel time; none within 45 minutes travel time	None within 1-hour travel time	None within 2-hour travel time
Point Value: 6	0–3	4–6	7–10	11–14	15–18
Carrying capacity[5] Total Points: 14	Minimum facility for development for public health and safety	Basic facility to conduct activity(ies)	Adequate facilities to conduct without deterioration of the resource or activity experience	Optimum facilities to conduct activity at site potential	Ultimate facilities to achieve intent of selected alternative
Point Value: 10	0–2	3–5	6–8	9–11	12–14
Accessibility Total Points: 18	Limited access by any means to site or within site	Fair access, poor quality roads to site; limited access within site	Fair access, fair road to site; fair access, good roads within site	Good access, good roads to site; fair access, good roads within site	Good access, high standard road to site; good access within site
Point Value: 16	0–3	4–6	7–10	11–14	15–18
Environmental quality Total Points: 20	Low esthetic factors[6] that significantly lower quality[7]	Average esthetic quality; factors exist that lower quality to minor degree	Above average esthetic quality; any limiting factors can be reasonably rectified	High esthetic quality; no factors exist that lower quality	Outstanding esthetic quality; no factors exist that lower quality
Point Value: 13	0–2	3–6	7–10	11–15	16–20
Total Point Value					**59**

Source: Economics Guidance Memorandum, 09-03, Unit Day Values for Recreation, Fiscal Year 2009.

1. Value for water-oriented activities should be adjusted if significant seasonal water level changes occur.
2. General activities include those that are common to the region and that are usually of normal quality. This includes picnicking, camping, hiking, riding, cycling, and fishing and hunting of normal quality.
3. High quality value activities include those that are not common to the region and/or Nation, and that are usually of high quality.
4. Likelihood of success at fishing and hunting.
5. Value should be adjusted for overuse.
6. Major esthetic qualities to be considered include geology and topography, water, and vegetation.
7. Factors to be considered to lowering quality include air and water pollution, pests, poor climate, and unsightly adjacent areas.

3.2.3 Conversion of Points to Dollar Value

The point values assigned in Table 4 were converted to dollar values based on the EGM 14-03, Unit Day Values for Recreation, 2014, which is based on ER 1105-2-100. Values provided for FY 2014 may be used to convert points to a UDV dollar amount if the point assignment method is used. The table was adjusted from Table K-31, *Federal Register* Vol. 44, No. 242, p. 72962, December 14, 1979, and the subsequent Table VIII-3-1 "Conversion of Points to Dollar Values," Economic and Environmental Principles and Guidelines for Water and Related Land Resources Implementation Studies, March 10, 1983, using the Consumer Price Index (CPI) factors published by the Bureau of Labor Statistics. The CPI basis of Table VIII-3-1 from Principles and Guidelines is July 1, 1982 (CPI value = 97.5). The FY 2014 CPI basis is September, 2013 (CPI value = 234.149).

Table 4 displays the point value conversion of a unit day value in fiscal year 2014 (FY14) to dollars. The 59 total points from Table 3 falls between the General Recreation Point values for 50 points and 60 points. The General Recreation Dollar Value for 50 points is $8.17 and for 60 points is $8.89. The difference between $8.17 and $8.89 is $0.72. The 59 total points represents 90 percent of the $0.72 difference. Therefore, 90 percent of the $0.72 was added to $8.17 to produce the UDV of $8.89 for the 59 General Recreation Point Value.

Table 4. Conversion of Points to Dollar Values

General Recreation Point Values	General Recreation Dollar Values
0	$3.84
10	4.56
20	5.04
30	5.76
40	7.20
50	8.17
60	8.89
70	9.37
80	10.33
90	11.05
100	11.53

Source: Economic Guidance Memorandum, 14-03, Unit Day Values for Recreation for Fiscal Year 2014.

3.2.4 Most Likely Recreation Participation User Day Projection Scenario

The PR SCORP does not provide recreation user-day guidelines for resource based outdoor recreation activities. The capacity method is an alternative method of estimating use according to USACE Economic Guidance Memorandum (EGM), 14-03, Unit Day Values for Recreation for Fiscal Year 2014:

> "*The capacity procedure involves the estimation of annual recreation use under without-project and with-project conditions through the determination of resource or facility capacities (taking into consideration instantaneous rates of use, turnover rates, and weekly and seasonal patterns of use). Seasonal use patterns are dependent on climate and culture and probably account for the greatest variation in use estimates derived through this method. In general, annual use of outdoor recreation areas, particularly in rural locations and in areas with pronounced seasonal variation, is usually about 50 times the design load, which is the number of visitors to a recreation area or site on an average summer Sunday. In very inaccessible areas and in those known for more restricted seasonal use, the multiplier would be less; in urban settings or in areas with less pronounced seasonal use patterns, the multiplier would be greater. In any case, the actual estimation of use involves an analytical procedure using instantaneous capacities, daily turnover rates, and weekly and seasonal use patterns as specific data inputs.*
>
> *Because the capacity method does not involve the estimation of site-specific demand, its use is valid only when it has been otherwise determined that sufficient demand exists in the market area of project alternatives to accommodate the calculated capacity. Its greatest potential is therefore in urban settings where sufficient demand obviously exists. Additionally, its use should be limited to small projects with (1) a facility orientation (as opposed to a resource attraction), and (2) restricted market areas that would tend to make the use of alternative use estimating procedures less useful or efficient*."

The guidance provided in EGM 14-03 to estimate reasonable user rate projections requires determination of resource or facility capacities and assumes that adequate demand exists. As mentioned in EGM 14-03, use is valid if it is determined that sufficient demand exists in the market area of project alternatives to accommodate the calculated capacity. Therefore, its greatest potential lies in urban settings, where sufficient demand exists due to the especially densely populated conditions of the CMP neighboring communities. The PR SCORP determined that sufficient demand exists in the market area for facilities associated with the enjoyment of nature and the enhancement of physical and emotional health. Among the facilities most frequently mentioned were: walking trails, bike trails and parks with trees and vegetation. The PR SCORP also reported that sufficient demand exists for restored and revitalized urban centers. The recreation facilities proposed for the CMP-ERP would address these needs.

The recreation plan has a linear park, nine recreation access parks, and 12 recreation parks (6 with 1,000 square feet of trail and 6 without trails). The facility capacity of the recreation parks is designed to accommodate less than 100 individuals. The recreation access parks are designed for more than 100 individuals participating in passive recreation. In this densely populated urban setting with no pronounced seasonal use patterns, the multiplier is estimated as the instantaneous capacity. The estimation of use involves an analytical procedure using instantaneous capacities, daily turnover rates, and weekly and seasonal use patterns as specific data inputs. Instantaneous capacity was estimated as the design capacity of the recreation facilities. The instantaneous capacity is the expected number of users and it is estimated at 90 for the recreation parks with trails, 80 for each of the recreation parks without trails, 110 for each of the recreation access areas, and 50 for the linear park. The 90 users for the recreation park with trail are 10 percent less than the 100 users, and the 80 users for the recreation park without trail are 20 percent less. The 110 users for the recreation access park are 10 percent more than 100. The 50 users of the linear park are based on 2 users per 60 feet of the 1,500-foot facility.

According to the PR SCORP, most of the people were engaged in outdoor recreational activities throughout the 12 months of the year due to a tropical marine climate, which is mild with little seasonal temperature variations. Therefore, 365 user days were selected as the number of days available annually for outdoor recreation for this analysis. With weekends accounting for 104 user days, and with 19 Public and National Holidays in Puerto Rico, a total of 123 days would be available for peak use. The remaining 242 user days for the rest of year are identified as off peak use days. Daily turnover rates were estimated to be two per day for peak use days and one per day for off peak use days. The number of units provided times the daily turnover rate times the peak use days or off peak use days provides the projected expected user days shown in Table 5.

The EGM for Unit Day Value states that the application of the selected value to estimated annual use over the project life, in the context of the with- and without-project framework of analysis, provides the estimate of recreation benefits. The starting point of the evaluation is the value in the without-project condition. This report estimates that all the without-project values for all criteria equals zero, because under without-project conditions the area is not suitable for recreational activities. The next step was the point evaluation of the with-project recreation facilities. The difference in points between the without-project and with-project conditions is the basis for the benefits.

Table 5. Most Likely Recreation Participation User Day Projection Scenario

Activity	Units Provided	Daily Turnover Rates	Capacity Guidelines	User Occasions	Project Expected Users
Recreation Access Parks	9	2/day weekends and holidays	110	123	243,540
Recreation Access Parks	9	1/day weekdays	110	242	239,580
Recreation Parks	6	2/day weekends and holidays	80	123	118,080
Recreation Parks	6	1/day weekdays	80	242	116,160
Recreation Parks with trail	6	2/day weekends and holidays	90	123	132,840
Recreation Parks with trail	6	1/day weekdays	90	242	130,680
Linear Park	6	2/day weekends and holidays	50	123	73,800
Linear Park	6	1/day weekdays	50	242	72,600
General Recreation Total					**1,127,280**[1]

3.3 ECONOMIC JUSTIFICATION OF RECREATION PLAN

The justification of incurring additional costs for recreation features is derived by utilizing a benefit to cost ratio. The tangible economic justification of the proposed project can be found by comparing the equivalent average annual costs with the estimated equivalent average annual benefits, which would be realized over the period of analysis. The federally mandated project evaluation interest rate of 3.375 percent, an economic period of analysis of 50 years and current prices were used to evaluate economic feasibility (FY15 rate is 3.375%, per EGM #15-01). ER 1105-2-100 provides economic evaluation procedures to be used in all federal water resources planning studies. The ER guidelines were used in preparing this benefit to cost analysis.

[1] Capped at 750,000 (ER 1105-2-100 Appendix E, Paragraph E-50 b.(4), when the Unit Day Approach is to be used annual usage cannot exceed 750,000 users).

3.3.1 Recreation Facilities Cost Estimate

Only cost shared items were included in the recreation cost. The cost of clearing and grubbing, grading and land form are for the restoration project and the proposed recreation facilities take up only 0.1 percent of the ecosystem restoration area. The costs of the recreation facility components are: nine Recreation Access Parks $2,829,584, six Recreation Parks without trail $486,021, six Recreation Parks with trail $1,011,644, the Linear Park $4,055,381, and Mobilization and Demobilization $557,370, for a total cost of $8,940,000 (Table 6).

Table 6. Recreation Facilities Cost Estimate (Project First Cost)

Recreation Facilities	Cost
Recreation Access Area (9)	$2,829,584
Recreation Park (6)	$486,021
Recreation Park w/trail (6)	$1,011,644
Linear Park (1,500 linear feet)	$4,055,381
Mobilization and Demobilization	$557,370
Total Cost	**$8,940,000**

The proposed recreation facilities project first costs are $8,940,000. Preconstruction Engineering and Design (PED) is estimated at 9 percent and Construction Management (CM) is estimated at 6.1 percent, for a total of 15.1 percent for PED and CM, or $1,348,000. Interest during construction was calculated to be $150,863, bringing the total recreation investment to $10,438,863 Table 7. The Federal share of the project first cost of the recreation facilities is 50 percent of $10,288,000 or $5,144,000. This represents 3.7 percent of the non-recreation Federal share of the recreation facilities project first cost of $138,851,000 and is in compliance with the 10 percent maximum of the non-recreation total Federal cost share of the project.

3.3.2 Recreation Facilities Benefits

The annual benefits were calculated by multiplying the User Day Value of $8.89 by the user day projection scenario capped at 750,000 per year. The average annual benefit of the proposed recreation facilities is $6,667,500. The benefit-to-cost ratio of 6.9 to 1 was calculated by dividing the average annual benefits of $6,667,500 by the total annual costs of $968,882. Net annual benefits are $5,698,618 (average annual benefits $6,667,500 minus total annual costs $968,882).

Table 7. Summary of Recreation Costs and Benefits

Recreation Construction Costs	**$8,940,000**
PED & CM (15.1%)	$1,348,000
Total Recreation Construction Cost	**$10,288,000**
Construction Duration	27 months
Interest During Construction Costs	$150,863
Total Recreation Investment	**$10,438,863**
Period of Analysis	50 years
Annualized Cost	$378,882
OMRR&R	$590,000
Total Annual Costs	**$968,882**
Annual Benefits	
User Day Value	$8.89
Average Daily Use	2,055
Annual Use	750,000
Average Annual Benefit	**$6,667,500**

3.3.3 Sensitivity Analysis

A sensitivity analysis was performed to determine what the impacts would be if actual benefits fell far short of the expected benefits and to provide additional justification for the proposed recreation features (Table 8). This sensitivity analysis suggests there would be ample benefits to conservatively justify the construction of the proposed recreation facilities for the CMP-ERP. If annual use was only 25 percent of capacity, the number of annual users would be 187,500 and annual benefits would be $1,666,875 (187,500 annual users multiplied by the $8.89 User Day Value). Dividing the annual benefits of $1,666,875 by the total annual costs of $968,882 produces a benefit to cost ratio of 1.7 to 1. Net annual benefits would be the annual benefits $1,666,875 minus the total annual costs of $968,882, or $697,993.

Table 8. Sensitivity Analysis

Scenario	Annual Users	Daily Users	Annual Benefit
Most Likely	750,000	2,055	$6,667,500
Worst Case	187,500	514	$1,666,875

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4.0 CONCLUSION

As a result of economically driven and car oriented urban development, the metropolitan area of Puerto Rico lacks an efficient integration of public recreational spaces as well as an effective infrastructure of public transportation. The SJBE and CMP provide an excellent opportunity for alternate modes of transportation to develop in the municipality of San Juan as well as the development of recreational outlets such as the areas described in section 2.4. The implementation of recreational areas along the CMP could provide a forum where some of the community's economic needs would be met by the local tourism, inversely fueled by these recreation areas and parks, in addition to providing leisure space for the community. The impact of the recreation access parks, linear park and recreation parks would fill a need for environment-oriented urban parks in the city. These much-needed public urban recreation spaces would be visited by many urban dwellers looking for nature related activities in the heart of the municipality.

The Federal Recreation Plan for the CMP-ERP would consist of a linear park along a portion of the CMP, nine recreation access parks, six recreation parks with a trail to the CMP, and 6 recreation parks without a trail. The linear park would extend an existing linear park that is currently located at the western project limit. The trail would be constructed over the sheet pile bulkhead. If possible, benches may be placed in strategic locations to provide rest and/or observation areas. The recreation access parks would provide open access to the CMP. They would include picnic tables and benches to encourage educational gatherings and nature enthusiast to enjoy the restored ecosystem. The recreation parks would be smaller in scale than the proposed recreational access park. The recreation parks would not have direct access to the CMP, except in those locations where a trail would be built to connect to the CMP, and would include strategically positioned benches to enhance nature watching and create an outdoor classroom. In each of the recreational areas, there would be an entrance sign, instructional signs and interpretive signs to educate the public on the ecosystem restoration project, proper use of the recreational area, and educational facts about the restored ecosystem. A gate and fence, or wall, would be placed along the recreation area and CMP where applicable for safety, and to discourage the disposal of materials into the CMP. Guardrails, handrails, steps, ramps, and lighting would be used as appropriate to maintain a safe and accessible recreation area.

The Federal Recreation Plan is considered an essential component of the ecosystem restoration plan as it provides for a significant increase in recreational opportunities along the CMP, as well as helping alleviate the historic primary cause of ecosystem degradation in the area. The proposed recreational features are compatible with the ecosystem outputs for which the project is designed. They are compatible with the ecosystem restoration purpose by providing an appropriate interface within the urban environment and the aquatic environment. The features are appropriate in scale and have no impacts to the ecosystem restoration benefits that justify the CMP-ERP. The acreage necessary for the recreation features does not result in a loss of mangroves as the existing acreage of wetlands would be replaced with a net increase of higher-functioning wetlands in the CMP, even with the 5 acres reserved for recreational features. In addition, the tidal connectivity for mangroves would still occur through the water, and the fish and wildlife that inhabit the mangroves would still be able to connect to other mangrove areas along the CMP through this water connection.

The recreational features are economically justified with a benefit to cost ratio of 6.9 to 1, and appropriately cost-shared 50 percent non-federal and 50 percent Federal. The total recreation facilities first cost is $10,288,000 and the Federal share is $5,144,000, or 3.7 percent of the estimated non-recreation Federal cost share of $142,995,000 for the ecosystem restoration project. The 3.7 percent is in compliance with the requirement of not exceeding 10 percent of the non-recreation Federal project cost. The features are appropriate in scale and have no impacts to the ecosystem restoration benefits that justify the CMP-ERP.

The linear nature of the project area provides recreational uses for all eight neighboring communities; careful placement of these measures throughout the project area is also intended to protect the investment in ecosystem restoration by facilitating appropriate uses of the project area after the CMP-ERP is constructed. This approach facilitates the creation of larger, uninterrupted restored ecosystems, allows for easy access for project maintenance, and discourages improper and unmanaged uses of the area. It also aids educational programs in increasing the environmental stewardship of this urban wetland. For example, improved and formalized access to the CMP and the resulting community engagement would facilitate strict enforcement of trash-dumping regulations and incentivize local conservation, thus avoiding future degradation in the process.

Provision of recreational access infrastructure has been demonstrated to foster community connection to the restored ecosystem and build and maintain a positive connection to their local landscapes (Golet et al., 2006; Ulrika Åberg & Tapsell, 2013). Additionally, increases in recreational activities such as wildlife viewing, hunting, and fishing often translate to increases in support for conservation actions (Ulrika Åberg & Tapsell, 2013). These activities provide the basis for new and existing community-based enterprises to flourish (e.g., Excursiones Eco, Bici-Caño).

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Appendix D

Cost Engineering

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DRAFT
COST ENGINEERING
CAÑO MARTÍN PEÑA
ECOSYSTEM RESTORATION PROJECT
SAN JUAN, PUERTO RICO

Prepared for:

PROYECTO ENLACE DEL CAÑO MARTÍN PEÑA

Corporación del Proyecto ENLACE del Caño Martín Peña
Apartado Postal 41308
San Juan, Puerto Rico 00940-1308

September 2015

Appendix D-1

Planning Level Cost Estimate

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Planning Level Cost Estimate
Caño Martín Peña Ecosystem Restoration Project
San Juan, Puerto Rico **23-Jul-15**

Number	Description	Alternative				
		75' X 10' PAVED BOTTOM	100' x 10'	125' x 10'	150' x 10'	200' x 10'
01	LANDS & DAMAGES					
01 01	REAL ESTATE REPORTS					
	Real Estate Cost Operations	$176,000	$176,000	$176,000	$176,000	$176,000
02	RELOCATIONS					
02 03	UTILITIES					
	Utility Terminations - Water Mains	$35,000	$35,000	$35,000	$35,000	$35,000
	Utility Terminations - Sanitary Sewers	$50,000	$50,000	$50,000	$50,000	$50,000
02 04	RELOCATION COST TO OWNER/TENANT					
	Acquisition by Local Sponsor	$1,695,100	$1,695,100	$1,695,100	$1,695,100	$1,695,100
	Condemnations by Local Sponsor	$1,935,000	$1,935,000	$1,935,000	$1,935,000	$1,935,000
	Appraisals by Local Sponsor	$847,500	$847,500	$847,500	$847,500	$847,500
	Real Estate Payments by Local Sponsor	$16,747,000	$16,747,000	$16,747,000	$16,747,000	$16,747,000
09	CHANNELS AND CANALS					
09 01	CHANNELS					
	Sediment and Erosion Control	$65,294	$64,233	$66,319	$66,319	$61,708
	Barrio Obrero Marina Temporary Dam	$3,696,350	$3,696,350	$3,696,350	$3,696,350	$3,696,350
	Western Bridges Turbidity Containment Temporary Dam	$710,400	$710,400	$710,400	$710,400	$710,400
	Utility Relocation - Rexach Trunk Sewer Demolition	$858,488	$858,488	$858,488	$858,488	$858,488
	Utility Relocation - Borinquen Water Transmission Demolition	$801,664	$801,664	$801,664	$801,664	$801,664
	Demolition	$2,206,790	$2,206,790	$2,206,790	$2,206,790	$2,206,790
	Clearing and Grubbing	$250,191	$250,191	$250,191	$250,191	$250,191
	Earthwork	$1,522,125	$1,336,500	$1,150,875	$965,250	$519,750
	Dredged Solid Waste Disposal	$1,931,864	$2,180,160	$2,513,240	$2,816,040	$3,512,480
	Dredged Sediments Disposal	$24,202,530	$27,313,200	$31,486,050	$35,279,550	$44,004,600
	PZ-22 30' Sheet Pile	$22,167,200	$22,167,200	$22,167,200	$22,167,200	$22,167,200
	PZ-27 30' Sheet Pile	$2,025,000	$2,025,000	$2,025,000	$2,025,000	$2,025,000
	PZ-22 40' Sheet Pile	$29,186,500	$29,186,500	$29,186,500	$29,186,500	$29,186,500
	PZ-27 40' Sheet Pile	$0	$0	$0	$0	$0
	Stormwater Management	$225,000	$225,000	$225,000	$225,000	$225,000
	Scour Protection - Western Bridges (Weir)	$1,792,065	$1,792,065	$1,792,065	$1,792,065	$1,792,065
	Scour Protection - Dr. Barbosa Avenue Bridge	$1,580,205	$1,580,205	$1,580,205	$1,580,205	$1,580,205
	Scour Protection - 75' wide channel bottom	$10,772,355	$0	$0	$0	$0
09 02	MITIGATION COST					
	Mangrove Restoration and Establishment	$340,440	$301,920	$261,480	$220,920	$139,320
14	RECREATION FACILITIES					
	Recreation Access Area - Water Plaza (9)	$2,279,990	$2,279,990	$2,279,990	$2,279,990	$2,279,990
	Recreation Park with out Boardwalk (6)	$391,198	$391,198	$391,198	$391,198	$391,198
	Recreation Park with Trail (6)	$817,027	$817,027	$817,027	$817,027	$817,027
	Linear Park (1,500 LF)	$3,233,497	$3,233,497	$3,233,497	$3,233,497	$3,233,497
	Park Mobilization and Demobilization	$447,911	$447,911	$447,911	$447,911	$447,911
	SUB TOTAL	**$132,989,685**	**$125,351,090**	**$129,633,041**	**$133,503,156**	**$142,392,935**
	CONTINGENCY (25%)	$33,247,421	$31,337,773	$32,408,260	$33,375,789	$35,598,234
30	PRE-CONSTRICTION ENGINEERING AND DESIGN (6%)	$7,979,381	$7,521,065	$7,777,982	$8,010,189	$8,543,576
31	CONSTRUCTION MANAGEMENT (5.5%)	$7,314,433	$6,894,310	$7,129,817	$7,342,674	$7,831,611
	GRAND TOTAL	**$181,530,921**	**$171,104,238**	**$176,949,101**	**$182,231,808**	**$194,366,356**
	YEARLY OPERATING & MAINTENANCE (1%)	$1,815,309	$1,711,042	$1,769,491	$1,822,318	$1,943,664

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Appendix D-2

Project Cost Summary Estimate

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**** TOTAL PROJECT COST SUMMARY ****

Printed:8/27/2015

PROJECT: Caño Martín Peña Ecosystem Restoration Project
PROJECT NO: 354852
LOCATION: San Juan, Puerto Rico

DISTRICT: SAJ Jacksonville PREPARED: 8/27/2015
POC: CHIEF, COST ENGINEERING, Tracy Leeser

This Estimate reflects the scope and schedule in report; Caño Martín Peña Ecosystem Restoration Project
and is based on the Detailed cost estimate file 354852_CMP_Feasibility_Update_Rev7_Ver10_2015_0825.mlp

SAN JOSÉ LAGOON DISPOSAL OPTION

Civil Works Work Breakdown Structure		ESTIMATED COST				PROJECT FIRST COST (Constant Dollar Basis)						TOTAL PROJECT COST (FULLY FUNDED)		
						Program Year (Budget EC): 2016								
						Effective Price Level Date: 1-Oct-14								
WBS NUMBER	Civil Works Feature & Sub-Feature Description	COST ($K)	CNTG ($K)	CNTG (%)	TOTAL ($K)	ESC (%)	COST ($K)	CNTG ($K)	**TOTAL ($K)**	Spent To Date ($K)	TOTAL FIRST COST	COST ($K)	CNTG ($K)	FULL ($K)
A	*B*	*C*	*D*	*E*	*F*	*G*	*H*	*I*	*J*	*K*	*L*	*M*	*N*	*O*
02	*RELOCATIONS (Cost to Date)*	*$263*								*$263*	*$ 263*			***$263***
02	**RELOCATIONS**	$13,900	$3,205	23.1%	$17,105	1.948%	$14,171	$3,268	**$17,438**		**$ 17,438**	$14,975	$3,453	**$18,429**
06	**FISH & WILDLIFEFACILITIES**	$5,050	$1,165	23.1%	$6,215	2.1%	$5,157	$1,189	**$6,346**		**$ 6,346**	$5,450	$1,257	**$6,707**
09	**CHANNEL & CANAL**	$40,286	$9,290	23.1%	$49,576	2.2%	$41,164	$9,492	**$50,656**		**$ 50,656**	$43,501	$10,031	**$53,533**
14	**RECREATION**	$7,194	$1,659	23.1%	$8,852	0.988%	$7,265	$1,675	**$8,940**		**$ 8,940**	$7,677	$1,770	**$9,447**
16	**BANK STABILIZATION**	$54,230	$12,505	23.1%	$66,735	2.4%	$55,541	$12,808	**$68,349**		**$ 68,349**	$58,695	$13,535	**$72,230**
18	**CULT RESOURTCE PRESERVATION**	$103	$24	23.1%	$126	1.0%	$104	$24	**$127**		**$ 127**	$109	$25	**$135**
	CONSTRUCTION ESTIMATE TOTALS:	$121,025	$27,848		$148,610	2.2%	$123,401	$28,456	$151,857	$263	$152,120	$130,408	$30,072	$160,744
01	*LANDS AND DAMAGES (Cost to Date)*	*$6,038*								*$6,038*	*$ 6,038*			***$6,038***
01	**LANDS AND DAMAGES**	$39,562	$9,123	23.1%	$48,684	1.5%	$40,166	$9,262	**$49,428**		**$ 49,428**	$40,750	$9,397	**$50,147**
30	**PRECONST'N, ENGINEERING, DESIGN**	$10,901	$2,514	23.1%	$13,415	1.5%	$11,065	$2,551	**$13,616**		**$ 13,616**	$11,894	$2,743	**$14,637**
31	**CONSTRUCTION MANAGEMENT**	$7,268	$1,676	23.1%	$8,944	1.5%	$7,377	$1,701	**$9,078**		**$ 9,078**	$8,211	$1,893	**$10,104**
	PROJECT COST TOTALS:	$184,795	$41,160	22.3%	$225,955		$182,008	$41,971	**$223,979**	$6,301	**$230,280**	$191,263	$44,105	**$241,669**

COST SHARE TABLE BELOW IS BASED ON PROJECT FIRST COST

LERRD COST SHARE (Includes PED and CM for Relocation Only)		
ESTIMATED FEDERAL COST:		**$0**
ESTIMATED NON-FEDERAL COST:		**$75,040**
NON RECREATION COST SHARE (Includes PED and CM)		
ESTIMATED FEDERAL COST:		**$142,995**
ESTIMATED NON-FEDERAL COST:		**$1,957**
SUB TOTAL NON RECREATION COST SHARE (Includes PED and CM)		
ESTIMATED FEDERAL COST:	**65%**	**$142,995**
ESTIMATED NON-FEDERAL COST:	**35%**	**$76,997**
SUB TOTAL RECREATION (Includes PED and CM)		
ESTIMATED FEDERAL COST:	**50%**	**$5,144**
ESTIMATED NON-FEDERAL COST:	**50%**	**$5,144**
TOTAL PROJECT COST BY AGENCY(Includes PED and CM)		
ESTIMATED FEDERAL COST:	**65%**	**$148,139**
ESTIMATED NON-FEDERAL COST:	**35%**	**$82,141**
ESTIMATED TOTAL PROJECT FIRST COST:		**$230,280**

______________________ **CHIEF, COST ENGINEERING, Tracy Leeser**

______________________ **PROJECT MANAGER, Jim Suggs**

______________________ **CHIEF, REAL ESTATE, Audrey Ormerod**

______________________ CHIEF, PLANNING,

______________________ CHIEF, ENGINEERING, Laureen Borochaner

______________________ CHIEF, OPERATIONS, Jim Jeffords

______________________ CHIEF, CONSTRUCTION, Steve Duba

______________________ CHIEF, CONTRACTING, Carlos Clarke

______________________ CHIEF, PM-PB, xxxx

______________________ CHIEF, DPM,

Filename: 354852_CMP_TPCS_SJLagoon_Disposal_Rev7_Ver10_2015_0827.xlsx
TPCS, 23.05% Contingency

**** TOTAL PROJECT COST SUMMARY ****

Printed:8/27/2015

**** CONTRACT COST SUMMARY ****

PROJECT: Caño Martín Peña Ecosystem Restoration Project
LOCATION: San Juan, Puerto Rico
This Estimate reflects the scope and schedule in report; Caño Martín Peña Ecosystem Restoration Project

DISTRICT: SAJ Jacksonville PREPARED: 8/27/2015
POC: CHIEF, COST ENGINEERING, Tracy Leeser

354852_CMP_Feasibility_Update_Rev7_Ver10_2015_0825.mlp

FUTURE COST - COST TO COMPLETE ONLY

Civil Works Work Breakdown Structure		ESTIMATED COST				PROJECT FIRST COST (Constant Dollar Basis)				TOTAL PROJECT COST (FULLY FUNDED)				
SAN JOSÉ LAGOON DISPOSAL		Estimate Prepared:			25-Aug-2015	Program Year (Budget EC):			2016					
		Effective Price Level:			1-Oct-2014	Effective Price Level Date:			1-Oct-14					
WBS NUMBER	Civil Works Feature & Sub-Feature Description	COST ($K)	CNTG ($K)	CNTG (%)	TOTAL ($K)	ESC (%)	COST ($K)	CNTG ($K)	TOTAL ($K)	Mid-Point Date	INFLATED (%)	COST ($K)	CNTG ($K)	FULL ($K)
A	*B*	*C*	*D*	*E*	*F*	*G*	*H*	*I*	*J*	*P*	*L*	*M*	*N*	*O*
02	RELOCATIONS	$13,900	$3,205	23.1%	$17,105	1.948%	$14,171	$3,268	$17,438	2018Q2	5.7%	$14,975	$3,453	$18,429
06	FISH & WILDLIFE FACILITIES	$5,050	$1,165	23.1%	$6,215	2.112%	$5,157	$1,189	$6,346	2018Q2	5.7%	$5,450	$1,257	$6,707
09	CHANNELS & CANALS	$40,286	$9,290	23.1%	$49,576	2.179%	$41,164	$9,492	$50,656	2018Q2	5.7%	$43,501	$10,031	$53,533
14	RECREATION FACILITIES	$7,194	$1,659	23.1%	$8,852	0.988%	$7,265	$1,675	$8,940	2018Q2	5.7%	$7,677	$1,770	$9,447
16	BANK STABILIZATION	$54,230	$12,505	23.1%	$66,735	2.418%	$55,541	$12,808	$68,349	2018Q2	5.7%	$58,695	$13,535	$72,230
18	CULTURAL RESOURCE PRESERVATION	$103	$24	23.1%	$126	0.988%	$104	$24	$127	2018Q2	5.7%	$109	$25	$135
	CONSTRUCTION ESTIMATE TOTALS:	$120,762	$27,848	23.1%	$148,610		$123,401	$28,456	$151,857			$130,408	$30,072	$160,480
01	LANDS AND DAMAGES	$39,562	$9,123	23.1%	$48,684	1.527%	$40,166	$9,262	$49,428	2016Q1	1.5%	$40,750	$9,397	$50,147
30	PRECONSTRUCTION, ENGINEERING, DESIGN													
0.5%	Project Management	$607	$140	23.1%	$747	1.500%	$616	$142	$758	2017Q2	7.0%	$659	$152	$811
1.0%	Planning & Environmental Compliance	$1,213	$280	23.1%	$1,493	1.5%	$1,231	$284	$1,515	2017Q2	7.0%	$1,318	$304	$1,621
6.0%	Engineering & Design	$7,261	$1,674	23.1%	$8,935	1.5%	$7,370	$1,700	$9,069	2017Q2	7.0%	$7,887	$1,819	$9,706
	Reviews, ATRs, IEPRs, VE	$0	$0	23.1%	$0	0.0%	$0	$0	$0	0	0.0%	$0	$0	$0
	Life Cycle Updates (cost, schedule, risks)	$0	$0	23.1%	$0	0.0%	$0	$0	$0	0	0.0%	$0	$0	$0
0.5%	Contracting & Reprographics	$607	$140	23.1%	$747	1.5%	$616	$142	$758	2017Q2	7.0%	$659	$152	$811
1.0%	Engineering During Construction	$1,213	$280	23.1%	$1,493	1.5%	$1,231	$284	$1,515	2018Q2	11.3%	$1,370	$316	$1,686
	Planning During Construction	$0	$0	23.1%	$0	0.0%	$0	$0	$0	0	0.0%	$0	$0	$0
	Project Operations	$0	$0	23.1%	$0	0.0%	$0	$0	$0	0	0.0%	$0	$0	$0
31	CONSTRUCTION MANAGEMENT													
5.5%	Construction Management	$6,661	$1,536	23.1%	$8,197	1.500%	$6,761	$1,559	$8,320	2018Q2	11.3%	$7,525	$1,735	$9,260
	Project Operation:	$0	$0	23.1%	$0	0.0%	$0	$0	$0	0	0.0%	$0	$0	$0
0.5%	Project Management	$607	$140	23.1%	$747	1.500%	$616	$142	$758	2018Q2	11.3%	$686	$158	$844
	CONTRACT COST TOTALS:	$178,493	$41,160		$219,653		$182,008	$41,971	**$223,979**			$191,263	$44,105	**$235,368**

Filename: 354852_CMP_TPCS_SJLagoon_Disposal_Rev7_Ver10_2015_0827.xlsx
TPCS, 23.05% Contingency

Appendix D-3

MCACES Report

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Note: This Section Purposefully Omitted

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Appendix D-4

Cost and Schedule Risk Analysis

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DRAFT
COST & SCHEDULE RISK ANALYSIS
CAÑO MARTÍN PEÑA
ECOSYSTEM RESTORATION PROJECT
SAN JUAN, PUERTO RICO

Prepared for:

Corporación del Proyecto ENLACE del Caño Martín Peña
Apartado Postal 41308
San Juan, Puerto Rico 00940-1308

September 2015

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EXECUTIVE SUMMARY

The Project Development Team (PDT) has prepared the Risk Based Cost Analysis of the Caño Martín Peña (CMP) Ecosystem Restoration Project, which is based on the current estimate developed for the project, and has been performed to incorporate current and relevant risk and opportunities to the project to be used as a contingency amount. The experience of the entire PDT has been surveyed and considered in the development of the recommended contingency. Because of this, and in part due to the relatively small sample sizes, a single contingency factor has been developed for the project. This factor is based on the opportunities and risk identified by the PDT, assumed probabilities of occurrence, and impacts to the project for the individual items. Additional detail and explanation of specific considerations beyond the Cost & Schedule Risk Analysis Report may be found in the Project Risk Register and Crystal Ball Model for the management of the individual factors.

The results of the probability run after these factors were evaluated and considered are shown in the following table. At an 80% level of confidence, the contingency level is approximately 23.1% of the estimate reviewed in the CSRA, and has been used as contingency on the entire project.

Table 1. Contingency Results
Contingency Analysis ($ in millions)

Most Likely Cost Estimate	$178.4	
Confidence Level	**Value**	**Contingency**
0%	$184.7	5.5%
10%	$199.6	11.8%
20%	$202.8	13.7%
30%	$205.4	15.0%
40%	$207.7	16.4%
50%	$210.0	17.8%
60%	$212.7	19.3%
70%	$215.8	21.0%
80%	$219.7	23.1%
90%	$224.8	25.7%
100%	$251.7	33.8%

Based on the Total Project Cost Summary (TPCS) revision for this estimate, the recommended contingency of 23.1% on all remaining project costs results in a present day estimate of $219.7 million, escalated to a program year 2016 cost of $224.0 million. Adding expended costs of $6.3 million results in a "Project First Cost" in program year 2016 of $230.3 million.

Table 2. Summary of "Project First Cost" in Program Year 2016 ($ in millions)

Base Cost Estimate	Contingency at 80%	Cost with Contingency	Cost with Escalation	Project First Cost (including expended)
$178.5	**$41.2**	**$219.7**	**$224.0**	**$230.3**

The primary cost risk factors driving the recommended 23.1% contingency amount are as follows (in order based on the impact on the cost variance in the model):

Included with each risk factor is the likelihood of occurrence and the range of potential impact ($ in millions). Additional detail can be found in the Crystal Ball Risk Model.

1. Risk CH-23: Concern is that the San Jose Lagoon pits may not be available; therefore, the spoils may have to be taken to upland disposal sites. Lack of pits availability could be due to uncontainable contamination levels or public opposition. Risk of going to upland sites is also the cost of containing any contaminated material.

   Likelihood of Occurrence: 100%; Range of impact, (Low, Likely, High) = $0; $0; $25.0

2. Risk GE-01: Market conditions in Puerto Rico and in the construction industry may have a greater chance of increasing greater than historical escalation rates, and the PDT felt the costs could be volatile at the higher end, although they have recently been stable. This includes the risk for potential fuel and steel cost variance, and for the price variance for dredging at the time of bidding. The high end is based on an increase in the construction costs of 10%.

   Likelihood of Occurrence: 100%; Range of impact, (Low, Likely, High) = $0; $0; $12.1

3. Risk EA-4: Dredging Production Rates: The PDT considered that there could be a large variance in the dredging production rates from that included in the estimate. These rates could vary from +/- 20%.

   Likelihood of Occurrence: 100%: Range of impact, (Low, Likely, High) = -$8.0; $0.0; $8.0

4. Risk PM-06: Potential for Change Orders during construction was considered by the team as a very likely risk that has a high potential range of impact. Considering the risk for unforeseen conditions and potential changes during construction, this is considered one of the greatest risks on the projects. Several smaller risks that were identified by the team are considered to be included in this risk total, such as the potential for items that could negatively impact the construction productivity. The range of results is an increase to the total project costs of from 3% at low end to 10% at the high end.

   Likelihood of Occurrence: 100%; Range of impact, (Low, Likely, High) = $5.3; $10.7; $17.8

5. Risk EA-2: Sheet Pile Wall Quantities. There is some uncertainty with the exact quantity of sheet pile wall that will be required for the project. The PDT put the uncertainty at +/- 10% from the current estimate.

   Likelihood of Occurrence: 100%: Range of impact, (Low, Likely, High) = $-3.5; $0.0; $3.5

6. Risk CH-22: Disposal Material Quantity Variation. Quantity for special handling and disposal of dredged material. Based on borings taken, the estimate includes 10% of the dredged material that will have to be sorted and handled separately when containing solid waste. This risk is that this quantity could be greater than estimated.

   Likelihood of Occurrence: 100%: Range of impact, (Low, Likely, High) = $0; $0; $4.0

The schedule risks identified with the greatest contribution to variance in the model were the following:

1. Risk GE-04: Funding Constraints. This was the predominant schedule risk driver, as the Project is dependent on Water Resources Development Act authorization. Current local matching is 35% plus O&M and if no local share than the project could extend. Congress yearly appropriations could also impact phasing of the project.

   Likelihood of Occurrence: 100%: Range of impact, (Low, Likely, High) = 0, 0, 36

2. Risk PM-07: Project Closeout: Delays to closing out the project are considered a potential. These range from contract closeout to final inspections.

   Likelihood of Occurrence: 100%: Range of impact, (Low, Likely, High) = 0, 0, 5

3. Risk GE-09: Public Opposition: Could range from a demonstration to a lawsuit, but considered unlikely by the team.

   Likelihood of Occurrence: 100%: Range of impact, (Low, Likely, High) = 0, 0, 12

4. Risk RL-06: Relocation of Residents: Although considered unlikely by the PDT, there is some risk that a delay in the relocation of residents will delay the start of construction.

   Likelihood of Occurrence: 100%: Range of impact, (Low, Likely, High) = 0, 0, 6

5. Risk RL-04a: Utility relocations of the Borinquen Water Line & the Rexach Trunk Sewer: Work requires coordination with installation of CMP sheet pile walls. Delays could impact project schedule or require design modifications for future installation.

   Likelihood of Occurrence: 100%: Range of impact, (Low, Likely, High) = 0, 0, 3

6. Risk GE-02: Weather impacts: Weather was also considered to be a schedule risk, with the potential of weather events delaying construction.

   Likelihood of Occurrence: 100%: Range of impact, (Low, Likely, High) = 0, 0, 3

The schedule risks result in up to 20 months of potential delay at the 80% confidence level.

These are the major risks considered in the CSRA, and combined with other risks have made up the contingency amount noted for the CMP Ecosystem Restoration Project. These risks result in a Project First Cost of $224.1 million.

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1.0 PURPOSE

The purpose of this risk based cost analysis was to study the potential impact on the cost and schedule of risks and opportunities that are specific to the Caño Martín Peña (CMP) Ecosystem Restoration Project (CMP-ERP) and which may cause cost and schedule overruns. Moreover it is to assess whether an appropriate contingency has been established and provide a basic outline for mitigation of the identified risks. The risks and opportunities have been studied from a probabilistic approach whereby the estimated cost is presented as a probability curve. The United States Army Corp of Engineers (USACE) recommends the contingency in the cost estimate be compared against the 80% value on the resultant probability curve.

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2.0 PROJECT BACKGROUND

The CMP is a natural tidal channel 3.75 miles long in metropolitan San Juan, Puerto Rico, south of Santurce and north of Hato Rey, dividing these two densely populated wards of the city. It is one of eight interconnected bodies of water within the San Juan Bay Estuary (SJBE), the only tropical estuary in the U.S. Environmental Protection Agency (EPA) National Estuary Program (NEP). The SJBE interior coastal lagoons and tidal channels are connected to the Atlantic Ocean at both ends. The drainage area of the CMP comprises about 2,500 acres. The drainage area of the canal is only about four square miles (2,500 acres) and is a tributary to the Rio Puerto Nuevo basin with a drainage area of about 25 square miles. Extending from east to west through eight densely populated impoverished communities in San Juan, the CMP connects the San Juan Bay with the San José and Los Corozos Lagoons, which are further connected by the Suárez Canal to La Torrecilla Lagoon and the Atlantic Ocean. A project location map is included as Figure 1.

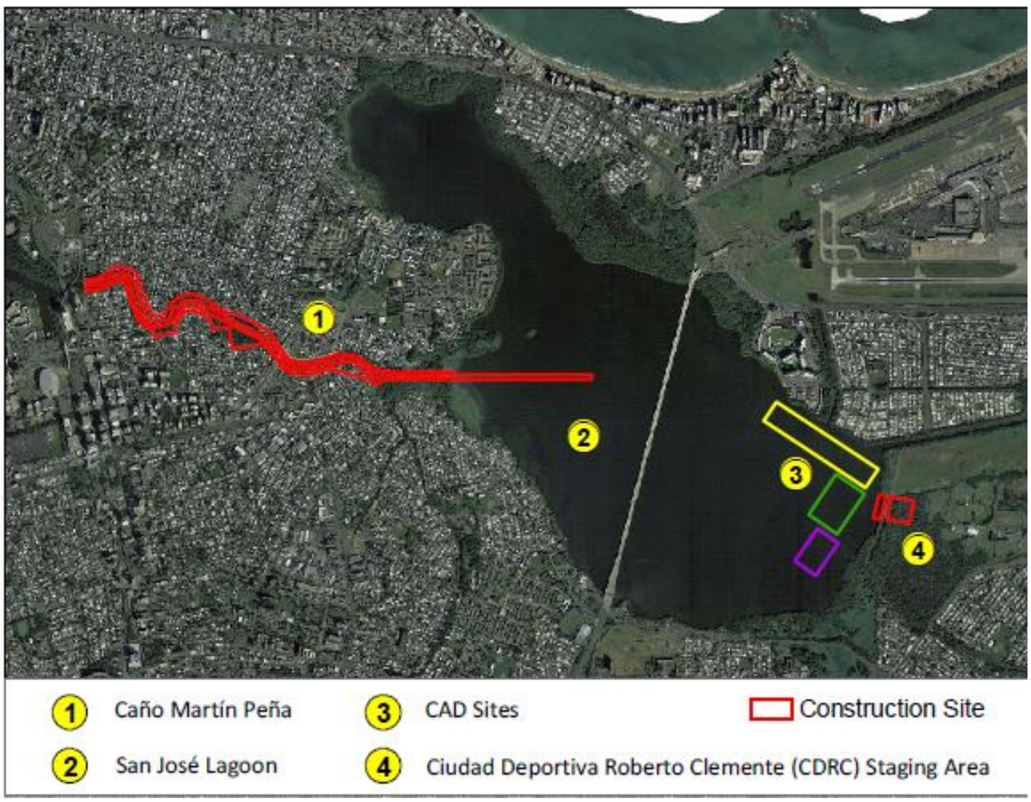

Figure 1. The Caño Martin Peña Ecosystem Restoration Project Area

Historically, the CMP had an average width of approximately 200 feet and provided tidal exchange between San Juan Bay and the San José Lagoon. Since the 1920s, the CMP channel and its associated wetlands began to be modified as a result of development pressures. Low-income migrants from rural Puerto Rico constructed housing structures throughout the wetlands. As the housing developments lacked basic utilities, such as storm and sanitary sewer systems, and adequate road infrastructure for a proper solid waste collection system, thousands of structures have discarded their refuse into the CMP for decades. Consequently, siltation, accumulation of household and construction debris, encroachment of housing and other structures, and sedimentation from urban runoff have almost completely blocked the CMP's ability to convey flows, thus affecting the habitat functional value and water quality in both the CMP and San José Lagoon. The main ecosystem restoration benefits will occur to benthic habitat within the 702-acre San José Lagoon. Habitat Units will be calculated for this area and, along with alternative plan costs and other criteria, used to compare and select an alternative plan.

The National Ecosystem Restoration Plan (NER Plan) consists of dredging the eastern segment of the channel (2.2 miles long) to restore the CMP and adjacent areas and increase tidal flushing of the San José Lagoon, restoring the benthic habitat and reducing the harmful salinity gradient and de-oxygenated areas that have become prevalent. Additionally, mangrove wetlands to the north and south of the CMP would be re-established, and, as ancillary benefits that were not quantified, reduce flooding within the CMP's eight adjacent communities. In addition, the CMP-ERP incorporates a recreation plan that will include the creation of recreation access parks that will formalize human interaction with the restored waterfront. The CMP-ERP would also allow for the potential of environmentally sound waterway transportation and promote recreation and tourism in the adjacent communities of Barrio Obrero Oeste and San Ciprian, Barrio Obrero Marina, Buena Vista Santurce, Israel-Bitumul, Buena Vista Hato Rey, Las Monjas and Parada 27 that make up the CMP Special Planning District (the District).

The Caño Martín Peña ENLACE Project Corporation (ENLACE), the non-Federal sponsor, is the public entity within the Government of Puerto Rico that is legally designated with the coordination and implementation of the District Comprehensive Development Plan (DCDP). The DCDP includes the CMP Ecosystem Restoration Project, as well as a series of other improvements that ENLACE has been coordinating in preparation and are necessary for project success. These improvements include family relocations, the creation of sanitary sewer systems for the residences and business within the District, and the prevention of new development and fill in of the CMP.

3.0 REPORT SCOPE

3.1 Project Scope

The project scope as defined in Section 2 (Background). The approximate design stage is near 30%.

3.2 USACE Risk Analysis Process

In accordance with USACE Engineer Regulation 1110-2-1302, a formal risk analysis is required for any projects exceeding $40 million and which are going forward to Congress requesting funding. Due to the age of the prior analysis and estimate, (greater than 2 years) the Cost, Schedule, and Risk Analysis are indicated for review and updating. The CMP-ERP is subject to this requirement. Before beginning this analysis, the USACE provided a draft copy of its Cost and Schedule Risk Analysis Guidance document dated May 17, 2009. This document was utilized in the performance of the risk analysis and this update. The guidance document identifies the following key aspects of the risk analysis process:

- Uses probabilistic cost and schedule risk analysis methods within the framework of the Crystal Ball software;
- Establishes reasonable contingencies reflective of an 80 percent confidence level;
- Provides project leadership with contingency information for scheduling, budgeting, and project control purposes;
- Provides tools to support decision making and risk management as the project progresses through planning and implementation; and
- Recognizes that to fully recognize its benefits, cost and schedule risk analyses should be considered as an ongoing process conducted concurrent to, and iteratively with, other important project processes such as scope and execution plan development, resource planning, procurement planning, cost estimating, budgeting, and scheduling.

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4.0 METHODOLOGY/PROCESS

For the purpose of performing the CMP-ERP risk analysis a team was assembled and lead by Atkins. The Project Development Team (PDT) was comprised of the following individuals:

- Mr. Carlos Rivera - USACE Jacksonville District
- Mr. Raymond Wimbrough – USACE Jacksonville District
- Mr. Alfred Walker – USACE Jacksonville District
- Ms. Katia Aviles Vazquez – ENLACE
- Mr. Carlos Muñiz – Pérez – ENLACE
- Mr. Webb Smith – ATKINS – Project Manager
- Mr. William Stevenson – ATKINS - Senior Estimator/Scheduler
- Mr. Dave Carter – ATKINS - Risk Analyst
- Mr. Donald Ator – ATKINS
- Mr. Francisco Perez – ATKINS
- Mr. Steven Pophal – ATKINS
- Mr. Don Deis – ATKINS

The PDT held its initial risk analysis workshop on Thursday, February 28, 2013. A copy of the agenda is provided in Appendix C along with the PowerPoint presentation orienting the PDT to the methodology and risk analysis process. In the workshop the team identified the risks and opportunities the project could experience, the likelihood of their occurrence and the potential impact both to cost and schedule. The information was captured in the risk register provided in Appendix D. With the input obtained from the team, the risk analysts then performed the market and Monte Carlo quantitative probability analysis on the cost estimate utilizing the Crystal Ball software. A follow-up call was held on Thursday, March 7, 2013 to review the risk register preliminary information and to discuss the probability assumptions. The team then agreed on an appropriate contingency to be used in the cost estimate. Once the team made the decision to utilize the "Ocean Disposal Site Work Plan", an update call was held on Wednesday, September 11, 2013. In this meeting the updated estimate was utilized in reviewing changes to the Risk Register resulting from using Ocean Disposal, and these changes were included in a previous CSRA draft report.

Once the Ocean Disposal Site Work Plan was rejected in 2014, the option of disposing dredged material in San Jose Lagoon (SJL) pits was developed. The PDT met via conference call on October 31, 2014 to discuss the risk impact of utilizing the SJL pits in lieu of ocean disposal. The current risk register and results in this report all are on the basis of the SJL pits disposal option. The project cost was updated for this report in August 2015.

In regard to the schedule, Appendix E is the current implementation schedule for the project showing a scheduled construction completion date for the project of September 2020. The team identified the risks that could impact the schedule, with the major risks identified that could have major impacts on the schedule. When a more detailed schedule is developed, a more comprehensive risk analysis can be performed.

The risk analysis process for this study is intended to determine the probability of various cost outcomes and quantify the required contingency needed in the cost estimate to achieve any desired level of cost confidence. A parallel process is also used to determine the probability of various project schedule duration outcomes and quantify the required schedule contingency (float) needed in the schedule to achieve any desired level of schedule confidence.

In simple terms, contingency is an amount added to an estimate (cost or schedule) to allow for items, conditions, or events for which the occurrence or impact is uncertain and that experience suggests will likely result in additional costs being incurred or additional time being required. The amount of contingency included in project control plans depends, at least in part, on the project leadership's willingness to accept risk of project overruns. The less risk that project leadership is willing to accept, the more contingency should be applied in the project control plans. The risk of overrun is expressed, in a probabilistic context, using confidence levels.

The Cost Engineering DX guidance for cost and schedule risk analysis generally focuses on the 80-percent level of confidence (P80) for cost contingency calculation. It should be noted that use of P80 as a decision criteria is a risk adverse approach (whereas the use of P50 would be a risk neutral approach, and use of levels less than 50 percent would be risk seeking). Thus, a P80 confidence level results in greater contingency as compared to a P50 confidence level.

The risk analysis process uses *Monte Carlo* techniques to determine probabilities and contingency. The *Monte Carlo* techniques are facilitated computationally by a commercially available risk analysis software package (Crystal Ball) that is an add-in to Microsoft Excel. Cost estimates are packaged into an Excel format and used directly for cost risk analysis purposes. Because Crystal Ball is an Excel add-in, the schedules for each option are recreated in an Excel format from their native format. The level of detail recreated in the Excel-format schedule is sufficient for risk analysis purposes that reflect the established risk register, but generally less than that of the native format.

The primary steps, in functional terms, of the risk analysis process are described in the following subsections. Risk analysis results would be provided in section 6.

4.1 Identify and Assess Risk Factors

Identifying the risk factors via the PDT are considered a qualitative process that results in establishing a risk register that serves as the document for the further study using the Crystal Ball risk software. Risk factors are events and conditions that may influence or drive uncertainty in project performance. They may be inherent characteristics or conditions of the project or external influences, events, or conditions such as weather or economic conditions. Risk factors may have either favorable or unfavorable impacts on project cost and schedule.

Checklists or historical databases of common risk factors are sometimes used to facilitate risk factor identification; however, key risk factors are often unique to a project and not readily derivable from historical information. Therefore, input from the entire PDT is obtained using creative processes such as brainstorming or other facilitated risk assessment meetings. In practice, a combination of professional judgment from the PDT and empirical data from similar projects in desirable and is considered.

Formal PDT meetings are held (include the name of the location in the report) for the purposes of identifying and assessing risk factors. The meetings (include the date) should include capable and qualified representatives from multiple project team disciplines and functions, for example:

- Project/program managers
- Contracting/acquisition
- Real Estate
- Relocations
- Environmental
- Civil, structural, geotechnical, and hydraulic design
- Cost and schedule engineers
- Construction
- Key sponsors

The initial formal meetings should focus primarily on risk factor identification using brainstorming techniques, but also include some facilitated discussions based on risk factors common to projects of similar scope and geographic location. Subsequent meetings should focus primarily on risk factor assessment and quantification.

Additionally, numerous conference calls and informal meetings are conducted throughout the risk analysis process on an as-needed basis to further facilitate risk factor identification, market analysis, and risk assessment.

4.2 Quantify Risk Factor Impacts

The quantitative impacts of risk factors on project plans are analyzed using a combination of professional judgment, empirical data, and analytical techniques. Risk factor impacts are quantified using probability distributions (density functions), because risk factors are entered into the Crystal Ball software in the form of probability density functions.

Similar to the identification and assessment process, risk factor quantification involves multiple project team disciplines and functions; however, the quantification process relies more extensively on collaboration between cost engineering, designers, and risk analysis team members with lesser inputs from other functions and disciplines.

The following is an example of the PDT quantifying risk factor impacts by using an iterative, consensus-building approach to estimate the elements of each risk factor:

- Maximum possible value for the risk factor
- Minimum possible value for the risk factor
- Most likely value (the statistical mode), if applicable
- Nature of the probability density function used to approximate risk factor uncertainty
- Mathematical correlations between risk factors
- Affected cost estimate and schedule elements

In this example, the risk discussions focused on the various project features as presented within the USACE Civil Works Work Breakdown Structure for cost accounting purposes. It was recognized that the various features carry differing degrees of risk as related to cost, schedule, design complexity, and design progress. The example features under study are presented in table 3:

Table 3. Work Breakdown Structure by Feature

CODE	DESCRIPTION
01	LANDS AND DAMAGES
02	RELOCATIONS
09	CHANNELS & CANALS
14	RECREATION
16	BANK STABILIZATION
18	CULTURAL RESOURCES PRESERVATION
30	PLANNING, ENGINEERING & DESIGN
31	CONSTRUCTION MANAGEMENT

The resulting product from the PDT discussions is captured within a risk register as presented in section 6 for both cost and schedule risk concerns. Note that the risk register records the PDT's risk concerns, discussions related to those concerns, and potential impacts to the current cost and schedule estimates. The concerns and discussions are meant to support the team's decisions related to event likelihood, impact, and the resulting risk levels for each risk event.

4.3 Analyze Cost Estimate and Schedule Contingency

Contingency is analyzed using the Crystal Ball software, an add-in to the Microsoft Excel format of the cost estimate and schedule. *Monte Carlo* simulations are performed by applying the risk factors (quantified as probability density functions) to the appropriate estimated cost and schedule elements identified by the PDT. Contingencies are calculated by applying only the moderate and high level risks identified for each option (i.e., low-level risks are typically not considered, but remain within the risk register to serve historical purposes as well as support follow-on risk studies as the project and risks evolve).

For the cost estimate, the contingency is calculated as the difference between the P80 cost forecast and the base cost estimate. Each option-specific contingency is then allocated on a civil works feature level based on the dollar-weighted relative risk of each feature as quantified by *Monte Carlo* simulation. Standard deviation is used as the feature-specific measure of risk for contingency allocation purposes. This approach results in a relatively larger portion of all the project feature cost contingency being allocated to features with relatively higher estimated cost uncertainty.

For schedule contingency analysis, the option schedule contingency is calculated as the difference between the P80 option duration forecast and the base schedule duration. These contingencies are then used to calculate the time value of money impact of project delays that are included in the presentation of total cost contingency in section 6. The resulting time value of money, or added risk escalation, is then added into the contingency amount to reflect the USACE standard for presenting the "total project cost" for the fully funded project amount.

Schedule contingency is analyzed only on the basis of each option and not allocated to specific tasks. Based on Cost Engineering DX guidance, only critical path and near critical path tasks are considered to be uncertain for the purposes of contingency analysis.

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5.0 KEY ASSUMPTIONS

The following are considered to be the key assumptions made by the PDT during the CSRA for the project.

- The project is at an approximate 30% design stage.
- The PDT has confidence in the design scope, particularly for the amount of subsurface information, including some soil borings along the channel walls.
- Disposal in San Jose Lagoon pits will be allowed for the dredged / filtered material. A risk is included for alternate disposal, should this not be allowed.
- There are no life cycle costs included in the risk analysis. All risk is related to design and construction time frames.
- Funding is considered to be a risk, with yearly funding appropriations from Congress and a 35% local match.
- Assumed that debris would be included in 10% to 20% of the dredged material, with 10% included in the cost estimate and an additional 10% in the risk amount.
- Have confidence in the cost estimate as it has been developed over a long term with good quantity and price information at this project stage.
- Assumed potential change orders during the construction stage could range from 2% at the low end to 10% at the high end, in addition to other risks identified for the project.
- Assumed dredging production rates could be 20% slower than included in the cost estimate.
- Assumed a risk that market conditions would primarily impact the project on the higher side for labor, equipment and materials, with additional risks included for impacts from fuel and steel costs increasing well above the cost estimate.
- Assumed potential delay and cost impact due to weather.
- Assumed a low chance that an earthquake could impact the project during construction.
- Did not include a catastrophic risk, as it was considered that these would completely stop the project and the future of the project.
- Assumed that HTRW materials would not be present within the project area in any significant volumes.

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6.0 RISK ANALYSIS RESULTS

Table 4 displays the results of the risk analysis for the Project First Cost for Program Year 2016:

Table 4. Project First Cost

CATEGORY	ESTIMATED COST (in millions)
Base Cost Estimate	$178.5
Risk Analysis Contingency Result (80% confidence)	$41.2
Subtotal Estimated Cost	**$219.7**
Escalation to Project First Cost (Program Year 2016)	$4.3
Subtotal Estimated Cost	**$224.0**
Expended Costs	$6.3
Total Project First Cost	**$230.3**

The major cost risks making up the contingency amount include the following (note that some of these risks are combined in the major risks related to the potential for changes and for varying market conditions):

- Potential for change orders during construction
- Market conditions in Puerto Rico and in the construction industry
- Increased quantities of dredged material requiring special handling and disposal
- The risk of steel cost variances for the sheet pile channel walls
- The potential of having to work through limestone on the eastern end of the CMP, which could require a king pile supported sheet pile wall in lieu of the cantilevered sheet pile wall estimated
- The potential for increased fuel costs
- The potential for an earthquake to damage the project
- The potential for vibrations from project construction to impact adjacent structures
- The potential for excess H_2S from project excavations
- Lower productivity of construction around existing bridges or damage to existing bridges
- Potential for alternate disposal (other than SJL pits disposal) being required
- Potential quantity variations of dredged material and sheet pile wall material
- Potential lower productivity than estimated, particularly for the dredging operation

Many of the cost risks also had schedule impact included with them. Other major schedule risks beyond the cost risks are the following:

- Funding Constraints
- Weather impacts
- Delays to dredging and disposal of material
- Delays due to identification of hazardous or potential human remains during the dredging
- Delay to completing and closing out the project

6.1 Risk Register

Provided in Appendix A is the Risk Register developed by the team. The risks were placed in the following categories. The corresponding USACE Civil Works project feature code is identified in the left column.

CODE	DESCRIPTION
	General and Economic
01	Lands and Damages
02	Relocations
09	Canals & Detention Ponds
14	Recreation Facilities
18	Cultural Preservation
	Estimating Assumptions
30 & 31	Project and Program Management

Cost and Schedule impacts, in terms of dollars, have been estimated for each of the risk factors, based on the estimated value of work that could potentially be affected by its occurrence.

The likelihood of occurrence was also identified and applied to the previously identified Cost and Schedule risks, in dollars, which yielded a most likely impact to the project for use in the Crystal Ball Model Analysis.

In accordance with USACE guidance, the level of risk was measured using the following criteria:

Table 5. Risk Level Assessment

Risk Level

Likelihood of Occurrence	Negligible	Marginal	Significant	Critical	Crisis
Very Likely	Low	Moderate	High	High	High
Likely	Low	Moderate	High	High	High
Unlikely	Low	Low	Moderate	Moderate	High
Very Unlikely	Low	Low	Low	Low	High

Impact or Consequence of Occurrence

Table 6 depicts a condensed version of the Risk Register showing the establishment of the risk level based on Table 5 above. The "Rough Order Impact" columns for cost and schedule impact are based on the most likely impacts as developed by the PDT. Note that the most likely result is typically no change to the current estimate, while the high end is typically used should a risk occur. For risks like scope changes and construction change orders, a likely result is included since there is no allowance in the current estimate for these risks.

Table 6. Condensed Risk Register

Caño Martín Peña Ecosystem Restoration Project									
		Project Cost				Project Schedule			
Risk No.	Risk/Opportunity Event	Likelihood*	Impact*	Risk Level*	Rough Order Impact ($)	Likelihood*	Impact*	Risk Level*	Rough Order Impact (mo)
Contract Risks (Internal Risk Items are those that are generated, caused, or controlled within the PDT's sphere of influence.)									
GENERAL AND ECONIMIC RISKS									
GE-01	Market Conditions	Likely	Significant	HIGH	$0			LOW	
GE-02	Weather Impacts	Likely	Marginal	MODERATE	$0	Likely	Significant	HIGH	2
GE-03	Energy Costs	Likely	Significant	HIGH	$0			LOW	
GE-04	Funding Constraints	Likely	Critical	HIGH	$0	Likely	Critical	HIGH	24
GE-05	Availability of Skilled Resources	Very Unlikely	Marginal	LOW	$0			LOW	
GE-06	Project Reauthorization	Very Unlikely	Significant	LOW	$0			LOW	
GE-07	Steel Costs	Likely	Significant	HIGH	$0			LOW	
GE-08	Recreational Fishermen	Very Unlikely	Negligible	LOW	$0			LOW	
GE-9	Public Opposition	Very Unlikely	Marginal	LOW	$0	Unlikely	Marginal	LOW	1
GE-10	Potential Earthquake	Unlikely	Crisis	HIGH	$0	Unlikely	Critical	HIGH	6
LANDS AND DAMAGES RISKS									
LD-01	Mitigation Cost	Very Unlikely		LOW	$0			LOW	
LD-02	Public Domain footprint	Very Unlikely		LOW	$0			LOW	
LD-03	Vibration Impacts	Very Likely	Significant	HIGH	$0			LOW	

Caño Martín Peña Ecosystem Restoration Project									
Risk No.	Risk/Opportunity Event	Project Cost				Project Schedule			
		Likelihood*	Impact*	Risk Level*	Rough Order Impact ($)	Likelihood*	Impact*	Risk Level*	Rough Order Impact (mo)
RELOCATIONS									
RL-01	Cost Variances	Very Unlikely	Negligible	LOW	$0			LOW	
RL-02	Condemnation	Very Unlikely		LOW	$0			LOW	
RL-03	Unknown Utilities	Very Unlikely		LOW	$0			LOW	
RL-04	Reduced project footprint	Very Unlikely	Marginal	LOW	$0			LOW	
RL-04a	Borinquen Water Line & Rexach Trunk Sewer	Likely	Marginal	MODERATE	$0	Likely	Significant	HIGH	2
RL-05	Air Quality	Very Likely	Significant	HIGH	$0			LOW	
RL-06	Relocation of residents	Unlikely	Negligible	LOW	$0	Unlikely	Significant	MODERATE	4
CANALS AND DETENTION PONDS									
CH-01	Historic Finds	Unlikely	Marginal	LOW	$0			LOW	
CH-02	HTRW (Hazardous Material)	Unlikely	Significant	MODERATE	$0	Unlikely	Critical	HIGH	2
CH-03	Contaminated Material	Very Unlikely	Negligible	LOW	$0			LOW	
CH-04	Debris Removal and Sorting	Likely	Marginal	LOW	$0			LOW	
CH-05	Heavily Urbanized Area			LOW	$0			LOW	
CH-06	Work Hours / Site Access	Very Unlikely	Marginal	LOW	$0			LOW	
CH-07	Soil Conditions	Very Unlikely	Marginal	LOW	$0			LOW	
CH-08	Access Routes	Very Unlikely	Marginal	LOW	$0			LOW	

Caño Martín Peña Ecosystem Restoration Project									
Risk No.	Risk/Opportunity Event	Project Cost				Project Schedule			
		Likelihood*	Impact*	Risk Level*	Rough Order Impact ($)	Likelihood*	Impact*	Risk Level*	Rough Order Impact (mo)
CH-09	Construction Sequencing	Very Unlikely	Negligible	LOW	$0			LOW	
CH-10	Sediment Containment	Very Unlikely	Negligible	LOW	$0			LOW	
CH-11	Sediment Contamination	Very Likely	Negligible	LOW	$0			LOW	
CH-12	Human remains	Very Likely	Marginal	MODERATE	$0		Marginal	MODERATE	0.5
CH-13	Equipment Access	Very Likely	Marginal	MODERATE	$0	Very Likely		LOW	
CH-14	Work under existing bridges	Very Likely	Significant	HIGH	$0			LOW	
CH-14a	Potential damage to existing bridges	Unlikely	Significant	MODERATE	$0	Unlikely	Significant	MODERATE	1.5
CH-15	Issues with Sediment Pumping	Very Unlikely	Negligible	LOW	$0	Very Unlikely	Negligible	LOW	
CH-16	Issues with Sediment Screening	Unlikely	Marginal	LOW	$0	Unlikely	Marginal	LOW	1
CH-17	Coordination with PRPA	Very Unlikely	Negligible	LOW	$0			0	
CH-18	Operations interruption with AquaExpresso	Unlikely	Marginal	LOW	$0	Unlikely	Marginal	LOW	1
CH-19	Weather and coordination impact to Barging of Disposal Material	Unlikely	Marginal	LOW	$0	Unlikely	Negligible	LOW	
CH-20	Trucking	Very Unlikely	Marginal	LOW	$0			LOW	
CH-21	Limestone in dredging	Likely	Marginal	LOW	$0	Likely	Significant	HIGH	3
CH-22	Disposal Material Quantity Variation	Very Likely	Critical	HIGH	$0	Likely	Significant	HIGH	3
CH-23	Alternate Disposal Options	Unlikely	Critical	MODERATE	$0	Unlikely	Critical	MODERATE	

Caño Martín Peña Ecosystem Restoration Project									
Risk No.	Risk/Opportunity Event	Project Cost				Project Schedule			
		Likelihood*	Impact*	Risk Level*	Rough Order Impact ($)	Likelihood*	Impact*	Risk Level*	Rough Order Impact (mo)
OPPORTUNITIES									
CH-24	Source of Sand	Very Unlikely	Negligible	LOW	$0				
RECREATION									
RC-02	Variations in Design Concepts	Very Unlikely	Marginal	LOW	$0			LOW	
RC-03	Squatters	Very Unlikely	Marginal	LOW	$0			LOW	
CULTURAL PRESERVATION									
CP-01	Site Access	Very Unlikely	Marginal	LOW	$0			LOW	
CP-02	Encounter cultural conditions	Likely	Marginal	MODERATE	$0	Likely	Significant	HIGH	2
CP-03	Variations in Design Concepts	Very Unlikely	Marginal	LOW	$0			LOW	
ESTIMATING ASSUMPTIONS									
EA-1	Dredging Quantities	Very Likely	Marginal	MODERATE	$0	Very Unlikely	Marginal	LOW	
EA-2	Sheet Pile Wall Quantities	Very Likely	Marginal	MODERATE	$0	Very Unlikely	Marginal	LOW	
EA-3	Articulated Concrete Block Material Quantities	Very Likely	Marginal	MODERATE	$0	Likely	Marginal	MODERATE	
EA-4	Dredging Production Rates and Crews	Very Likely	Marginal	MODERATE	$0	Unlikely	Marginal	LOW	
EA-5	Sheet Pile Walls Production Rates and Crews	Very Likely	Marginal	MODERATE	$0	Unlikely	Marginal	LOW	
EA-6	Scope Changes	Very Unlikely	Marginal	LOW	$1,577,962	Unlikely	Marginal	LOW	

Caño Martín Peña Ecosystem Restoration Project									
		Project Cost				Project Schedule			
Risk No.	Risk/Opportunity Event	Likelihood*	Impact*	Risk Level*	Rough Order Impact ($)	Likelihood*	Impact*	Risk Level*	Rough Order Impact (mo)
PROJECT & PROGRAM MGMT									
PM-03	Rights of Entry	Very Unlikely	Marginal	LOW	$0			LOW	
PM-05	Program Management Resources	Very Unlikely	Marginal	LOW	$0			LOW	
PM-06	Change Management	Very Likely	Critical	HIGH	$10,150,555			LOW	
PM-07	Project Closeout	Likely	Marginal	MODERATE	$0	Likely	Significant	HIGH	2
PM-07a	Wetlands Impact			0	$0			0	

The condensed Risk Register shows the determination of those risks that were considered to have a "High" impact on the project, and the resulting cost / schedule impact. There were relatively few opportunities identified and modeled to reduce the project costs or reduce the schedule duration.

6.2 Combined Cost and Schedule Contingency Results

Table 7 shows the results of the contingency analysis for the project, demonstrating that at the 80% confidence level, the contingency is made up of approximately $37.5 million in cost related risks and $3.7 million in schedule related risks. Table 7 also demonstrates that the potential range of contingency from a very low confidence level to near 100% confidence is from $6.3 million to $73.2 million. These extremes are highly unlikely, but do demonstrate the high potential variability with the project costs and the opportunity for risk mitigation.

For those risk noted in the previous list, the following "Sensitivity Charts" (Figures 2 and 3) show the results of the impact of the major risks on the contingency results.

Table 7. Contingency Results Breakdown ($ in Millions)

Confidence Level	Cost Contingency	Schedule Contingency	Total Contingency	Contingency %
0%	$6.1	$0.1	$6.3	3.5%
5%	$18.1	$0.6	$18.7	10.5%
10%	$20.4	$0.8	$21.2	11.8%
15%	$22.0	$0.9	$22.9	12.8%
20%	$23.4	$1.0	$24.4	13.7%
25%	$24.7	$1.1	$25.8	14.4%
30%	$25.8	$1.2	$27.0	15.1%
35%	$26.8	$1.3	$28.1	15.7%
40%	$27.8	$1.4	$29.3	16.4%
45%	$28.9	$1.5	$30.4	17.0%
50%	$29.9	$1.7	$31.6	17.7%
55%	$31.0	$1.9	$32.9	18.4%
60%	$32.2	$2.1	$34.3	19.2%
65%	$33.5	$2.4	$35.9	20.1%
70%	$34.6	$2.8	$37.4	20.9%
75%	$35.9	$3.2	$39.1	21.9%
80%	$37.5	$3.7	$41.2	23.1%
85%	$39.1	$4.2	$43.4	24.3%
90%	$41.4	$4.9	$46.3	25.9%
95%	$44.7	$5.7	$50.4	28.2%
100%	$64.4	$8.9	$73.2	41.0%

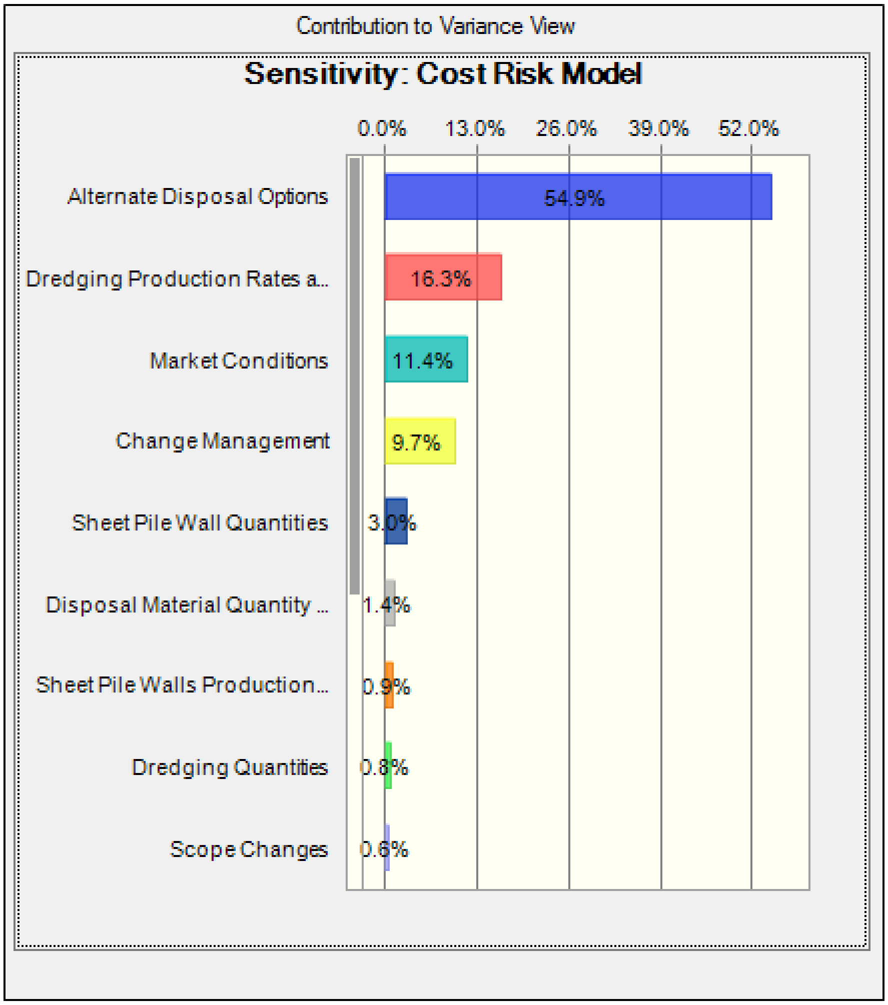

Figure 2. Cost Sensitivity Chart

Figure 2 demonstrates the potential impact of the risks related to dredging disposal, market conditions, dredging production rates and change management during construction have on the project. It also demonstrates that many of the risks with the greatest contribution to the risk variance are risks that the PDT has the ability to manage and mitigate during the final design and construction process.

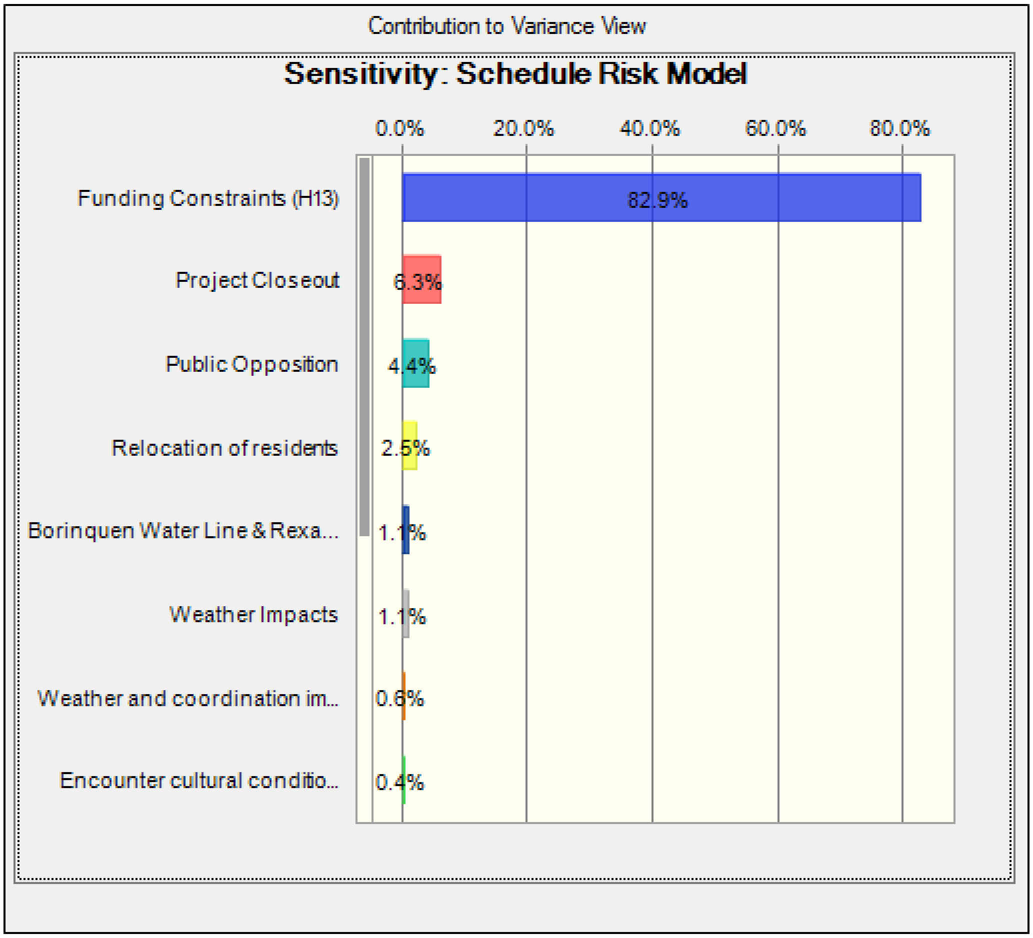

Figure 3. Schedule Sensitivity Chart

Figure 3 demonstrates that the potential for funding constraints has the greatest contribution to the schedule risk variance on the project, at over 80%. Other schedule risk impacts include a delay to project closeout, delay related to public opposition, delay to relocating residents prior to construction, and delay to utility relocations are risks that can be managed and mitigated by the PDT.

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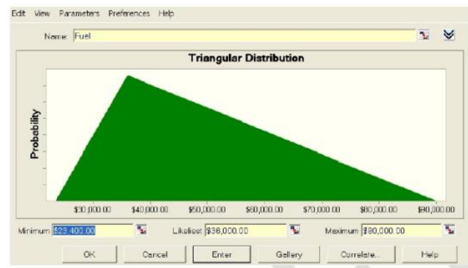
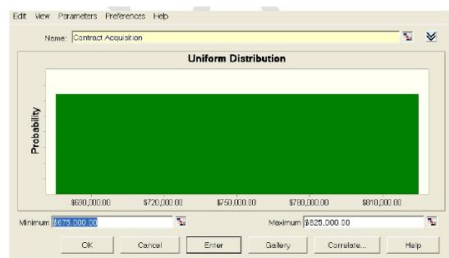
7.0 QUANTITATIVE RISK ANALYSIS

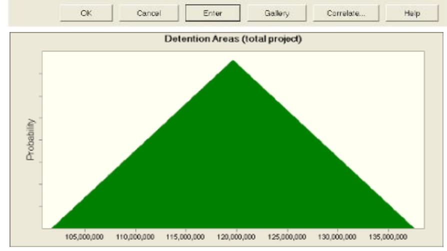
The quantitative risk analysis involved applying probability curves to the appropriate cost items of the current cost estimate based on the risks identified by the team. The probability curves were initially proposed by the risk analysts and then reviewed with the project development team. The probability curves were developed based on the risks documented in the risk register. It should be noted that in general, the risks were determined to be relatively low with the exception of those impacting the excavation and hauling of the excavated material from detention ponds. Also, the risks were found to be consistent across the major construction elements, and in order to reduce the need to correlate the probability curves the risk analysts applied the curves at the summary level of the cost estimate. The input probability assumptions the team made are provided in Appendix E.



In accordance with the USACE guidelines, the team used only the triangular and uniform distributions curves. These curves are described as follows. The triangular distribution establishes a best case, most likely and worst case value. This distribution is recommended for the risk events that impact discreet areas or where one cost value is more likely to occur than another value.



The uniform distribution is used when any value between the best case and worst case are equally likely to occur. This distribution is recommended when the risk events are more global to the project and a most likely occurrence cannot be established.



The key distribution curve was the modeling of the risks and opportunities associated with the costs to excavate and haul away the material from the detention ponds. For this probability assumption the team used the following model. This model is slightly more conservative than used in the previous study, related to concern over current market conditions resulting in price inflation for these costs.

The cost contingency was then analyzed using the Crystal Ball software and a Monte Carlo simulation was performed. The results are provided in the following section.

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8.0 MAJOR FINDINGS/OBSERVATIONS

The PDT review of the CMP-ERP had the following major findings / observations during the study:

The project scope is well-defined and the limits of construction are established. Many risks have been mitigated through the current design process. This minimizes the risk of expanded scope on the project. Many risks were identified during the PDT review, with those having the highest potential impact as follows:

Summarized from the detail provided earlier in the report, the major cost risks making up the contingency amount include the following:

- Alternate Disposal Options for the dredged material (other than San Jose Lagoon pits disposal)
- Market conditions in Puerto Rico and in the construction industry
- Variance in dredging productions rates due to field conditions
- Potential for change orders during construction
- The risk of quantity variances for the sheet pile channel walls
- Increased quantities of dredged material requiring special handling and disposal

The major schedule risks beyond the cost risks are the following:

- Funding Constraints
- Delay to completing and closing out the project
- Delays to dredging and disposal of material
- Delays to the start of the project for Public Opposition
- Delays to the relocation of residents impacting construction
- Weather impacts

The PDT analyzed these and other potential risks to the project and worked to determine the best likelihood of the risk occuring and the potential impact to the project should the risk occur. Multiple potential changes to specific project activities were noted, with multiple risks have a potential cost impact to the project, with dredging and disposal of material and other construction change orders being the largest risks during construction. Market conditions can also be an impact that should be closely followed by the PDT as the construction bid approaches. Funding constraints was the greatest schedule risk identified by the PDT, with the potential for lengthy delays should funding needs not be met.

The results of the probability run using the risks identified results in a range of the potential total costs of the project, based on a contingency that varies based on the risks. At the low confidence levels (lower chance that results will be below these values), the contingency is relatively low showing that most major risks have been mitigated. At the higher confidence levels (higher chance that results will be below these values), the contingency is greater showing that more of the major risks have occurred and had a cost or schedule impact on the project.

The following table (Table 8) summarizes these confidence levels and contingency results:

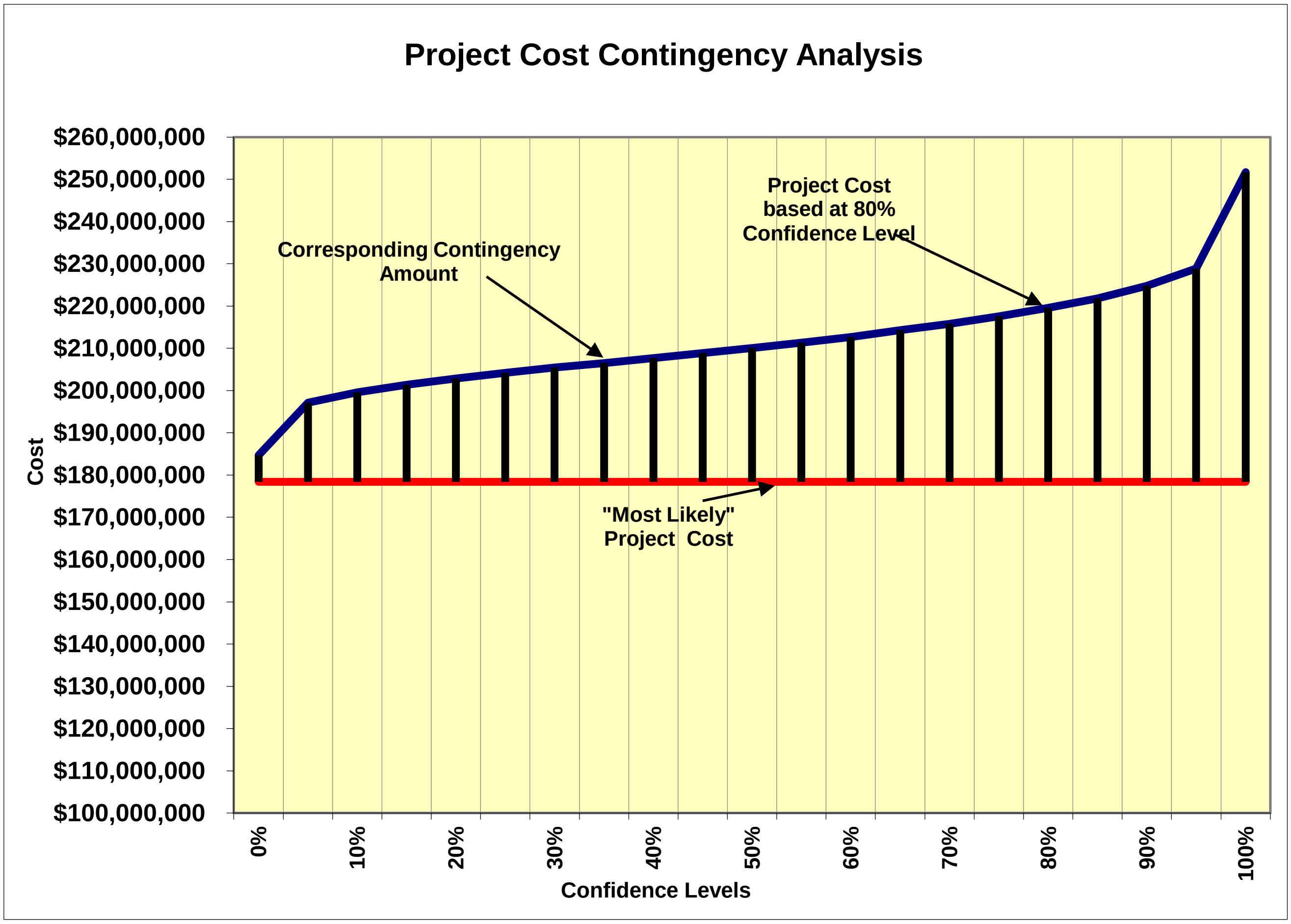
Table 8. Project Contingencies and Total Project Estimated Costs ($ in Millions)

Confidence Level	Project Cost (Base plus Contingencies)*	Total Contingency	Contingency %
0%	$184.7	$6.3	3.5%
10%	$199.6	$21.2	11.9%
20%	$202.8	$24.4	13.7%
30%	$205.4	$27.0	15.1%
40%	$207.7	$29.3	16.4%
50%	$210.0	$31.6	17.7%
60%	$212.7	$34.3	19.2%
70%	$215.8	$37.4	20.9%
80%	$219.7	$41.2	23.1%
90%	$224.8	$46.3	26.0%
100%	$251.7	$73.2	41.0%

*** Excludes costs expended**

Table 8 denotes the risk based contingency level and percentage based on the confidence levels resulting from the probability runs. Table 9 shows this in graphical form with the 80% confidence at $219.7 million.

Table 9. Confidence Levels of Total Project Estimated Costs



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9.0 MITIGATION RECOMMENDATIONS

The PDT now has a risk register that compiles the risks on the project. As the project moves forward, mitigation approaches need to be determined for each of the risks, with assigned project personnel to evaluate these risks. Those risks with the most significant potential that can be managed, such as the funding constraints, should have the greatest focus.

The PDT in providing input on the risk register was able to identify and begin discussions on possible mitigating strategies for managing the risks. Some of these strategies included:

- Additional subsurface testing of the area to be dredged to further determine content and risk definition;
- Improved criteria for the final design stage to manage elements that could have scope changes;
- Continued analysis of the industry to determine the price trends for the major labor, equipment and materials required for the CMP project;
- Continued determination of future project funding;
- Input from construction industry on potential productivity issues for the project; and
- Focus on management of the construction contract to address issues and minimize change orders

The recommendation is that the current risk register continue to be utilized by the project team moving forward to document and manage the risks on the project.

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Appendix A

Total Project Cost Summary

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Printed:8/27/2015

**** TOTAL PROJECT COST SUMMARY ****

PROJECT: Caño Martín Peña Ecosystem Restoration Project
PROJECT NO: 354852
LOCATION: San Juan, Puerto Rico

DISTRICT: SAJ Jacksonville PREPARED: 8/27/2015
POC: CHIEF, COST ENGINEERING, Tracy Leeser

This Estimate reflects the scope and schedule in report; Caño Martín Peña Ecosystem Restoration Project **SAN JOSÉ LAGOON DISPOSAL OPTION**
and is based on the Detailed cost estimate file 354852_CMP_Feasibility_Update_Rev7_Ver10_2015_0825.mlp

Civil Works Work Breakdown Structure		**ESTIMATED COST**				**PROJECT FIRST COST (Constant Dollar Basis)**						**TOTAL PROJECT COST (FULLY FUNDED)**		
						Program Year (Budget EC):				**2016**				
						Effective Price Level Date:				1-Oct-14				
WBS NUMBER	Civil Works Feature & Sub-Feature Description	COST ($K)	CNTG ($K)	CNTG (%)	TOTAL ($K)	ESC (%)	COST ($K)	CNTG ($K)	**TOTAL ($K)**	Spent To Date ($K)	TOTAL FIRST COST	COST ($K)	CNTG ($K)	FULL ($K)
A	*B*	*C*	*D*	*E*	*F*	*G*	*H*	*I*	*J*	*K*	*L*	*M*	*N*	*O*
02	*RELOCATIONS (Cost to Date)*	*$263*								*$263*	*$ 263*			***$263***
02	**RELOCATIONS**	$13,900	$3,205	23.1%	$17,105	1.948%	$14,171	$3,268	**$17,438**		**$ 17,438**	$14,975	$3,453	**$18,429**
06	**FISH & WILDLIFEFACILITIES**	$5,050	$1,165	23.1%	$6,215	2.1%	$5,157	$1,189	**$6,346**		**$ 6,346**	$5,450	$1,257	**$6,707**
09	**CHANNEL & CANAL**	$40,286	$9,290	23.1%	$49,576	2.2%	$41,164	$9,492	**$50,656**		**$ 50,656**	$43,501	$10,031	**$53,533**
14	**RECREATION**	$7,194	$1,659	23.1%	$8,852	0.988%	$7,265	$1,675	**$8,940**		**$ 8,940**	$7,677	$1,770	**$9,447**
16	**BANK STABILIZATION**	$54,230	$12,505	23.1%	$66,735	2.4%	$55,541	$12,808	**$68,349**		**$ 68,349**	$58,695	$13,535	**$72,230**
18	**CULT RESOURTCE PRESERVATION**	$103	$24	23.1%	$126	1.0%	$104	$24	**$127**		**$ 127**	$109	$25	**$135**
	CONSTRUCTION ESTIMATE TOTALS:	$121,025	$27,848		$148,610	2.2%	$123,401	$28,456	$151,857	$263	$152,120	$130,408	$30,072	$160,744
01	*LANDS AND DAMAGES (Cost to Date)*	*$6,038*								*$6,038*	*$ 6,038*			***$6,038***
01	**LANDS AND DAMAGES**	$39,562	$9,123	23.1%	$48,684	1.5%	$40,166	$9,262	**$49,428**		**$ 49,428**	$40,750	$9,397	**$50,147**
30	**PRECONST'N, ENGINEERING, DESIGN**	$10,901	$2,514	23.1%	$13,415	1.5%	$11,065	$2,551	**$13,616**		**$ 13,616**	$11,894	$2,743	**$14,637**
31	**CONSTRUCTION MANAGEMENT**	$7,268	$1,676	23.1%	$8,944	1.5%	$7,377	$1,701	**$9,078**		**$ 9,078**	$8,211	$1,893	**$10,104**
	PROJECT COST TOTALS:	$184,795	$41,160	22.3%	$225,955		$182,008	$41,971	**$223,979**	$6,301	**$230,280**	$191,263	$44,105	**$241,669**

______ **CHIEF, COST ENGINEERING, Tracy Leeser**

______ **PROJECT MANAGER, Jim Suggs**

______ **CHIEF, REAL ESTATE, Audrey Ormerod**

______ CHIEF, PLANNING,

______ CHIEF, ENGINEERING, Laureen Borochaner

______ CHIEF, OPERATIONS, Jim Jeffords

______ CHIEF, CONSTRUCTION, Steve Duba

______ CHIEF, CONTRACTING, Carlos Clarke

______ CHIEF, PM-PB, xxxx

______ CHIEF, DPM,

COST SHARE TABLE BELOW IS BASED ON PROJECT FIRST COST

LERRD COST SHARE (Includes PED and CM for Relocation Only)		
ESTIMATED FEDERAL COST:		**$0**
ESTIMATED NON-FEDERAL COST:		**$75,040**
NON RECREATION COST SHARE (Includes PED and CM)		
ESTIMATED FEDERAL COST:		**$142,995**
ESTIMATED NON-FEDERAL COST:		**$1,957**
SUB TOTAL NON RECREATION COST SHARE (Includes PED and CM)		
ESTIMATED FEDERAL COST:	**65%**	**$142,995**
ESTIMATED NON-FEDERAL COST:	**35%**	**$76,997**
SUB TOTAL RECREATION (Includes PED and CM)		
ESTIMATED FEDERAL COST:	**50%**	**$5,144**
ESTIMATED NON-FEDERAL COST:	**50%**	**$5,144**
TOTAL PROJECT COST BY AGENCY(Includes PED and CM)		
ESTIMATED FEDERAL COST:	**65%**	**$148,139**
ESTIMATED NON-FEDERAL COST:	**35%**	**$82,141**
ESTIMATED TOTAL PROJECT FIRST COST:		**$230,280**

Filename: 354852_CMP_TPCS_SJLagoon_Disposal_Rev7_Ver10_2015_0827.xlsx
TPCS, 23.05% Contingency

**** TOTAL PROJECT COST SUMMARY ****

Printed:8/27/2015

**** CONTRACT COST SUMMARY ****

PROJECT: Caño Martín Peña Ecosystem Restoration Project
LOCATION: San Juan, Puerto Rico
This Estimate reflects the scope and schedule in report; Caño Martín Peña Ecosystem Restoration Project

DISTRICT: SAJ Jacksonville PREPARED: 8/27/2015
POC: CHIEF, COST ENGINEERING, Tracy Leeser

354852_CMP_Feasibility_Update_Rev7_Ver10_2015_0825.mlp

FUTURE COST - COST TO COMPLETE ONLY

Civil Works Work Breakdown Structure		ESTIMATED COST				PROJECT FIRST COST (Constant Dollar Basis)				TOTAL PROJECT COST (FULLY FUNDED)				
SAN JOSÉ LAGOON DISPOSAL		Estimate Prepared:			25-Aug-2015	Program Year (Budget EC):			2016					
		Effective Price Level:			1-Oct-2014	Effective Price Level Date:			1-Oct-14					
WBS NUMBER	Civil Works Feature & Sub-Feature Description	COST ($K)	CNTG ($K)	CNTG (%)	TOTAL ($K)	ESC (%)	COST ($K)	CNTG ($K)	TOTAL ($K)	Mid-Point Date	INFLATED (%)	COST ($K)	CNTG ($K)	FULL ($K)
A	*B*	*C*	*D*	*E*	*F*	*G*	*H*	*I*	*J*	*P*	*L*	*M*	*N*	*O*
02	RELOCATIONS	$13,900	$3,205	23.1%	$17,105	1.948%	$14,171	$3,268	$17,438	2018Q2	5.7%	$14,975	$3,453	$18,429
06	FISH & WILDLIFE FACILITIES	$5,050	$1,165	23.1%	$6,215	2.112%	$5,157	$1,189	$6,346	2018Q2	5.7%	$5,450	$1,257	$6,707
09	CHANNELS & CANALS	$40,286	$9,290	23.1%	$49,576	2.179%	$41,164	$9,492	$50,656	2018Q2	5.7%	$43,501	$10,031	$53,533
14	RECREATION FACILITIES	$7,194	$1,659	23.1%	$8,852	0.988%	$7,265	$1,675	$8,940	2018Q2	5.7%	$7,677	$1,770	$9,447
16	BANK STABILIZATION	$54,230	$12,505	23.1%	$66,735	2.418%	$55,541	$12,808	$68,349	2018Q2	5.7%	$58,695	$13,535	$72,230
18	CULTURAL RESOURCE PRESERVATION	$103	$24	23.1%	$126	0.988%	$104	$24	$127	2018Q2	5.7%	$109	$25	$135
	CONSTRUCTION ESTIMATE TOTALS:	$120,762	$27,848	23.1%	$148,610		$123,401	$28,456	$151,857			$130,408	$30,072	$160,480
01	LANDS AND DAMAGES	$39,562	$9,123	23.1%	$48,684	1.527%	$40,166	$9,262	$49,428	2016Q1	1.5%	$40,750	$9,397	$50,147
30	PRECONSTRUCTION, ENGINEERING, DESIGN													
0.5%	Project Management	$607	$140	23.1%	$747	1.500%	$616	$142	$758	2017Q2	7.0%	$659	$152	$811
1.0%	Planning & Environmental Compliance	$1,213	$280	23.1%	$1,493	1.5%	$1,231	$284	$1,515	2017Q2	7.0%	$1,318	$304	$1,621
6.0%	Engineering & Design	$7,261	$1,674	23.1%	$8,935	1.5%	$7,370	$1,700	$9,069	2017Q2	7.0%	$7,887	$1,819	$9,706
	Reviews, ATRs, IEPRs, VE	$0	$0	23.1%	$0	0.0%	$0	$0	$0	0	0.0%	$0	$0	$0
	Life Cycle Updates (cost, schedule, risks)	$0	$0	23.1%	$0	0.0%	$0	$0	$0	0	0.0%	$0	$0	$0
0.5%	Contracting & Reprographics	$607	$140	23.1%	$747	1.5%	$616	$142	$758	2017Q2	7.0%	$659	$152	$811
1.0%	Engineering During Construction	$1,213	$280	23.1%	$1,493	1.5%	$1,231	$284	$1,515	2018Q2	11.3%	$1,370	$316	$1,686
	Planning During Construction	$0	$0	23.1%	$0	0.0%	$0	$0	$0	0	0.0%	$0	$0	$0
	Project Operations	$0	$0	23.1%	$0	0.0%	$0	$0	$0	0	0.0%	$0	$0	$0
31	CONSTRUCTION MANAGEMENT													
5.5%	Construction Management	$6,661	$1,536	23.1%	$8,197	1.500%	$6,761	$1,559	$8,320	2018Q2	11.3%	$7,525	$1,735	$9,260
	Project Operation:	$0	$0	23.1%	$0	0.0%	$0	$0	$0	0	0.0%	$0	$0	$0
0.5%	Project Management	$607	$140	23.1%	$747	1.500%	$616	$142	$758	2018Q2	11.3%	$686	$158	$844
	CONTRACT COST TOTALS:	$178,493	$41,160		$219,653		$182,008	$41,971	**$223,979**			$191,263	$44,105	**$235,368**

Filename: 354852_CMP_TPCS_SJLagoon_Disposal_Rev7_Ver10_2015_0827.xlsx
TPCS, 23.05% Contingency

Appendix B

Risk Workshop Agenda and Presentation

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Cano Martin Pena
Ecosystem Restoration Project

Cost & Schedule Risk Analysis (CSRA)
CSRA Workshop

February 28, 2013

U.S. Army
Corps of Engineers

ATKINS

Plan Design Enable

CSRA Workshop Agenda

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- Introductions
- Overview of Process (including CSRA checklist)
- Overview of Current Project Cost Estimate
- Identification and development of Risk items
  - Real estate acquisition and relocations
  - Cultural Preservation
  - Water Quality and Fisheries
  - Potential design changes prior to construction
  - Construction
  - Schedule
  - Other
  - Final review of checklist
- Next Steps

2

Project Overview

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- 4-mile long tidal canal
- Connects the San Juan Bay with the San Jose Lagoon and Los Corozos Lagoon in San Juan, Puerto Rico
- Dredging ~ 2.2 miles of the canal
- Main channel with structurally supported rectangular cross section
- Preliminary estimate: $267.1 million (excludes contingency and escalation)

3

Project Location Map

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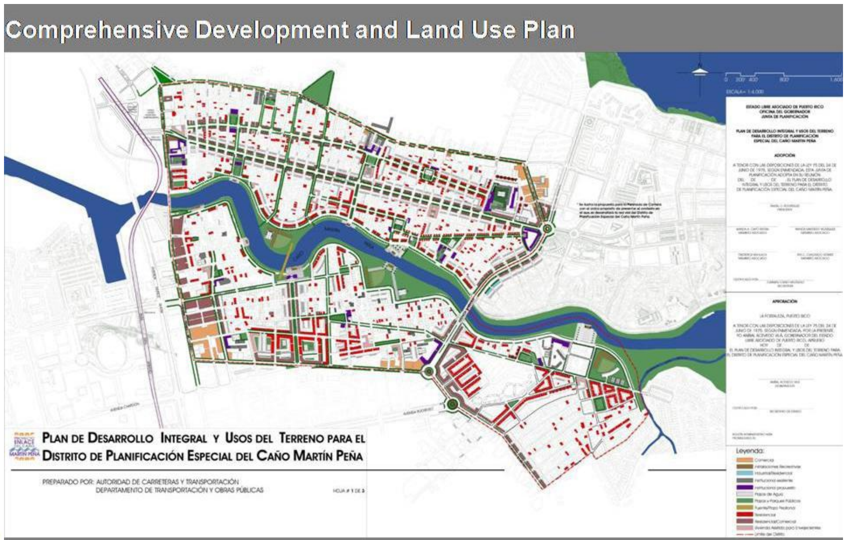
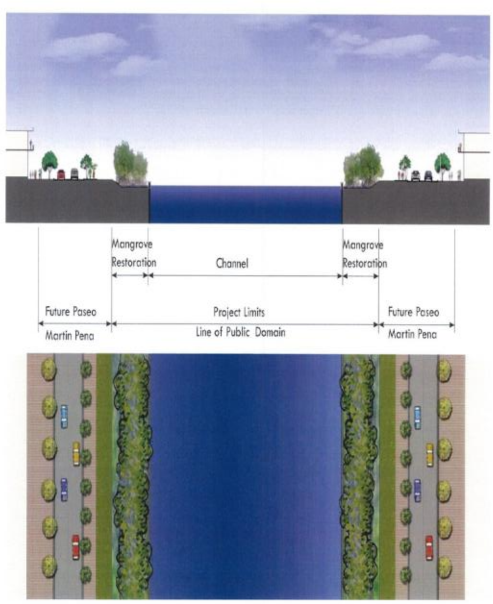
Comprehensive Devt. & Land Use Plan



5

Channel Plan and Section



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Risk Workshop Outline

- Overview & key goal
- Key Concepts
- Performed on total construction cost
- PDT – Project Development Team
- Identification of Risks & Opportunities
- Risk Assessment – Qualitative
- Risk Analysis – Quantitative
- Updating and tracking requirements

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Overview and Key Goal

- Key Goal: Define an appropriate contingency
- Risk analysis done on current cost estimate without contingency or escalation

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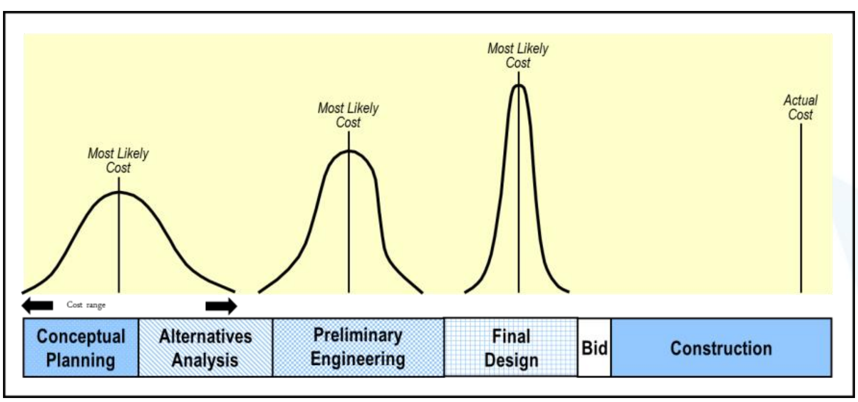
Key Concepts: Risk and Probability

- Risk:
  - the possibility of suffering harm or loss; danger
- Probability:
  - a measure of how likely it is that some event will occur

Key Concepts: Risk and Probability over Time



Key Concepts: Components of Risk Analysis

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- Identification
- Assessment
- Documentation
- Monitoring

Risk No.	PDT-developed Risk/Opportunity Event (logic by feature, contract, responsibility)	PDT Event Concerns (include all to archive)	PDT Discussions (support the likelihood and impact)
Contract Risks (Internal Risk Items are those that are generated, caused, or controlled within the PDT's sphere			
PROJECT & PROGRAM MGMT			
PPM-1	Contracting Plan	Contracting Plan may not be fully develpoed for the projects. Some uncertainty of	
PPM-1	Local Government	Local Sponsor influences on the design and scope of the project	
PPM-2	Legal Issues	Ongoing lawsuit may influence the design criteria and design plans for the project	
	OPPORTUNITIES		
OP-1	Bidding Climate	With many contractors searching for work nationally, large scale contratcrors may	
GENERAL AND ECONOMIC RISKS			
GE-1	Availablity of Resources	Capable contractors may be working outside of the local area reducing the qualified	
GE-2	Inflation / Esclation	Material pricing may rise as a result of inflation and other market economy factors.	
Feature Code 01 - LANDS & DAMAGES			
LD-1	Real Estate Recovery	Real Estate recovery may continue to affect fair market pricing	
LD-2	Acquisition Costs	Individual land owners may be unwilling to cooperate with acquisition plan.	

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Qualitative Risk Assessment

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Risk Level

Likelihood of Occurrence	Negligible	Marginal	Significant	Critical	Crisis
Very Likely	Low	Moderate	High	High	High
Likely	Low	Moderate	High	High	High
Unlikely	Low	Low	Moderate	Moderate	High
Very Unlikely	Low	Low	Low	Low	High

Impact or Consequence of Occurrence

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Determining Risk

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Collaborative Process that incorporate feedback from all members of the Project Delivery Team (PDT) to form a comprehensive picture of the probable project risks to cost AND schedule.

- Planning director
- Designer
- ROW
- Hydraulics
- Environmental
- Construction
- Cost Estimator
- Risk Analyst

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Total Project Cost

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The Risk Analysis builds on the Total Estimated Project Cost to determine an appropriate Contingency for each Feature Code.

- (01) Lands and Damages
- (02) Relocations
- (09) Channels and Canals
- (15) Detention Basins – Flood Control
- (30) Planning, Engineering and Design
- (31) Construction Management

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Steps to Identify Risk

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- Identify Risk (or Opportunity)
- Describe Risk
- Analyze Qualitatively
- Analyze Quantitatively
- Develop Risk Response Plan
- Establish Risk Monitoring and Control Plan
- Establish estimated cost for response and avoidance

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Documenting Risk: The Risk Register

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- Identify Risk (or Opportunity)
- Describe Risk
- Analyze Qualitatively and Quantitatively
- See CSRA guidance, Appendix A

Contract Acquisition Risks

- ❑ Undefined acquisition strategy
- ❑ Lack of acquisition planning support/involvement
- ❑ Preference to SDB and 8(a) contracts
- ❑ Acquisition planning to accommodate funding stream or anticipated strategy
- ❑ Numerous separate contracts
- ❑ Acquisition strategy decreasing competition
- ❑ Acquisition strategy results in higher scope risk (Design Build)

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Quantitative Analysis of Risk

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Risk Level

Likelihood of Occurrence	Negligible	Marginal	Significant	Critical	Crisis
Very Likely	Low	Moderate	High	High	High
Likely	Low	Moderate	High	High	High
Unlikely	Low	Low	Moderate	Moderate	High
Very Unlikely	Low	Low	Low	Low	High

Impact or Consequence of Occurrence

← Qualitative Analysis

- **Likelihood of Occurrence (Y axis)**
  - Measured in percentage chance of occurrence
  - Example: Highly Unlikely = 10% chance
- **Impact or Consequence of Occurrence (X axis)**
  - Measured in $ impact to current project estimate
  - Include low, most likely and high assessment of impact with variance distributions

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Variance Distributions

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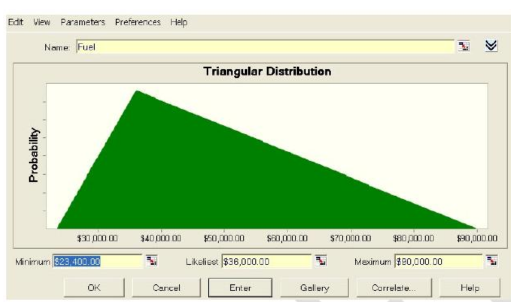
- Triangular Distribution



The triangular distribution (figure 3) is commonly used when the market research has established the best case, most likely, and worst cases: three distinct points, measured in dollars or percent. By definition, the most likely estimate has established what is most likely to occur. This distribution is recommended for the risks events that impact discreet areas or details of the estimate where one can determine that one cost value is more likely to occur than another value.

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Variance Distributions

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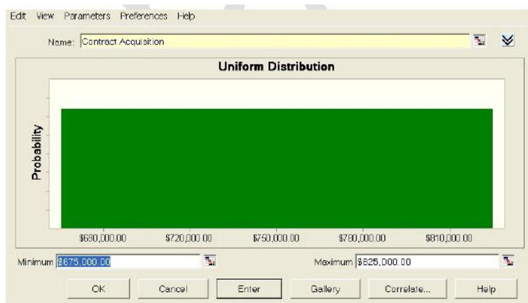
- Uniform Distribution



The uniform distribution (figure 4) is used when any value between the best case and worst case are equally likely to occur. In these instances, only two points are needed, the best and the worse case. This distribution is recommended when the risk events are more global to the project and a most likely occurrence cannot be established. Within the model, the best case is assigned a value equal-to/or less-than the most likely (cost estimate) value and the worst case is assigned a value equal-to/or greater-than the most likely (cost estimate) value.

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Variance Distributions - Outcome

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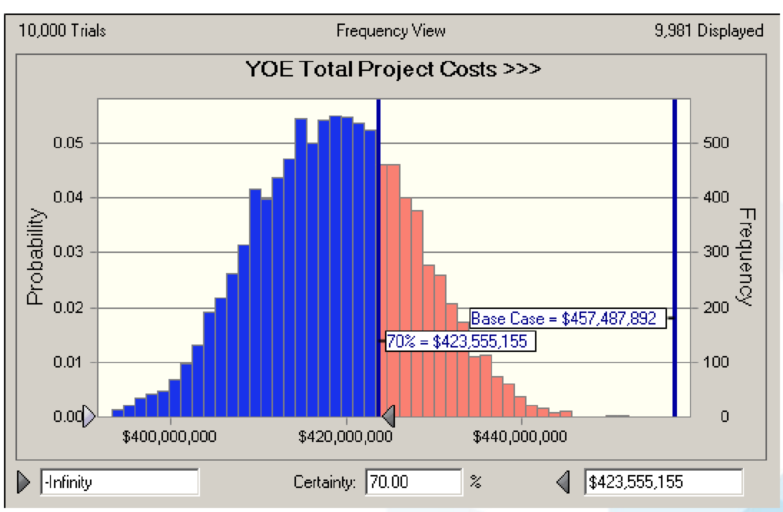
- Monte Carlo Analysis



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Evaluation of Contingency

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Most Likely Cost Estimate	$	283,798,120
Confidence Level	**Value**	**Contingency**
0%	$196,251,351	-30.85%
5%	$265,301,883	-6.52%
10%	$278,356,727	-1.92%
15%	$287,628,329	1.35%
20%	$294,426,931	3.75%
25%	$300,576,519	5.91%
30%	$306,044,712	7.84%
35%	$311,348,193	9.71%
40%	$316,463,923	11.51%
45%	$321,561,018	13.31%
50%	$325,920,859	14.84%
55%	$330,801,756	16.56%
60%	$335,990,370	18.39%
65%	$340,890,506	20.12%
70%	$346,028,517	21.93%
75%	$351,266,705	23.77%
80%	$357,691,114	26.04%
85%	$365,347,118	28.73%
90%	$373,567,089	31.63%
95%	$385,963,837	36.00%
100%	$455,670,837	60.56%

Reporting

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Updating and Tracking

- CSRA Guidance suggests:
  - conducting periodic risk review meetings
  - revisit risks from original identification
  - continually refine the analysis and responses

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Questions?

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Appendix C

Risk Register

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Caño Martín Peña Ecosystem Restoration Project

Risk Level

Likelihood of Occurrence	Negligible	Marginal	Significant	Critical	Crisis
Very Likely	Low	Moderate	High	High	High
Likely	Low	Moderate	High	High	High
Unlikely	Low	Low	Moderate	Moderate	High
Very Unlikely	Low	Low	Low	Low	High

Impact or Consequence of Occurrence

Risk No.	Risk/Opportunity Event	Concerns	PDT Discussions	Project Cost			Project Schedule			Variance Distribution	Correlation to Other(s)	Responsibility/POC	Affected Project Component
				Likelihood*	Impact*	Risk Level*	Likelihood*	Impact*	Risk Level*				
Contract Risks (Internal Risk Items are those that are generated, caused, or controlled within the PDT's sphere of influence.)													
GENERAL AND ECONOMIC RISKS													
GE-01	Market Conditions	Update in June 2014 - Labor costs are likely declining in PR, as unemployment has been increasing. There is still some risk with material costs, although the major ones are covered in other risks.	Will require smaller specialized equipment. Most of cost is related to the dredging and the steel sheet pile. June 2014 update; used 100% based on USACE approach; based on labor costs decreasing and material cost stabilizing, used 0 as most likely and 10% as the high end based on project team input and input from CSRA reviews	Likely	Significant	HIGH			LOW	Triangular	GE-03; GE-07		
GE-02	Weather Impacts	Construction will span multiple Hurricane Seasons	Ongoing construction during a weather event may require control Demobilization and Re-Mobilization. In addition the damage to permanent work may be significant. Any cost increase not related to delay is inclued in PM-06 (Change Orders). Concern is severe storm that stops operations.	Likely	Marginal	MODERATE	Likely	Significant	HIGH	Triangular	GE-10		
GE-03	Energy Costs	Fuel Costs continue to hedge upward	Fuel pricing continues to hedge upward, and is not expected to fall. Much of the work on the CMP (dredging, trucking, barge transport) is heavily affected by fuel costs. This risk has not been modeled, as GE-01; Market Conditions includes the potential impact of this risk; revise to be current	Likely	Significant	HIGH			LOW	Triangular	GE-01		
GE-04	Funding Constraints	Inavailability of Sponsor funds to match Federal Assistance	Project is dependent on Water Resources Devt Act authorization. Current local matching is 35% plus O&M. Congress yearly appropriations may impact phasing of the project. If no local share, then the project could extend up to 7 years. Considering there will likely be local share, used a potential extended construction duration from 1 to 3 years, with a uniform distribution. Only costs considered are additional project extension related costs in the schedule risks.	Likely	Critical	HIGH	Likely	Critical	HIGH	Triangular			
GE-05	Availability of Skilled Resources	Will the skilled resources be available locally? For example, will qualified and capable dredging companies, trucking companies, barging companies be available locally within Puerto Rico.	Surplus of skilled resources at this time. There is some concern that the work in an urban environment will pose challenges to the contractors. June 2014 update: this risk considered low as unemployment is high in Puerto Rico and it is very likely skilled workers will be available for the project.	Very Unlikely	Marginal	LOW			LOW				

Note: with rounding differences, there is a slight delta between the Risk Register results (~ $219.6 Million excluding costs expended) vs the TPCS and CSRA report (~ $219.5 Million, also excluding costs expended).

Risk No.	Risk/Opportunity Event	Concerns	PDT Discussions	Project Cost			Project Schedule			Variance Distribution	Correlation to Other(s)	Responsibility/POC	Affected Project Component
				Likelihood*	Impact*	Risk Level*	Likelihood*	Impact*	Risk Level*				
GE-06	Project Reauthorization	All alternative plans, including the recommended plan, exceeds 902 cost limitations and must be reauthorized prior to construction. Reauthorizataion timeline is uncertain, but assumed to occur prior to planned 2016 start of construction.	Authorizing legislation has become less regular and predictable in occurance. Delays may result in additional cost inflation. If no reauthorization, then there would be no Federal participation.	Very Unlikely	Significant	LOW			LOW				
GE-07	Steel Costs	Fluctuating cost of steel could effect the cost of the sheet pile	Steel sheet pile is the highest priced item in the project and increases could easily make dramatic increases in the project cost. There is also the chance that steel prices could decrease lower than estimated. This risk was not modeled, as the risk "GE-01; Market Conditions" includes the potential cost increase related to this risk	Likely	Significant	HIGH			LOW	Triangular	GE-01		
GE-08	Recreational Fishermen	Recreational fishermen strongly oppose the disposal of dredged sediments in San Jose Lagoon.	They may have to be economically compensated since their industry will be directly impacted. Industry value has been estimated on a yearly basis, although the impact may not be as severe as estimated.	Very Unlikely	Negligible	LOW			LOW	Triangular			
GE-9	Public Opposition	Public may attempt to stop the start of construction	Could range from a demonstration to a lawsuit, but considered unlikely by the team	Very Unlikely	Marginal	LOW	Unlikely	Marginal	LOW	Triangular	RL-04, RL-06		
GE-10	Potential Earthquake	Puerto Rico lies in a zone of active seismicity. Area of CMP is considered a concern for liquefaction of the soils should a powerful event occur. June 2014 update: discussed that if a major catastrophic earthquake occurs, the entire project would likely be changed and the landscape would be changed. Agreed to consider a moderate earthquake that would impact the project, but non-catastrophic	June 2014 update: Since an earthquake would likely be catastrophic and fundamentally change the project, this risk was not modeled.	Unlikely	Crisis	HIGH	Unlikely	Critical	HIGH	Triangular			
LANDS AND DAMAGES RISKS													
LD-01	Mitigation Cost	Incomplete design and analysis of Mitigation	Mitigation plan has not been finalized as of estimate completion: more applicable to completion of current cost estimate; will likely not be a future cost risk, and the cost is not expected to vary from what is included in the estimate.	Very Unlikely		LOW			LOW				
LD-02	Public Domain footprint	More detailed surveys may indicate a smaller footprint for which the project can be implemented. UPDATE: The project footprint is not subject to change. Limits have been set, and surveys have confirmed the limits.	Footprint not subject to change	Very Unlikely		LOW			LOW				
LD-03	Vibration Impacts	Heavily populated area with structures on fill dirt adjacent to the project area	Previous construction efforts on the island have resulted in structural damage to adjacent residences and sturctures as a result of vibrations from construction equipment, thus causing liquefication of underlying soils; (Carlos Muniz): some projects have impact on structures: 1) Cantera project in 2010 impacted structures from constr vibration for compaction of the roadbed. Concern that future construction could similarly impact adjacent structures. Will be 90' separation between sheet pile and existing structures. Most adjacent structures do not have proper foundations. Some structures will be removed in the ROW for the Paseo construction, some prior to the channel construction. All relocations and structures are included in the estimated related to the project footprint.	Very Likely	Significant	HIGH			LOW	Triangular			

Risk No.	Risk/Opportunity Event	Concerns	PDT Discussions	Project Cost			Project Schedule			Variance Distribution	Correlation to Other(s)	Responsibility/POC	Affected Project Component
				Likelihood*	Impact*	Risk Level*	Likelihood*	Impact*	Risk Level*				
RELOCATIONS													
RL-01	Cost Variances	Major Public Utility Relocations	6-14 update: currently the only utility costs for major public utilities are the demolition of the Boriquen Water Line and Rexach Trunk Sewer (Risk RL-04a), so this risk no longer applies)	Very Unlikely	Negligible	LOW			LOW				
RL-02	Condemnation	Necessity for Condemnation to acquire property	Condemnation may result in delays and additional administrative cost. Condemnation is planned on 55 of 371 structures; have not had to condemn unless cannot locate the owner (limited). Proportion is consistent with experience. The 55 condemnations are included in the project cost and schedule, and there is negligible risk of additional condemnations that could impact the project.	Very Unlikely		LOW			LOW				
RL-03	Unknown Utilities	Impacts to cost and schedule from unknown and unmapped utilities	June 2014 update: The only major utilities on the project are modeled in risk RL-04a. There are no additional impacts anticipated from utilities, as the other utilities are no longer included in the project.	Very Unlikely		LOW			LOW				
RL-04	Reduced project footprint	Relocations as part of the Federal project may be diminished	If the public lands available for the project are recuced, then less relocations will be an element of the cost estimate; UPDATE: footprint and relocation will remain as estimated.	Very Unlikely	Marginal	LOW			LOW				
RL-04a	Borinquen Water Line & Rexach Trunk Sewer	Timing of Major Public Utility Relocations	Work requires coordination with installation of CMP sheet pile walls. Delays could impact project schedule or require design modifications for future installation. UPDATE: would like to have utility relocations occur concurrently with the channel construction to take advantage of items such as turbidity control.	Likely	Marginal	MODERATE	Likely	Significant	HIGH	Uniform			
RL-05	Air Quality	H2S concentrations have been identified as a concern (lethal concentrations), but the detailed analysis was perceived as "non-realistic" because it considered that the H2S would be realeased at the same time.	Preliminary control measures are recommended in the FR. Once construction begins, monitoring is highly recommended. If monitoring conditions exceed standards then evacuation could occur. There have been no documented events of H2S evacuations in open atmosphere by the USACE. Consider that H2S will be a nuisance, and will not be to evacuation standards. The "nuisance" may require temporary relocations. Mitigation measures have been included in the cost estimate that reduce the chance of this occurrence. Sound barriers also help mitigate this issue, and these are being considered for the project. Sept 13 Update: with the ocean disposal the area of impact has expanded. Thought is that the H2S will not be dissipated by the time the material is on the barge (barge area has large potential residential impact). Increase likelihood by 10% and potential impact by 20% to account for this.	Very Likely	Significant	HIGH			LOW	Triangular			
RL-06	Relocation of residents	Relocation of families may take longer than anticipated schedule and could delay the start of construction	There is a potential that the relocation of residents could delay the start of the project. This is only a schedule impact risk.	Unlikely	Negligible	LOW	Unlikely	Significant	MODERATE	Uniform			

Risk No.	Risk/Opportunity Event	Concerns	PDT Discussions	Project Cost			Project Schedule			Variance Distribution	Correlation to Other(s)	Responsibility/POC	Affected Project Component
				Likelihood*	Impact*	Risk Level*	Likelihood*	Impact*	Risk Level*				
CANALS AND DETENTION PONDS													
CH-01	Historic Finds	As Excavation work progresses archeological finds may be uncovered delaying progress or causing need for redesign	Preliminary Studies indicate a high likelihood of Cultural Finds Cost is included in the estimate for monitoring at ~$200,000 for the dredging duration, however no cost is contained in the estimate for work stoppages, inventories, or preservation activities. UPDATE: covered in "Cultural" item; RC-02 as a potential schedule impact. Any cost impacts are covered in PM-06; Construction Change Orders.	Unlikely	Marginal	LOW			LOW				
CH-02	HTRW (Hazardous Material)	The spoils may contain some degree of HTRW that would need to be contained and disposed of	The spoils may contain some degree of HTRW that would need to be contained and disposed of; however, all testing and analysis to date has resulted in a determination that there is no HTRW at the project site. Significant discussion on HTRW resulted in a low likelihood of occurrence with a high impact should it occur (in $500K range). This impact is included in the Construction Change Orders risk PM-06.	Unlikely	Significant	MODERATE	Unlikely	Critical	HIGH	Triangular			
CH-03	Contaminated Material	Spoils may included contaminated material that needs to be contained, including a sand cap to help prevent leaching of any contaminants.	Debris will be placed into geotextile fabric on barge for transport and placement in the disposal areas. Turbidity curtains will be installed at the disposal site, however no cost for flocculation or additional measure to contain contaminated material is included. This risk is considered to be relatively low in cost impact and is covered in PM-06; Construction Change Orders.	Very Unlikely	Negligible	LOW			LOW				
CH-04	Debris Removal and Sorting	Excavated material, in addition to Cultural Finds are expected to contain household debris from adjacent areas	This risk is included in CH-22, which considers the potential additional handling of dredged material for items including household debris	Likely	Marginal	LOW			LOW				
CH-05	Heavily Urbanized Area		Discussed through other items related to potential temporary relocations			LOW			LOW				
CH-06	Work Hours / Site Access	Given proximity to residential properties, restrictions on work hours and activities may be required.	Strict noise regulations, particularly at night. Daylight operations only. Recent local study shows amended noise requirements for 60 db in residential areas in daylight (50 db at night). Sept 13 update: The pumps will run for 12 hours, 2 hours to clean sediment from lines. This is in compliance with the ordinance for 12 hours per day of construction.	Very Unlikely	Marginal	LOW			LOW				
CH-07	Soil Conditions	Soil conditions and site conditions may vary from expectations and plans, requiring additional surveys and analysis and potentially higher construction costs.	Numerous existing boring data were used in feasibility, however, additional boring data and other geotech analyses during PED may not confirm existing data and inputs for the feasibility phase. Recent borings in area show limestone at 20' depth in some areas. The PDT considers impact from this risk very unlikely to occur.	Very Unlikely	Marginal	LOW			LOW				
CH-08	Access Routes	Work will progress linearly down the channel	Work is expected to begin nearest the San Jose Lagoon and move to Open Water. Recreational fisherman will not be allowed in channel during construction. May be small delays to clear residential fisherman when beginning to work (considered minor resovled in less than a day).	Very Unlikely	Marginal	LOW			LOW				

Risk No.	Risk/Opportunity Event	Concerns	PDT Discussions	Project Cost			Project Schedule			Variance Distribution	Correlation to Other(s)	Responsibility/POC	Affected Project Component
				Likelihood*	Impact*	Risk Level*	Likelihood*	Impact*	Risk Level*				
CH-09	Construction Sequencing	Impact that a delay in the start of one element of the overall project could impact other elements.	Based on the Dredge Material Management Plan (DMMP), several phases of work will be undertaken with each reliant upon the other for sequencing. The DMMP assumed a 16 hour work day. Sept 13 update: the current schedule is based on a 12 hour work day. Other risks related to dredging (risks CH-12,14a,15,16) have already covered the impact of the potential schedule delay.	Very Unlikely	Negligible	LOW			LOW				
CH-10	Sediment Containment	Additional sediment containment may be required for turbidity	Installation of turbidity curtains is contained in the estimate, both at the excavation site and disposal site. Installation of turbidity curtain is in estimate at excavation site. Estimate also included sheet pile wall and turbidity curtain at San Jose Lagoon disposal site. Any risk impact from the sediment containment is considered very unlikely	Very Unlikely	Negligible	LOW			LOW				
CH-11	Sediment Contamination	Sediment and trash may contain unexpected and/or extreme levels of contaminants	A bioassay will be completed during PED, the results of which could significantly impact mitigation efforts to deal with the issue, or restrict/prevent placement in the San Jose Lagoon pits. June 2014 update; indications are that contaminants are at a low level, and this risk was not modeled.	Very Likely	Negligible	LOW			LOW				
CH-12	Human remains	The CMP is purported to have been a place for the disposal of human remains	There is a likelihood that human remains could be encountered during the dredging operations. Whether the remains are of cultural significance or needing to be processed as part of police investigations is unclear. Time frame for investigations are considered to be in days (not months). Any cost impact not related to delay is considered included in PM-06; Construction Change Orders.	Very Likely	Marginal	MODERATE		Marginal	MODERATE	Triangular	RC-02		
CH-13	Equipment Access	Difficulty of access of dredging and other equipment for construction to the CMP	There could be difficulty of access. Some of these costs are included in the estimate. The impact is considered on the mobilization costs of approximately $3 million, and a high end impact of $750K is included in the model.	Very Likely	Marginal	MODERATE	Very Likely		LOW	Triangular			
CH-14	Work under existing bridges	Difficulty of access and work under 3 existing bridges on the West end of the project	Could impact the cost of construction in this area of the project. Approximately 500' of construction. Likely 50% to 70% more difficult to work in this area than in the remainder of the project.	Very Likely	Significant	HIGH			LOW	Triangular			
CH-14a	Potential damage to existing bridges	There is a low probability chance that one of the existing bridges could be damaged when the operations are occuring in close proximity to the bridges.	Low probabilty of damage. The cost of repair could be high if this does occur, and the higher end was modeled.	Unlikely	Significant	MODERATE	Unlikely	Significant	MODERATE	Triangular			
CH-15	Issues with Sediment Pumping	While pumping sediment issues could occur that would include the possible breakdown of the pumps or lines: November 2014 update - this risk is no longer valid as San Jose Lagoon pits are the disposal option moving forward	Pumping from the dredge area to the W end of project (2 mile length of project) and then barging the material an additional 3.2 miles to end of harbor and then 1.6 miles to disposal site. Schedule has 2 hours per day of time for maintenance of line. With the potential makeup of the material, it is anticipated there will be clogging and other issues with the pumps and pipe. Critical element is the screening at the dredge site prior to pumping, which makes the impact marginal. This risk is no longer valid as SJL pits are the disposal option moving forward.	Very Unlikely	Negligible	LOW	Very Unlikely	Negligible	LOW	Triangular			

Risk No.	Risk/Opportunity Event	Concerns	PDT Discussions	Project Cost			Project Schedule			Variance Distribution	Correlation to Other(s)	Responsibility/POC	Affected Project Component
				Likelihood*	Impact*	Risk Level*	Likelihood*	Impact*	Risk Level*				
CH-16	Issues with Sediment Screening	Sediment screening could be slowed down by items that are not easily separated by the screening process.	Because of the diversity of materials, there is the likelihood that items will not be easily separated and could slow down the screening operation to be properly separated. The screening operation has some "trial and error" flexibility to resolve issues and expected to have only marginal impact to the schedule. 11-14 update: risk is still valid but much less than before	Unlikely	Marginal	LOW	Unlikely	Marginal	LOW	Triangular			
CH-17	Coordination with PRPA	Coordination of maintenance dredging of the Western end of the CMP canal and the scheduling of this portion with Ferrys and Barges	Need to coordinate with the PR Ports Authority related to maintenance dredging for a portion of the W portion of the CMP channel that could restrict barge traffic and the use of the waterways under the PRPA. The maintenance dredging item is being investigated for potential impact. Item being followed up with PRPA for dredge maintenance and the Maritime Transport Authority channel coordination. After further discussion determined that this is negligible since it is outside of the project limits and would not impact barges ability to navigate the channel.	Very Unlikely	Negligible	LOW			0				
CH-18	Operations interruption with AquaExpresso	There is some concern that the AquaExpresso boats for the new "Downtown" are could conflict with and delay the barge traffic.	ENLACE will meet with ATM to work an agreement to decrease/limit transit on that area of the CMP. There is also discussion that much of the barge traffic can be move to night time movements that would minimize this potential conflict. Used a 30% chance of occurrence, with a most likely impact to the project schedule of 1 month.	Unlikely	Marginal	LOW	Unlikely	Marginal	LOW	Triangular			
CH-19	Weather and coordination impact to Barging of Disposal Material	Recent history has demonstrated that weather can delay barge traffic	Will now be using shallow draft barges since operating only in the San Jose Lagoon. Therefore, the risk of weather and coordination impact in less than ocean disposal. The dredging duration is ~ 19 months of the project.	Unlikely	Marginal	LOW	Unlikely	Negligible	LOW	Triangular			
CH-20	Trucking	10% of the total volume of dredged material is estimated to be debris slated for sorting, collection and hauling to a landfill. Sand will also be brought in by truck for the encapsulation of material.	Significant number of truck trips to deliver debris to landfill and return for another load, possibly impacting road system. Have good arteries that are considered adequate. May have to improve some interior roads to accommodate the trucking. This risk is considered minimal and is covered in the estimate.	Very Unlikely	Marginal	LOW			LOW				
CH-21	Limestone in dredging	Risk associated with having to work though limestone on eastern end of the CMP for sheet pile and channel dredging. Assumption is additional installation costs for approximately 800 lf of king pile supported wall in lieu of cantilevered wall.	The potential additional 800 lf of wall is priced in the risk item for the eastern end of the CMP. The solution is to use a king pile supported wall in lieu of the cantilevered wall for this 800 lf.	Likely	Marginal	LOW	Likely	Significant	HIGH	Triangular			
CH-22	Disposal Material Quantity Variation	Risk associated with the potential for additional amounts of the dredging material having to be handled and disposed of separately due to trash content	Estimate assumes approximately 10% of the dredged quantity will include trash that has to be handled and disposed of separately. High end of risk includes 76,200 CY additional in channels; 4,687 CY additional under bridges; and 13,500 CY additional with the earthwork. Used estimate rate of $37.15 for handling and disposing of this material.	Very Likely	Critical	HIGH	Likely	Significant	HIGH	Uniform			
CH-23	Alternate Disposal Options	Concern is that the SJL pits may not be available; the spoils may have to be taken to upland disposal sites	Concern is that the SJL pits may not be available; the spoils may have to be taken to upland disposal sites. Lack of pits availability could be due to uncontainable contamination levels or public opposition. Risk of going to upland sites is also the cost of containing the contaminated material.	Unlikely	Critical	MODERATE	Unlikely	Critical	MODERATE				
	OPPORTUNITIES												

Risk No.	Risk/Opportunity Event	Concerns	PDT Discussions	Project Cost			Project Schedule			Variance Distribution	Correlation to Other(s)	Responsibility/POC	Affected Project Component
				Likelihood*	Impact*	Risk Level*	Likelihood*	Impact*	Risk Level*				
CH-24	Source of Sand	Contractor may be able to find a less costly source of capping material	Important is the potential availability of sand or other capping material during construction. Any material would need to be tested to ensure meeting the conditions reqd for the cap. Least cost possibility would be sediment from the channel.	Very Unlikely	Negligible	LOW				Triangular			
RECREATION													
RC-02	Variations in Design Concepts	Variations in Rec Feature sizing	The estimate was based on a smaller Recreation feature design and scaled up to approximate the requirements of the local sponsor in the MCACES. Size of features are set by the Comprehensive Devt Plan. May require additional wetlands in a mitigation plan, but this was considered very unlikely by the PDT.	Very Unlikely	Marginal	LOW			LOW				
RC-03	Squatters	The area is currently largely occupied by residents with no titles because of the high cost fo land and the convenient location in San Juan. Once the relocations are completed, how can it be assured that the area will not be reoccupied during construction or following completion of construction?	The estimate was based on reoccupation by squatters not being a problem during construction or following completion of construction. UPDATE: completed features will mitigate this issue (returning squatters).	Very Unlikely	Marginal	LOW			LOW				
CULTURAL PRESERVATION													
CP-01	Site Access	Site access limitations	Limited site access limitations; access will be limited to walkers along the cano. Ensuring existing residents are informed of all construction to not have site access being a concern.	Very Unlikely	Marginal	LOW			LOW				
CP-02	Encounter cultural conditions	Encountering cultural conditions during construction that delay construction	There is the potential to encounter items during the dredging/construction that would be have to be addressed and could delay construction. Will likely be more of a documenting situation with the dredged material. Any cost impact not related to schedule is considered to be covered in the risk PM-06, Change Orders during construction.	Likely	Marginal	MODERATE	Likely	Significant	HIGH	Triangular			
CP-03	Variations in Design Concepts	Variations in Rec Feature sizing	The estimate was based on a smaller Recreation feature design and scaled up to approximate the requirements of the local sponsor in the MCACES. Size of features are set by the Comprehensive Devt Plan. May require additional wetlands in a mitigation plan if recreation areas increase. UPDATE: These costs have been included in the esitmate for mitigation and additional increases are very unlikely	Very Unlikely	Marginal	LOW			LOW	Triangular			
ESTIMATING ASSUMPTIONS													
EA-1	Dredging Quantities	Actual dredging quantities may vary from estimate, Actual side slopes may not be as stable as estimated and additional quantities may be required.	PDT does not see much reason for the dredging to vary. It is considered a simple template, and the dredging operation will initially dredge, place excess material on the bank, install the sheet pile, and then backfill with the material. This process will minimize any quantity variance. A plus or minus 5% quanitity variance is included	Very Likely	Marginal	MODERATE	Very Unlikely	Marginal	LOW				
EA-2	Sheet Pile Wall Quantities	Actual sheet pile wall quantities could increase based on the required driving depth. Some concern that the design for a cantilevered wall may not be effective.	PDT noted that the Sheet Pile Wall design was based on substantial core boring information that provided reliable geotech information. Therefore, the length and strength of the sheet pile walls are considered to only have minor variance. A plus or minus 10% quantity variance is included.	Very Likely	Marginal	MODERATE	Very Unlikely	Marginal	LOW				

Risk No.	Risk/Opportunity Event	Concerns	PDT Discussions	Project Cost			Project Schedule			Variance Distribution	Correlation to Other(s)	Responsibility/POC	Affected Project Component
				Likelihood*	Impact*	Risk Level*	Likelihood*	Impact*	Risk Level*				
EA-3	Articulated Concrete Block Material Quantities	Potential quantity variation witth ACBM material.	PDT considered that the ACBM Quantities will not vary much. However, there is a risk that ACBM base material may have to be replaced if existing material is found to be unsuitable. The risk is related to over 2 acres of area with a maximum of 2' depth	Very Likely	Marginal	MODERATE	Likely	Marginal	MODERATE				
EA-4	Dredging Production Rates and Crews	Possibility that the estimated dredging production rate may not be able to achieved.	PDT considered there is an equal chance that the dredging prodcutivity could be increase as it could decrease. The 200 CY per hour production estimated was considered to vary plus or minus 20% depending on conditions. To be conservative, only the potential higher end of the productivity range was modeled.	Very Likely	Marginal	MODERATE	Unlikely	Marginal	LOW				
EA-5	Sheet Pile Walls Production Rates and Crews	Possibility that the estimated sheet pile wall installation production rate may not be able to achieved.	PDT considered that the sheet pile wall productivity could be lower than the 60 lf per hour estimated. This variance was considered to be 10%.	Very Likely	Marginal	MODERATE	Unlikely	Marginal	LOW				
EA-6	Scope Changes	Possibility that scope changes will occur during the final design of the project.	The PDT considered that scope changes during the design stage are covered in the other risks identified. However, an additional risk of 2% has been included for unknown scope changes that could occur during the design completion.	Very Unlikely	Marginal	LOW	Unlikely	Marginal	LOW				
PROJECT & PROGRAM MGMT													
PM-03	Rights of Entry	ROE may be held up or delayed due to unknown circumstances and situations.	Item not likely to occur	Very Unlikely	Marginal	LOW			LOW				
PM-05	Program Management Resources	Program Management and Construction Management Resources may be limited	Risk very unlikely to occur	Very Unlikely	Marginal	LOW			LOW				
PM-06	Change Management	Change Orders during Construction	There is a high likelihood that change orders will occur on the project during construction due to unforeseen conditions and/or design changes. These change orders are considered to cover multiple risks already noted in the risk register, plus additional risks for unknowns that could occur during construction. A range of cost increase from 3% to 10% of the construction value has been modeled, with an ~ 6% increase the most likely result.	Very Likely	Critical	HIGH			LOW	Triangular			
PM-07	Project Closeout	Contract Closeout, Government Inspection, and Project Turnover may experience interruptions or delays creating the need for additional repairs.	Delay could likely occur during the project closeout that should have minimal impact on the project costs. This is modeled in the schedule delay. Any potential moderate cost increase is included in PM-06, change orders during construction.	Likely	Marginal	MODERATE	Likely	Significant	HIGH	Triangular			
PM-07a	Wetlands Impact	Project location may impact wetlands areas requiring additional mitigation efforts and costs	Included in RC-03: Variations in Design Concepts			0			0				

Risk No.	Risk/Opportunity Event	Concerns	PDT Discussions	Project Cost			Project Schedule			Variance Distribution	Correlation to Other(s)	Responsibility/POC	Affected Project Component
				Likelihood*	Impact*	Risk Level*	Likelihood*	Impact*	Risk Level*				
Programmatic Risks (External Risk Items are those that are generated, caused, or controlled exclusively outside the PDT's sphere of influence.)													
PR-1						0			0				
PR-2						0			0				
PR-3						0			0				
PR-4						0			0				
PR-5						0			0				
PR-6						0			0				
PR-7						0			0				

*Likelihood, Impact, and Risk Level to be verified through market research and analysis (conducted by cost engineer).

1. Risk/Opportunity identified with reference to the Risk Identification Checklist and through deliberation and study of the PDT.
2. Discussions and Concerns elaborates on Risk/Opportunity Events and includes any assumptions or findings (should contain information pertinent to eventual study and analysis of event's impact to project).
3. Likelihood is a measure of the probability of the event occurring -- **Very Unlikely**, **Unlikely**, **Moderately Likely**, **Likely**, **Very Likely.** The likelihood of the event will be the same for both Cost and Schedule, regardless of impact.
4. Impact is a measure of the event's effect on project objectives with relation to scope, cost, and/or schedule -- **Negligible**, **Marginal**, **Significant**, **Critical**, or **Crisis.** Impacts on Project Cost may vary in severity from impacts on Project Schedule.
5. Risk Level is the resultant of Likelihood and Impact **Low**, **Moderate**, or **High**. Refer to the matrix located at top of page.
6. Variance Distribution refers to the behavior of the individual risk item with respect to its potential effects on Project Cost and Schedule. For example, an item with clearly defined parameters and a solid most likely scenario would probably follow a triangular or normal distribution. A risk item for which the PDT has little data or probability of modeling with respect to effects on cost or schedule (i.e. "anyone's guess") would probably follow a uniform or discrete uniform distribution.
7. The responsibility or POC is the entity responsible as the Subject Matter Expert (SME) for action, monitoring, or information on the PDT for the identified risk or opportunity.
8. Correlation recognizes those risk events that may be related to one another. Care should be given to ensure the risks are handled correctly without a "double counting."
9. Affected Project Component identifies the specific item of the project to which the risk directly or strongly correlates.
10. Project Implications identifies whether or not the risk item affects project cost, project schedule, or both. The PDT is responsible for conducting studies for both Project Cost and for Project Schedule.
11. Results of the risk identification process are studied and further developed by the Cost Engineer, then analyzed through the Monte Carlo Analysis Method for Cost (Contingency) and Schedule (Escalation) Growth.

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Appendix D

Project Schedule

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The following schedule outlines the remaining planning, PED, and construction tasks required to implement the Tentatively Selected Plan.

Milestone	Schedule
Request PED Funding	November 2015
Final Report Approval (end of feasibility)	December 2015
Request Construction Funding	January 2016
Execute Cost Sharing Agreement for PED	February 2016
Begin Preconstruction Engineering and Design	April 2016
Execute Project Partnership Agreement (PPA)	October 2016
Start baseline monitoring	April 2017
Complete Design Documentation Report	October 2017
Complete Plans and Specifications	October 2017
Advertise Construction	November 2017
Award the contract	December 2017
Complete Real Estate Acquisition	February 2018
Start construction*	October 2018
Complete Construction*	December 2020
Turn Over Project to Local Sponsor	2020
Initiate Monitoring and Adaptive Management	January 2021
Complete Monitoring and Adaptive Management	2026

*Conceptual construction schedule on the following page.

CMP-ERP Construction Schedule

Dredge/ Disposal Event	Details	Operational Duration (Days)	Operational Start (No. Days From NTP)	Operational Finish (No. Days from NTP)	Calendar Finish Date (Month)
Start Construction		0	0	0	0
Channels and Canals	Mobilization & Site Preparation	150	0	150	5
Channels and Canals	Clearing and Grubbing	213	150	363	13
Channels and Canals	Dredge Excavation and enlarge SJ1 & SJ2 pits	350	163	513	18
Channels and Canals	Dredge, separate solid wastes and haul to Humacao Landfill	520	163	683	23
Channels and Canals	Dredge sediments and place in SJ1 & SJ2 pits	520	163	683	23
Channels and Canals	Upland Excavation and Earthwork	248	193	441	15
Channels and Canals	Install Weir	122	283	405	14
Channels and Canals	Prepare mangrove beds and plant mangroves	90	441	531	189
Recreation	Recreation Structures	720	0	720	24
Bank Stabilization	Sheet Piling	382	283	665	23
Cultural Resource Preservation	Ongoing	810	0	810	27
Complete Construction	Final Inspection, Demob. and Acceptance	90	720	810	27

Appendix E

Adaptive Management Plan

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DRAFT
ADAPTIVE MANAGEMENT PLAN
CAÑO MARTÍN PEÑA
ECOSYSTEM RESTORATION PROJECT
SAN JUAN, PUERTO RICO

Prepared for:

Corporación del Proyecto ENLACE del Caño Martín Peña
Apartado Postal 41308
San Juan, Puerto Rico 00940-1308

September 2015

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Executive Summary

The Caño Martín Peña Ecosystem Restoration Project (CMP-ERP) is an urban ecosystem restoration project to restore the Caño Martín Peña (CMP) and surrounding areas of the San Juan Bay Estuary (SJBE). Restoration of the CMP would re-establish the tidal connection between the San José Lagoon and the San Juan Bay, which would improve dissolved oxygen levels and reduce salinity stratification, increase biodiversity by restoring fish habitat and benthic conditions, and improve the functional value of mangrove habitat within the estuary.

The CMP is a 3.75-mile-long tidal channel in metropolitan San Juan, Puerto Rico. It is an integral part of the SJBE, the only tropical estuary included in the U.S. Environmental Protection Agency (USEPA) National Estuary Program (NEP). The SJBE's watershed covers 97 square miles. It is heavily urbanized, with a population density of over 5,000 people per square-mile. The SJBE includes over 33 percent of the mangrove forests on the island with over 124 species of fish and 160 species of birds. The eastern half of the CMP, historically between 200 and 400 feet wide and navigable, currently ranges in depth from 3.94 feet to 0 foot towards San José Lagoon. Due to years of encroachment and fill of the mangrove swamps along the CMP, the channel no longer serves as a functional connection between San Juan Bay and San José Lagoon. Sedimentation rates within the CMP are nearly two orders of magnitude higher than in other parts of the SJBE. Open waters in areas closer to the San José Lagoon have been lost, as the area has started transitioning into a wetland. A combination of sediment and solid waste is found in the CMP, of which the solid waste accounts for approximately 10 percent of its composition. In some sites, the solid waste extends to depths 10 feet below the sediment surface.

The conditions within the eastern side of CMP (the immediate Project Area), have led to degradation within the entire estuary. Connectivity of the ecosystem has been severed and the biodiversity within the lagoons has been compromised, as more individuals of a reduced number of species are found when compared with other lagoons throughout the SJBE. The decreases in biodiversity in turn have reduced the ability of fish and invertebrates to respond to natural changes, disease and other factors, resulting in a depletion of fish stock, biodiversity, and losses of economic and recreational resources.

The current condition of the CMP has resulted in the degradation of the environmental condition within areas of SJBE around the CMP. Water residence time in the San José Lagoon is approximately 17 days. The lack of tidal flushing causes strong salinity stratification and in turn leads to low oxygen or no oxygen levels in the 702 acres of lagoons with depth below 4 to 6 feet, severely affecting benthic habitats. Mangrove habitat, extremely important for native aquatic invertebrates, has been severely impacted, reducing habitat where important commercial fish species spend their juvenile life stages.

A conceptual ecological model was developed for the Caño Martín Peña. This model was used to develop hypotheses about relationships within the system and to assist in understanding changes brought about by planned project elements. The planning objectives for the Caño Martín Peña Feasibility Study include:

1. Improve fish habitat in the SJBE system by increasing connectivity and tidal access to estuarine areas;
2. Restore benthic habitat in San José Lagoon by increasing dissolved oxygen in bottom waters and improving the salinity regime to levels that support native estuarine benthic species; and
3. Increase the distribution and population density and diversity of native fish and aquatic invertebrates in the mangrove community by improving hydrologic conditions in the SJBE system.

After many considerations, it was determined that dredging the CMP could provide a way of reconnecting eastern and western segments of the SJBE system, as they were several decades ago. The plan formulation process built directly upon previous planning and design efforts. Structural management measures for the channel dredging, erosion control, dredged material disposal, mangrove planting and construction, recreation, as well as non-structural measures were identified and screened. An initial array of alternatives consisting of rectangular channel cross sections ranging between 75 to 200 feet widths and either 10 or 15 feet depths was developed and evaluated. Screening criteria such as completeness, acceptability, cost effectiveness, and secondary effects on adjacent communities, were then used to eliminate unfavorable plans and develop a final array of alternatives. The final array of alternatives consisted of four alternative plans ranging from no action to a 125 foot-wide by 10-foot-deep natural bottom channel. All constructed alternatives include an elongated weir under the Martín Peña, Tren Urbano, and Luis Muñoz Rivera bridges involving a 115-foot-wide by 6.5-foot-deep channel with riprap on side slopes and articulated concrete mats at the channel bottom to reduce water velocity and erosion, and to control scour.

Performance measures for Benthic Habitat, Fish Habitat, and Mangrove Habitat were developed to measure alternative output, and ecosystem restoration measure benefits were calculated for each alternative. A cost effectiveness and incremental cost analysis (CE/ICA) was conducted based on a project life of 50 years and a Federal Discount Rate of 3.5 percent and a base year of 2019. Each alternative was considered to be independent and not combinable with the other alternative. Due to weir restrictions to prevent erosion at bridges and other structures for all three action alternatives, average annual habitat units (AAHUs) would be nearly identical among alternatives, totaling 6,133 AAHUs per alternative. As a result, Alternative 2, with a slightly less average annual equivalent cost when compared to Alternatives 1 and 3 was determined to be cost effective and the best buy.

Alternative 2, the Tentatively Selected Plan (TSP) consists of a 100-foot-wide by 10-foot-deep natural bottom channel; the elongated weir described above; dredging approximately 762,000 cy of mixed materials along 2.2 miles of the eastern CMP; and construction of a vertical concrete-capped steel sheet pile with hydraulic connections with the surrounding lands; and restoration of 25.57 acres of open water and 34.48 acres of wetland. This represents a net increase of approximately 18.17 acres of open water and 1.02 acres of mangroves.

The TSP is the National Ecosystem Restoration Plan (NER) plan and provides a complete solution to the problems identified for the study. It is also the most effective plan and meets the project objectives. The NER Plan is acceptable and has been determined to be in the national and public interest and can be constructed while protecting the human environment from unacceptable impacts.

The CMP-ERP is a project that has a low uncertainty and high confidence that, once the project is constructed, the anticipated benefits will be observable and measureable, as demonstrated by the dredging of the western half of the CMP. In addition, other similar projects involving tidal and water flow restoration have resulted in improved water quality. Furthermore, several modeling efforts, specific to restoring tidal connectivity along the SJBE, have predicted improvements in water quality with concomitant benefits to habitats and fish and wildlife resources.

This Adaptive Management Plan (AMP) addresses the planning objectives, described above, that are directly related to water quality and ecosystem benefits obtained from tidal flow connectivity improvements across the SJBE, and mainly, between the San Juan Bay and San José Lagoon through the CMP.

This AMP includes those actions and measures that would be carried out:

- During project planning: Provide new knowledge to better define anticipated ecological responses;
- Before project implementation: Tidal flow, water quality, benthic and mangrove roots community characterization studies, fish censuses (including indicator species of ecosystem wellness) to be performed (or reviewed if they exist) at established stations to provide baseline information;
- During project construction: Monitoring and assessment of tidal/flow, water quality, benthic and mangrove roots community. Management measures would be implemented to avoid or reduce temporary impacts.
- After its implementation: Monitoring and assessment of tidal flow, water quality, benthic and mangrove roots communities, fish (including indicator species of ecosystem wellness). Management measures would be implemented, or existing ones would be adapted (adaptive management), to achieve goals and objectives. Adaptive management measures currently proposed and that would be implemented, if needed, would include planting mangrove trees along the new channel to promote wetland habitat restoration. In addition, conduct maintenance dredging at both of its ends to address any sedimentation and its effects on water flow.

These adaptive management activities would be refined during future phases of CMP-ERP, and the AMP would be updated accordingly. At such time, more baseline data and lessons learned would be available from the project itself as well as from other monitoring programs and restoration projects.

Given the new knowledge and data regarding Project's benefits, the adaptive management strategies and options proposed in this AMP may need enhancement.

This AMP addresses the requirements of the United States Army Corps of Engineers (USACE) Implementation Guidance for Section 2039—Monitoring Ecosystem Restoration, Memorandum (CECW-PB) dated 31 August 2009 (Guidance for Section 2039 of Water Resources Development Act 07) (USACE, 2009).

Acronyms and Abbreviations

AAHU	Average Annual Habitat Units
ACM	Articulated Concrete Mat
AMP	Adaptive Management Plan
BI	Benthic Index
BMPs	Best Management Practices
CCMP	Comprehensive Conservation & Management Plan for the San Juan Bay Estuary
CDRC	Ciudad Deportiva Roberto Clemente
CE/ICA	Cost Effectiveness/Incremental Cost Analysis
CEM	Conceptual Ecological Model
CH3D-WES	Curvilinear Hydrodynamics in 3-Dimensions-Waterways Experiment Station model
CMP	Caño Martín Peña
CMP-ERP	Caño Martín Peña Ecosystem Restoration Project
cy	cubic yard
DO	dissolved oxygen
EC	Engineering Circular
ECO-PCX	USACE Ecosystem Restoration Planning Center of Expertise
EFH	Essential Fish Habitat
EIS	Environmental Impact Statement
ENLACE	Corporación del Proyecto ENLACE del Caño Martín Peña
ENLACE Project	Caño Martín Peña ENLACE Project
ER	Engineering Regulation
ERDC	USACE Engineer Research and Development Center
ERP	Ecosystem Restoration Project
FR	Feasibility Report
FRM	Flood Risk Management
ft^2	square feet
ft/s	feet per second
ft/y	feet per year
g	grams
H&H	Hydrodynamic and Hydrologic
HU	Habitat Unit
GIS	Geographic Information System
mg/kg	milligrams per kilogram

mg/L	milligrams per liter
mi^2	square mile
mL	milliliter
MLLW	mean low low water
mm/yr	millimeters per year
mph	miles per hour
MTZ-CMP	Public Domain lands within the Caño Martín Peña Maritime Terrestrial Zone
NED	National Economic Development Account
NEP	USEPA's National Estuary Program
NEPA	National Environmental Policy Act
NER	National Ecosystem Restoration
NMFS	National Marine Fisheries Service
NOAA	National Oceanic and Atmospheric Administration
O&M	Operations and Maintenance
ODMDS	San Juan Bay Ocean Dredged Material Disposal Site
P&G	United States Water Resources Council Principles and Guidelines
PED	Planning, Engineering and Design
PMP	Project Management Plan
PPA	Project Partnership Agreement
ppm	parts per million
PR	Commonwealth of Puerto Rico
PREQB	Puerto Rico Environmental Quality Board
PRHTA	Puerto Rico Highway and Transportation Authority
Project Channel	2.2 miles of the Eastern CMP associated with the CMP-ERP
PRWQSR	Puerto Rico Water Quality Standards Regulation
SJBE	San Juan Bay Estuary
SJBEP	San Juan Bay Estuary Program
SJHP	San Juan Bay Harbor
T&E	Threatened and Endangered Species
TSP	Tentatively Selected Plan
µg/g	micrograms per gram
USACE	United States Army Corp of Engineers
USEPA	United States Environmental Protection Agency
USFWS	United States Fish and Wildlife Service
WQC	Water Quality Certification

1.0 INTRODUCTION

1.1 BACKGROUND

The Caño Martín Peña (CMP) is a 3.75-mile-long tidal channel in metropolitan San Juan, Puerto Rico. It is part of the San Juan Bay Estuary (SJBE), the only tropical estuary included in the U.S. Environmental Protection Agency (USEPA) National Estuary Program (NEP). The SJBE and its associated marine ecosystems are considered the "Study Area," because the proposed CMP-ERP is expected to have direct, indirect, and cumulative beneficial effects on this whole region (Figure 1). The "Project Area," which mostly lays out the construction footprint, has been defined as the Project Channel, where dredging would take place, and the adjacent delimitation of the public domain lands within the Public Domain lands within the Caño Martín Peña Maritime Terrestrial Zone (MTZ-CMP) where relocations are scheduled to occur. Also included in the Project Area is the 6-acre dredged material staging area within the 35-acre Ciudad Deportiva Roberto Clemente (CDRC) site, the boating routes from the eastern limit of the CMP to the CDRC and the nearby San José Lagoon pits, and the five pits in San José Lagoon (Figure 2).

Figure 1. The San Juan Bay Estuary Study Area

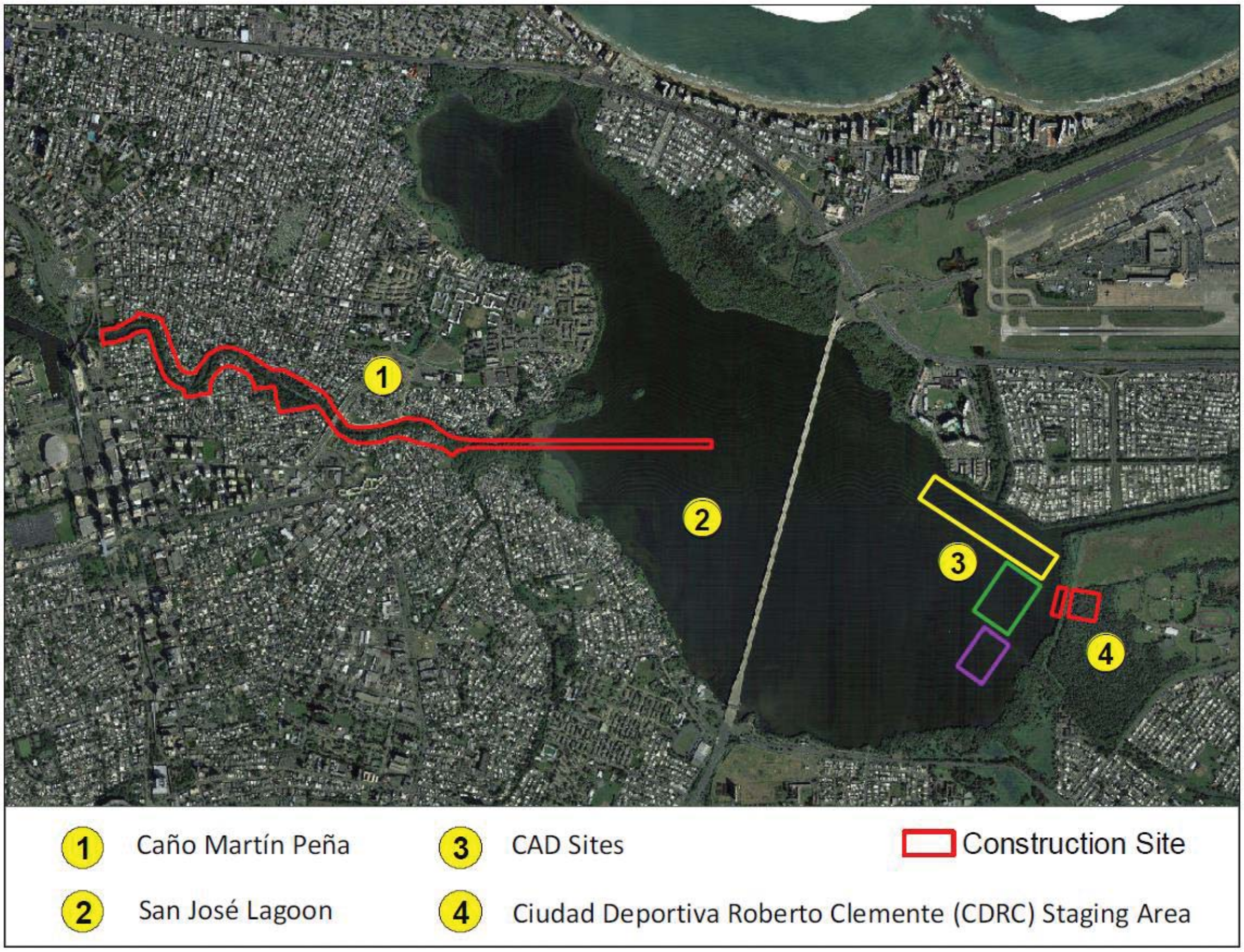

Figure 2. The Caño Martín Peña Ecosystem Restoration Project Area

The SJBE, along the northern coast of Puerto Rico, is the largest system of its kind on the island. Located within the largest urbanized and most densely populated region in Puerto Rico, the SJBE's watershed includes the municipalities of Toa Baja, Cataño, Bayamón, San Juan, Guaynabo, Carolina, Loíza, and Trujillo Alto. The system is characterized by a network of lagoons, channels, man-made canals, permanently and seasonally flooded woody and herbaceous wetlands, and the San Juan Bay, which is home to Puerto Rico's busiest port. In spite of its urbanized setting, the SJBE includes over 33 percent of the mangrove forests on the island with over 124 species of fish and 160 species of birds.

The SJBE and its associated marine ecosystems are considered the "Study Area", since the proposed Caño Martín Peña Ecosystem Restoration Project (CMP-ERP) is expected to have direct, indirect, and cumulative beneficial effects on this whole region (Figure 1). The SJBE includes the San Juan Bay, the Condado Lagoon, the San José Lagoon (including its northwestern section known as Los Corozos Lagoon), La Torrecilla Lagoon, and the Piñones Lagoon, the interconnecting Caño Martín Peña (CMP), San Antonio Channel, and the Suárez Canal, as well as the Piñones mangrove forest and Las

Chucharillas Swamp. Fresh water flows into the system from the creeks and rivers flowing mostly north from its watershed, covering approximately 97 square miles (Figure 1). These include the Río Piedras (Puerto Nuevo) River, Juan Méndez Creek, San Antón Creek, Blasina Creek, and the Malaria Canal. During medium to extreme flood events, fresh water is also received from the Río Grande de Loíza River, located east of the Piñones State Forest. Several flood control pump stations, as well as storm water sewers, discharge fresh water into the system. Ocean water enters the SJBE through three openings or outlets: Boca del Morro at the San Juan Bay, El Boquerón at the Condado Lagoon, and Boca de Cangrejos at La Torrecilla Lagoon. The Puerto Nuevo River, whose drainage area is of about 25 square miles, flows into the western end of the CMP, close to the San Juan Bay. The western half of the CMP was dredged during the 1980s as part of a waterway transportation project. This portion of the CMP is navigable and has a channel width and depth of 200 feet and 10 feet, respectively. The total drainage area of the CMP is about 4 square miles (2,500 acres).

The water quality of the SJBE has been significantly altered from its natural state not only by land-use activities, but also by the modification of its hydraulic properties through the dredging and filling of many of its water bodies. Water quality within both the Caño Martín Peña and San José Lagoon has been previously documented as being degraded [Kennedy et al. 1996, Webb and Gomez-Gomez 1998, San Juan Bay Estuary Program 2000, Puerto Rico Environmental Quality Board (PREQB) 2008] and data suggest that the Caño Martín Peña is a source of turbidity and bacteria to the waters of San José Lagoon; however, the CMP does not appear to be a source of nutrients for the San José Lagoon (Atkins, 2011a).

Impacts to the water quality of the CMP and San José Lagoon include prior on-ongoing inflows from combined storm sewer overflows, inflows from areas lacking sanitary sewers, untreated industrial discharges, surface runoff and subsurface seepage over areas with household waste, and from direct dumping of household waste. While water quality concerns remain within both the CMP and San José Lagoon, there is ample evidence of substantial improvements in water quality within San José Lagoon in recent decades, due mostly to improvements in the collection and treatment of wastewater loads in the San Juan Bay region (Webb and Gomez-Gomez, 1996 and 1998; Webb et al. 1998). In western San José Lagoon, in the part of the Lagoon closest to the CMP, phosphorus concentrations have decreased more than 50 percent since the late 1970s to early 1980s, and water clarity (as measured by Secchi disk depth) has doubled since the early 1980s (Atkins, 2011a).

The recent trends of improved water quality in much of the San Juan Bay Estuary have been achieved only after the investment of substantial time and resources. Since the late 1980s alone, the USEPA has awarded in excess of $650 million to the Commonwealth of Puerto Rico via the Clean Water State Revolving Fund program (Caribbean Business Journal 2012). As a result of these and other coordinated actions, there is an obvious trend of improving water quality in the San José Lagoon, as outlined in the report "Technical Memorandum for Task 2.6 – Water and Sediment Quality Studies" (Atkins, 2010b). Similar findings of improving water quality in the greater San Juan Bay estuary system have been previously reported by Webb and Gomez-Gomez (1996 and 1998) and by Webb et al. (1998). Webb and Gomez-Gomez (1998) concluded that "these records document the improved water quality that has resulted from implementing pollution control measures established in the 1970s."

The ongoing and reduced ecological integrity of the San José Lagoon, despite substantial reductions in pollutant loads, appears to be mostly due to salinity stratification and the development of hypoxic conditions (low levels of dissolved oxygen) in waters deeper than 4 to 6 feet (Atkins, 2011b). Model results lead to the conclusion that restoration of the tidal exchange capacity of the CMP would increase salinity in the surface waters of the San José Lagoon, which would decrease salinity stratification and thus reduce the spatial extent and severity of hypoxic conditions (Atkins, 2011b). Although acceptable levels of dissolved oxygen exist in those portions of the San José Lagoon that are shallower than approximately 4 feet, hypoxic to anoxic conditions are encountered throughout approximately 700 acres of the Lagoon where the water depths are greater than 4 feet. One of the most severe water quality problem in the CMP is levels of dissolved oxygen. Also, Webb and Gomez-Gomez (1998) found ammonia concentrations up to 2.3 milligrams per liter (mg/L) (as nitrogen) and orthophosphate concentrations of 0.22 mg/L (as phosphorus) as well as anoxic conditions within the CMP water column. Also in the Caño Martín Peña, recent studies have documented from 2,000,000 to 6,000,000 fecal coliform bacteria colonies per 100 milliliters (ml) well above guidance criteria of 200 colonies per 100 ml (SJBEP, 2012). Additionally, levels as high as 1,200,000 for Enterococci bacteria colonies per 100 ml, where the guidance criteria of 35 colonies per 100 ml (SJBEP, 2012).

The existing high sedimentation rates, presence of contaminants within the sediments, low dissolved oxygen levels, and salinity stratification within the CMP and/or the San José lagoon do not provide a healthy ecosystem for benthic organisms (e.g., infauna, meiofauna, epifauna) or organisms relying upon the estuarine water column (e.g., fish and invertebrates; Kennedy et al. 1996, Otero, 2002, SJBEP 2000, PREQB 2008). Benthic habitats in and around the Project Channel area are highly degraded due to the contaminant loads and reduced tidal flushing present, which result in limited light penetration, poor water quality, and anoxic, highly organic sediments.

Soft bottoms in these shallow areas, the mangrove roots that line the lagoons, seawalls, rip-rap and other surfaces at these depths are covered with a thriving community dominated by mussels. Rivera (2005) estimated 66.7 acres of this mussel reef within the San José lagoon, which he hypothesized, is a "large source of food for the Lagoon" and provides a water filtering function "which must help maintain the water quality."

Species abundance and diversity (important indicators of healthy habitats) of the encrusting community of red mangrove prop roots is higher in the La Torrecilla Lagoon (closest to the Atlantic Ocean), becomes less diverse and less abundant within the San José Lagoon (farthest from the flushing source), and is non-existent or limited (severely limited flushing) within the CMP. This could be related to dissolved oxygen and salinity concentrations.

This macrofauna follows a general pattern of reduced diversity and abundance along a gradient from La Torrecilla Lagoon to Suárez Canal, to the San José Lagoon to the CMP. In general, sponges, crabs, worms and mussels become less abundant to absent along a gradient from the eastern end of Suárez Canal, along San José Lagoon and into the CMP.

In summary, the results of the benthic habitat survey in the shallow portions of San José Lagoon indicate that diverse and healthy biological communities are restricted to the shallowest (less than four feet water depth) regions, where salinity stratification does not occur, and where sufficient levels of dissolved oxygen exist. These are the conditions that support a healthy benthic habitat, that type that would support sustenance and recreational fishery in the Lagoons; however, at the minimal dissolved oxygen conditions found in the approximately 700 acres of waters deeper than four feet water depth in San José Lagoon, the presence of hydrogen sulfide in the sediments is a strong indicator that the water layer above the sediments is also hydrogen sulfide laden. Therefore, these areas of the bottom of the lagoons cannot sustain a benthic habitat.

Some of the 124 fish species that have been documented in the SJBE system have been locally identified as important target species for both recreational and commercial fisheries. The important target species of common snook (*Centropomus undecimalis*) and tarpon (*Megalops atlanticus*) are caught within San José Lagoon itself (Yoshiura and Lilyestrom 1999). The commercially important offshore fishery for mutton snapper (*L. analis*) is dependent, in part, on the maintenance of a healthy inshore, lower-salinity mangrove habitat for post-larval and juvenile phases (Faunce et al. 2007). Out of the 124 species of fish documented within the SJBE system, fifteen of these are also found within the 84 managed species included in the Caribbean Fishery Management Council's Fisheries Management Program (FMP) (Yoshiura and Lilyestrom 1999).

Due to the current clogging of the eastern CMP, there is essentially no tidal exchange between San Juan Bay and the San José Lagoon. As a result, fish within San Juan Bay cannot directly access the mangroves, seagrass meadows, and open water habitats of San José Lagoon, Los Corozos Lagoon, the Suarez Canal, La Torrecilla Lagoon, and Piñones Lagoon, just as fish within those waterbodies cannot directly access the habitats afforded by San Juan Bay.

There are still some mangrove wetlands, albeit of extremely low functional quality, along the CMP. If the CMP was dredged, much of these wetlands would be within the construction area and impacted by the project. In order to maintain a mangrove fringe of wetlands along the CMP for habitat, nutrient reduction, water quality, and other wetland functions, mangrove wetlands could be re-established in areas along a dredged canal. This measure would provide immediate restoration within the project area, as the existing low quality mangrove areas would be removed along the CMP channel for construction purposes and replaced by high functioning mangrove wetlands. The north and south slopes of the channel above the sheet pile would be graded to receive tidal influence and then planted with appropriate mangrove species. Microtopography would be added to diversify habitat for mangroves, with higher contours being available over time as sea level change occurs.

The CMP-ERP is an urban ecosystem restoration project to restore the CMP and surrounding areas of the SJBE. Restoration of the CMP would re-establish the tidal connection across the SJBE, substantially improving the water quality of the entire SJBE and promoting the establishment of more diverse and healthy fish and wildlife habitats (USACE, 2004). This means helping to reduce water renewal time in the San José Lagoon and its salinity stratification, as well as to improve dissolved oxygen levels, fish and benthic habitat, and thus biodiversity, including the functional value of mangrove habitat within this system (Atkins, 2015).

Several modeling efforts have been conducted to further assess the effectiveness of the proposed project on the hydrology and hydrodynamics of the SJBE, and its possible effects on fish and wildlife resources. In 2000, the USACE's Research and Development Center published the report titled Hydrodynamic and Water Quality Model Study of the San Juan Bay Estuary (SJBE). This study was performed for the SJBE Program (Bunch et al. 2000). The researchers used a three-dimensional, coupled, hydrodynamic and water quality model of the SJBE system that was calibrated using field observations in order to estimate the effectiveness of various alternatives to increase flushing and reduce loadings for improving water quality. Dredging the CMP to 150 feet wide and 9 feet deep, in order to improve water flow along this water body was one of the scenarios modeled, showing improvements in the channel's water conveyance capacity and that of the San José Lagoon.

The CH3D-WES hydrodynamic model was used to quantify the improvement (decrease) in residence time in the San José Lagoon and improved connectivity between this water body and the San Juan Bay as a result of increasing the cross-sectional area and thus, the water flow capacity of the CMP within the Project Area. It was also used to predict ecological improvement for various parameters, such as dissolved oxygen and salinity. The output on residence time was combined with data from a recently developed Benthic Index (BI) for the SJBE (PBS&J, 2009). The relationship between residence time and benthic community health in the San José Lagoon was found to be significant. It was determined, as a result, that restoring tidal flow through the CMP would improve the lagoon's circulation, helping to decrease water stratification and thus, hypoxic to anoxic conditions affecting its waters and associated submerged habitats (Atkins, 2011a; 2011b; 2015; Bunch et al, 2000; PBS&J, 2009).

Preliminary hydrologic modeling for different channel configurations indicated that if the channel dredging measure was implemented, erosion control features would be necessary to protect the CMP channel from scouring, and to protect existing bridges and shoreline stabilization structures in the western CMP such as sheet piles. Three erosion control features were formulated, evaluated, and retained for these purposes. These erosion control features are all dependent on dredging of the existing CMP channel. First, articulated concrete mats (ACMs) would be required to provide scour protection for any high velocity dredged channel configurations. The soils in the CMP Project Channel are predominantly hard silts and clays at a depth of 10 to 15 feet below the existing bottom, and these soils could be subject to scour at velocities greater than approximately 4.0 feet per second. Table 1 provides within-channel bottom velocities that could be produced by the different channel dimensions. Those indicated in red would require ACM to prevent channel scouring. The other configurations are considered wide enough to slow within-channel velocities to an acceptable rate, and a 100-foot wide channel would be the most marginal that could be acceptable.

Table 1. Maximum Bottom Velocities within the CMP Project Channel

Channel Dimensions (feet wide x feet deep)	CMP Bottom Velocity (ft/s)
(75 x 10)	4.22
(100 x 10)	4.09
(125 x 10)	3.95
(125 x 15)	3.45
(150 x 10)	3.85
(150 x 15)	3.13
(200 x 10)	3.13

Second, riprap would be a necessary feature for protection along any structures such as bridges. Lastly, initial hydrologic analysis for the project determined that a weir would be necessary to slow velocities in the western portion of the CMP above channel dimensions greater than 75 x 10 feet.

Two main project constraints for the proposed project is that the plan should not damage the shoreline and sheet pile structures in the downstream western CMP, and that the foundations of the existing four bridges in the western portion of the Project Channel must be protected. During recent years, three bridges and shoreline stabilization projects have been constructed in the western CMP, and these structures were not designed with a wider, higher velocity CMP channel in mind. Preventing erosion is essential to maintaining a functional project as any effects to the structures in the western CMP could require major construction and cost for repairs in the future, thus impacting funding for general channel maintenance. To evaluate this constraint, western CMP velocities were calculated and evaluated for the potential to damage bridges and sheet pile structures (Table 2). With the exception of the 75-x-10-foot channel, every other channel dimension would be considered unacceptable.

Table 2. Maximum Bottom Velocities within the CMP and the Adjacent Western Channel

Channel Dimensions (feet wide x feet deep)	Western CMP Bottom Velocity (ft/s)
(75 x 10)	2.20
(100 x 10)	2.80
(125 x 10)	3.25
(150 x 10)	3.65
(200 x 10)	4.09

Because a 75-foot-wide by 10-foot-deep channel was the only dimension that resulted in a bottom velocity that was low enough to prevent unacceptable scour in the western CMP, every larger channel dimension that was modeled (e.g., 100-, 125-, 150-, and 200-foot widths) must include a design component to reduce water flow at the western end of the Project Channel consistent with the model output for the 75-x-10-foot channel if they were to be retained as viable, feasible dimensions. The inclusion of a weir (115-foot-wide by 6.5-foot-deep) would enable the larger channels to replicate the cross-sectional area of the smaller 75-x-10-foot channel, and, in turn, maintain the same flow characteristics. With such a weir in place, the potential for unacceptable scour in the western CMP would be resolved while accommodating wider channel widths in the rest of the Project Channel.

In order to protect the structural integrity of the four bridges in the western portion of the Project Channel, it was recommended that channel depths in their vicinity do not extend below 6.5 feet in depth, which is consistent with the weir depth; however, in light of this depth restriction around the bridges, the 75-x-10-foot channel must also include the 115-x-6.5-foot weir. Thus, the inclusion of the weir in the 75-x-10-foot channel is in response to the protection of the existing bridges, not because of the need to reduce water flows to an acceptable bottom velocity in the western CMP, as is the case with the 100-, 125-, 150-, and 200-foot-wide channels.

Although the western and eastern CMP channel segments have different cross-sectional areas and bottom elevations, water flow through a tidal system such as the CMP is, and would continue to be, restricted by the smallest cross-sectional area. More specifically, the water flow characteristics of potential wider channel configurations with the weir would be not significantly different than those associated with that narrower channel configuration of 75 feet.

Benefits for the CMP-ERP are directly related to water flow, which controls differences in residence time and tidal range. With respect to benefits derived from the various channel alternatives, there is a significant benefit to the San José Lagoon (based on the benthic index score) once the CMP channel is widened to 75 feet due to tidal amplitude, or volume of water flowing into and out of the lagoon. Increasing channel widths to 100, 125, 150, and 200 feet would progressively result in additional, albeit marginal, benefits as a result of the increased water flows and reduced water residence times.

After many considerations, it was determined that dredging the CMP could provide a way of reconnecting eastern and western segments of the SJBE system, as they were several decades ago. The plan formulation process built directly upon previous planning and design efforts. Structural management measures for the channel dredging, erosion control, dredged material disposal, mangrove planting and construction, recreation, as well as non-structural measures were identified and screened. An initial array of alternatives consisting of rectangular channel cross sections ranging between 75- to 200-foot widths and either 10- or 15-foot depths was developed and evaluated. Screening criteria such as completeness, acceptability, cost effectiveness, and secondary effects on adjacent communities, were then used to eliminate unfavorable plans and develop a final array of alternatives. The final array of alternatives consisted of four alternative plans ranging from no action to a 125-foot-wide by 10-foot-deep natural bottom channel. All constructed alternatives include an elongated weir under the Martín Peña, Tren Urbano, and Luis Muñoz Rivera bridges involving a 115-foot-wide by 6.5-foot-deep channel with riprap on side slopes and articulated concrete mats at the channel bottom to reduce water velocity and erosion, and to control scour.

The CMP-ERP is a project that has a low uncertainty and high confidence that, once the project is constructed, the anticipated benefits will be observable and measureable. The western half section (approximately 2 miles long) was dredged to 200 feet wide by 10 feet deep to allow inland navigation (Acuaexpreso). In 2004, the USACE carried out a reconnaissance of the western side of the CMP and stated that "mangrove had established along both sides of the channel and flow, as well as water quality in this area, has slightly improved" (USACE, 2004). In addition, other reference or similar tidal restoration projects, (i.e., reestablishment of historical tidal connections) have shown improvements in water quality, benthic community health and fish abundance/diversity over time (Atkins, 2015).

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2.0 CMP-ERP OBJECTIVES: IDENTIFICATION OF PROBLEMS AND OPPORTUNITIES

The health of the SJBE has been compromised by the lack of tidal interchange between the San Juan Bay and the San José Lagoon, resulting from habitat destruction and the near-complete blockage of the CMP. The fragmented estuary has functionally been divided in half, which can cause such severe ecological effects as crowding, increased competition, and loss of population density and species diversity. The habitat fragmentation leaves the ecosystem extremely susceptible to changes in climate or shifts in available resources, which can have devastating effects on the community and can alter the overall species composition of the estuary.

The SJBE, being in an area of relatively low tidal amplitude, now suffers from a lack of tidal flushing that has led to decreases in dissolved oxygen and adverse changes in salinity stratification. The poor water quality conditions cause disruptions to the normal levels of species evenness and richness, leading to poor benthic habitat. These conditions have also led to poor species distribution and populations density within the mangrove root community. Research within the estuary has indicated that the mangrove root habitat decreased in overall quality with closer proximity to the CMP. Specifically, the current conditions within the Caño Martín Peña have led to the following problems:

1. Aquatic habitat in the SJBE has been fragmented due to the near complete obstruction of the CMP, eliminating connectivity throughout the entire estuary.
2. Severe hypoxic/anoxic bottom water conditions and poor salinity stratification exist in the San José lagoon due to a lack of tidal flushing and resulting in decreased habitat for benthic species in the estuary.
3. Mangrove wetland habitat in the CMP, the San José lagoon, and the Suárez Canal has been adversely impacted due to the lack of tidal flow and the subsequent reduction in density of native species that use this habitat.

Atkins (2010) developed a conceptual ecological model to better understand the relationship between stressors within the system and their effects on the ecosystem. Another conceptual ecological model was later developed by the USACE during their review process. The models worked by the technical teams were combined into one Conceptual Ecological Model featured in Figure 3.

The following opportunities were identified:

1. Increase tidal flushing, and in turn reduce sedimentation rates, in the SJBE by restoring the historic connectivity through the eastern CMP;
2. Reconnect surrounding estuarine areas and increase biodiversity and fish and wildlife populations by restoring access to historic habitats ;

3. Increase dissolved oxygen levels and reduce salinity stratification (enhance existing conditions) in the CMP and the San José Lagoon.
4. Improve mangrove and benthic habitats in the SJBE, especially within the CMP and San José Lagoon.

Subsequently, objectives were produced to address those problems and opportunities that have been identified. These describe the desired results of the planning process by solving these and taking advantage of the opportunities identified. The planning objectives must be directly related to the problems and opportunities identified for the project and would be used for the formulation and evaluation of plans. Objectives must be clearly defined and provide information on the desired effect (quantified, if possible), the subject of the objective (what would be changed by accomplishing the objective), the location where the expected result would occur, the timing of the effect (when would the effect occur) and the duration of the effect.

The following objectives have been developed for the CMP-ERP.

1. Improve fisheries in the San Juan Bay Estuary system by increasing connectivity and tidal access to estuarine areas;
2. Restore benthic habitat in San José and Los Corozos lagoons by increasing dissolved oxygen in bottom waters and improving the salinity regime to levels that support native estuarine benthic species; and
3. Increase the distribution and population density and diversity of native aquatic fish and invertebrates in the mangrove community by improving hydrologic conditions in the SJBE system.

The timing and duration for the objectives would occur over the period of analysis, beginning with project implementation in year 2019 and continuing for 50 years.

According to the Monitoring Plan (MP) prepared for the CMP-ERP, there are some metrics that would be assessed before project construction (pre-construction) and others that would be monitored after project construction (post-construction), in order to evaluate project success. Table 2 includes those metrics, as well as the adaptive management actions needed in the case monitoring data shows that Project is not complying with objectives and goals set forth according to those metrics.

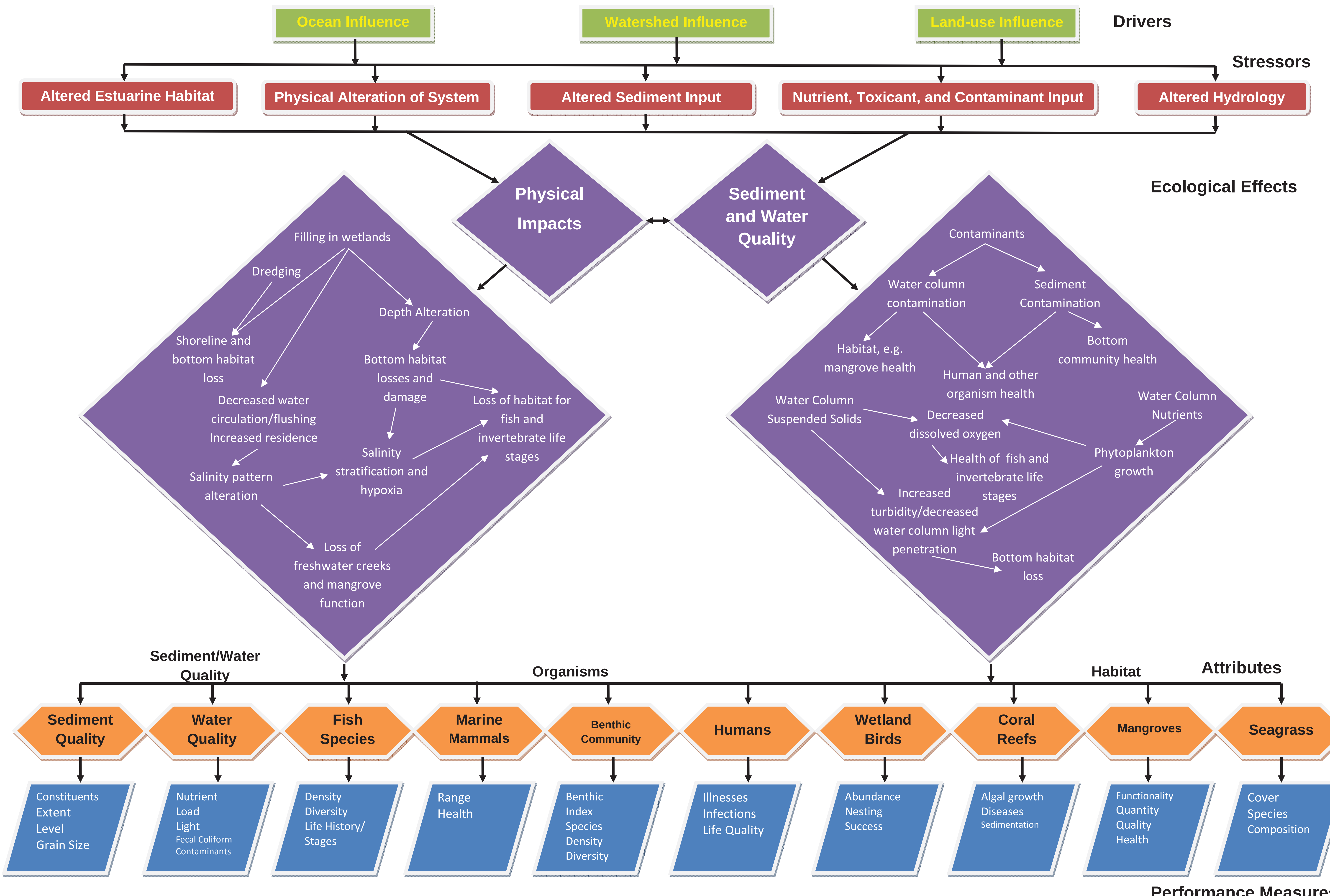

Figure 3. San Juan Bay Estuary Conceptual Ecological Model (Atkins, 2015)

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3.0 ADAPTIVE MANAGEMENT PROGRAM DEVELOPMENT

Ecosystem restoration is one of the primary missions of the USACE Civil Works program. The USACE objective in ecosystem restoration planning is to contribute to national ecosystem restoration. Contributions to national ecosystem restoration, or National Ecosystem Restoration (NER) outputs, are increases in the net quantity and/or quality of desired ecosystem resources. Measurement of NER is based on changes in ecological resource quality as a function of improvement in habitat quality and/or quantity and expressed quantitatively in physical units or indexes (but not monetary units). These net changes are measured in the planning area and in the rest of the Nation.

With respect to benefits to the SJBE derived from the various channel alternatives, modeling concludes that there is a significant benefit to the San José Lagoon (based on the benthic index score, explained below) once the CMP channel is widened to 75 feet due to tidal amplitude, or volume of water flowing into and out of the lagoon. Increasing channel widths to 100 and 125 feet would progressively result in additional, albeit marginal, benefit as a result of the increased water flows and reduced water residence times. Although the western and eastern segments of the Project Channel have different cross-sectional areas and bottom elevations for the 100- and 125-foot alternatives with the weir, water flow through a tidal system such as the CMP is, and would continue to be, restricted by the smallest cross-sectional area. Accordingly, once the weir is included in the larger channel configurations, there is no further benefit to residence time in San José Lagoon with channel widths wider than 75 feet, and thus no additional national ecosystem restoration benefits. Therefore, the NER benefits related to ecological uplift for all alternatives would be the same as the 75-foot channel alternative. The only difference would be the variation in habitat scores as it related to open water and mangrove habitat within the Project Channel.

The performance metrics/models for the benefits analysis were mostly based on assessments developed from existing efforts and from the relationships and hypotheses developed in the Conceptual Ecological Model (CEM) (Figure 3) contained in the NER Benefits Evaluation Appendix (Atkins, 2015). These prior efforts include a hydrodynamic model originally produced for San Juan Bay by Bunch et al. (2000), which was recreated with various potential tidal reestablishment scenarios by Atkins (2011a). The hydrodynamic model used was the Curvilinear-grid Hydro-dynamics model in 3-Dimensions, developed by USACE researchers from the Waterways Experimental Station model (i.e., Curvilinear Hydrodynamics in 3 Dimensions, WES version = CH3D-WES). The physical boundaries of the hydrodynamic model (Bunch et al. 2000) are consistent with the physical boundaries of the estuary and nearshore waters used by the San Juan Bay Estuary Program in developing its various resource management programs. The hydrodynamic model is an approved model by USACE Headquarters, and the habitat models have been evaluated by the USACE Ecosystem Restoration Planning Center of Expertise (ECO-PCX) and approved for single-use by the Model Certification Team, USACE HQ.

In order to calculate habitat units, performance metrics were developed from project planning documents, and relationships and hypotheses developed in the CEM. The CEM displays relationships demonstrating that the planned CMP-ERP would result in:

1. Improved fish habitat in the SJBE system by increasing connectivity and tidal access to estuarine areas;
2. Restored benthic habitat in San José and Los Corozos lagoons by increasing dissolved oxygen in bottom waters and improving the salinity regime to levels that support native estuarine benthic species; and
3. Increased distribution and population density and diversity of native aquatic fish and invertebrates in the mangrove community by improving hydrologic conditions in the SJBE system.

3.1 FISH HABITAT MODEL

The restoration of the inter-connectedness of mangrove forests, seagrass meadows, open water and coral reefs as the "seascape" is essential to improving the health, viability and number of fish within the SJBE. Currently, fish within San Juan Bay cannot directly access the mangroves, seagrass meadows, and open water habitats of San José Lagoon, the Suarez Canal, La Torrecilla Lagoon and Piñones Lagoon, just as fish within those waterbodies cannot directly access the habitats afforded by San Juan Bay (located to the west of the western end of the CMP). Due to the current condition of the CMP, there is essentially no tidal exchange between San Juan Bay and the San José Lagoon, i.e. the eastern and western sides of San Juan Bay Estuary system, creating essentially two estuary systems connected independently to the ocean waters by inlets.

The restoration of the CMP is not only expected to benefit water quality and fish habitat within the Caño Martín Peña, San José Lagoon, and Los Corozos Lagoon (Atkins, 2011a), it would benefit fisheries outside of these water bodies by allowing easier access to the variety of fish habitat (i.e., open water, seagrass meadows, hard bottom, mangrove fringes) found throughout the newly inter-connected waters of San Juan Bay, San José Lagoon, the Suarez Canal, La Torrecilla Lagoon and Piñones Lagoon (i.e., the entire San Juan Bay Estuary system).

The construction of the CMP-ERP would result in the eventual benefit to open water and reef habitat of additional net habitat units based upon the scaling factors and the proposed Caño Martín Peña channel alternatives (5,154.0 HUs for the 75-foot Alternative; 5.159.2 HUs for the 100-foot Alternative with weir; and 5,164.6 HUs for the 125-foot Alternative with weir). The net average annual Habitat Units (AAHUs) for the Fish Habitat Model varies between the proposed Caño Martín Peña channel alternatives (Table 3) (5,050.9 AAHUs for the 75-foot Alternative; 5,056.0 AAHUs for the 100-foot Alternative with weir; and 5,061.3 AAHUs for the 125-foot Alternative with weir) and is based upon the recovery time of 3 years (linearly from the existing condition to the predicted, modeled score) and a project period of 50 years.

3.2 BENTHIC INDEX MODEL

Benthic habitat is evaluated using an index originally developed for the SJBE Program to report on the status and trends of the health of the SJBE and its individual component water bodies. The technique is consistent with the wider body of literature on how such indices should be constructed, and it is consistent with guidance provided by USEPA (2008) on the requirements of a benthic index which is a refinement of the standard diversity index for SJBE. The index combines information on benthic community diversity, the presence or absence of pollution-tolerant benthic taxa, and the presence or absence of pollution-sensitive taxa (PBS&J 2009). The Benthic index is designed to increase as beneficial factors (i.e., species richness [number of species present], species evenness [number of individuals present from each species is not dominated by one species in particular], and presence of pollution-sensitive taxa) increase. Conversely, if species richness and/or evenness decline and the proportion of pollution-tolerant taxa increases, the Benthic Index will decline. An extensive database on benthic species composition by Riviera (2005) was used to produce benthic index scores throughout SJBE. In the original report (PBS&J 2009), it was determined that benthic index scores were lowest in SJBE in the Caño Martín Peña, followed by the San José Lagoon and that distance from the Atlantic Ocean, used as a surrogate for tidal influence, was a better predictor of benthic index scores than water depth.

Output from the hydrodynamic model was used to determine whether the correlation between benthic index scores and distance from the Atlantic Ocean could be replicated with residence time. The model variables used for the linked hydrodynamic-Benthic Index Model are the hydrodynamic model (CH3D-WES) output of residence time (as an independent variable) and benthic index scores (as a potentially statistically significant independent response variable). The model assumptions are that residence time affects benthic index scores, and the derived mathematical equation reveals the direction of the relationship, the variability associated with the derived relationship, and the statistical significance of the relationship. The Benthic Index Model was properly associated with the residence time within San José Lagoon because the benthic index improvement in San José Lagoon depends upon the water within the Lagoon turning over with the reduced residence time and increased dissolved oxygen levels are anticipated in bottom waters of San José Lagoon as a function of decreased salinity stratification (which is currently occurring in the lagoon), brought about through increasing the exchange of more saline surface waters. Larger, deeper waterbodies like San Juan Bay proper will not experience a significant reduction in residence time with the opening of the CMP; whereas, smaller, fairly shallow waterbodies like San José Lagoon will experience significant reductions in residence time.

To estimate the spatial extent of benthic communities expected to benefit, with regard to the benthic index model, the water quality surveys conducted in the Hydrodynamic and Water Quality Modeling Effort (Atkins. 2011a) were examined in greater detail. A close examination of the water column profiles contained in that report shows that salinity stratification and bottom water hypoxia/anoxia occurs at depths greater than about 4 feet. Waters shallower than 4 feet do not show evidence of salinity stratification. There are a number of deep dredge pits in the San José Lagoon, mostly in the southeastern portion of the lagoon. The deep waters of these dredge pits grade down to depths in excess of 20 feet from a more typical depth within the lagoon of approximately 6 feet. It was thus concluded that waters shallower than 4 feet would not likely benefit from enhanced tidal circulation, as they are too shallow to exhibit hypoxia/anoxia brought about by salinity stratification. Those bottom areas associated with deep dredge pits which will likely continue to be problematic in terms of hypoxia and anoxia.

Those portions of San José Lagoon that are between 4 and 6 feet in depth represent the portions of the lagoon that are anticipated to have improved benthic index scores upon restoration of the historical tidal connection between San Juan Bay and San José Lagoon. The spatial extent of the bay bottom to benefit in this manner is quantified at 702 acres.

The performance of the Benthic Index Model is based on achieving a Benthic Index value of 3.0, which would be approximately the maximum predicted value for the Benthic Index in San José Lagoon after restoring the CMP to its original width and depth of an estimated 200 feet by 10 feet. The Habitat Unit score is based upon the project performance and the maximum spatial extent of the area of San José Lagoon that would benefit from the opening of the CMP (702 acres). The net AAHUs (294.5 Habitat Units) for the Benthic Index Model is based upon the recovery of the area in San José Lagoon to the predicted, modeled Benthic Index HUs (663.8) starting from no action (363.0 Habitat Units) with the expected time of recovery of 3 years (linearly from the existing condition to the predicted, modeled score) and the project period of 50.

3.3 MANGROVE HABITAT MODEL

The Sport Fisheries Study (Atkins, 2011b) includes an assessment of the red mangrove prop root community within the CMP and within zones in designated distances away from the CMP. It was found that the numbers and diversity of the attached (e.g., mussels and oysters) and mobile (e.g., crabs) organisms found on the roots increased from the CMP and western San José Lagoon out to La Torrecilla Lagoon, thus providing an indicator of water quality improvement that would likely respond to the improvements provided by the opening of the CMP. Through this preliminary study, a significant relationship was found between the number of crabs found on mangrove prop roots and distance from the CMP. This relationship uses the connectivity of habitat described above for fish habitat and may be expanded to further species individuals and groups or overall density and diversity of organisms with further data collection.

The net HUs would be those HUs (803.8 HUs for the 75-foot Alternative; 798.6 HUs for the 100-foot Alternative with weir; and 793.2 HUs for the 125-foot Alternative with weir) gained with each project alternative above the no action alternative. The net AAHUs for the Mangrove Habitat Model (787.7 for the 75-foot Alternative; 782.7 for the 100-foot Alternative with weir; and 777.4 for the 125-foot Alternative with weir) is based upon the recovery time of 3 years (linearly from the existing condition to the predicted, modeled score) and a project period of 50 years.

Table 3
Average Annual Habitat Unit Lift for the project alternatives

Project Condition	Residence Time (days)	Benthic Index[1]	Benthic Index Project Perfor-mance	Benthic Index Habitat Units (HU)[2]	Benthic Index Net HU	Net Benthic Index Net Average Annual HU[3]	Fish Habitat Model Net HU[4]	Fish Habitat Model Net Average Annual HU[3]	Mangrove Habitat Model Net HU[4]	Mangrove Habitat Model Net Average Annual HU[3]	Total Net Habitat Units	Total Net Average Annual HU[5]
No action	16.9	1.55	51.70%	362.95	0	0	0	0	0	0	0	0
75-ft-wide Alternative	3.9	2.84	94.56%	663.81	300.86	294.54	5,154.01	5,050.93	803.77	787.69	6,258.64	6,133.16
100-ft-wide Alternative with weir	3.9	2.84	94.56%	663.81	300.86	294.54	5,159.16	5,055.98	798.63	782.66	6,258.65	6,133.17
125-ft-wide Alternative with weir	3.9	2.84	94.56%	663.81	300.86	294.54	5,164.56	5,061.27	793.23	777.37	6,258.65	6,133.17

[1] Based upon a maximum Benthic Index Score of 3.0 (see text for further explanation).

[2] Based upon an expected area to benefit = those regions between -4 and -6 feet in water depth within San José Lagoon (= 702 acres maximum).

[3] Average annual habitat unit lift from existing condition based upon a 3-year recovery time after project construction.

[4] See text for explanation.

[5] Combined Benthic Index Average Annual HU lift, Fish Habitat Model Average Annual HU lift and Mangrove Habitat Model HU lift based upon a 3-year recovery time after project construction [Columns F + H + J = K].

3.4 PROJECT PLAN ALTERNATIVE SELECTION

Pursuant to the calculation of habitat units, planning level cost estimates were developed for the Final Array. A cost effective analysis was conducted to determine which plans reasonably maximize ecosystem restoration benefits compared to costs. A cost effectiveness and incremental cost analysis (CE/ICA) was conducted based on a project life of 50 years and a Federal Discount Rate of 3.5 percent and a base year of 2019. Each alternative was considered to be independent and not combinable with the other alternative. Due to weir restrictions to prevent erosion at bridges and other structures for all three action alternatives, average annual habitat units (AAHUs) would be nearly identical among alternatives, totaling 6,133 AAHUs per alternative (see Table 3). As a result, Alternative 2, with a slightly less average annual equivalent cost when compared to Alternatives 1 and 3 was determined to be cost effective and best buy.

For ecosystem restoration projects, a plan that reasonably maximizes ecosystem restoration benefits compared to costs, consistent with the Federal objective, shall be selected and designated as the NER Plan. The NER plan must be shown to be cost effective and justified to achieve the desired level of output. Alternative Plan 2, the 100-x-10-foot channel, was selected as the NER plan as it reasonably maximizes the amount of environmental restoration compared to costs. This alternative is an economically viable solution to the problems identified for the proposed project and would produce significant and meaningful improvements to the natural environment of the SJBE.

Alternative 2 is the NER plan and has been selected as the TSP for the CMP-ERP. Alternative 2 consists of a 100-foot-wide by 10-foot-deep natural bottom channel; the elongated weir described above; dredging approximately 762,000 cy of mixed materials along 2.2 miles of the eastern CMP; and construction of a vertical concrete-capped steel sheet pile with hydraulic connections with the surrounding lands; and restoration of 25.57 acres of open water and 34.48 acres of wetland, representing a net increase of approximately 18.17 acres of open water and 1.02 acres of mangroves. This plan would meet all three of the project objectives and would not violate any project constraints. The TSP is both cost effective and a best buy, and has been demonstrated to be acceptable to state and local agencies as well as the public. The plan is also compatible with all applicable laws and policies.

Fish habitat within the SJBE would be restored with populations more resilient to change through increased genetic diversity. Commercial, recreational, and subsistence fishing would be improved as populations of native fish recover from currently degraded environmental conditions. The restoration of mangrove habitat will serve to provide increased habitat for juvenile fish, while increasing populations of native crabs and other invertebrates. Benthic habitat within the San José and Los Corozos Lagoons would be restored, with corresponding improvements to species such as wading birds that utilize the area for foraging grounds.

3.5 ADAPTIVE MANAGEMENT PROCESS

August 2009 guidance from USACE headquarters, implementing Section 2039 of WRDA 2007, requires that ecosystem restoration projects include plans for monitoring success and adaptively managing ecosystem restoration projects. The aspects of the guidance pertinent to the CMP-ERP are summarized in the following.

- The Adaptive Management Plan (AMP) should be appropriately scoped to the project scale and monitoring efforts.
- AMPs should discuss the uncertainty of achieving desired outputs.
- Monitoring should be tied to key parameters, desired outcomes and management decisions.
- The nature and costs of monitoring and potential adaptive management adjustments should be explicitly described in the plan.

The basic stages of the adaptive management process are planning, implementation, and monitoring. The more detailed steps are illustrated in Figure 4 and include:

1. Planning a program or project, including the development of an AMP;
2. Designing the corresponding project;
3. Building the project (construction/implementation);
4. Operating and maintaining the project;
5. Monitoring selected parameters to measure project performance; and
6. Assessing the results of monitoring, which will lead to decisions to:
7. Continuing project monitoring with no adjustment; or
8. Adjusting the project if goals and objectives are not being achieved; or
9. Determining whether the project has successfully produced the desired outcomes and is complete.

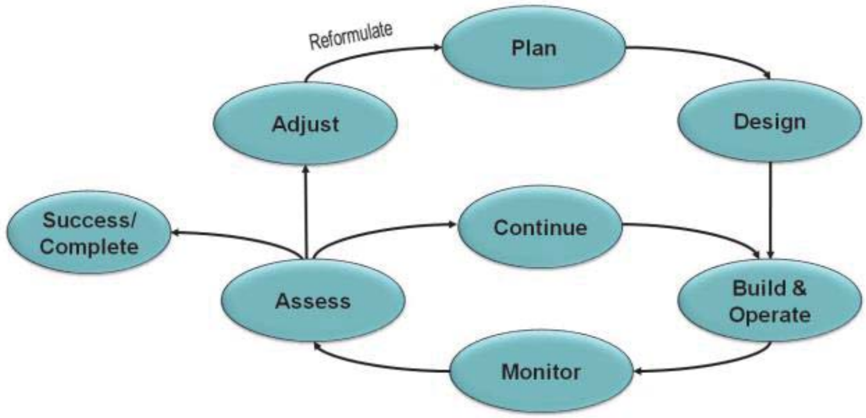

Figure 4. Steps in adaptive management (taken from Fischenich, et al. 2012)

According to Guidance for Section 2039 of WRDA 07 (USACE, 2009), "Monitoring includes the systemic collection and analysis of data that provides information useful for assessing project performance, determining whether ecological success has been achieved, or whether adaptive management may be needed to attain project benefits."

Mangrove restoration success and water flow through the Eastern CMP are the two major uncertainties that would be addressed by several actions proposed as part of the AM plan. The AMP components selected for monitoring and assessment target these uncertainties.

This AMP is currently in the planning stage of development. The next stages (design and implementation) will include further refinement and implementation of the AMP. Periodic assessments are performed using monitoring data, which would be reported to the USACE and the Caño Martín Peña Ecosystem Restoration Adaptive Management Planning Team (ERAMPT). The ERAMPT would be made up of the representatives from member agencies and entities of the ENLACE Technical Advisory Committee. This team would review the assessment reports and make recommendations to ENLACE (non-federal sponsor) and the USACE for adaptive management actions.

4.0 ADAPTIVE MANAGEMENT PROGRAM COMPONENTS

4.1 EXPECTED LOCALIZED BENEFITS

Mangrove area restoration: The TSP includes the restoration of 34.48 acres of mangrove forested wetland or habitat fringing the Eastern CMP channel would be the expected localized benefits resulting from the CMP-ERP. Mangrove forest restoration would be considered successful if 85 percent or more of all red mangrove propagules are able to survive and develop within 5 years after planting. If seedling survival falls below 85 percent, adaptive management measures would be triggered, assuming that under foreseeable worst case circumstances, no less than 70 percent of all planted propagules would survive.

Two adaptive management actions have been proposed to restore propagule or tree numbers in order to reach an amount equal to 85 percent of that originally planted. These would be implemented after first assessing and identifying those factors (natural or man-made) responsible for propagule mortality. If seedling mortality is determined to have been caused by natural conditions (e.g. propagule unviability), new propagules would be planted to replace those lost.

If the topographic relief of the planting beds is found to be unsuitable to allow periodic tidal flow and soil saturation, two actions would be considered in order to select the one that is most effective and efficient in improving the area's hydrologic regime. These include the following.

- The area of the inlets (windows) in the sheet pile walls could be increased by 50 percent. The proposal would require cutting 252 15"x72" windows into the upper most panels of the sheet pile.

- Minor grading of the planting bed could be performed. This would be done either by raising or lowering the planting bed by 12 inches. Raising the planting bed would require the importation of suitable fill material, spreading and replanting the mangroves. The imported fill would be placed utilizing a long-reach excavator placed on adjacent uplands and hand spreading into the mangrove beds. Lowering the planting bed would require stripping and disposing topsoil and replanting with new mangroves. It is anticipated that the excavated material would be removed with a small dozer and the material spread along the embankments. Under a worst case scenario, it is assumed that the area that could require minor grading would not exceed 10 percent (3.5 acres) of the total planting bed area. It is estimated that an approximate volume of 4,078 cubic yards would be handled, respectively, under any of the two grading works proposed.

Replacement of those propagules lost would then be conducted after new "windows" and or grading works have been completed.

4.2 EXPECTED SYSTEM WIDE BENEFITS

Physical, water quality and habitat attributes: The CMP-ERP is anticipated to restore and improve tidal flow between the eastern and western portions of the SJBE, which is considered one of the major stressors, i.e. altered hydrology, responsible for water and habitat quality in the project and study areas. The dredging of the channel will increase bottom water velocity throughout the eastern CMP. Tidal flow will be initiated between San Juan Bay and San José Lagoon. This will lead to a reduction in water residence time at the San José Lagoon and variation in tidal flow in the areas of SJBE around the CMP.

The success of the project will be determined by initial physical changes in the system and eventual chemical and biological changes. The physical changes in the SJBE system, e.g. water velocity, tidal amplitude, should be measureable almost immediately after construction. As indicated in the background section, the hydrodynamic modeling indicates that the bottom channel velocity in the TSP within the eastern CMP will be approximately 4 ft/s and the weir at the western end of the CMP will reduce that to less than 2.5 ft/s. Essentially, the TSP is designed to move sediment through the newly constructed eastern CMP, preventing sedimentation from occurring faster than anticipated, and prevent scour in the existing western CMP and around the existing bridges. Hydrodynamic modeling also indicates that the tidal amplitude in San José Lagoon will increase from a change of approximately 10 cm to 40 cm with the opening of the CMP. Using these measurements, the changes in residence time can be calculated showing the decrease from about 17 days to between 3 and 4 days. These performance metrics are very measureable and can be compared to the anticipated results of the hydrodynamic modeling. AM measures for tidal flow, bottom channel velocities and residence time would be triggered if (1) the tidal amplitude is 20 percent less than the anticipated modeled increase; (2) bottom velocity in the Eastern CMP are less than 3 ft/s making them conducive to its sedimentation; and (3) the bottom velocity in the western CMP is greater 3 ft/s resulting in scouring of the channel.

These physical changes would result in the improvement of water quality in San José Lagoon. It is anticipated that the opening of the CMP will result in the elimination of the salinity stratification occurring at water depths greater -4 ft in the shallow waters of San José Lagoon. The dredged pits in San José Lagoon will remain stratified below the bottom depth of the lagoon. This would mean that we would anticipate the bottom water quality values (i.e., temperature, salinity, dissolved oxygen, pH, and turbidity) to be equivalent to the surface water quality values, i.e. equivalence throughout the water column profile. AM measures that will considered if the anticipated results do not occur are the same as those AM measures for the anticipated physical changes.

Several AM measures will be considered and implemented if these physical changes do not occur as the models predicted. A one-time early dredging would be performed to remove sediment that has accumulated in the eastern end of the CMP at its confluence with the Juan Méndez Creek prior to its scheduled maintenance 5-year cycle dredging. This one-time dredging work would be conducted to provide a sump to store additional sedimentation as an adaptive management measure, and thus, to restore tidal flow conditions in the channel and in the San José Lagoon to those conditions anticipated immediately after project construction. It would also serve to restore water residence time in the lagoon and other physical changes anticipated post construction. The total volume of material that is expected to be removed under a worst case scenario would be that equivalent to the annual estimated accumulation of 35,000 cubic yards (cy) times 2.5, or 87,500 cy. This management action would also help to offset any shortcomings related to salinity stratification that were not expected from the CMP-ERP.

Boulders, rip rap, and/or other appropriate concrete structure would be placed at those sites that may scour in the Eastern CMP if flow velocities are stronger than expected. Scour is most likely to occur, if at all, in any of the outside bends of the channel (6 bends in total) and limited to an area from the face of the sheet pile wall to approximately 30 feet into the channel. A layer of riprap, 30 feet wide with an average stone size of 3 feet (spherical) would be placed in any of the bends affected; and monitored to determine if the scour has been abated. A total volume of 12,600 tons of riprap could be used if it is needed to intervene at all of the six channel's bends. The riprap would be placed from both sides of the channel by employing a long reach loader.

If this measure proves insufficient, additional boulders, rip rap and/or other appropriate concrete structure would be placed on either side of the weir's channel to constrict flow. A low wall of rip rap, 3.4 ft. high by 11 ft. wide by 40 ft. deep, could project into the channel from each side. This would effectively reduce the cross sectional area by 10 percent and slow the velocity in the channel accordingly. Rip-rap with an average size of 3 feet (spherical) with a combined weight of 17 tons would be required and placed with a long-reach loader.

The beneficial effects that the construction of the CMP would have on tidal flow, residence time and water quality are also going to improve overall ambient conditions for benthic habitat, mangrove prop-root communities and open water column habitat, leading to an increase in the diversity and abundance of associated organisms (e.g. macroinvertebrates and fish). The changes in these communities will take more time to realize than the physical and water quality changes. Monitoring measures will be in place and AM measures can be implanted; however, it is anticipated that the AM measures that may be implemented for the physical and water quality parameters would be sufficient to ensure that the anticipated organism changes will occur over time. Efforts to eliminate or reduce watershed based loadings from point and nonpoint sources of pollution would be encouraged as a mean to improve water quality, and overall habitat conditions in the event that adaptive actions to improve tidal flow and reduce water residence time prove to be insufficient to achieve expected targets or performance measures. These would be coordinated with the corresponding government agencies in charge of their implementation.

Table 4
Management Options Matrix for the CMP-ERP

Attribute/ Performance Metric	Target or Performance Measure (Timeframe)	Trigger/Threshold for Management Action	Management Action Option 1	Management Action Option 2	Management Action Option 3
Mangrove habitat	Increase in the mangrove forest canopy cover within the monitoring plots over the 34.48 acres of planted mangrove wetland area after two years of project construction.	A mortality exceeding 15% of planted mangrove trees	Assess if mortality is due to natural causes (e.g. herbivores) or improper hydro period.	Replace dead mangrove propagules in order to increase up to 85% the number of trees initially planted.	Improve hydroperiod conditions either by removing the uppermost panels of the sheet piles or by conducting minor topographic grading.
Tidal Amplitude in San José Lagoon	Increase in tidal flow resulting in an increased tidal amplitude in San José Lagoon (immediately after Construction Phase ends).	Significant (an average of 20% or more) decrease in anticipated tidal amplitude between San Juan Bay and the San José Lagoon.*	A one-time early dredging would be performed to remove sediment that has accumulated at the eastern end of the CMP.	N/A	N/A
CMP Bottom Velocity	Achieve existing bottom velocities to approximately 4.0 ft/s within the CMP and less than 2.5 ft/s at the western end of the CMP (immediately after Construction Phase ends).	Bottom velocities conducive to sedimentation within the eastern CMP (less than 3 ft/s).	A one-time early dredging would be performed to remove sediment that has accumulated at the eastern end of the CMP.	Adopt best management practices to reduce erosion and sedimentation within San José Lagoon and the CMP watershed.	N/A
		Bottom velocities conducive to scouring within the western CMP (greater than 3 ft/s).	Placement of boulders, rip rap, and/or appropriate concrete structure at areas being scoured.	Placement of rip-rap on either side of weir's channel to constrict flow.	N/A
Residence Time	Reduction in residence time from approximately 17 days to between 3 and 4 days (immediately after Construction Phase ends).	Residence time greater than 4 days.*	A one-time early dredging would be performed to remove sediment that has accumulated at the eastern end of the CMP.	N/A	N/A

Table 4, cont'd

Attribute/ Performance Metric	Target or Performance Measure (Timeframe)	Trigger/Threshold for Management Action	Management Action Option 1	Management Action Option 2	Management Action Option 3
Field Parameter: Dissolved Oxygen	The bottom dissolved oxygen values are not equal to the surface values in shallow waters of San José Lagoon, i.e. an equivalent profile, not in the dredged pits (1-2 years).	Concentration of dissolved oxygen does not increase within timeframe or stays as observed during pre-construction monitoring	A one-time early dredging would be performed to remove sediment that has accumulated at the eastern end of the CMP leading to improvements in water flow and water quality.	Elimination/reduction of raw sewage and polluted storm water discharges, coordination with related agencies.	N/A
Field Parameter: Salinity	The bottom salinity values are not equal to the surface values in shallow waters of San José Lagoon, i.e. an equivalent profile, not in the dredged pits (1-2 years). (1-2 years).	Salinity stratification is found in areas shallower than 4 feet deep and/or is spatially more frequent.	A one-time early dredging would be performed to remove sediment that has accumulated at the eastern end of the CMP leading to improvements in water flow and water quality.	N/A	N/A
Sedimentation	No variation in channel depth	20% reduction in cross-sectional area in channel.	A one-time early dredging would be performed to remove sediment that has accumulated at the eastern end of the CMP leading to improvements in water flow.	Adopt best management practices to reduce erosion and sedimentation within San José Lagoon and the CMP watershed.	N/A
Benthic Habitats: Bottom/Sediment Communities	Achieve a benthic index score of 3.0 in the CMP and the San José Lagoon (2-3 years).	The lack of improvement in the benthic index score from pre-construction values.**	A one-time early dredging would be performed to remove sediment that has accumulated at the eastern end of the CMP leading to improvements in water flow and water quality.	Elimination/reduction of raw sewage and polluted storm water discharges, coordination with related agencies.	N/A

Table 4, cont'd

Attribute/ Performance Metric	Target or Performance Measure (Timeframe)	Trigger/Threshold for Management Action	Management Action Option 1	Management Action Option 2	Management Action Option 3
Benthic Habitats: Red Mangrove (*Rhizophora mangle*) Prop Root Community	The colonization and diversity of fish, crustaceans, snails, and encrusting species would be within 10% in numbers and diversity across the zones (2-3 years).	A greater than 10% reduction of existing functional values (cover, species diversity, etc.)/habitat units. Increase in pollution-tolerant species (or reduction in pollution-sensitive species).**	A one-time early dredging would be performed to remove sediment that has accumulated at the eastern end of the CMP leading to improvements in water flow and water quality.	Elimination/reduction of raw sewage and polluted storm water discharges, coordination with related agencies.	N/A
Open Water Column Habitat	Increase in fish populations and diversity, as well as other nekton groups with the numbers and kinds of fish nearly equal throughout SJBE (2-3 years).	Reduction of existing fish populations and diversity from pre-construction estimates. Increase in pollutant-tolerant species (or reduction in pollution-sensitive species).**	A one-time early dredging would be performed to remove sediment that has accumulated at the eastern end of the CMP leading to improvements in water flow and water quality.	Elimination/reduction of raw sewage and polluted storm water discharges, coordination with related agencies.	N/A

*Based on Atkins (2011a).

** Based on Atkins (2015).

5.0 IMPLEMENTATION

The components of the AM plan are summarized in Table 4. Adaptive management provides a structured course for lowering risk, increasing certainty and informing decisions. It is successful only if its actions/strategies are implemented during the entire project-life cycle: from first steps of planning through all aspects of monitoring, engineering, design, construction, operations, and maintenance components. In addition, mechanisms must be in place to collect, manage, analyze, synthesize, coordinate, and integrate new information into management decisions. Figure 5 shows the implementation phase of adaptive management (Fischenich, et al. 2012).

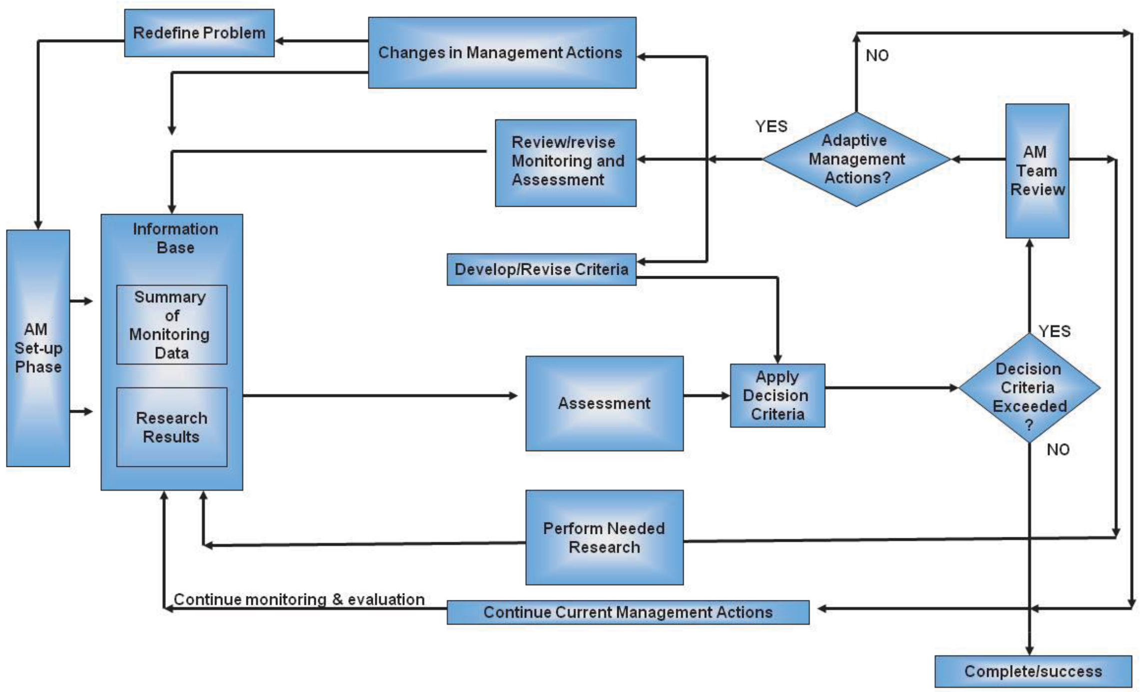

Figure 5. Implementation phase of adaptive management (Fischenich, et al. 2012)

The CMP-ERP's AM plan must be recognized as a "living" document that would be improved and fine-tuned through the incorporation of new data and information that as it becomes available as part of proposed monitoring activities. In particular, as each project component is implemented, specific adaptive management strategies and monitoring should be reviewed and adjusted as necessary. Table 5 shows the implementation schedule for the different AMP phases.

Table 5
Adaptive Management and Monitoring Plan Implementation Schedule

Milestone	Schedule
Draft Adaptive Management Plan	During FR/EIS preparation
Finalize Adaptive Management Plan	During PED
Initiate Implementation of Adaptive Management and Monitoring Plan	At the beginning of project construction
Complete Adaptive Management and Monitoring Plan Implementation	5 years after project construction has been completed

6.0 COSTS

Table 6
Management Options Estimated Costs

Management Actions	Costs
One-time early dredging	$1,350,000
Placement of boulders, rip rap, and/or concrete structures in scoured areas	$750,000
Placement of rip-rap on either side of weir's channel to constrict flow	$1,005,890
Increase size of inlets within sheet piles	$52,500
Elevate mangrove planting bed relief	$175,000
Lower mangrove planting bed relief	$50,000
Replanting of mangrove planting bed	$42,000
Total	$3,425,390

Assumptions:

One-time early dredging would be performed as an adaptive management action. Subsequent dredging (annual dredging) is included in the O&M costs.

Mangrove re-planting would be carried out to replace dead mangroves propagules in order to increase up to 85% the number of trees initially planted.

Actions related to the implementation of best management practices to reduce erosion and sedimentation within San José Lagoon and the CMP watershed and eliminating/reducing raw sewage and polluted storm water discharges in coordination with related agencies would be funded by existing or future government watershed management programs.

Grading of mangrove planting beds could require either elevating or lowering its topography, or combining a limited scope of both actions. As such, total costs would be lower than those shown under any of these two cases for the total expenses related to the implementation of proposed management measures.

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Appendix F

Monitoring Plan

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DRAFT
MONITORING PLAN
CAÑO MARTÍN PEÑA
ECOSYSTEM RESTORATION PROJECT
SAN JUAN, PUERTO RICO

Prepared for:

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September 2015

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Executive Summary

The Caño Martín Peña Ecosystem Restoration Project (CMP-ERP) is an urban ecosystem restoration project to restore the Caño Martín Peña (CMP) and surrounding areas of the San Juan Bay Estuary (SJBE). Restoration of the CMP would reestablish the tidal connection between the San José Lagoon and the San Juan Bay, which would improve dissolved oxygen levels and reduce salinity stratification, increase biodiversity by restoring fish habitat and benthic conditions, and improve the functional value of mangrove habitat within the estuary.

The CMP is a 3.75-mile-long tidal channel in metropolitan San Juan, Puerto Rico. It is an integral part of the SJBE, the only tropical estuary included in the U.S. Environmental Protection Agency (USEPA) National Estuary Program (NEP). The SJBE's watershed covers 97 square miles. It is heavily urbanized, with a population density of over 5,000 people per square mile. The SJBE includes over 33 percent of the mangrove forests on the island with over 124 species of fish and 160 species of birds. The eastern half of the CMP, historically between 200 and 400 feet wide and navigable, currently ranges in depth from 3.94 feet to 0 foot towards San José Lagoon. Due to years of encroachment and fill of the mangrove swamps along the CMP, the channel no longer serves as a functional connection between San Juan Bay and San José Lagoon. Sedimentation rates within the CMP are nearly two orders of magnitude higher than in other parts of the SJBE. Open waters in areas closer to the San José Lagoon have been lost, as the area has started transitioning into a wetland. A combination of sediment and solid waste is found in the CMP, of which the solid waste accounts for approximately 10 percent of its composition. In some sites, the solid waste extends to depths 10 feet below the sediment surface.

The conditions within the eastern side of the CMP Project Channel have led to degradation within the entire estuary. Connectivity of the ecosystem has been severed and the biodiversity within the lagoons has been compromised, as more individuals of a reduced number of species are found when compared with other lagoons throughout the SJBE. The decreases in biodiversity in turn have reduced the ability of fish and invertebrates to respond to natural changes, disease and other factors, resulting in a depletion of fish stock, biodiversity, and losses of economic and recreational resources.

The current condition of the CMP has resulted in the degradation of the environmental condition within areas of SJBE around the CMP. Water residence time in the San José Lagoon is approximately 17 days. The lack of tidal flushing causes strong salinity stratification and in turn leads to low oxygen or no oxygen levels in the 702 acres of lagoons with depth below 4 to 6 feet, severely affecting benthic habitats. Mangrove habitat, extremely important for native aquatic invertebrates, has been severely impacted, reducing habitat where important commercial fish species spend their juvenile life stages.

A conceptual ecological model was developed for the Caño Martín Peña. This model was used to develop hypotheses about relationships within the system and to assist in understanding changes brought about by planned project elements. The planning objectives for the Caño Martín Peña Feasibility Study include:

1. Improve fish habitat in the SJBE system by increasing connectivity and tidal access to estuarine areas;
2. Restore benthic habitat in San José Lagoon by increasing dissolved oxygen in bottom waters and improving the salinity regime to levels that support native estuarine benthic species; and
3. Increase the distribution and population density and diversity of native fish and aquatic invertebrates in the mangrove community by improving hydrologic conditions in the SJBE system.

After many considerations, it was determined that dredging the CMP could provide a way of reconnecting eastern and western segments of the SJBE system, as they were several decades ago. The plan formulation process built directly upon previous planning and design efforts. Structural management measures for the channel dredging, erosion control, dredged material disposal, mangrove planting and construction, recreation, as well as non-structural measures were identified and screened. An initial array of alternatives consisting of rectangular channel cross sections ranging between 75- and 200-foot widths and either 10- or 15-foot depths was developed and evaluated. Screening criteria such as completeness, acceptability, cost effectiveness, and secondary effects on adjacent communities, were then used to eliminate unfavorable plans and develop a final array of alternatives. The final array of alternatives consisted of four alternative plans ranging from no action to a 125-foot-wide by 10-foot-deep natural bottom channel. All constructed alternatives include an elongated weir under the Martín Peña, Tren Urbano, and Luis Muñoz Rivera bridges involving a 115-foot-wide by 6.5-foot-deep channel with riprap on side slopes and articulated concrete mats at the channel bottom to reduce water velocity and erosion, and to control scour.

Performance measures for Benthic Habitat, Fish Habitat, and Mangrove Habitat were developed to measure alternative output, and ecosystem restoration measure benefits were calculated for each alternative. A cost effectiveness and incremental cost analysis (CE/ICA) was conducted based on a project life of 50 years and a Federal Discount Rate of 3.5 percent and a base year of 2019. Each alternative was considered to be independent and not combinable with the other alternative. Due to weir restrictions to prevent erosion at bridges and other structures for all three action alternatives, average annual habitat units (AAHUs) would be nearly identical among alternatives, totaling 6,133 AAHUs per alternative. As a result, Alternative 2, with a slightly less average annual equivalent cost when compared to Alternatives 1 and 3 was determined to be cost effective and the best buy.

Alternative 2, the Tentatively Selected Plan (TSP) consists of a 100-foot-wide by 10-foot-deep natural bottom channel; the elongated weir described above; dredging approximately 762,000 cy of mixed materials along 2.2 miles of the eastern CMP; and construction of a vertical concrete-capped steel sheet pile with hydraulic connections with the surrounding lands; and restoration of 25.57 acres of open water and 34.48 acres of wetland. This represents a net increase of approximately 18.17 acres of open water and 1.02 acres of mangroves.

The TSP is the National Ecosystem Restoration Plan (NER) plan and provides a complete solution to the problems identified for the study. It is also the most effective plan and meets the project objectives. The NER Plan is acceptable and has been determined to be in the national and public interest and can be constructed while protecting the human environment from unacceptable impacts.

This monitoring plan (MP) includes those actions and measures associated to the Adaptive Management (AM) Plan that has been prepared for the Project. These actions and measures are listed below:

- During project planning: Provide new knowledge to better define anticipated ecological responses.
- Before project implementation: Tidal/flow velocity, water quality, benthic and mangrove roots community characterization studies, fish and bird censuses (including indicator species of ecosystem wellness) to be performed (or reviewed if they exist) at established stations to provide baseline information.
- During project construction: Monitoring and assessment of tidal/flow velocity, water quality, benthic and mangrove roots community. Management measures would be implemented to avoid or reduce temporary impacts.
- After its implementation: Monitoring and assessment of tidal flow, water quality, benthic and mangrove roots communities, and fish (including indicator species of ecosystem wellness). Management measures would be implemented, or existing ones would be adapted (adaptive management), in order to achieve goals and objectives. Adaptive management measures currently proposed, and that would be implemented, if needed, include planting mangrove trees along the new channel to promote wetland habitat restoration. In addition, conduct maintenance dredging at both of the CMP ends to address any sedimentation and its effects on water flow.

This MP address the requirements of the U.S. Army Corps of Engineers (USACE) Implementation Guidance for Section 2039—Monitoring Ecosystem Restoration, Memorandum (CECW-PB) dated 31 August 2009 (Guidance for Section 2039 of Water Resources Development Act 07).

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Acronyms and Abbreviations

AAHU	Average Annual Habitat Units
ACM	Articulated Concrete Mat
BI	Benthic Index
BMPs	Best Management Practices
CCMP	Comprehensive Conservation & Management Plan for the San Juan Bay Estuary
CDRC	Ciudad Deportiva Roberto Clemente
CE/ICA	Cost Effectiveness/Incremental Cost Analysis
CEM	Conceptual Ecological Model
CH3D-WES	Curvilinear Hydrodynamics in 3-Dimensions-Waterways Experiment Station model
CMP	Caño Martín Peña
CMP-ERP	Caño Martín Peña Ecosystem Restoration Project
cy	cubic yard
DO	dissolved oxygen
EC	Engineering Circular
ECO-PCX	USACE Ecosystem Restoration Planning Center of Expertise
EFH	Essential Fish Habitat
EIS	Environmental Impact Statement
ENLACE	Corporación del Proyecto ENLACE del Caño Martín Peña
ENLACE Project	Caño Martín Peña ENLACE Project
ER	Engineering Regulation
ERDC	USACE Engineer Research and Development Center
ERP	Ecosystem Restoration Project
FR	Feasibility Report
FRM	Flood Risk Management
ft^2	square feet
ft/s	feet per second
ft/y	feet per year
g	grams
HU	Habitat Unit
GIS	Geographic Information System
mg/Kg	milligrams per kilogram
mg/L	milligrams per liter
mi^2	square mile
mL	milliliter

MLLW	mean low low water
mm/yr	millimeters per year
mph	miles per hour
MP	Monitoring Plan
MTZ-CMP	Public Domain lands within the Caño Martín Peña Maritime Terrestrial Zone
NED	National Economic Development
NEP	USEPA's National Estuary Program
NEPA	National Environmental Policy Act
NER	National Ecosystem Restoration
NMFS	National Marine Fisheries Service
NOAA	National Oceanic and Atmospheric Administration
O&M	Operation and Maintenance
ODMDS	San Juan Bay Ocean Dredged Material Disposal Site
P&G	U.S. Water Resources Council Principles and Guidelines
PED	Preconstruction, Engineering and Design
PMP	Project Management Plan
PPA	Project Partnership Agreement
ppm	parts per million
PR	Commonwealth of Puerto Rico
PREQB	Puerto Rico Environmental Quality Board
PRHTA	Puerto Rico Highway and Transportation Authority
Project Channel	2.2 miles of the Eastern CMP associated with the CMP-ERP
PRWQSR	Puerto Rico Water Quality Standards Regulation
SJBE	San Juan Bay Estuary
SJBEP	San Juan Bay Estuary Program
SJHP	San Juan Bay Harbor Project
T&E	Threatened and Endangered Species
TSP	Tentatively Selected Plan
µg/g	micrograms per gram
USACE	United States Army Corp of Engineers
USEPA	United States Environmental Protection Agency
USFWS	United States Fish and Wildlife Service
WQC	Water Quality Certification

1.0 BACKGROUND AND INTRODUCTION

The Caño Martín Peña (CMP) is a 3.75-mile-long tidal channel in metropolitan San Juan, Puerto Rico. It is part of the San Juan Bay Estuary (SJBE), the only tropical estuary included in the U.S. Environmental Protection Agency (USEPA) National Estuary Program (NEP). The SJBE and its associated marine ecosystems are considered the "Study Area," because the proposed CMP-ERP is expected to have direct, indirect, and cumulative beneficial effects on this whole region (Figure 1). The "Project Area," which mostly lays out the construction footprint, has been defined as the Project Channel, where dredging would take place, and the adjacent delimitation of the public domain lands within the Public Domain lands within the Caño Martín Peña Maritime Terrestrial Zone (MTZ-CMP) where relocations are scheduled to occur. Also included in the Project Area is the 6-acre dredged material staging area within the 35-acre Ciudad Deportiva Roberto Clemente (CDRC) site, the boating routes from the eastern limit of the CMP to the CDRC and the nearby San José Lagoon pits, and the five pits in San José Lagoon (Figure 2).

Figure 1. The San Juan Bay Estuary Study Area

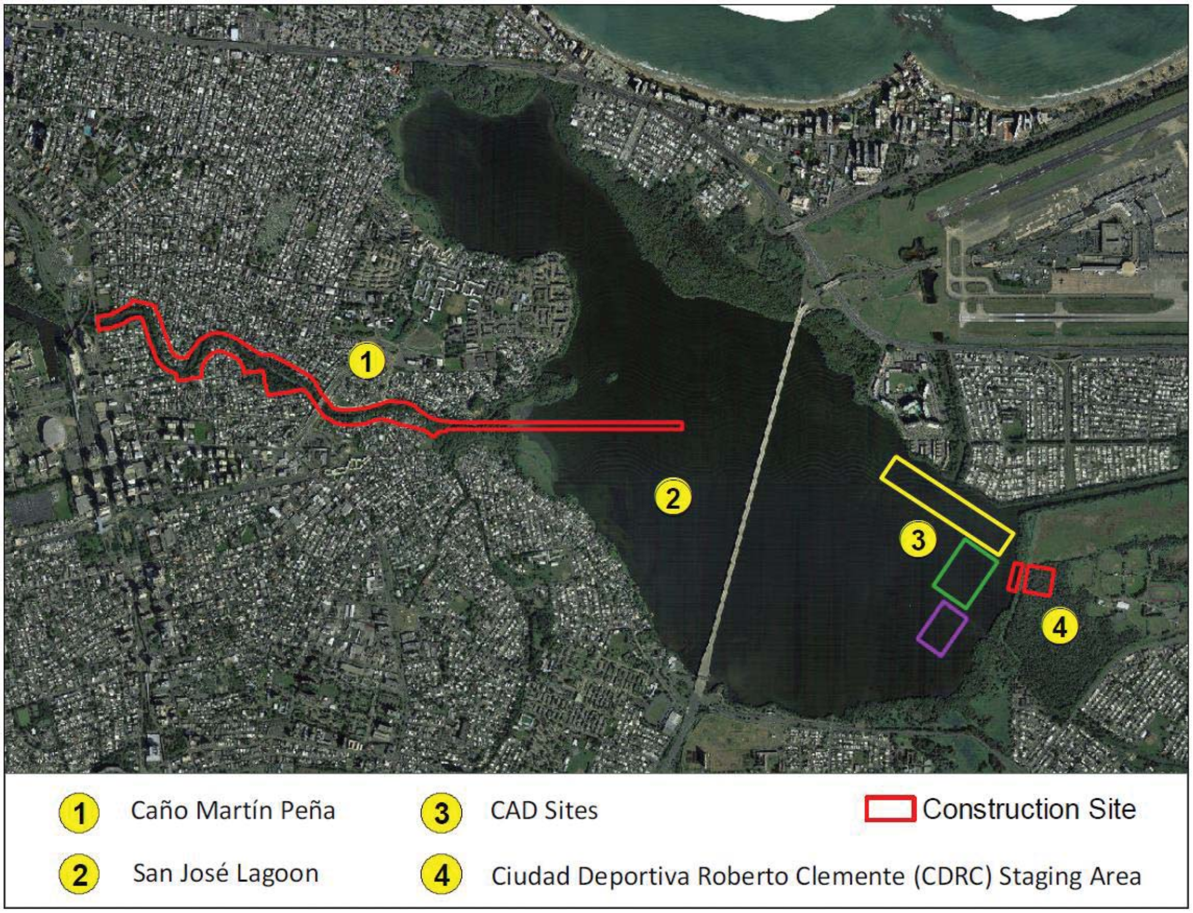

Figure 2. The Caño Martín Peña Ecosystem Restoration Project Area

The SJBE, along the northern coast of Puerto Rico, is the largest system of its kind on the island. Located within the largest urbanized and most densely populated region in Puerto Rico, the SJBE's watershed includes the municipalities of Toa Baja, Cataño, Bayamón, San Juan, Guaynabo, Carolina, Loíza, and Trujillo Alto. The system is characterized by a network of lagoons, channels, man-made canals, permanently and seasonally flooded woody and herbaceous wetlands, and the San Juan Bay, which is home to Puerto Rico's busiest port. In spite of its urbanized setting, the SJBE includes over 33% of the mangrove forests on the island with over 124 species of fish and 160 species of birds.

The SJBE and its associated marine ecosystems are considered the "Study Area," since the proposed Caño Martín Peña Ecosystem Restoration Project (CMP-ERP) is expected to have direct, indirect, and cumulative beneficial effects on this whole region (Figure 1). The SJBE includes the San Juan Bay, the Condado Lagoon, the San José Lagoon (including its northwestern section known as Los Corozos Lagoon), La Torrecilla Lagoon, and the Piñones Lagoon, the interconnecting Caño Martín Peña (CMP), San Antonio Channel, and the Suárez Canal, as well as the Piñones mangrove forest and Las Chucharillas Swamp. Fresh water flows into the system from the creeks and rivers flowing mostly north from its watershed, covering approximately 97 square miles (Figure 1). These include the Río Piedras (Puerto Nuevo) River, Juan Méndez Creek, San Antón Creek, Blasina Creek, and the Malaria

Canal. During medium to extreme flood events, fresh water is also received from the Río Grande de Loíza River, located east of the Piñones State Forest. Several flood control pump stations, as well as storm water sewers, discharge fresh water into the system. Ocean water enters the SJBE through three openings or outlets: Boca del Morro at the San Juan Bay, El Boquerón at the Condado Lagoon, and Boca de Cangrejos at La Torrecilla Lagoon. The Puerto Nuevo River, whose drainage area is of about 25 square miles, flows into the western end of the CMP, close to the San Juan Bay. The western half of the CMP was dredged during the 1980s as part of a waterway transportation project. This portion of the CMP is navigable and has a channel width and depth of 200 feet and 10 feet, respectively. The total drainage area of the CMP is about 4 square miles (2,500 acres).

The water quality of the SJBE has been significantly altered from its natural state not only by land-use activities, but also by the modification of its hydraulic properties through the dredging and filling of many of its water bodies. Water quality within both the Caño Martín Peña and San José Lagoon has been previously documented as being degraded [Kennedy et al. 1996, Webb and Gomez-Gomez 1998, SJBEP 2000, Puerto Rico Environmental Quality Board (PREQB) 2008] and data suggest that the Caño Martín Peña is a source of turbidity and bacteria to the waters of San José Lagoon; however, the Caño Martín Peña does not appear to be a source of nutrients for the San José Lagoon (Atkins 2011a).

Impacts to the water quality of the Caño Martín Peña and San José Lagoon include prior ongoing inflows from combined storm sewer overflows, inflows from areas lacking sanitary sewers, untreated industrial discharges, surface runoff and subsurface seepage over areas with household waste, and from direct dumping of household waste. While water quality concerns remain within both the Caño Martín Peña and San José Lagoon, there is ample evidence of substantial improvements in water quality within San José Lagoon in recent decades, due mostly to improvements in the collection and treatment of wastewater loads in the San Juan Bay region (Webb and Gomez-Gomez 1996 and 1998; Webb et al. 1998). In western San José Lagoon, in the part of the Lagoon closest to the Caño Martín Peña, phosphorus concentrations have decreased more than 50 percent since the late 1970s to early 1980s, and water clarity (as measured by Secchi disk depth) has doubled since the early 1980s (Atkins 2011a).

The recent trends of improved water quality in much of the San Juan Bay Estuary have been achieved only after the investment of substantial time and resources. Since the late 1980s alone, the USEPA has awarded in excess of $650 million to the Commonwealth of Puerto Rico via the Clean Water State Revolving Fund program (Caribbean Business Journal 2012). As a result of these and other coordinated actions, there is an obvious trend of improving water quality in the San José Lagoon, as outlined in the report "Technical Memorandum for Task 2.6 – Water and Sediment Quality Studies" (Atkins 2010b). Similar findings of improving water quality in the greater San Juan Bay estuary system have been previously reported by Webb and Gomez-Gomez (1996 and 1998) and by Webb et al. (1998). Webb and Gomez-Gomez (1998) concluded that "these records document the improved water quality that has resulted from implementing pollution control measures established in the 1970s."

The ongoing and reduced ecological integrity of the San José Lagoon, despite substantial reductions in pollutant loads, appears to be mostly due to salinity stratification and the development of hypoxic conditions (low levels of dissolved oxygen) in waters deeper than 4 to 6 feet (Atkins 2011b). Model results lead to the conclusion that restoration of the tidal exchange capacity of the Caño Martín Peña would increase salinity in the surface waters of the San José Lagoon, which would decrease salinity stratification and thus reduce the spatial extent and severity of hypoxic conditions (Atkins 2011b). Although acceptable levels of dissolved oxygen exist in those portions of the San José Lagoon that are shallower than approximately 4 feet, hypoxic to anoxic conditions are encountered throughout approximately 700 acres of the Lagoon where the water depths are greater than 4 feet. One of the most severe water quality problem in the Caño Martín Peña is levels of dissolved oxygen. Also, Webb and Gomez-Gomez (1998) found ammonia concentrations up to 2.3 milligrams per liter (mg/L) (as nitrogen) and orthophosphate concentrations of 0.22 mg/L (as phosphorus) as well as anoxic conditions within the Caño Martín Peña water column. Also in the Caño Martín Peña, recent studies have documented from 2,000,000 to 6,000,000 fecal coliform bacteria colonies per 100 milliliters (ml) well above guidance criteria of 200 colonies per 100 ml (SJBEP 2012). Additionally, levels as high as 1,200,000 for Enterococci bacteria colonies per 100 ml, where the guidance criteria of 35 colonies per 100 ml (SJBEP 2012).

The existing high sedimentation rates, presence of contaminants within the sediments, low dissolved oxygen levels, and salinity stratification within the CMP and/or the San José lagoon do not provide a healthy ecosystem for benthic organisms (e.g., infauna, meiofauna, epifauna) or organisms relying upon the estuarine water column (e.g., fish and invertebrates; Kennedy et al. 1996, Otero 2002, SJBEP 2000, PREQB 2008). Benthic habitats in and around the Project Channel area are highly degraded due to the contaminant loads and reduced tidal flushing present, which result in limited light penetration, poor water quality, and anoxic, highly organic sediments.

Soft bottoms in these shallow areas, the mangrove roots that line the lagoons, seawalls, rip-rap and other surfaces at these depths are covered with a thriving community dominated by mussels. Rivera (2005) estimated 66.7 acres of this mussel reef within the San José lagoon, which he hypothesized, is a "large source of food for the Lagoon" and provides a water filtering function "which must help maintain the water quality."

Species abundance and diversity (important indicators of healthy habitats) of the encrusting community of red mangrove prop roots is higher in the La Torrecilla Lagoon (closest to the Atlantic Ocean), becomes less diverse and less abundant within the San José Lagoon (farthest from the flushing source), and is non-existent or limited (severely limited flushing) within the CMP. This could be related to dissolved oxygen and salinity concentrations.

This macrofauna follows a general pattern of reduced diversity and abundance along a gradient from La Torrecilla Lagoon to Suárez Canal, to the San José Lagoon to the CMP. In general, sponges, crabs, worms and mussels become less abundant to absent along a gradient from the eastern end of Suárez Canal, along San José Lagoon and into the CMP.

In summary, the results of the benthic habitat survey in the shallow portions of San José Lagoon indicate that diverse and healthy biological communities are restricted to the shallowest (less than 4 feet) regions, where salinity stratification does not occur, and where sufficient levels of dissolved oxygen exist. These are the conditions that support a healthy benthic habitat, that type that would support sustenance and recreational fishery in the Lagoons; however, at the minimal dissolved oxygen conditions found in 702 acres of waters deeper than 4 feet in San José lagoon, the presence of hydrogen sulfide in the sediments is a strong indicator that the water layer above the sediments is also hydrogen sulfide laden. Therefore, these areas of the bottom of the lagoons cannot sustain a benthic habitat.

Some of the 124 species that have been documented in the SJBE system have been locally identified as important target species for both recreational and commercial fisheries. The important target species of common snook (*Centropomus undecimalis*) and tarpon (*Megalops atlanticus*) are caught within San José Lagoon itself (Yoshiura and Lilyestrom 1999). The commercially important offshore fishery for mutton snapper (*L. analis*) is dependent, in part, on the maintenance of a healthy inshore, lower-salinity mangrove habitat for post-larval and juvenile phases (Faunce et al. 2007). Out of the 124 species of fish documented within the SJBE system, 15 of these are also found within the 84 managed species included in the Caribbean Fishery Management Council's Fisheries Management Program (FMP) (Yoshiura and Lilyestrom 1999).

Due to the current clogging of the eastern CMP, there is essentially no tidal exchange between San Juan Bay and the San José Lagoon. As a result, fish within San Juan Bay cannot directly access the mangroves, seagrass meadows, and open water habitats of San José Lagoon, Los Corozos Lagoon, the Suárez Canal, La Torrecilla Lagoon, and Piñones Lagoon, just as fish within those waterbodies cannot directly access the habitats afforded by San Juan Bay.

There are still some mangrove wetlands, albeit of extremely low functional quality, along the CMP. If the CMP was dredged, much of these wetlands would be within the construction area and impacted by the project. In order to maintain a mangrove fringe of wetlands along the CMP for habitat, nutrient reduction, water quality, and other wetland functions, mangrove wetlands could be reestablished in areas along a dredged canal. This measure would provide immediate restoration within the project area, as the existing low quality mangrove areas would be removed along the CMP channel for construction purposes and replaced by high functioning mangrove wetlands. The north and south slopes of the channel above the sheet pile would be graded to receive tidal influence and then planted with appropriate mangrove species. Microtopography would be added to diversity habitat.

The CMP-ERP is an urban ecosystem restoration project to restore the Caño Martín Peña and surrounding areas of the SJBE. Restoration of the CMP would reestablish the tidal connection across the SJBE, substantially improving the water quality of the entire SJBE and promoting the establishment of more diverse and healthy fish and wildlife habitats (USACE 2004). This means helping to reduce water renewal time in the San José Lagoon and its salinity stratification, as well as to improve dissolved oxygen levels, fish and benthic habitat, and thus biodiversity, including the functional value of mangrove habitat within this system (Atkins 2015).

Several modeling efforts have been conducted to further assess the effectiveness of the proposed project on the hydrology and hydrodynamics of the SJBE, and its possible effects on fish and wildlife resources. In 2000, the USACE's Research and Development Center published the report titled Hydrodynamic and Water Quality Model Study of the San Juan Bay Estuary (SJBE). This study was performed for the SJBE Program (Bunch et al. 2000). The researchers used a three-dimensional, coupled, hydrodynamic and water quality model of the SJBE system that was calibrated using field observations in order to estimate the effectiveness of various alternatives to increase flushing and reduce loadings for improving water quality. Dredging the Caño Martín Peña (CMP) to 150 feet wide and 9 feet deep, in order to improve water flow along this water body was one of the scenarios modeled, showing improvements in the channel's water conveyance capacity and that of the San José Lagoon.

The CH3D-WES hydrodynamic model was used to quantify the improvement (decrease) in residence time in the San José Lagoon and improved connectivity between this water body and the San Juan Bay as a result of increasing the cross-sectional area and thus, the water flow capacity of the CMP within the Project Area. It was also used to predict ecological improvement for various parameters, such as dissolved oxygen and salinity. The output on residence time was combined with data from a recently developed Benthic Index (BI) for the SJBE (PBS&J 2009). The relationship between residence time and benthic community health in the San José Lagoon was found to be significant. It was determined, as a result, that restoring tidal flow through the CMP would improve the lagoon's circulation, helping to decrease water stratification and thus, hypoxic to anoxic conditions affecting its waters and associated submerged habitats (Atkins 2011a; 2011b; 2015; Bunch et al. 2000; PBS&J 2009).

Preliminary hydrologic modeling for different channel configurations indicated that if the channel dredging measure was implemented, erosion control features would be necessary to protect the CMP channel from scouring, and to protect existing bridges and shoreline stabilization structures in the western CMP such as sheet piles. Three erosion control features were formulated, evaluated, and retained for these purposes. These erosion control features are all dependent on dredging of the existing CMP channel. First, articulated concrete mats (ACMs) would be required to provide scour protection for any high velocity dredged channel configurations. The soils in the CMP Project Channel are predominantly hard silts and clays at a depth of 10 to 15 feet below the existing bottom, and these soils could be subject to scour at velocities greater than approximately 4.0 feet per second. Table 1 provides within-channel bottom velocities that could be produced by the different channel dimensions. Those indicated in red would require ACM to prevent channel scouring. The other configurations are considered wide enough to slow within-channel velocities to an acceptable rate, and a 100-foot-wide channel would be the most marginal that could be acceptable.

Table 1. Maximum Bottom Velocities Within the CMP Project Channel

Channel Dimensions (feet wide x feet deep)	CMP Bottom Velocity (ft/s)
(75 x 10)	4.22
(100 x 10)	4.09
(125 x 10)	3.95
(125 x 15)	3.45
(150 x 10)	3.85
(150 x 15)	3.13
(200 x 10)	3.13

Second, riprap would be a necessary feature for protection along any structures such as bridges. Lastly, initial hydrologic analysis for the project determined that a weir would be necessary to slow velocities in the western portion of the CMP above channel dimensions greater than 75 x 10 feet.

Two main project constraints for the proposed project is that the plan should not damage the shoreline and sheet pile structures in the downstream western CMP, and that the foundations of the existing four bridges in the western portion of the Project Channel must be protected. During recent years, three bridges and shoreline stabilization projects have been constructed in the western CMP, and these structures were not designed with a wider, higher velocity CMP channel in mind. Preventing erosion is essential to maintaining a functional project as any effects to the structures in the western CMP could require major construction and cost for repairs in the future, thus impacting funding for general channel maintenance. To evaluate this constraint, western CMP velocities were calculated and evaluated for the potential to damage bridges and sheet pile structures (Table 2). With the exception of the 75-x-10-foot channel, every other channel dimension would be considered unacceptable.

Table 2. Maximum Bottom Velocities within the CMP and the Adjacent Western Channel

Channel Dimensions (feet wide x feet deep)	Western CMP Bottom Velocity (ft/s)
(75 x 10)	2.20
(100 x 10)	2.80
(125 x 10)	3.25
(150 x 10)	3.65
(200 x 10)	4.09

Because a 75-foot-wide by 10-foot-deep channel was the only dimension that resulted in a bottom velocity that was low enough to prevent unacceptable scour in the western CMP, every larger channel dimension that was modeled (e.g., 100-, 125-, 150-, and 200-foot widths) must include a design component to reduce water flow at the western end of the Project Channel consistent with the model output for the 75-x-10-foot channel if they were to be retained as viable, feasible dimensions. The inclusion of a weir (115-foot-wide by 6.5-foot-deep) would enable the larger channels to replicate the cross-sectional area of the smaller 75-x-10-foot channel, and, in turn, maintain the same flow characteristics. With such a weir in place, the potential for unacceptable scour in the western CMP would be resolved while accommodating wider channel widths in the rest of the Project Channel.

In order to protect the structural integrity of the four bridges in the western portion of the Project Channel, it was recommended that channel depths in their vicinity do not extend below 6.5 feet in depth, which is consistent with the weir depth; however, in light of this depth restriction around the bridges, the 75-x-10-foot channel must also include the 115-x-6.5-foot weir. Thus, the inclusion of the weir in the 75-x-10-foot channel is in response to the protection of the existing bridges, not because of the need to reduce water flows to an acceptable bottom velocity in the western CMP, as is the case with the 100, 125, 150, and 200-foot wide channels.

Although the western and eastern CMP channel segments have different cross-sectional areas and bottom elevations, water flow through a tidal system such as the CMP is, and would continue to be, restricted by the smallest cross-sectional area. More specifically, the water flow characteristics of potential wider channel configurations with the weir would be not significantly different than those associated with that narrower channel configuration of 75 feet.

Benefits for the CMP-ERP are directly related to water flow, which controls differences in residence time and tidal range. With respect to benefits derived from the various channel alternatives, there is a significant benefit to the San José Lagoon (based on the benthic index score) once the CMP channel is widened to 75 feet due to tidal amplitude, or volume of water flowing into and out of the lagoon. Increasing channel widths to 100, 125, 150, and 200 feet would progressively result in additional, albeit marginal, benefits as a result of the increased water flows and reduced water residence times.

After many considerations, it was determined that dredging the CMP could provide a way of reconnecting eastern and western segments of the SJBE system, as they were several decades ago. The plan formulation process built directly upon previous planning and design efforts. Structural management measures for the channel dredging, erosion control, dredged material disposal, mangrove planting and construction, recreation, as well as non-structural measures were identified and screened. An initial array of alternatives consisting of rectangular channel cross sections ranging between 75- and 200-foot widths and either 10- or 15-foot depths was developed and evaluated. Screening criteria such as completeness, acceptability, cost effectiveness, and secondary effects on adjacent communities, were then used to eliminate unfavorable plans and develop a final array of alternatives. The final array of alternatives consisted of four alternative plans ranging from no action to a 125 foot-wide by 10-foot-deep natural bottom channel. All constructed alternatives include an elongated weir under the Martín Peña, Tren Urbano, and Luis Muñoz Rivera bridges involving a 115-foot-wide by 6.5-foot-deep channel with riprap on side slopes and articulated concrete mats at the channel bottom to reduce water velocity and erosion, and to control scour.

The main goal of the proposed project is to restore water flow through the CMP and connectivity within the SJBE system by dredging and removing artificial fill deposited during past decades. These would lead to the restoration of open water and forested wetlands, the enhancement of benthic habitats, fish habitats and fisheries.

According to Guidance for Section 2039 of WRDA 07 (USACE 2009), "Monitoring includes the systemic collection and analysis of data that provides information useful for assessing project performance, determining whether ecological success has been achieved, or whether adaptive management may be needed to attain project benefits."

Periodic assessments are performed using monitoring data, which would be reported to the Caño Martín Peña Ecosystem Restoration Adaptive Management Planning Team (ERAMPT). The ERAMPT would be made up of the representatives from member agencies and entities of the ENLACE Technical Advisory Committee. This team would review the assessment reports and make recommendations to ENLACE (non-federal cost sharing partner) and the USACE for adaptive management actions.

The following sections describe the key components of the Monitoring Plan for the CMP-ERP.

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2.0 MONITORING PLAN

The Implementation Guidance for Section 2039 of the Water Resources Act of 2007 – Monitoring Ecosystem Restoration (USACE 2009) states that monitoring includes the systematic collection and analysis of data that provides information useful for assessing project performance, determining whether ecological success has been achieved, or whether adaptive management may be needed to attain project benefits. Development of a monitoring plan… should focus on key indicators of project performance.

A monitoring plan is fundamental to evaluate the success of the CMP-ERP by measuring different physical, chemical, ecological and biological parameters. Important baseline data and concepts have been produced in some of the documents used to produce the Feasibility Study and the Environmental Impact Statement. Studies such as *The Sport Fisheries Study* (Atkins 2011b), the *Existing Wildlife Habitat* (Atkins 2011c), *Hydrodynamic and Water Quality Modeling Efforts* (Atkins 2011a), *Benthic Index within San José Lagoon and San Juan Bay* (PBS&J 2009; Atkins 2011b), *National Ecosystem Restoration Benefit Evaluation* (Atkins 2015), and SJBE Program, Volunteer-Based Monitoring Program, among others, provide useful baseline information to be compared with post-construction monitoring data to assess Project's performance.

The performance metrics/models for the benefits analysis were mostly based on assessments developed from existing efforts and from the relationships and hypotheses developed in the Conceptual Ecological Model (CEM) (Figure 3) contained in the NER Benefits Evaluation Appendix (Atkins 2015). These prior efforts include a hydrodynamic model originally produced for San Juan Bay by Bunch et al. (2000), which was recreated with various potential tidal reestablishment scenarios by Atkins (2011a). The hydrodynamic model used was the Curvilinear-grid Hydrodynamics model in 3-Dimensions, developed by USACE researchers from the Waterways Experimental Station model (i.e., Curvilinear Hydrodynamics in 3 Dimensions, WES version = CH3D-WES). The physical boundaries of the hydrodynamic model (Bunch et al. 2000) are consistent with the physical boundaries of the estuary and nearshore waters used by the SJBE Program in developing its various resource management programs. The hydrodynamic model is an approved model by USACE Headquarters, and the habitat models have been evaluated by the USACE Ecosystem Restoration Planning Center of Expertise (ECO-PCX) and approved for single-use by the Model Certification Team, USACE HQ.

In order to calculate habitat units, performance metrics were developed from project planning documents, and relationships and hypotheses developed in the CEM. The CEM displays relationships demonstrating that the planned CMP-ERP would result in:

1. Improved fish habitat in the SJBE system by increasing connectivity and tidal access to estuarine areas;

2. Restored benthic habitat in San José and Los Corozos lagoons by increasing dissolved oxygen in bottom waters and improving the salinity regime to levels that support native estuarine benthic species; and
3. Increased the distribution and population density and diversity of native aquatic fish and invertebrates in the mangrove community by improving hydrologic conditions in the SJBE system.

The performance measures are described in detail in *National Ecosystem Restoration Benefit Evaluation* (Atkins 2015) and in the Adaptive Management Plan. Three models were developed to address the relationships described above.

1. A fish habitat model describing the benefits accrued from construction of the project through the interconnectedness of mangrove forests, seagrass meadows, open water and coral reefs as the "seascape," which is essential to improving the health, viability and number of fish within the SJBE.
2. A benthic index model which is associated with the decrease in residence time within San José Lagoon. Those portions of San José Lagoon that are between 4 and 6 feet in water depth represent the portions of the lagoon that are anticipated to have improved benthic index scores upon restoration of the historical tidal connection between San Juan Bay and San José Lagoon. The spatial extent of the bay bottom to benefit in this manner is quantified at 702 acres.
3. A mangrove habitat model describing the benefits to mangrove habitat accrued from the construction of the project to increased numbers and diversity of organisms found on and within the mangrove root community.

The basic elements of the program include the following components:

1. Mangrove restoration – Ten 1,000 m^2 plots would be established along the restored CMP channel to assess mangrove seedling survival and growth.
2. Tidal fluctuation/water quality stations – Four tidal fluctuation/water quality stations are proposed. The tidal stations would measure tidal fluctuations for translation into tidal exchange and residence time and collect water quality parameters such as temperature, salinity/conductivity, dissolved oxygen, and pH.
3. Water quality profiles – Ten water quality profiles are proposed to be monitored on a monthly basis. Parameters to be measured would be temperature, salinity/conductivity, dissolved oxygen, and pH.
4. Benthic sampling stations – Thirty stations would be sampled (three grabs per station); and the organisms sorted and identified sufficient to create Benthic Index scores yearly at each station. The stations would be spaced through the San Juan Bay Estuary system with samples intensified within the 702 acres between –4 and –6 foot depth within San José Lagoon.
5. Mangrove prop root community study – Sampling of the stations in and around the Project Area to evaluate the encrusting community diversity and juvenile fish diversity.

6. Post-construction sedimentation rate – Bathymetric surveys to determine post-construction sedimentation rates and maintenance dredging requirements within the CMP.

The monitoring parameters have been selected to assess the Project's success, as well as to determine whether adaptive management actions are required in the event that established thresholds are reached and detected. These parameters are related to localized, as well as system-wide expected benefits.

2.1 EXPECTED LOCALIZED BENEFITS

The difference between the evaluated project alternatives is the width of the channel of the eastern portion of the CMP and the resulting amount of open water in the channel versus the constructed mangrove habitat along the channel edges. The TSP includes the restoration of 34.48 acres of mangrove forested wetland or habitat fringing the Eastern CMP channel would be the expected localized benefits resulting from the CMP-ERP. Failure of areas of the mangroves planted along the Eastern CMP will most likely occur early in the restoration project from improper flooding or ponding of water behind the retaining walls or improper elevation from settling or redistribution of sediment. Mangrove establishment is highly dependent on tidal influence, and thus, hydric soils, which at the same time helps to exclude other potentially invasive plant species from growing in this type of habitat. The monitoring program will identify problems in the ability of tidal water to access the planting areas or elevation problems that may result in other plant species entering the planting areas, or the failure of the planted mangroves.

The thresholds that trigger management actions for each metric or parameter related to expected localized benefits (i.e., mangrove restoration along Eastern CMP) are included in Table 3.

Table 3. Threshold for management actions to expected localized benefits
(i.e., mangrove restoration along Eastern CMP)

Attribute/Performance Metric	Target or Performance Measure (Timeframe)	Trigger/Threshold for Management Action
Mangrove habitat	Increase in mangrove forest canopy cover within the monitoring plots, over the 34.48 acres of planted area, 2 years after project construction.	A mortality exceeding 15% of planted mangrove trees

2.2 EXPECTED SYSTEM-WIDE BENEFITS

2.2.1 Physical Attributes

The proposed project seeks to restore and improve tidal flow between the eastern and western portions of the SJBE system, which is considered one of the major stressors responsible for water and habitat quality (and its current degraded state) in the project and study areas. In order to determine whether the project goals are accomplished, flow velocity would be measured in the CMP and the Suárez Canal, as well as tidal amplitude, to determine the trend towards equalization of tides and tidal velocities with eastern and western SJBE system and shorter water residence time in the San José Lagoon. Table 4 includes the thresholds that trigger management actions for each metric or parameter related to the physical attributes.

Table 4. Thresholds for management actions for each measured parameter (i.e., physical attributes) related to expected system-wide benefits.

Attribute/Performance Metric	Target or Performance Measure (Timeframe)	Trigger/Threshold for Management Action
Tidal Amplitude in San José Lagoon	Increase in tidal flow and amplitude (immediately after Construction Phase ends).	Significant (an average of 20% or more) decrease in tidal oscillation between San Juan Bay and the San José Lagoon.*
CMP Bottom Velocity	Achieve existing bottom velocities to approximately 4.0 ft/s within the CMP and less than 2.5 ft/s at the western end of the CMP (immediately after Construction Phase ends).	Bottom velocities conducive to sedimentation within the eastern CMP (less than 3 ft/s). Bottom velocities conducive to scouring within the western CMP (greater than 3 ft/s).
Residence Time	Reduction in residence time from approximately 17 days to between 3 and 4 days (immediately after Construction Phase ends).	Residence time greater than 4 days.*
Sedimentation	No variation in channel depth	20% reduction in cross-sectional area in channel.

*Based on Atkins (2011a)

2.2.2 Water Quality Attributes

The physical changes are anticipated to effect the water quality predicted to occur in San José Lagoon. It is anticipated that the opening of the CMP will result in the elimination of the salinity stratification occurring at water depths greater –4 feet in the shallow waters of San José Lagoon. The dredged pits in San José Lagoon will remain stratified below the bottom depth of the lagoon. This would mean that we would anticipate the bottom water quality values (i.e., temperature, salinity, dissolved oxygen, pH, and turbidity) to be equivalent to the surface water quality values, i.e., equivalence throughout the water column profile. Table 5 includes the thresholds that trigger management actions for each metric or parameter related to the water quality attributes.

Table 5. Thresholds for management actions for each measured parameter (i.e., water quality attributes) related to expected system wide benefits.

Attribute/Performance Metric	Target or Performance Measure (Timeframe)	Trigger/Threshold for Management Action
Field Parameter: Dissolved Oxygen	The bottom dissolved oxygen values are not equal to the surface values in shallow waters of San José Lagoon, i.e. an equivalent profile, not in the dredged pits (1–2 years).	Concentration of dissolved oxygen does not increase within timeframe or stays as observed during pre-construction monitoring
Field Parameter: Salinity	The bottom salinity values are not equal to the surface values in shallow waters of San José Lagoon, i.e., an equivalent profile, not in the dredged pits (1–2 years).	Salinity stratification is found in depths shallower than 4 feet and/or is spatially more frequent.

2.2.3 Habitat Attributes

The beneficial effects that the construction of the CMP would have on tidal flow, residence time and water quality are also going to improve overall ambient conditions for benthic habitat, mangrove prop-root communities and open water column habitat, leading to an increase in the diversity and abundance of associated organisms (e.g., macroinvertebrates and fish). The changes in these communities will take more time to realize than the physical and water quality changes.

Benthic Habitat

Benthic habitat is evaluated using an index originally developed for the SJBEP to report on the status and trends of the health of the SJBE and its individual component water bodies. The Benthic Index (BI) combines information on benthic community diversity, the presence or absence of pollution-tolerant benthic taxa, and the presence or absence of pollution-sensitive taxa (PBS&J 2009). The BI is designed to increase as beneficial factors increase (e.g., species richness, species evenness, and presence of pollution-sensitive taxa). Conversely, if species richness and/or evenness decline and the proportion of pollution-tolerant taxa increases, the BI would decline. The performance of the BI Model is based on achieving a BI value of 3.0, which would be the approximate maximum predicted value for the BI in the San José Lagoon after restoring flow through the CMP.

Benthic habitat in those areas shallower than –4 to –6 feet deep in the San José Lagoon are expected to improve as a result of the proposed project. This would be verified by sampling for an increase in diversity and abundance of benthic pollution-sensitive species (e.g., invertebrates). The data that would be collected would be employed in the BI model in order to determine that a benthic index score of 3.0 has at least been achieved. Table 6 includes the thresholds that trigger management actions for each metric or parameter related to benthic habitat attributes.

Table 6. Thresholds for management actions for each measured parameter (i.e., benthic habitat attributes) related to expected system wide benefits.

Attribute/Performance Metric	Target or Performance Measure (Timeframe)	Trigger/Threshold for Management Action
Benthic Habitats: Bottom/Sediment Communities	Achieve a benthic index score of 3.0 in San José Lagoon (2–3 years).	The lack of improvement in the benthic index score from pre-construction values.**

** Based on Atkins (2015)

Mangrove Prop Root Habitat

The Sport Fisheries Study (Atkins 2011b) includes an assessment of the red mangrove prop root community within the CMP, and within six zones in designated distances away from the CMP (see Figure 3). It was found that the numbers and diversity of the attached (e.g., mussels and oysters) and mobile (e.g., crabs) organisms found on the roots increased from the CMP and western San José Lagoon out to La Torrecilla Lagoon, thus providing an indicator of water quality improvement that would likely respond to the improvements that will be provided by the opening of the CMP (see Figure 4). Through this preliminary study, a significant relationship was found between the number of crabs found on mangrove prop roots and its distance from the CMP (Atkins 2015).

Monitoring activities would document the numbers and diversity of attached mobile organisms within the mangrove prop root community to determine whether an increase leading to habitat uplift similar to those conditions presently found in the Suárez Canal (Zone D) has been achieved as a result of the project.

Table 7. Thresholds for management actions for each measured parameter (i.e., mangrove prop root habitat attributes) related to expected system wide benefits.

Attribute/Performance Metric	Target or Performance Measure (Timeframe)	Trigger/Threshold for Management Action
Red Mangrove (*Rhizophora mangle*) Prop Root Community	The colonization and diversity of fish, crustaceans, snails, and encrusting species would be within 10% in numbers and diversity across the zones (2–3 years).	A greater than 10% reduction of existing functional values (cover, species diversity, etc.)/habitat units. Increase in pollution-tolerant species (or reduction in pollution-sensitive species).**

** Based on Atkins (2015)

Figure 3. Mangrove prop root habitat sampling segments (Atkins 2011b)

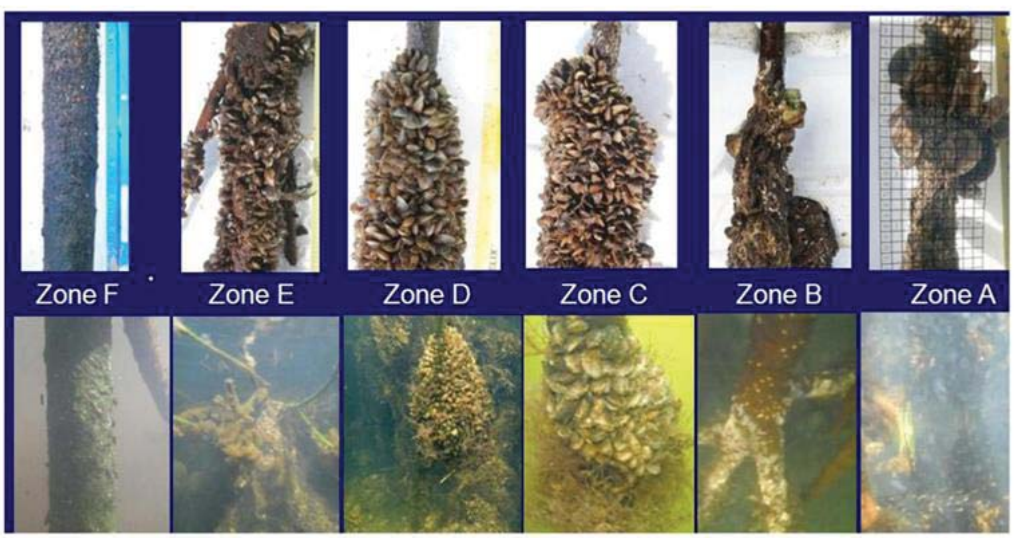

Figure 4. Mangrove prop root habitat fouling community
in various portions of the SJBE (Atkins 2011b)

Open Water Column Habitat

Existing fish populations and diversity would be assessed in San José Lagoon and the CMP as part of the pre-construction baseline data sampling in order to compare said data with that resulting from the post-construction monitoring activities.

Table 8. Thresholds for management actions for each measured parameter (i.e., fish diversity and abundance) related to expected system wide benefits.

Attribute/Performance Metric	Target or Performance Measure (Timeframe)	Trigger/Threshold for Management Action
Open Water Fish Habitat	Increase in fish populations and diversity, as well as other nekton groups with the numbers and kinds of fish nearly equal throughout SJBE (2–3 years).	Reduction of existing fish populations and diversity from pre-construction estimates. Increase in pollutant-tolerant species (or reduction in pollution-sensitive species).**

** Based on Atkins (2014)

Implementation of a pre-project monitoring plan would be necessary to establish baseline data of those metrics that are not available prior to construction. It would be carried out by in-house agency resources or via contracts with CMP-ERP partner agencies and/or contracted universities or consultants to most efficiently and effectively execute the pre-construction monitoring efforts. Table 7 includes the monitoring plan matrix, which contains the parameters to be measured, methods, monitoring period and frequency, as well as proposed monitoring sites.

Table 9. Monitoring Plan Matrix

Metric	Specific Property to be Monitored	Method	Monitoring Period	Frequency of Monitoring	Monitoring Site/Station
Tidal Fluctuation/ Water Velocity	Tidal oscillation between the SJB, and the San José and Los Corozos lagoons. Current velocity at ends and within the CMP and other locations as needed to calculate residence time.	Acoustic Doppler Current Profilers (ADCP); appropriate tide gauge stations	Post-construction	Digital recording at appropriate intervals throughout tidal cycles	See Figure 3
Field Parameters (Dissolved oxygen, salinity, temperature, turbidity, pH, and Secchi disk depth)	Dissolved oxygen (mg/L), salinity (psu), temperature (C°), turbidity (ntu), and Secchi disk depth (meters) at water surface, mid-depth and bottom.	Multi parameter sensors	Pre-construction, post-construction	Pre-construction: existing data, pre-construction baseline study of water column profiles and continuous monitoring stations. Post-construction both monthly profiles and continuous monitoring stations.	See Figure 3
Benthic Habitats: Bottom/Sediment Communities	Presence of bottom/sediment species and bottom sediment composition.	Petite Ponar Grab sampling	Pre-construction, post-construction	Pre-construction baseline study. Post-construction: twice yearly	See Figure 3
Benthic Habitats: Mangrove/wetland	Sampling density, survival rate, diversity, overall condition/health, wildlife utilization.	Plot (quadrat) establishment.	Post-construction	Post-construction: twice yearly, first 3 years. Annually: next 2years	Mangrove restoration areas

Table 9, concluded

Metric	Specific Property to be Monitored	Method	Monitoring Period	Frequency of Monitoring	Monitoring Site/Station
Red Mangrove (*Rhizophora mangle*) Prop root community	Presence, diversity of organisms, including fish.	*In situ* characterization, optical methods; sampling for attached and cryptic organisms	Pre-construction, post-construction	Pre-construction: existing data. Post-construction: twice a year	Mangroves in CMP, Suárez Canal, San José and Los Corozos lagoons
Open water habitat	Fish species density, diversity.	Creel surveys	Pre-construction, post-construction	Pre-construction: existing data. Post-construction: sport fisheries data/creel surveys, twice a year	Along CMP, and San José and Los Corozos lagoons
Sedimentation at CMP	Sedimentation rate.	Multibeam Bathymetry Survey System (MBSS)	Post-construction	Yearly	Along CMP

These parameters would be monitored at specific site or stations, as shown in Figure 5.

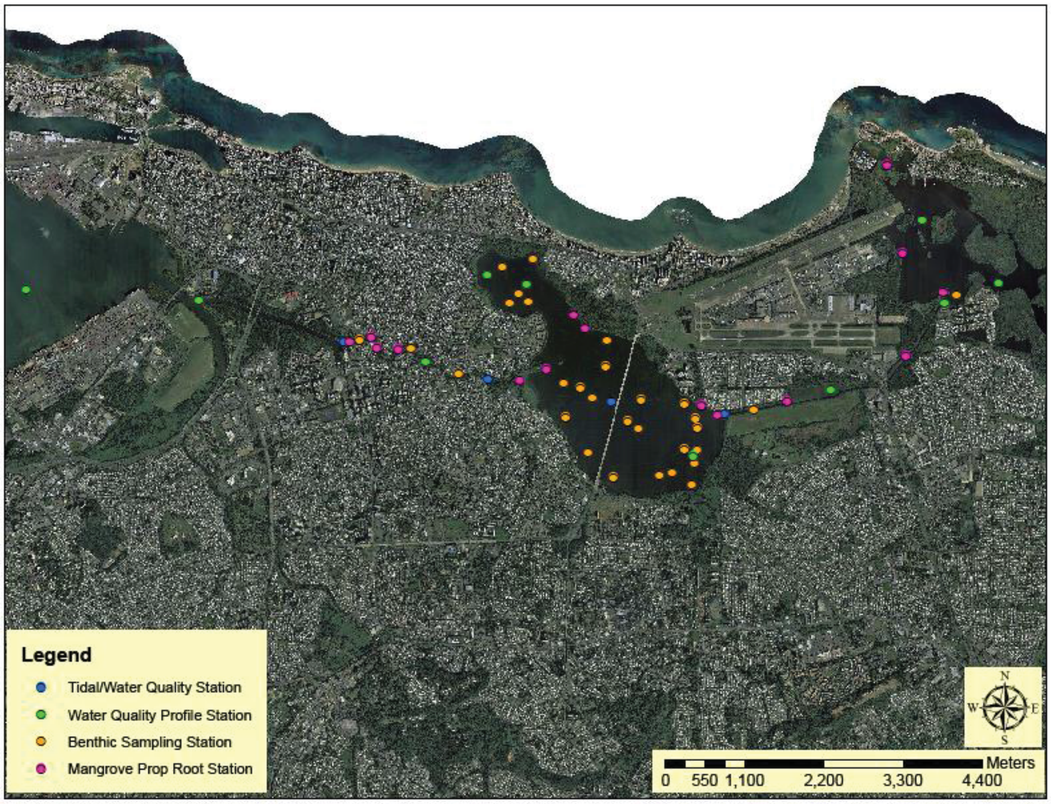

Figure 5. Proposed monitoring stations (mangrove planting sampling stations not shown)

2.3 MONITORING METHODS

The following sections describe the pre-construction and post-construction methodology that would be employed to monitor the established metrics.

2.3.1 Pre-Construction Monitoring

Pre-construction baseline data would be collected to document the condition for several parameters related to the expected benefits of the project system-wide. Pre-construction data consists of a combination of pre-construction field sampling and the use of existing data from long-term studies and site specific studies. Some of the proposed monitoring sites would be located within stations that were previously or currently used in these studies. The proposed approach is also comparable to the methods used in these previous or existing studies. Therefore, pre-construction data would be suitable for comparison with post-construction monitoring.

Physical Attributes – Tidal Fluctuation/Residence Time

Improvement of tidal exchange is crucial metric the CMP-ERP acting to decrease salinity stratification (among other benefits) and thus improve the ecological health of San José Lagoon and the rest of the SJBE (Atkins 2011a). Existing tidal volume residence time within San José Lagoon has been estimated at an average of approximately 17 days. This data would be used as the pre-construction existing condition; therefore, no additional sampling of tidal velocity to translate it to residence time is necessary before project begins. Tidal gauge stations and velocity meters would be used tom record post-construction changes and provide the data needed to calculate post-construction residence times. The velocity meters would be used to record and understand the current velocity within and around the CMP.

Physical Attributes – Water Quality

Field parameters such as dissolved oxygen (mg/L), salinity (psu), temperature (C°), turbidity (ntu) and pH would be sampled using a multi parameter sensor. This methodology (*in situ* measurement) is likely to be more accurate and precise than measurements made in samples removed from their source (Gibs 2007). A Secchi Disk would be used to measure water transparency (depth, meters). Dissolved oxygen, salinity, temperature, turbidity and pH are intrinsically related to water quality.

Existing field parameters data, sampled by the SJBEP or others, is useful as pre-construction baseline data. The SJBE Water Quality Volunteer Monitoring Program samples water quality parameters every month. Some of the proposed sampling stations are placed within the same location as the SJEBP water quality sampling stations. Monitoring would consist of permanent fixed stations and water column profile stations.

Habitats: Benthic, Mangrove Prop Roots, and Open Water Column Communities

Thirty benthic monitoring stations are proposed. A petite ponar type grab sampler would be employed to sample bottom/sediment communities such as mussel reefs and other soft-bottom macro-invertebrate communities in the 30 sampling stations. Sampling methodology would follow the *Standard Guide for Collection, Storage, Characterization, and Manipulation of Sediments for Toxicological Testing and for Selection of Samplers Used to Collect Benthic Invertebrates* (ASTM E1391-03). The data produced during benthic sampling would be analyzed and also uploaded into a Geographical Information System (GIS) to produce a map of benthic communities within Project area before construction begins. The BI would be calculated for each station during each sampling period.

Mangrove prop root community monitoring methodology would include *in situ* characterization and observations, as well as optical methods (video and still camera documentation). Optical equipment would include a scale system or grid to determine percent coverage. If any species cannot be identified in the field, a sample would be taken to the laboratory for further identification.

Pre-construction fish monitoring would be conducted through creel surveys combining roving and access points components (Wilberg and Humphrey 2008). Also, meetings and interviews of anglers would be performed. Angler interviews and questionnaires would be prepared and administered to receptive anglers at nearby marinas, access points (including shoreline and boat ramps) and boat to boat. These methods are valuable tools to get information about the effort, harvest, and size distribution of several important species of fish (Malvestuto 1996).

2.3.2 Post-Construction Monitoring

Localized Project Benefits – Mangrove Restoration

The CMP-ERP includes the restoration of approximately 34.48 acres of forested wetlands. After the restoration area has been constructed, ten (1,000 m^2) permanent plots within mangrove restoration areas would be established randomly (five at each side of the restored CMP channel). In these plots a time-zero or restoration area post-construction monitoring would be carried out to:

- Establish the density of planted propagules;
- Evaluate hydroperiod within restoration site; and
- Document wildlife utilization.

This would serve as the baseline data to compare tree density in future monitoring events.

Subsequent monitoring of wetland restoration area would be performed twice yearly during the first 3 years, and annually in the last 2 years (5 years in total). These monitoring events would include:

- Determination of tree density;
- Determination of survival rate of planted trees;
- Species diversity;
- Overall condition/health of planted trees;
- Determination of a functional hydroperiod; and
- Wildlife utilization (presence of species from different trophic levels).

Project success would be achieved if:

- At least 85% of planted trees are alive;
- 85% of vegetative cover is composed of native, desirable species;
- Hydroperiod (hydrological connectedness and frequency of inundation/saturation) is correct for planted species; and
- An increase of wildlife utilization is observed.

These are standard monitoring methods required in restoration and mitigation projects approved by the USACE.

System-Wide Project Benefits

Given that post-construction information would be obtained using similar methodologies as the ones used for pre-construction data production, both data sets may be compared to evaluate project success.

Physical Attributes – Tidal Fluctuation/Residence Time

Tidal velocity would be monitored using an Acoustic Doppler Current Profiler (ADCP). ADCPs would be permanently deployed in four stations along the CMP and the San José Lagoon (see Figure 5). Tidal amplitude will be measured at tide gauge stations located with San José Lagoon. Tidal amplitude and flow would be translated into the calculation of residence time within San José Lagoon. Monitoring of tidal flow would take place automatically on a timed basis sufficient to understand the tidal velocity through tidal cycles. The tide gauges will be automatic recording gauges with sufficient timing to understand tidal cycle changes. Also, these stations would collect water quality parameters, such as dissolved oxygen, conductivity/salinity, temperature and pH. This represents four additional stations, besides the proposed ten water quality stations (see below) to collect water quality parameters. At sufficient intervals to understand the changes in water quality through tidal cycles.

Sedimentation rates would be monitored along the CMP using a Multibeam Bathymetry Surveying System (MBSS). The MBSS measures bottom elevation identifying changes (erosion or accumulation) of sediment between survey intervals. This method, in combination with the proposed tide and current stations would identify any degradation in tide or current, indicating that the CMP channel is potentially filling in, or that flow is being restricted near the Quebrada Juan Méndez confluence with the CMP. The MBSS surveys would be conducted on a yearly basis.

Physical Attributes – Water Quality

Project success would be achieved if water quality parameters (temperature, DO, salinity, and pH) become equal throughout the water column in areas shallower than 6 feet when compared with pre-construction data. The project related water quality sampling program would consist of a series of permanent continuously monitoring stations and stations where the water column profile is measured on a monthly basis. To augment the project related program, field parameters also could be monitored on a monthly basis by a volunteer program, such as the San Juan Bay Estuary Water Quality Volunteer Monitoring Program. Sampling would follow the *Standard Operating Procedures for Water Quality Monitoring*, prepared by the San Juan Bay Estuary Water Quality Volunteer Monitoring Program (2008).

Habitats: Benthic, Mangrove Prop Roots, and Open Water Column Communities

Post-construction monitoring to determine project success regarding benthic, mangrove prop roots, and open water column communities would follow the same methods as those described for pre-construction monitoring. Post-construction monitoring for these habitat attributes would occur twice yearly for the 5-year monitoring period.

To augment the project related program, other metrics may be monitored by volunteer programs, such as the SJBE Program Volunteer-Based Monitoring Program. These metrics would include the monitoring of water quality lab parameters (Ammonia, BOD, chlorophyll a, fecal coliforms, enterococcus, nitrate + mitrite, total nitrogen Kjeldahl (TKN), oil & grease, total organic carbon (TOC) and total phosphorus.), non-native invasive and native nuisance flora/fauna species, as well as avifauna species density and diversity.

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3.0 IMPLEMENTATION

Monitoring and assessment of data is a fundamental step of adaptive management. It provides a structured course for lowering risk, increasing certainty and informing decisions. It is successful only if its actions/strategies are implemented during the entire project-life cycle: from first steps of planning through all aspects of monitoring, engineering, design, construction, operations, and maintenance components. In addition, mechanisms must be in place to collect, manage, analyze, synthesize, coordinate, and integrate new information into management decisions. The Adaptive Management Plan outlines the steps for the use of monitoring data in this process.

A five (5) year monitoring plan is proposed. However, if ecological success is determined earlier (prior to 4 years post-construction), for some of the monitored parameters, these would cease to be measured; associated costs would be reduced accordingly. For those parameters that would be measured on continuously (data recorders) or monthly basis, monitoring would cease once these meet target or performance measures for a continuous period of a whole year. Those parameters that would be measured quarterly or biannually would cease to be monitored once these meet target or performance measures for a continuous period of two years. Sedimentation rate is the only parameter that would be measured for the whole post-construction monitoring period of four years.

Table 10 shows the implementation schedule for the different Monitoring Plan phases.

Table 10. Monitoring Plan Implementation Schedule

Milestone	Schedule
Draft Monitoring Plan	During FR/EIS preparation
Finalize Monitoring Plan	During final FR/EIS revisions
Pre-construction Baseline Study	Within one year before construction begins
Initiate Implementation of Monitoring Plan	At the beginning of project construction
Complete Monitoring Plan Implementation	5 years after project construction has been completed

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4.0 COSTS

The total cost for all monitoring activities proposed for a 5-year period has been estimated at $1,673,750, considering a 3% inflation rate.

Table 11. Monitoring Plan Estimated Costs

Monitoring Plan Element	Estimated Equipment Cost	Estimated Annual Maintenance, Monitoring, and Reporting	Total Estimated Maintenance/ Monitoring/ Reporting	Source of Cost Estimate
Pre-construction baseline studies and mapping	$15,000	$60,000[1]	$60,000	Coll Rivera Environmental / NOAA
Four permanent tidal/water quality stations	$40,000	$34,000[2]	$170,000	Atkins
Inspection and bathymetric survey	–	$23,000[3]	$115,000	Atkins
Ten water quality profile stations (Lab/field)	$10,000	$30,000[2]	$150,000	Atkins and consultation with SJBEP
Thirty benthic sampling stations	$10,000	$80,000[2]	$400,000	Atkins
Mangrove prop root community monitoring	–	$50,000[2]	$250,000	Atkins
Creel survey	$5,000	$10,000	$50,000	Coll Rivera Environmental
End of monitoring period benthic mapping	–	$60,000[1]	$60,000	Coll Rivera Environmental / NOAA
Data Analysis Evaluation and Assessment	–	$50,000[2]	$250,000	Coll Rivera Environmental
Equipment maintenance/ transportation	–	$8,000[2]	$40,000	Atkins, Coll Rivera Environmental
SUBTOTALS	**$80,000**	**$405,000**		
		Total Equipment and 5 Year Cost	**$1,625,000**	
		Total 5-Year Cost with 3% Inflation	**$1,673,750**	

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