A.R.M. LOXAHATCHEE NATIONAL WILDLIFE REFUGE

ENHANCED WATER QUALITY PROGRAM

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ACRONYMS AND ABBREVIATIONS

AC area of canal
ACME Special Drainage District
acre-ft acre-feet (volume reported as one acre in size by one foot in depth)
A_M area of marsh
ATLSS Across Trophic Level System Simulation
CERP Comprehensive Everglades Restoration Plan
cfs cubic feet per second **for 24 hours**
Cl chloride
cm centimeter
CMF completely-mixed flow
DBHYDRO SFWMD's web portal for water quality data
DCS depth to consolidated substrate
DD dry deposition
DEM Digital Elevation Model
DMSTA Dynamic Model of Stormwater Treatment Areas
E evaporation
EAA Everglades Agricultural Area
EDEN Everglades Depth Estimation Network
EFA Everglades Forever Act
ELM Everglades Landscape Model
ENRWET Atmospheric deposition site located at STA-1W
ET evapotranspiration
EVPA Federal Consent Decree compliance network for Refuge
ft feet
FWM flow-weighted mean
G groundwater recharge
G_C groundwater loss in canal
G_M groundwater loss in marsh
ha hectare
HSI Habitat Suitability Indices
km kilometer
L liter
LOXA Refuge's expanded water quality monitoring network
m meter
mg milligram
MIKE-FLOOD coupled one and two-dimensional finite difference model
mm millimeter
NAD North American Datum
NGVD National Geodetic Vertical Datum
NO_x oxides of nitrogen (e.g., NO2 and NO3)
P precipitation
ppb parts per billion (micrograms per liter)
R correlation coefficient
Refuge A.R.M. Loxahatchee National Wildlife Refuge

RMSE root mean square error
s second
SFWMD South Florida Water Management District
SFWMM South Florida Water Management Model
SO_4 sulfate
STA Stormwater Treatment Area
T transpiration
Tdepth depth of clear water column
TN total nitrogen
TP total phosphorus
µg microgram
µS microSiemen (measure of conductivity)
USACE U.S. Army Corps of Engineers
USFWS U.S. Fish and Wildlife Service
USGS U.S. Geological Survey
WASP Water Quality Analysis Simulation Program
WCA Water Conservation Area
XYZ monitoring and research transect in southwest Refuge

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EXECUTIVE SUMMARY

Congress appropriated funds to the U.S. Fish and Wildlife Service in 2004 to develop an enhanced water quality monitoring network and hydrodynamic and water quality models to improve the scientific understanding of water quality in the Arthur R. Marshall Loxahatchee National Wildlife Refuge[1] (Refuge). The network and models provide information that is used in management decisions to better protect Refuge resources. The enhanced water quality monitoring network complements the compliance network created under the 1992 Federal Consent Decree (Case No. 88-1886-CIV-MORENO) by characterizing the water quality of a larger Refuge area, particularly the fringe area potentially impacted by canal water intrusions. Monthly grab samples have been collected at 37 to 39 sites located in the marsh and canal since June 2004. Further, continuous measurements of conductivity have been collected along seven transects, four of which extend from the canal near surface water discharge points into the interior. This report is the fourth annual report, with analyses of the period from January through December 2007 with comparison made to the preceding years (2004 through 2006). This period of record includes a significant range of environmental conditions, from average to drier conditions. Drought conditions for South Florida began in late 2005 and continued through 2007. These drier conditions have not lead to decreases in total phosphorus (TP) concentrations over the entire Refuge (mean for the marsh and canal combined) during the extent of this program (2004 – 2007).

Analyses of canal water intrusion into the Refuge marsh and water quality presented in this report documents continued intrusion of rim canal water into the Refuge interior, adding to a growing information base about canal water impacts to the Refuge. Intrusion of nutrient-rich and high conductivity water from the canal network surrounding the Refuge has been shown to negatively impact Refuge flora and fauna. Important insights gained from 2007 canal water intrusion analysis include:

- Canal water intruded into the marsh from 0.5 to 2.3 km (0.3 to 1.4 miles) depending on timing and location.
- Intrusion was not as extensive as in previous years, likely because the Refuge received less canal inflows than in previous years.
- Overall meteorological drought conditions in South Florida began in 2005 and persisted through 2007. Although the Refuge received less rain and canal water inflows, outflows were reduced significantly when compared to previous years, and this operation likely reduced the potential for an extended hydrologic drought for the Refuge. However, 2007 hydroperiods for areas of the marsh greater than 15.5 ft were shorter than during the period from 2004 through 2006.
- In October 2007, canal inflow rates exceeded 2,500 cfs (4,959 acre-ft; 6,114 ML^{-1}), maximum outflow rates were less than half the inflow rates, and canal and marsh stage increased above 17 ft (5.18 m), resulting in intrusion extending up to 2 km into the marsh.

[1] Public Law 108-108; see House Report No. 108-195, p. 39-41 (2004)

- Elevated inflow rates, increased stages, and extended intrusion distances in October 2007 were coincident with a Consent Decree excursion that month.

Analyses of these data continue to support previously suggested management practices that have the potential to minimize intrusion. A few of these recommendations are summarized as balancing inflow and outflow volumes, reducing the duration of inflows, and reducing inflow rates when the canal stage is lower than the marsh stage.

Based on the surface water conductivity data, the Refuge was classified into four geographic zones: (1) Canal Zone; (2) Perimeter Zone, located from the canal to 2.5 km (1.6 miles) into the marsh; (3) Transition Zone, located from 2.5 km (1.6 miles) to 4.5 km (2.8 miles) into the marsh; and (4) Interior Zone, greater than 4.5 km (2.8 miles) into the marsh. Overall, water quality conditions in the Perimeter and Transition Zones continue to be different from, and more impacted than, the Interior Zone. Cattail expansion in the Refuge marsh, *Xyris* spp. negative response to nutrient and mineral enrichment, and displacement of sawgrass in the canal water exposed areas of the marsh are a few examples of marsh ecosystem functionality alterations.

This report continues to document that water movement between the canals and the marsh is influenced by rainfall, structure-controlled water inflow and outflow into perimeter canals, the difference between canal and marsh stages, and marsh elevation. In 2007, when inflows to Refuge canals were greater than outflows from Refuge canals, and when canal stages were greater than marsh stages, intrusion extended between 1 and 2 km (0.6 and 1.2 miles) into the marsh interior. Additionally, this report documents a positive relationship between structure inflows and canal TP concentrations, reflecting stormwater treatment area discharges into the Refuge. When combined with our understanding of canal water intrusion's influence on the marsh, these data continue to suggest that high-nutrient water is having a negative impact on the Refuge marsh (e.g., enriched soil TP, displacement of sawgrass by cattails, loss of *Xyris* spp., etc.).

An excursion to the long-term TP level, as defined by the Federal Consent Decree, occurred in October 2007 (Lehr 2008). Rainfall was greater than one inch (25.4 mm) in July. Daily canal inflows increased, beginning in July, and were greater than 2,500 cfs (3,083 acre-ft; 3,801 ML^{-1}) by the beginning of October. Marsh and canal stages increased more than 0.6 ft (0.18 m) since the September 2007 sampling event. Canal water intrusion into the marsh increased as canal inflows and stages increased. By late August 2007, canal water intrusion (movement of water from the perimeter canal into the marsh interior) was observed at 1 km or greater into the marsh on both the east and west sides of the Refuge. Concentrations of TP, total nitrogen, chloride, and sulfate in the Canal and Perimeter Zones increased above the annual means for each parameter along with the increase in canal water intrusion. In October 2007, most of the monitored concentrations in the Canal and Perimeter Zone peaked, and canal water intrusion increased to 2.3 km on the west side of the Refuge, representing the highest level of recorded intrusion in the west over the past three years. Intrusion increased to 1.7 km on the east side of the Refuge – the highest intrusion recorded on the east side of the Refuge in 2007. Increased canal water intrusion was coincident with increased inflows of long

durations (greater than six consecutive weeks) which were not matched by similar outflows. The excursion of the long-term TP level occurred coincident with these hydrologic conditions.

Nutrient and mineral-enriched water has negative consequences on vegetation dynamics in the Refuge interior. The fringe of the marsh is most susceptible to canal water influence because of its proximity. Seed bank germination research identified differences in plant species response to different levels of mineral enrichment, including germination failure of non-preferred native species (e.g., *Mikania scandens, Typha* spp.) when marsh soils are not enriched by canal waters. These findings coincide with the observation of cattail (*Typha* spp.) in the western marsh fringe where cattails are densely distributed up to 1.5 km into the marsh from the canal on the west side of the Refuge. This area is the most influenced by canal water intrusion.

A simple water budget model was developed to predict canal and marsh volumes and stages. Statistical analyses demonstrate the ability of this model to predict temporal variation of water levels in both the marsh and the Refuge perimeter canal. This model already is being used for examining regional water management scenarios, including an effort to better define the Refuge's water needs. A more complex hydrodynamic model allows examination of Refuge hydrology at a scale of 400 m by 400 m (1,312 ft by 1,312 ft) – a much higher resolution than the 2-miles by 2-miles hydrodynamic model presently available for the Refuge. Water quality constituents are being incorporated into both models to allow for both a better understanding of water movement within the marsh and understanding phosphorus levels in the water column. An independent model advisory review panel continues to provide valuable insights that have been incorporated into the modeling program. Finally, a series of management scenarios has been identified for application of these modeling tools.

Literature Citation

Lehr P, 2008. Settlement Agreement report presentation: October – December 2007. South Florida Water Management District, West Palm Beach, FL.

CHAPTER 1. INTRODUCTION[2]

The Arthur R. Marshall Loxahatchee National Wildlife Refuge (Refuge), located in Palm Beach County, Florida, includes approximately 58,300 ha (144,000 acres) of northern Everglades habitats (**Figure 1-1**). Approximately 57,085 ha (141,000 acres) of interior marsh is Water Conservation Area 1 (WCA-1), an impounded marsh established in the 1950s and 1960s for water supply, flood protection, and wildlife habitat. It is managed by the U.S. Fish and Wildlife Service (USFWS) under a License Agreement with the South Florida Water Management District (SFWMD). The Refuge is part of the greater Everglades ecosystem that extends from the Kissimmee Chain of Lakes south to Florida Bay. Canals impound the Refuge interior marsh and the system is surrounded by agriculture to the north and west, and urban areas and agriculture to the east.

The Refuge was established in 1951 under the Migratory Bird Conservation Act of 1929 which states that the Refuge is "…for use as an inviolate sanctuary, or for any other management purposes, for migratory birds." (16 USC. 715d). The Refuge provides habitat for over 300 vertebrate species including the endangered snail kite and wood stork. A current goal of the Refuge is to restore and conserve the natural diversity, abundance, and ecological function of Refuge flora and fauna. To this aim, the fourth water Regulation Schedule was implemented in 1995 to aid in improving Refuge ecology through better control of hydrologic conditions.

Hydrologic inputs once came from direct rainfall, overland sheet flow, and possibly groundwater. Today, the Refuge is isolated hydrologically by levees and canals, receives no sheet flow, and inflows now occur as rainfall and surface water discharges into perimeter canals from water management structures (gates and pumps) (**Figure 1-1**). Water delivered through structures from runoff of adjacent agricultural and urban areas is treated, in part, by Stormwater Treatment Areas (STA-1W and STA-1E) designed to reduce phosphorus inputs. During the period from 2004 through 2007, untreated water could enter from structures on the east side (ACME-1 and ACME-2 – discontinued in 2006), or as bypass (untreated) through the G-300 and G-301 at the north end (**Figure 1-1**). Water entering the perimeter canals through structures is generally poorer in quality than rain. Under certain canal stages or flow regimes, the poorer canal water may flow into the marsh altering the water quality of the marsh.

Hydrologic outflows through structures are for stage regulation and flood protection (S-10 structures and S-39 at the south), and water supply (G-94 structures and S-39). Evapotranspiration and seepage loss are other sources of water outputs from the Refuge. Location, amount, and timing of inflows and outflows may affect marsh water flow, depths, and nutrient and other ion concentrations.

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[2] Prepared by Donatto Surratt[a], Matthew C. Harwell[b], Michael G. Waldon[b], and Nicholas G. Aumen[a]
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Areas of pristine marsh throughout the Everglades have been impacted to various degrees by water with high nutrients and other constituents. Information from the Refuge and other wetlands indicates that increases in phosphorus and major ions cause undesirable ecological changes in flora and fauna. A large amount of research conducted by state, federal and private entities has demonstrated the impacts of small increases in total phosphorus concentrations (Richardson et al. 1990; Childers et al. 2003; McCormick and Crawford 2006; Rejmankova et al. 2008). Changes in Everglades flora and fauna begin to occur at total phosphorus concentrations slightly higher than 10 $\mu g\ L^{-1}$ (10 ppb) (Payne and Weaver 2004). Recognition that increases in total phosphorus concentrations have caused changes in Everglades communities led to the establishment of legal mandates including a Federal Consent Decree in 1992 that established phosphorus levels and a compliance methodology for the Refuge. Interim levels for the Refuge have been in effect since February 1999 and long-term levels took effect December 31, 2006. Florida's Everglades Forever Act (EFA) was passed in 1994 and led to the establishment of a numeric criterion for total phosphorus in 2005.

The Everglades, including the Refuge, developed as a rainfall-driven system with surface waters low in nutrients and inorganic ions such as chloride, sodium, and calcium (USFWS 2007a, b, Harwell 2008). Conductivity was, therefore, naturally low. Conductivity is a field measurement that provides a good surrogate for concentrations of major ions from canal water compared to the naturally low conductivity Refuge marsh interior. In addition to elevated phosphorus concentrations, canal water has high conductivity. There is no appropriate state conductivity water quality standard for the Everglades. However, there are concerns that increases in canal water intrusion into the Refuge marsh may cause negative ecological consequences because canal water is high in conductivity as well as nutrients.

The highest soil elevation in the Refuge interior is approximately 5.6 m (18.5 ft), and the lowest interior elevation is roughly 3.2 m (10.6 ft) (1929 NGVD unless expressed otherwise). The Refuge interior exhibits a general slope in elevation from north to south, with typical wet prairie or slough elevations as high as 5.0 m (16.3 ft) in the north, and as low as 3.9 m (12.5 ft) in the south (Richardson et al. 1990; Desmond 2003; USFWS 2007a, b). Average interior marsh soil surface elevation is approximately 4.6 m (15.0 ft). Historically, water flowed generally from north to south following the natural elevation gradient. Impoundment of the area has altered flow magnitude and direction. Water discharged into the Refuge perimeter canals either stays in the canals, eventually passing out through discharge structures on the east or south, or flows in and out of the marsh on the east and west sides (USFWS 2007a, b).

Water levels are managed by the U.S. Army Corps of Engineers (USACE) and SFWMD based on a Water Regulation Schedule (USFWS 2000; USFWS 2007a, b). The current schedule (**Figure 1-2**), implemented in 1995, has an upper level of 5.3 m (17.5 ft) and a floor of 4.3 m (14 ft). There are four zones defined in the Regulation Schedule and Zone A1 declines from January through early May by 0.32 ft $month^{-1}$ (0.098 m $month^{-1}$) or 0.01 ft d^{-1} (0.003 m d^{-1}) from 17.12 ft (5.2 m) down to 15.75 ft (4.8 m). Zone A1 is is constant at 15.75 ft (4.8 m) from early May through mid-June. From mid-June (15.75 ft;

4.8 m) through late September (17.5 ft; 5.3 m) the schedule rises at a rate of 0.66 ft month^{-1} (0.2 m month^{-1}) or 0.02 ft d^{-1} (0.01 m d^{-1}). The schedule is constant from late-September through November and declines through December at a rate of 0.37 ft month^{-1} (0.11 m month^{-1}) or 0.01 ft d^{-1} (0.003 m d^{-1}) down to 17.13 ft (5.22 m). Based on this schedule, outflows are determined from stage and the need for water supply and flood protection.

The marsh is a mosaic of habitats including slough, wet prairie, sawgrass, brush, tree islands, and cattail. Community location and type are determined by elevation, hydrology, and soil and water quality (USFWS 2007a, b). Hydroperiods near canals in the central and north part of the marsh are shorter than in the center and southern marsh. In general, water depths are shallower in the north and deeper in the south. Hydroperiod and water depth are key factors in determining vegetation patterns in the marsh. Dry conditions result in predominance of brush or sawgrass. Areas that are wet are characterized by slough or open water.

To protect Refuge resources, resource managers must be able to identify potential threats to the Refuge, keep unimpacted areas from becoming impacted, and maximize the potential for the recovery of impacted areas. Hydrology and water quality information is critical for management decisions to meet the multiple purposes of the Refuge and for overall Everglades restoration. In 2004, as a result of this recognition, Congress appropriated funds specifically to the Refuge for development of an enhanced water quality monitoring network and hydrodynamic and water quality models. The appropriation was intended to improve the scientific understanding of water quality issues in the Refuge and provide information for better water management decisions.

A work plan was developed (Brandt et al. 2004) outlining studies to provide scientifically supported management recommendations. In this report, we attempt to address the following questions:

- What are the general patterns of environmental conditions to include: hydrology, water quality, and ecological links to hydrology and water quality?
- Under what operational or environmental conditions does canal water flow (intrude) into the marsh and how far does it intrude?
- How does relative flow through different structures affect water flow and water quality within the interior marsh?
- If there are potential negative impacts of pump, structure, or STA operations, how can they be minimized/eliminated?
- When water supply releases from the eastern Refuge boundary are made up by increased Refuge inflows, what is the optimal pattern of structure operations?
- When canal stages are below the interior marsh elevation, what are the impacts of water supply releases on interior surface water and groundwater conditions?
- Does the water depth (duration and frequency) satisfy the needs of plant communities and associated wildlife?
- What are the spatial and temporal distributions of phosphorus concentrations within the Refuge?

- What was the impact of moving the location of inflows?
- What are the impacts of management decisions and strategies on the water quality?
- What can be done to eliminate exceedances to the interim and long-term levels of the Consent Decree?

Completely answering most of these questions requires a broader range of environmental conditions (e.g., canal inflows). Since 2004, canal water inflows to the Refuge have remained below historic annual inflows, with 2007 inflow volume more than one standard deviation below mean inflow volumes from 1999 through 2007. The ability to completely answer most of these previous questions will be possible when the Refuge experiences higher than average inflows..

Questions from the original work plan that have not yet been extensively addressed include:

- Should we continue to require that all make-up water be provided prior to water supply releases?
- What is the impact of different management scenarios on the hydroperiod?
- What are the impacts of alternative regulation schedules on the water quantity (stage) and quality (total phosphorus, chloride, and possibly other constituents (e.g., sulfate) in the Refuge?
- How does (and what are the effects of) surface and ground water interact in the Refuge?
- How do new inflow volume and concentration boundary conditions representing STA design alternatives impact the Refuge hydrology and water quality?

Four areas of study were implemented to provide information for addressing all the above questions:

1. additional monthly water quality sampling sites;
2. continually monitored conductivity transects to provide a better understanding of how and when water from the canals moves into the interior marsh;
3. ecological experiments and monitoring; and
4. application of hydrodynamic and water quality modeling to the Refuge.

The original extent of the project was two years. However, additional funds have allowed for the continuation of the projects for an additional three years. This report is the fourth annual report, with analyses of the period from January through December 2007. The 2007 analysis is compared to the preceding years, 2004 through 2006 (Harwell et al. 2005; USFWS 2007a, b).

This report is intended to provide a better understanding of the hydrological, water quality, and ecological conditions of the Refuge. The intended audiences for this report are those interested in tracking the implementation of the project, those interested in the technical details of the work, and resource managers who can use the information as

support for future management decisions. Other information about this program can be found at http://sofia.usgs.gov/lox_monitor_model/.

The report is organized into five chapters. Chapter 1 (this chapter) provides background information for the analyses and interpretations to follow. Chapter 2 presents a descriptive summary of environmental conditions affecting the Refuge, surface water quality in the Refuge, and an analysis of canal water intrusion into the Refuge interior utilizing data from conductivity sondes. Chapter 3 introduces and present preliminary results of the ecological effects program. Chapter 4 presents an update on the hydrodynamic and water quality modeling efforts. Chapter 5 provides a management implications summary for the technical chapters and discusses unanswered questions and future monitoring and research needs.

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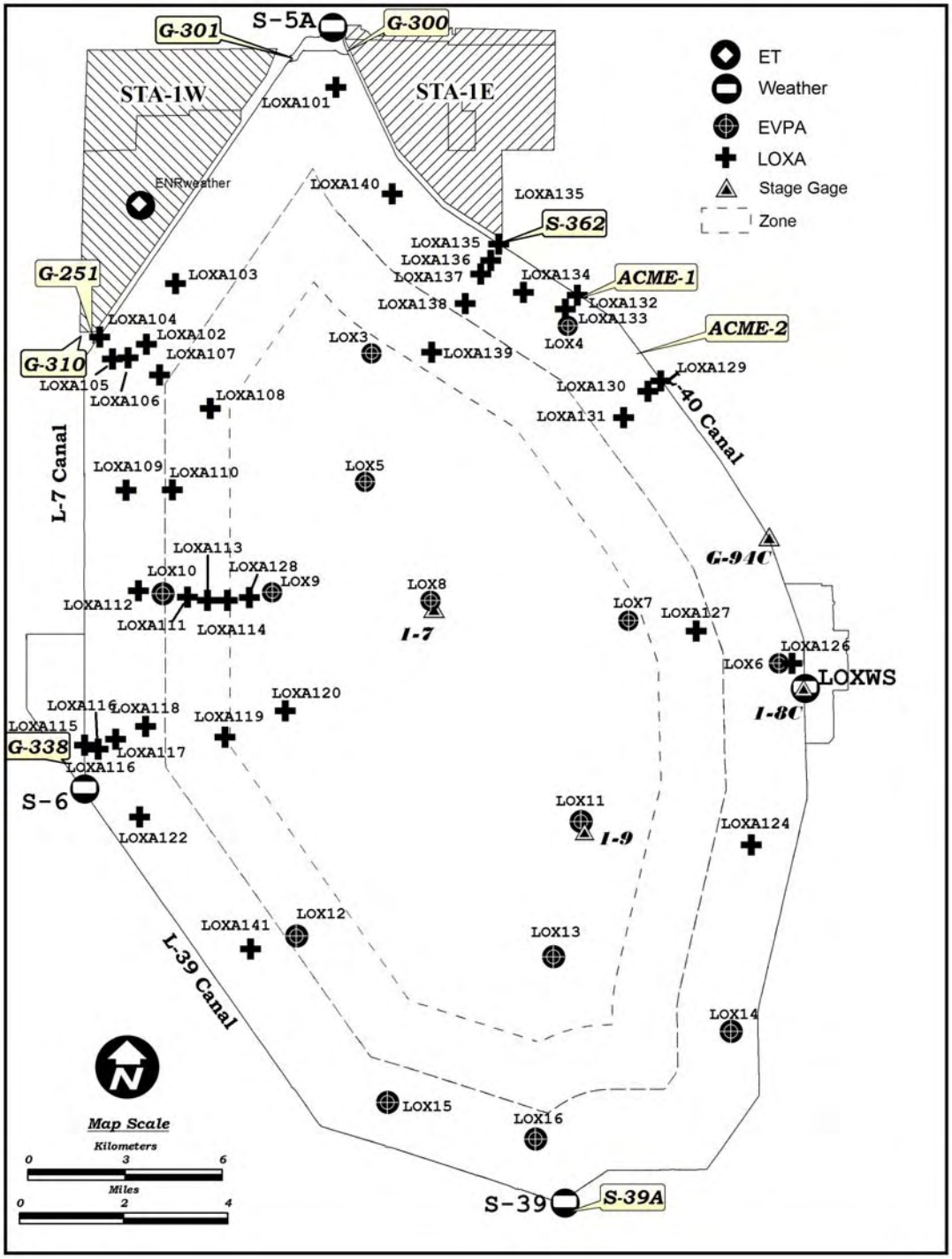
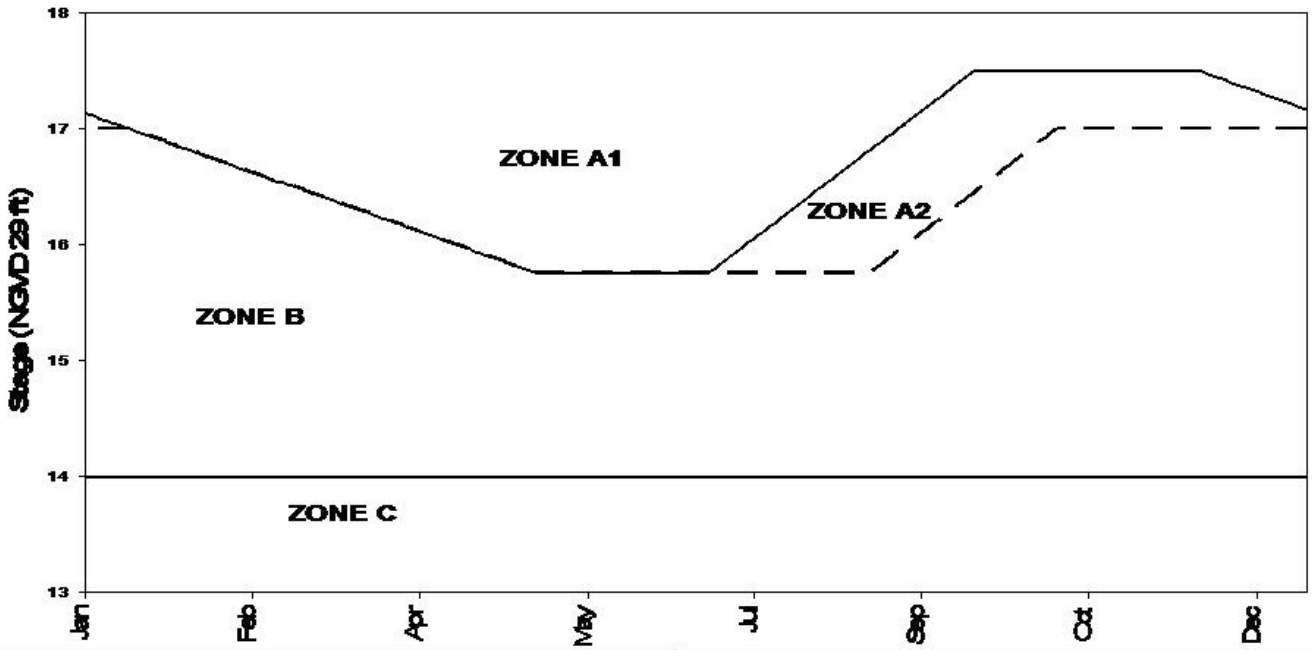


Figure 1-1. Map of the Arthur R. Marshall Loxahatchee National Wildlife Refuge with locations of monitoring stations, water control structures, weather gages, stage gages, and marsh zones used in the analysis presented through this report.



DATES	USE GAGE	CONDITIONS
1 Jan – 30 Jun	1-8 Canal	All
1 Jul – 31 Dec	1-8 Canal	Except as noted below
	Avg, 1-7, 1-8T, 1-9	During rising stage when canal stage exceeds average.

ZONE	RELEASES
A1	Up to maximum at S-10 (and S-39 when agreed between Corp and SFWMD. Water supply releases as needed.
A2	S-10 releases based on Corps forecasts. Water supply releases as needed. If Lake Okeechobee stage is above WCA-1 stage or no more than one foot below WCA-1 stage, then water supply release from WCA-1 must be preceeded by an equivalent volume of inflow.
B	Water supply as needed. If Lake Okeechobee stage is above WCA-1 stage or no more than one foot below WCA-1 stage, then water supply releases from WCA-1 must be preceeded by an equivalent volume of inflow.
C	No net releases from WCA-1. Any water supply releases must be preceeded by an equivalent volume of inflow.

Figure 1-2. Water Regulation Schedule for the Arthur R. Marshall Loxahatchee National Wildlife Refuge (USFWS 2000).

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CHAPTER 2: REFUGE ENVIRONMENTAL CONDITIONS[3]

Abstract

In June 2004, the A.R.M. Loxahatchee National Wildlife Refuge (Refuge) initiated an enhanced water quality monitoring network (LOXA) intended to improve the scientific understanding of water movement in and out of the Refuge, and water quality in the Refuge marsh. Combining monitoring data from the LOXA network with data from the longer running Federal Consent Decree compliance monitoring network (EVPA), and regional and local hydrologic data allows us to characterize environmental conditions in the Refuge marsh and provide suggestions to best manage water in the system. In 2007, most of South Florida experienced a third consecutive year of meteorological drought conditions. Total rainfall for the Refuge in 2007 was 42 inches (1,067 mm), slightly lower than the previous analyzed years (2004 through 2006), but much lower than the historic (1963 to 2006) annual rainfall (52 inches; 1,321 mm). Water inflow volumes (discharges into the Refuge through a network of canals) were 37 to 64% lower than annual inflow volumes from 2004 through 2006. The lower inflows in 2007 were partially a result of continuing rainfall deficit north of the Refuge. From March through July 2007, canal stages decreased below marsh stages. The canal stage decline resulted in a decline in marsh stages, and the decline in marsh stage exposed between 10 and 34% of the marsh. After July, canal stages increased to match marsh stages and both stages began to increase rapidly into October 2007 because of high canal inflows (> 2,500 cfs; 3,083 acre-ft; 3,801 ML^{-1})), canal water intrusion into the marsh (movement of water from the perimeter canal into marsh interior) extended as much as 2.3 km. Relative to previously analyzed years, constituents measured from monthly water quality samples (total phosphorus, total nitrogen, chloride, specific conductivity, and sulfate) in the marsh remained relatively low, with the exception of October 2007, when levels spiked in the marsh near the canal, triggering an excursion of the total phosphorus long-term limit as defined by the Federal Consent Decree. One Refuge management goal is protecting the Refuge ecology, thus protecting Refuge water quality is important because the historically oligotrophic, low mineral (soft water) environmental condition was a major Refuge ecosystem characteristic. Two major management recommendations from these analyses include maintaining inflows at low rates (≤ 200 cfs; 397 acre-ft; 489 ML^{-1})) for short durations (≤ 5 days), and if inflows have to be high, they should be balanced with equal or greater outflows.

Background

Prior to June 2004, water quality in the Refuge interior was primarily monitored using the 1992 Federal Consent Decree (Case No. 88-1886-CIV-MORENO) compliance network (EVPA). These 14 stations (**Figure 2-1**), monitored since 1978, characterize the central region of the interior marsh, leaving a relatively large region uncharacterized,

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predominantly in the outer, impacted fringe of the wetland (Harwell et al. 2005; USFWS 2007a, b). In June 2004, the Refuge initiated an enhanced water quality monitoring network (LOXA) intended to improve the scientific understanding of water movement in and out of the Refuge, water quality in the marsh, and to provide information that can be incorporated into water management decisions to better protect Refuge resources (Brandt et al. 2004). The enhanced monthly sampling focuses on areas near surface water discharge sites in areas uncharacterized by the EVPA network (**Figure 2-1**).

The objective of this chapter is to provide a general descriptive summary of environmental conditions, resulting canal water intrusion into the Refuge marsh (movement of water from the perimeter canal into the marsh interior), and associated water quality in the Refuge from January through December 2007 following approaches presented in previous annual reports (USFWS 2007a, b). Further, we compare results in 2007 to results presented in previous water quality reports covering the period from January 2004 through December 2006 (Harwell et al. 2005; USFWS 2007a, b). Thus, this chapter serves as an update to the 2006 annual report (USFWS 2007b). This chapter presents the following: characterization of environmental conditions, including rainfall, evapotranspiration (ET), atmospheric deposition, Refuge water inflows and outflows, canal and marsh stage, and canal water intrusion into the Refuge marsh; and characterization of water quality in the canal, perimeter, transition, and interior regions of the Refuge marsh.

We also compare hydrologic indicators (e.g., hydroperiod and storage) for the period from 2004 through 2007 to pre-1995 water Regulation Schedule implementation. This comparison is useful in determining whether the Refuge is meeting any of the expected schedule targets. Brandt (2006) showed that increasing hydroperiods above those observed prior to the 1995 Regulation Schedule has the potential to improve habitats for aquatic organisms and increase protection of the Refuge habitats from droughts. Increasing Refuge storage capacity helps the Refuge avoid yearly dry-outs, which has the potential to improve flood management operations.

Methods

Environmental Conditions. Rainfall, ET, atmospheric deposition, flow, stage, and additional water quality data were downloaded from the South Florida Water Management District (SFWMD) data web portal, DBHYDRO and data were current as of July 14, 2008 (http://my.sfwmd.gov/portal/page?_pageid=2235,4688582&_dad=portal&_schema=PORTAL). All stage data presented in this report are relative to the NGVD 1929 datum. Data from the USGS 1-7 stage gage (**Figure 2-1**) were used as estimates of marsh stage values; canal stage data from the headwater gage of the G-94C outflow spillway structure (**Figure 2-1**) were used for continuity with previous reports. Refuge inflow and outflow were aggregated as the total daily average flow. Inflow records for ACME-1, ACME-2, G-310, G-251, S-362, G-300, and G-301 were used for daily average inflow into the canals; outflow records at G-300, G-301, G-94A, G-94B, G-94C, S-10A, S-10C, S-10D, and S-39 were used for daily average outflow out of the canals (**Figure 2-1**). Data from

G-338 also were considered, but the data were sparse and not included in these analyses. Daily rainfall data were averaged from the LOXWS, S-6, S-39, and S-5A weather stations (**Figure 2-1**). Rainfall volumes were reported in inches and millimeters (mm) and also scaled up to acre-feet using a Refuge marsh area of 150,000 acres (for ease in calculations and estimations). Wet deposition of total phosphorus (TP), total nitrogen (TN, the sum of nitrate plus nitrite and Total Kjeldahl Nitrogen), chloride (Cl), and sulfate (SO_4) was estimated (median values) from the ENRWET site located in Stormwater Treatment Area (STA) 1W, northwest of the Refuge. Evapotranspiration (ET) was calculated at the ENRWET site using a calibrated model dependent on solar radiation and latent heat of water vaporization (Abtew et al. 2004). Groundwater seepage was assumed to be relatively small and less variable than rainfall and pumped inflows, and is not directly monitored. Loss to groundwater was therefore not considered in this analysis. Ongoing modeling studies should better characterize these losses. Water quality data were collected from DBHYDRO for all sites from January 2004 through May 2006 and for LOX3 through LOX16 from June 2006 through December 2007. Between June 2006 and December 2007, water quality data for LOXA101 through LOXA141 were analyzed by Columbia Analytical Services; these data are located on the Technical Oversight Committee pages within the SFWMD web portal (https://my.sfwmd.gov/portal/page?_pageid=2235,4688652,2235_7374096:2235_20510178&_dad=portal&_schema=PORTAL – Last accessed August 19, 2008).

Hydroperiod. Daily estimates of marsh hydroperiods were calculated using the difference between the 1-7 stage gage (**Figure 2-1**) and marsh elevations of 15 ft, 15.5 ft, and 16 ft (4.57, 4.72 and 4.88 m, respectively) for the period 2004 through 2007. The percent of the Refuge dry at these elevations were determined in ArcGIS based on the 400 square meter grid DEM (Desmond 2003). Marsh elevations of 15, 15.5, and 16 ft (4.57, 4.72 and 4.88 m, respectively) represent approximately 65, 34, and 10% of the Refuge marsh, respectively. Hydroperiod data are presented as cumulative frequency of daily water elevation greater than marsh elevations. Pre-1995 hydroperiods for the Refuge were acquired from Brandt (2006).

Storage. Annual storage for the period from 2004 through 2007 was determined based on the stage to storage relationship developed by the U.S. Army Corp of Engineers (Brandt 2006). Stages used to determine the storage are the annual mean stage at the 1-7 gage. The 2004 through 2007 storage volumes are compared to the pre-1995 storage volumes which were acquired from Brandt (2006).

Canal Water Intrusion. Thirty-four conductivity monitors (sondes) were deployed in the Refuge (**Table 2-1**) for the purpose of tracking movement of water toward and away from the perimeter canals. Sondes were deployed along six transects approximately perpendicular to the canal surrounding the Refuge marsh. Additional sondes also were deployed at sites perpendicular to the main transects to document conductivity parallel to the canal within the marsh. Sondes record hourly temperature and conductivity. This report presents canal water intrusion estimates only for transects originating at the STA-1W and STA-1E discharge structures. Other transects are not presented because marsh water levels were too low for sondes to record data. No attempts are made to fill in gaps

when dry-down occurs along the STA-1W and STA-1E transects and these periods are represented by gaps in the time-series. Historical information from other transects are presented in USFWS (2007a, b).

We used a time-series dataset of the 350 and 500 μS cm^{-1} conductivity isopleth locations as indicators of canal water intrusion into the marsh for the period from January through December 2007, and compared these findings to 2005 and 2006 results. Conductivity isopleths were determined by interpolating conductivity between sites that bracket each of the conductivity values (USFWS 2007a, b; Surratt et al. 2008). The 350 μS cm^{-1} isopleth was selected because negative impacts to plant growth have been observed at this conductivity level (McCormick and Crawford 2006); the 500 μS cm^{-1} isopleth was selected because in 2004 this value represented an approximate 50:50 mixture of canal water conductivity (~1,000 μS cm^{-1}) and water originating as rainfall within the interior (< 100 μS cm^{-1}) (USFWS 2007a).

Water Quality. Total phosphorus (TP) flow-weighted mean (FWM) concentrations at the STA structures discharging into the Refuge were estimated from outflow volumes, and TP outflow concentrations acquired from DBHYDRO.

Surface water grab samples were collected monthly as part of two monitoring networks (EVPA and LOXA) encompassing a total of 47 marsh stations, and five stations in the perimeter canals. Following SFWMD procedures (SFWMD 2005), samples were transferred to an analytical laboratory for individual analysis after being filtered (if necessary) and preserved, while complying with holding time restrictions. Water quality laboratory analysis was performed by the SFWMD from January 2004 through May 2006, and by Columbia Analytical Services from June 2006 through December 2007 for the LOXA network. All samples from the EVPA monitoring network were analyzed by the SFWMD.

Twenty-one parameters were analyzed from samples collected when depth of the clear water column (Tdepth) was greater than 20 cm (0.66 ft) (**Table 2-2**). To reduce sediment entrainment into the water column during sampling of water with depths less than 20 cm (0.66 ft) but greater than 10 cm (0.33 ft), smaller sampling bottles were used for sample collections. Only TP, Cl, and SO_4 are analyzed from smaller volumes collected when Tdepth was between 10 and 20 cm (0.33 and 0.66 ft, respectively) because of the small volume of water collected. When reported concentrations were below minimum detection limits (MDL), half the MDL was applied in data analyses.

Marsh water quality was characterized in this report using monthly values for TP, TN, conductivity, Cl, SO_4, Tdepth, and depth to consolidated substrate (DCS) following the methods presented in USFWS (2007a, b) and Harwell et al. (2008). Total phosphorus geometric mean concentrations for the entire marsh network (all 52 stations) also were summarized (**Appendix 2-1**). Gaps in data for any parameter were treated as missing data.

The Refuge interior was classified into several geographic zones based upon conductivity data variability and changes in median conductivity as a function of distance from the perimeter canal as presented in USFWS (2007a, b). For the analyses presented here, the following zones were identified:

- Canal: sites located in the canal
- Perimeter: sites located from the canal to 2.5 km (1.6 miles) into the marsh
- Transition: sites located from 2.5 km to 4.5 km (1.6 to 2.8 miles) into the marsh
- Interior: sites located greater than 4.5 km (2.8 miles) into the marsh

Results

Environmental Conditions

Rainfall. The rainfall pattern in 2007 was similar to the historic average, with heavy frequent rain events occurring from May through October and less intense and infrequent rain events occurring from January through May (**Figure 2-2a**). Monthly rainfall in 2007 averaged 3.5 inches (88.9 mm) (**Figure 2-3**), with a range of 0.2 inches (5 mm) in November to 8.0 inches (203 mm) in September. Average monthly rainfall in 2007 was similar to the 2004 (3.5 inches; 88.9 mm) and 2006 average (3.5 inches; 88.9 mm), but lower than the 2005 average (4.0 inches; 102 mm). Cumulative rainfall for 2007 was 42 inches (1,067 mm), similar to 2004 and 2006, lower than 2005 (48 inches; 1,218 mm), and 10 inches (254 mm) lower than historic (1963 through 2006 – data not shown).

Evapotranspiration. Monthly 2007 variation in ET was similar to the previous year's variation **(Figure 2-2a)**. Average monthly ET in 2007 was 4.4 inches; 112 mm);(**Figure 2-3**) with a range of 2.9 inches (74 mm) in December to 5.8 inches (147 mm) in May. Cumulative ET for 2007 was 52 inches (1,321 mm) and was similar to ET in 2004, slightly higher than in 2005 (50 inches; 1,270 mm) and slightly lower than in 2006 (54 inches; 1,362 mm). Over the course of the year, there was a 10.5 inches (267 mm) negative balance between rainfall and ET, meaning there was net 10.5 inches (267 mm) less rainfall than ET. This negative balance was similar to previous negative balances observed from 2004 through 2006.

Atmospheric Deposition. Median TP wet deposition concentration (**Table 2-3**) in 2007 (6 $\mu g\ L^{-1}$) was similar to 2005 and 2004 concentrations, but twice 2006 concentrations. Median TN (0.4 mg L^{-1}), Cl (0.8 mg L^{-1}), and SO_4 (0.8 mg L^{-1}) wet deposition concentrations in 2007 were similar to previous years.

Canal Inflows and Outflows. Average monthly inflow to the Refuge in 2007 was greatest between July (245 cfs; 486 acre-ft; 599 ML^{-1})) and October (1,000 cfs; 1,894 acre-ft; 2,446 ML^{-1}; **Figure 2-2b and Figure 2-4**). Average monthly inflow was lowest in April and May 2007 (< 1 cfs; 1.9835 acre-ft; 2.45 ML^{-1}) (**Figure 2-4**). These inflow rates were not as low in April and May for the period from 2004 through 2006. The lowest April inflow from 2004 through 2006 was observed in 2006 with an average inflow of 3 cfs

(5.95 acre-ft; 7.34 ML^{-1}), while the May lowest inflow from 2004 through 2006 was observed in 2004 with an average inflow rate of 92 cfs (182 acre-ft; 225 ML^{-1}).

Average monthly outflow rates from the Refuge never increased above 530 cfs (1,051 acre-ft; 1,296 ML^{-1}) in 2007 (**Figure 2-2b** and **Figure 2-5**). Peak average monthly outflow rates in 2007 were much lower than those observed in 2004 (3,100 cfs; 6,149 acre-ft; 7,583 ML^{-1}), 2005 (1,500 cfs; 2,975 acre-ft; 3,668 ML^{-1} average), and 2006 (1,300 cfs; 2,579 acre-ft; 3,179 ML^{-1} average; **Figure 2-5**) likely because of lower inflows in 2007. Highest average monthly outflows in 2007 were observed in March (346 cfs; 686 acre-ft; 846 ML^{-1}), October (530 cfs; 1,051 acre-ft; 1,296 ML^{-1},) and November (400 cfs; 793 acre-ft; 978 ML^{-1}). For the rest of the year, outflows ranged between 0 (May, September, and December) and 211 cfs (418 acre-ft; 516 ML^{-1} ; total; January).

Overall Hydrologic Inputs and Outputs. Hydrologic inputs are defined as the sum of canal water inflows and rainfall. Hydrologic outputs are defined as the sum of canal outflows and ET. Data in this section are presented in **Figure 2-3**.

Rainfall volumes totaled 523,000 acre-ft (644,859 ML^{-1}) in 2007 and monthly totals were low from January through April, ranging from 5,000 to 18,000 acre-ft (6,165 to 22,194 ML^{-1}). Rainfall volumes increased from 30,000 acre-ft (36,990 ML^{-1}) in May to more than 95,000 acre-ft (117,135ML^{-1}) in June and remained above 58,000 acre-ft (71,514 ML^{-1}) through October. Rainfall volumes observed in June and September (101,000 acre-ft; 124,533 ML^{-1} each month) 2007 were the highest observed since Tropical Storm Arlene in June 2005. The 2007 total rainfall volume was similar to annual rainfall volume from 2004 through 2006, but much lower than the historic (1963 through 2006) volume of 650,000 acre-ft (801,450 ML^{-1}).

Canal inflow volumes totaled 179,000 acre-ft (220,707 ML^{-1}) in 2007 and monthly totals were low from January through June, ranging from 28 to 4,400 acre-ft (34.5 to 5,425 ML^{-1}) . Canal inflow volumes increased monthly from July (15,000 acre-ft; 18,495ML^{-1}) through October (64,000 acre-ft; 78,912 ML^{-1}). Among the years from 2004 through 2007, 2007 was the only year to have monthly total volumes below 1,300 acre-ft (1,603 ML^{-1}) for five consecutive months. The 2007 total canal inflow volume was approximately 37% less than in 2005 and 2006 and 64% less than in 2004 (see also **Figure 2-2b**).

Evapotranspiration totaled 654,000 acre-ft (806,382 ML^{-1}) in 2007. Volumes increased from January (39,000 acre-ft; 48,087 ML^{-1}) through May 2007 (72,000 acre-ft; 88,776 ML^{-1}) and declined monthly from August through December (37,000 acre-ft; 45,621 ML^{-1}). The 2007 monthly ET pattern and annual volume were similar to monthly patterns and annual volumes observed from 2004 through 2006.

Canal outflow volumes totaled 108,000 acre-ft (133,164 ML^{-1}) in 2007 and were near zero in May, June, September, and December. The highest volume of canal outflow was observed in October at 33,000 acre-ft (40,869 ML^{-1}), which was much lower than maximum outflow volumes observed between 2004 and 2006. The 2007 total canal

outflow volume was approximately 50% less than in 2005 and 2006 and 76% less than in 2004 (see also **Figure 2-2b**).

Overall, total water into the Refuge (sum of rainfall and canal water inflow) for 2007 was substantially lower than annual values from 2004 through 2006. In 2007, total water into the Refuge was approximately 701,000 acre-ft (864,333 ML^{-1}), which was 14% less than in 2006, 20% less than in 2005, and 30% less than in 2004. Between 2004 and 2007, rainfall became an increasingly large fraction of the total water entering the Refuge – 50% and 75%, respectively.

Total water out of the Refuge (sum of ET and canal water outflow) for 2007 also was substantially lower than annual values from 2004 through 2006. In 2007, total water out of the Refuge was approximately 762,000 acre-ft, (939,546 ML^{-1}) which was 14% less than in 2006, 9% less than in 2005, and 30% less than in 2004. From 2004 through 2007, ET became an increasingly large fraction of the total water leaving the Refuge – 60% and 85%, respectively.

Canal and Marsh Stage. Mean canal stage in 2007 was 15.9 ft (4.85 m) and ranged from 13.6 (4.15 m) to 17.5 ft (5.33 m) (**Figure 2-2c**). Mean canal stage in 2007 was similar to 2004 and approximately 0.3 ft (0.09 m) lower than 2005 and 2006 mean canal stages. In March 2007, canal stage declined at a rate of 0.06 ft d^{-1} (0.18 m d^{-1}) from 16 ft (4.88 m) to 14.2 ft (4.33 m). Canal stage continued to decline through April and May, and by the beginning of June stage had declined to 13.6 ft (4.15 m). From the beginning of June through the middle of June, canal stages increased by more than a foot at a rate of 0.07 ft d^{-1} (0.021 m d^{-1}), From mid-September to mid-October 2007, canal stages increased more than 0.6 ft (0.18 m d^{-1}). This stage change increased canal stages above 17 ft (5.18 m) through early December 2007.

Mean marsh stage in 2007 was 16.3 ft (4.97 m) and ranged from 15.2 (4.64 m) to 17.4 ft (5.30 m) (**Figure 2-2c**). Mean marsh stage in 2007 was similar to the period from 2004 through 2006. Between early March 2007 and early April 2007, marsh stage declined at a rate of 0.02 ft d^{-1} (0.006 m d^{-1}) from 16.3 ft (4.97 m) to 15.7 ft (4.79 m) and declined to 15.24 ft (4.65 m) by mid-May, when stages began to increase. From early June through mid-June, marsh stages increased 0.8 ft (0.24 m) at a rate of 0.04 ft d^{-1} (0.012 m d^{-1}) From mid-September to mid-October 2007, marsh stages increased more than 0.6 ft 0.1m m). This stage change increased marsh stages above 17 ft (5.18 m) through late November 2007.

Canal and marsh stage relationships were similar between 2007 and 2004. Both 2007 and 2004 had notable decoupling of stages from late January to June (2007) and late February to August (2004). The decoupling began earlier in 2007 than in 2004, with canal stages more than 1.7 ft (0.52 m) lower than marsh stage in May 2007 and more than 2 ft (0.61 m) lower in June 2004.

Hydroperiods. Annual hydroperiods were 73%, 83%, 78%, and 70% for 2004, 2005, 2006, and 2007, respectively, at marsh elevations 16 ft (4.88 m) and greater (10% of the

Refuge area). Annual hydroperiods were 99%, 100%, 100%, 93% for 2004, 2005, 2006, and 2007, respectively, at marsh elevations 15.5 ft (4.72 m) and greater (34% of the Refuge area). Annual hydroperiods were 100% from 2004 through 2007 at marsh elevations 15 ft (4.57 m) and lower.

Beyond differences in hydroperiods among years, the period when the Refuge marsh experienced dry-down for each year differed from 2004 through 2007 (**Figure 2-6a**). The dry-down patterns between 2004 and 2007 were similar. In 2007, dry-down at the 16-ft (4.88 m) marsh elevation began in March and continued through June, while at 15.5 ft (4.72 m) dry-down began in April and lasted through most of May. In 2004, dry-down at the 16-ft (4.88 m) marsh elevation began in late April and continued through early August, while at 15.5 ft (4.72 m), dry-down lasted three days in early June. Marsh dry-down at 15.5 ft (4.72 m) was most extensive in 2007, likely linked to the reduced canal water inflows in 2007.

Annual hydroperiods at the 15.5-ft and 16-ft marsh elevations for each year from 2004 through 2007 were longer than the 1975 through 1995 (Brandt 2006) mean annual hydroperiods (**Figure 2-6b**). Mean annual hydroperiods at 15.5 and 16 ft from 1975 through 1995 were 88% ± 21% (%± standard deviation) and 63%±26%, respectively. Mean annual hydroperiods from 1975 through 2007 at 15.5 and 16 ft were 89.9 %± 19.6% and 69.7% ± 23.4%, respectively. Based on the hydropatterns, it appears that hydroperiods increased for the period from 1995 through 1999, but have been declining since 2000. The declining length of hydroperiods after 2000 is still longer than prior to 1981, but comparable to the period from 1981 through 1987.

Storage. Mean annual storage from 1975 through 1997 was 184,300 acre-ft (227,242 ML^{-1}) (Brandt 2006). Annual storage for each year from 2004 through 2007 was 204,500 acre-ft (252,149 ML^{-1}) (**Figure 2-7**). Annual storage for each year from 2004 through 2007 was also higher than the entire period from 1975 through 2007 (193,785 ± 42,651 acre-ft; 238,937 ± 52,589 ML^{-1}).

Canal Water Intrusion. Inflow and outflow (**Figure 2-8a**) and canal and marsh stage (**Figure 2-8b**) are presented again with intrusion (**Figure 2-8c,d**) data for interpretation purposes. In 2007, canal water intrusions along the STA-1W transect (**Figure 2-8c**) indicated by the 500 $\mu S\ cm^{-1}$ isopleth averaged 0.9 km (median: 0.8 km). Following the 350 $\mu S\ cm^{-1}$ isopleth, intrusions averaged 1.3 km (median: 1 km).

In 2007, intrusions along the STA-1E transect (**Figure 2-8d**) averaged 0.3 km (median: 0.2 km) as indicated by the 500 $\mu S\ cm^{-1}$ isopleth. Following the 350 $\mu S\ cm^{-1}$ isopleth, intrusions averaged 0.8 km (median: 0.8 km) .

Because of low water levels and sporadic malfunctioning sondes during a fraction of the year, intrusion was calculated for only a fraction of the year. Thus, the average intrusion for these transects may be biased to the period when water levels were high.

Maximum intrusion along the STA-1W transect indicated by the 500 μS cm^{-1} isopleth was 1.9 km and 2.3 km indicated by the 350 μS cm^{-1} isopleth. This intrusion represents the largest intrusion distances when data were available from 2005 through 2007. Maximum intrusion along the STA-1E transect indicated by the 500 μS cm^{-1} isopleth was 0.7 km and 1.7 km indicated by the 350 μS cm^{-1} isopleth. These maxima were observed in mid-October and were associated with high inflows (> 2,000 cfs; 3,967 acre-ft; 4,891 ML^{-1}) and low outflows in early October, when canal and marsh stages increased to greater than 17 ft (5.18 m). These patterns of elevated intrusion and associated flow operations are consistent with intrusion events recorded in 2005 and 2006. Peak intrusion in 2007 along the STA-1E transect was lower than in 2006, but greater than in 2005, likely because STA-1E began operations late in 2005 with small inflows. In June 2007, conductivity at 350 μS cm^{-1} was observed at 1.7 km into the marsh along the STA-1E transect and was likely linked to the rapid increase in canal and marsh stage observed in June.

Water Quality

TP. June and July 2007 had exceptionally high TP discharge concentrations (232 and 817 μg L^{-1} FWM, respectively) in STA-1W outflows (**Figure 2-9a**); however, the outflow volumes and therefore the TP loads were low (Lindstrom 2007a, b). Anomalous operations were related to these elevated TP concentrations (Lindstrom 2008). Ignoring the June and July highs, the STA-1W outflow TP concentrations ranged between 48 (November) and 80 μg L^{-1} FWM (May). The 2007 average annual FWM TP concentration was approximately 50% lower than FWM TP in 2006 and 2005, and 34% lower than FWM in 2004.

The 2007 STA-1E FWM TP concentration discharged to the Refuge was 21 μg L^{-1} and ranged from 17 (October) to 32 μg L^{-1} (April) (**Figure 2-9a**). The STA-1E 2007 FWM TP concentration was 50% lower than 2006, 69% lower than 2005, and 90% lower than 2004 FWM TP concentrations. The mean 2004 concentration reflected only the latter half of the year because discharges from STA-1E to the Refuge began in the middle of year.

In general, the canal TP concentrations followed the STA-1W flow-weighted mean TP pattern and the concentrations were less than STA-1W but greater than STA-1E, similar to patterns often observed from 2004 through 2006 (**Figure 2-9a**). In 2007, TP concentrations in the Refuge canal averaged 51 μg L^{-1} (median: 48 μg L^{-1}) and ranged between 21 (October) and 129 μg L^{-1} (June). Perimeter Zone TP concentrations in 2007 averaged 13 μg L^{-1} (median: 13 μg L^{-1}) and ranged from 7 (March) to 22 μg L^{-1} (October). Perimeter Zone TP concentrations, increased above 20 μg L^{-1} (**Figure 2-9b**) when the canal TP concentration was greater than 120 μg L^{-1} in June and again in September and October when canal water intrusion was greater than 1.5 km into the marsh. Transition and Interior Zone TP concentrations followed the Perimeter Zone TP pattern until September 2007 when both Transition and Interior Zone TP concentration declined (**Figure 2-2c**; **Figure 2-9b**) as canal and marsh water stages plateaued.

Transition Zone TP concentrations (annual mean 7 ± 2 μg L^{-1}; ± 1 SD; median: 7 μg L^{-1}) were not significantly different from Interior Zone (annual mean 9 ± 2 μg L^{-1}; median: 8 μg L^{-1}) concentration in 2007, and both zones had lower concentrations than those observed in 2004 and 2005, while they were similar to concentrations observed in 2006 (**Figure 2-9b**). Mean TP for the entire Refuge systems (mean of canal and marsh combined – data not shown) in 2007 (28 ± 22 μg L^{-1}; median 17 μg L^{-1}) was similar to concentrations observed in 2004 (28 ± 22 μg L^{-1}; median 19 μg L^{-1}) and 2005 (27 ± 13 μg L^{-1}; median 24 μg L^{-1}), but higher than 2006 (19 ± 5 μg L^{-1}; median 22 μg L^{-1}).

TN. In the canal, the 2007 TN concentration averaged 1.5 mg L^{-1} (1.5 mg L^{-1}) and increased from the annual low of 1.1 mg L^{-1} in January to the maximum of 2 mg L^{-1} in June (**Figure 2-10a**). TN concentration patterns through 2007 in the Perimeter, Transition, and Interior Zones were similar to the pattern in the canal, but TN concentrations were significantly lower than canal TN concentrations. Perimeter Zone TN concentrations (mean: 1.1 mg L^{-1}; median: 1 mg L^{-1}) were similar to Transition and Interior Zone TN concentrations. Mean canal TN concentrations were 27% lower than 2006 TN concentrations, 39% lower than 2005 TN concentrations, and 24% lower than 2004 TN concentrations.

Conductivity. In the canal, the 2007 conductivity averaged 530 μS cm^{-1} (median: 543 μS cm^{-1}) and increased from the low of 385 μS cm^{-1} in March to the maximum of 674 μS cm^{-1} in October (**Figure 2-10b**). Perimeter, Transition, and Interior Zone conductivity values were significantly lower than values in the canal. Perimeter Zone conductivity averaged 300 μS cm^{-1} (median: 270 μS cm^{-1}) and was significantly greater than transition (153 μS cm^{-1}; median: 144 μS cm^{-1}) and interior (137 μS cm^{-1}; median: 122 μS cm^{-1}) conductivity. Perimeter Zone conductivity was below 300 μS cm^{-1} from January through September with relatively low variability (< 13%). In October, Perimeter Zone conductivity (640 μS cm^{-1}) peaked to a value similar to the October canal conductivity. Maximum canal conductivity in 2007 was significantly lower than mean conductivity from 2004 through 2006.

Cl. In the canal, the 2007 Cl concentration averaged 69 mg L^{-1} (median: 69 mg L^{-1}) and remained around 50 mg L^{-1} from March through June and increased to 80 mg L^{-1} and greater through the remainder of the year (**Figure 2-10c**). From January through September, Perimeter, Transition, and Interior Zones Cl concentrations remained near or below 40 mg L^{-1} (samples not collected in May 2007 because of low water levels). In October, Cl concentration in the Perimeter Zone increased to 57 mg L^{-1} and decreased back down to approximately 40 mg L^{-1} in December, while Transition and Interior Zones were much lower than 20 mg L^{-1}. Mean canal Cl concentrations in 2007 were 44% lower than 2006 Cl concentrations, 36% lower than 2005 Cl concentrations, and 27% lower than 2004 Cl concentrations.

SO_4. In 2007, Canal Zone SO_4 concentrations averaged 21 mg L^{-1} (median: 17 mg L^{-1}) and ranged from 5 (March) to 42 mg L^{-1} (June) (**Figure 2-10d**). Canal concentrations were below 20 mg L^{-1} from January through May and Perimeter Zone SO_4 was below 3 mg L^{-1}, while transition and Interior Zones were less than 1 mg L^{-1} through the entire

year. From June through October, Canal Zone concentrations increased above 25 mg L^{-1}, while Perimeter Zone SO_4 concentrations reached a maximum (15 mg L^{-1}) in June. Mean canal SO_4 concentration in 2007 was less than 50% of the annual mean SO_4 concentrations observed from 2004 through 2006.

Discussion

Environmental Conditions

Continuing low rainfall conditions north of the Refuge and water management operations resulted in canal inflow reductions to the Refuge in 2007. Meteorological drought conditions within South Florida began in late-October 2005, intensified through 2006, and became less severe near the end of 2007 (NDMC 2008). Based on Refuge rainfall data, rainfall has been lower than the historic 12-month cumulative rainfall since 2004 and was lowest in 2007. Although rainfall in 2007 was approximately 20% lower than historic rainfall, the largest hydrologic impact was the reduction in canal inflows to the Refuge in 2007 relative to annual inflows for the period from 2004 through 2006 (37 to 64%).

The combination of lower rainfall, decreased inflows, and ET suggests the Refuge was drier in 2007 relative to the period from 2004 through 2006. However, outflows from the Refuge were also reduced in 2007, resulting in the amount of water stored in the Refuge remaining relatively stable over the past four years, but greater than mean historic storage from 1975 through 2007 and much higher than storage prior to the implementation of the 1995 Regulation Schedule. Rainfall, canal inflows, and canal outflows were low from January through May 2007, and during this time, ET had the strongest influence on marsh hydrology. Canal and marsh stages declined almost continuously through the first half of the year. Hydroperiods in 2007 were shorter than during the period from 2004 through 2006. Ten percent of the Refuge (≥ 16 ft ; 4.88 m) marsh elevation) was dry for 30% of the year, while 34% of the Refuge (≥ 15.5 ft; 4.72 m marsh elevation) was dry for 7% of the year. Hydroperiods since the implementation of the 1995 Regulation Schedule have been longer the pre-1995 operations. Since 2000, hydroperiods have become shorter and similar to the period from 1981 through 1987. Thus, it is not clear if post-1995 operations are responsible for the observed longer hydroperiods and greater storage or if climatic cycles (e.g., long-term oscillations in rainfall) are responsible. Regardless, the implementation of the 1995 Regulation Schedule is coincident with the increased hydroperiods and storage, which are anticipated to have direct positive effects for vegetation, small aquatic organisms, and wading birds in the Refuge (Brandt 2006).

Inflow pump operations controlled and ultimately changed the pattern of Refuge inflow and outflow by reducing total inflow to the Refuge in 2007, resulting in reduced TP levels in the Refuge canal. These reduced inflows also translated to reduced canal water intrusion into the marsh and a reduction in marsh TP levels below the long-term average. However, continued and extended decreased inflows to the Refuge below those needed for fully supporting ecosystem functionality can lead to negative flora and fauna impacts. For example, when marsh areas dry-out for several consecutive years, slough areas can

fill in with shrubs and cattails (Brandt 2006). These sloughs serve as habitat for small fish, and when the sloughs dry out, the small fish population density declines. It takes three consecutive years of flooded conditions to return small fish density to pre-dry down conditions (Trexler and Loftus 2001; Trexler et al. 2004; Brandt 2006). Further, when water depths decrease below 4 inches (0.1 m), particularly between April and June, apple snail reproductivity decreases (Brandt 2006).

Marsh elevated water quality conditions in June 2007 were likely related to the rapid (0.05 ft d^{-1}; 0.05 ft d^{-1} ; 0.015 m d^{-1}) re-wetting of the marsh and mixing of constituents from the settled floc layer into the water column. Elevated TP was not likely linked to the elevated STA-1W discharge concentrations in June, because the volumes and loads were exceptionally low (Lindstrom 2008). Conditions prior to the June sampling event included dry marsh with water depths at the east side sampling sites ranging from 10 to 13 centimeters (3.9 to 5.1 inches). From the end of May through mid-June, marsh stages increased by 0.8 ft (0.24 m), while canal stages increased by more than 1.4 ft (0.43 m). In June 2007, rainfall increased; conductivity at 1.5 km into the marsh was elevated; and TP, TN, and SO_4 concentrations spiked in the Canal and the Perimeter Zone, particularly on the east side of the Refuge. Atmospheric deposition was not linked to elevated surface water constituent concentrations, because atmospheric deposition constituent concentrations (data not shown) were consistently below surface water constituent concentrations through the year (NADP 2008). Interestingly, canal stages were below marsh stages, suggesting that canal water intrusion likely was not the cause of elevated water quality conditions observed in June, relative to average conditions for the year.

An excursion of the long-term TP level of the Federal Consent Decree occurred in October 2007 (SFWMD 2008). From August through October 2007, STA-1W and STA-1E discharges increased and flow-weighted mean TP concentrations ranged 50 to 70 mg L^{-1} from the STA-1W and 17 to 23 mg L^{-1} from STA-1E. These STA discharges lead to increased canal inflows beginning in August 2007, which lead to an increase in the extent of canal water intrusion ($\geq$ 1 km). By October 2007, most of the monitored parameter (TP, TN, Cl, conductivity, and SO_4) concentrations in the Canal and Perimeter Zones peaked, and canal water intrusion increased to 2.3 km on the west and 1.7 km on the east sides of the Refuge. Increased canal water intrusion was coincident with increased inflows of long durations (greater than six consecutive weeks) which were not matched by similar outflows and the combination of these conditions likely were linked to the long-term TP excursion in October 2007.

From November through December 2007, water quality constituent concentrations declined and the decline was likely linked to marsh zone mixing and diluting higher concentrations observed in the Perimeter Zone. Rainfall and canal inflows declined in November 2007, while canal outflows increased in October and continued through November at low rates. Canal and marsh stages peaked above 17 ft (5.18 m) in October, and remained relatively high through late November. Stages began to decline at a rate of approximately 0.009 ft d^{-1}, (0.0027 m d^{-1}) similar to the Water Regulation Schedule recession rate (see **Chapter 1**) in December. Canal water intrusion declined to less than or equal to 1 km on the east and west sides of the Refuge and water quality constituent

concentrations declined below or to annual mean levels from November through December because of zone mixing in the marsh.

Analysis Limitations

A number of limitations exist that have the potential to complicate the analyses presented in this report. We take extra care in these analyses to work around the limitation or at least acknowledge these limitations. Sampling frequencies, site spatial distribution, and several other limitation to these analyses are discussed below. Despite these limitations, we still produce valuable information that ultimately increases our certainty in the management recommendations provided in this report.

Sampling frequency is a limitation when trying to determine cause and effect relationships in the marsh. Sampling at monthly intervals creates gaps in system understanding, as many biochemical and hydrologic processes in the marsh (i.e., plant phosphorus uptake, nitrogen fixation, canal water intrusion, etc.) occur at a scale from seconds to days. For instance, data gaps complicated determining the source of the elevated water quality in the marsh during the June 2007 sampling event. If water quality data were available pre- and post-inflows that occurred in June 2007, it would have been easier to determine if constituent concentrations in the marsh were high preceding the event, resulted from intrusion, or resulted from sediment resuspension.

Sampling site distribution is another limitation with monitoring networks. Most of the marsh sites are located in the interior or in the perimeter of the Refuge near water control structures, leaving a large portion of the southern and northern-most areas of the Refuge unsampled and uncharacterized. The northern and southern areas of the Refuge present extremes in habitats and hydroperiods, as the southern area has not dried down from 2004 through 2007 and the northern area rarely is inundated. Better characterization of the northern area would result in better interpretation of how the system responds to continuous drying for several years consecutively. Better characterization of the southern area could translate into better understanding of the system when it remains in a flooded condition for several years consecutively.

Sampling site numbers also limits characterization of the Refuge marsh. The minimum distance between any two sampling points is 600 m; however, topographic and vegetative (i.e., periphyton, submergent, and emergent vegetation communities) patterns vary at a much finer scale. The failure to capture the spatial variability at a finer scale prevents valuable interpretation of ecosystem dynamics in areas unsampled.

Other limitations in these analyses include the topographic dataset, gage datums, the frequency of non-phosphorous sample collection in canal inflows, and lack of more atmospheric deposition sites. The available topographic dataset may be less accurate and precise then desired for analyses here and in the modeling chapter (**Chapter 4**), as has been shown when comparing ground-based estimates of soil elevation to the topographic dataset developed by the USGS. Datums for the gages are all subject to error and these errors may limit specific interpretation of relative depth and stage across the marsh.

Infrequent and often absent collection of non-phosphorus constituents at the inflows adds uncertainty to any attempt to draw cause and effect relationships between Refuge flow management and marsh ecosystem conditions. Lack of atmospheric deposition monitoring in the marsh makes interpretations of nutrient and contaminant sources more difficult.

Implications

Marsh hydroperiods were shorter in 2007 relative to the period from 2004 through 2006. While low water conditions are characteristic of the dry season in the historical Everglades, current conditions of lower water levels and shorter hydroperiods, during the dry season cause stress to the ecosystem (Brandt 2006; Waldon 2007). For example, habitat suitability for epiphytic periphyton assemblages in the Refuge marsh declines when extended (more than 34% of the year – similar to conditions observed at marsh elevations greater than 16 ft (4.88 m)) dry-downs occur, as shrubby vegetation invade in the dry areas, shading the macrophytes on which epiphytic periphyton grow (Gaiser et al. 2004). Further, dry habitats provide lower suitability for fish as extensive dry downs force fish into isolated refugia of limited area, depth, and number, which leads to increased fish mortality because of crowding and decreased oxygen levels (Trexler et al. 2004). Also, during the dry season, low water levels increase the potential for fire damage to vegetation, soils, and wildlife, and may contribute to the spread of invasive exotic species (USFWS 2000).

Alternatively, dry-down periods, mostly in the north, extending through multiple seasons may enhance breeding success of deer in the Refuge interior (USFWS 2008). Many other regions in South Florida (Big Cypress National Preserve, Everglades and Francis S. Taylor Wildlife Life Management Area, and Holey Land Wildlife Management Area) report enhanced deer breeding when water levels are maintained low enough to prevent flooding for several years (FGFWFC 1999). In every year between 2004 through 2007, the Refuge areas where marsh elevations are greater than 16 ft (4.88 m), 10% of the Refuge, dried down to or below the marsh surface. Casual observations of deer within the Refuge interior have been numerous in 2006 and 2007 (Fury 2009). Although dry-downs are beneficial for some species, and historically occurred as a natural driver of the Everglades landscape, dry-downs in the Refuge should not occur more than one year out of three to five consecutive years (Brandt 2006; Waldon 2007). Some of the reasons for this recommendation are to prevent sawgrass and brush from filling slough habitats, reduce the impact on small fish population density, and decrease negative impacts on apple snails during breeding season (Brand 2006). Because of the negative consequences of these consecutive dry periods, a careful balance in dry-downs and wet periods needs to be established.

Canal water intrusion into the Refuge marsh has been documented for decades to have adverse impacts on many vegetative species through the addition of nutrients and minerals (Swift 1984; McCormick and Crawford 2006). For example, desmid and diatom populations decline when conductivity increases above 230 $\mu S\ cm^{-1}$ (Sklar et al.

2005). *Xyris ambigua* has reduced productivity when the plants are exposed to conductivity greater than 350 μS cm^{-1} (McCormick and Crawford 2006). In general, from 2004 through 2007, canal water intrusion has followed periods of dry-down, when inflows tend to cause rapid stage rises in the canal and marsh. Alternatively, inflows when canal and marsh stages are similar tend to result in canal water intrusion. To reduce the negative impacts of canal water intrusion on the marsh, management strategies need to focus on controlling inflows and outflows to reduce canal inflows.

Previous annual reports for the Refuge (Harwell et al. 2005; USFWS 2007a, b) have presented water management suggestions including dry-down frequencies and minimization of canal water intrusion. Some of those suggestions focused on controlling inflows and outflows to minimize canal water intrusion into the marsh. The high extent of intrusion observed from late September through October 2007 was driven by the high rates and duration of canal inflows that were not balanced by equal or higher outflow rates and duration, particularly when canal stages were greater than marsh stages and both were greater than marsh sediment elevation. In the 2005 and 2006 annual reports, we suggested that if canal water inflows were necessary, the inflow rate should be below 200 cfs (397 acre-ft; 489 ML^{-1}) and for a short duration (< five days). One example of low inflows when canal and marsh stages were similar and above the marsh elevation occurred in mid to late December 2007. Inflows for about two weeks averaged 190 cfs (377 acre-ft; 465 ML^{-1}), outflow was zero, canal and marsh stages averaged 17 and 16.9 ft (5.18 and 5.15 m), while canal water intrusion on the west was less than 0.8 km (0.5 miles) and on the east was less than 0.6 km (0.4 miles). It should be noted that the inflows during this period were preceded with three weeks of no flow and total rainfall of more than 1 inch (25.4 mm). Alternatively, if high inflows were necessary and canal and marsh stages were greater than the marsh sediment elevation, then outflows should be timed to inflows and be greater than inflows. This timing of outflows to inflows was not extensively observed in 2007. Because the environmental conditions presented in this report are similar to those reported for 2005 and 2006, we continue to support the water management recommendation to reduce canal water intrusion as characterized here and in previous reports (USFWS 2007a, b). Some of these management recommendations include:

- Refuge inflows should be short duration (≤ 5 days) pulses of < 200 cfs (<5,665 L s^{-1}) when absolute canal/marsh stage difference is < 0.2 ft (< 0.1 m) and interior water depths are < 0.5 ft (< 0.2 m).

- Refuge inflow rates can be moderate (200 to 400 cfs; 5,655 to 11,310 L s^{-1}) for short durations if marsh stage is > 0.6 ft (> 0.2 m) higher than canal stage and waters depths are < 0.3 ft (< 0.1 m).

A previous recommendation (USFWS 2007a) suggested that outflows needed to be up to 3 – 4 times greater than inflows to minimize canal water intrusion. The addition of 2007 information to data from 2004 through 2006 suggests that the difference between outflows and inflows may not need to be as great. Thus, several earlier management recommendations have been further refined:

- Refuge inflows should be discontinued when the canal stage is > 0.2 ft (> 0.1 m) higher than marsh stage, unless the rainfall or outflow volumes are equal to or greater than inflows.

- If Refuge inflows must be extended beyond short-duration pulses, outflow should be equal to or greater than inflow and last several days longer.

- If Refuge inflows must be maintained at high rates, the S-10s and S-39 should be opened in conjunction with canal inflows to create outflow equal to higher than inflow.

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Table 2-1. Time-series conductivity summary statistics and distance from the canal for all transects. Distance around canal originates from LOXA116 and moves clock-wise.

				Conductivity (µS cm^{-1})								
Transect	**Site**	**Distance around canal (km)**	**Distance from canal (km)**	**Average 2007**	**Median 2007**	**Standard Deviation**	**Maximum**	**Minimum**	**25th Percentile**	**75th Percentile**	**Average 2006**	**Median 2006**
STA-1W	LOXA104	12.8	0.0	630	607	199	1069	211	436	784	962	992
	LOXA105	12.9	0.7	633	556	187	968	328	481	832	480	483
	LOXA106	13.4	1.1	396	302	211	921	199	231	571	291	249
	LOXA107	14.4	2.2	195	186	61	359	86	145	230	181	184
	LOXA108	11.1	3.9	130	129	25	209	70	109	143	185	189
S-6	LOXA115	0.1	0.0	608	469	221	1084	299	418	787	958	995
	LOXA116	0.0	0.4	558	502	231	957	233	347	781	768	781
	LOXA117	0.5	0.9	322	253	131	592	227	243	318	547	555
	LOXA118	1.3	1.8	248	213	98	703	133	169	303	250	260
	LOXA119	3.2	4.3	157	151	41	281	98	125	176	158	146
	LOXA120	5.2	6.1	201	157	106	593	91	139	229	164	145
West Central	LOX10	5.5	1.2	169	159	34	217	116	138	209	150	130
	LOXA112	5.0	1.6	254	186	136	1040	116	164	313	205	209
	LOXA111	5.4	3.1	172	168	33	283	97	153	183	140	129
	LOXA113	5.6	3.8	151	149	31	274	72	129	165	155	154
	LOXA114	6.0	4.4	128	132	16	159	83	119	138	142	142
	LOXA128	6.4	5.1	146	145	23	214	93	130	160	137	121
	LOX9	7.4	5.5	143	141	12	199	120	138	145	158	162
STA-1E	LOXA135	33.8	0.0	554	543	130	1019	281	490	627	868	842
	LOXA136	34.0	0.6	335	352	101	516	173	218	419	609	638
	LOXA137	34.1	1.1	280	297	96	458	149	181	365	445	482
	LOXA138	34.8	2.1	171	151	48	319	113	142	175	302	282
	LOXA139	36.2	3.9	95	95	10	122	73	88	104	159	164
ACME-1	LOXA132	36.7	0.0	539	546	115	948	291	468	605	822	789
	LOXA133	36.7	0.6	319	301	98	507	169	234	427	533	581
	LOX4	36.7	1.2	239	238	67	381	77	204	251	417	425
ACME-2	LOXA129	40.5	0.0	526	534	112	895	189	447	611	808	784
	LOXA130	40.6	0.5	341	339	76	602	186	299	401	575	563
	LOXA131	41.2	1.5	212	205	43	465	127	180	238	314	310
East Central	LOXA126	50.5	0.4	264	225	93	449	174	184	392	368	307
	LOX6	50.8	1.1	311	332	75	429	145	268	368	274	260
	LOXA127	50.0	3.1	148	140	32	228	96	126	176	157	156
	LOX7	47.4	5.5	120	111	32	235	70	99	126	171	162
	LOX8	48.4	9.7	112	106	22	168	86	95	126	159	145

Table 2-2. Water quality monitoring parameters for the A.R.M. Loxahatchee National Wildlife Refuge Enhanced Water Quality Program (LOXA).

PARAMETER	ID[1]	Units	MDL	Method
ALKALINITY, TOTAL as CACO3	ALKA	mg L^{-1}	1	EPA 310.1
CALCIUM	Ca	mg L^{-1}	0.2	SM3120B
CHLORIDE	Cl	mg L^{-1}	0.1	EPA 300.0
DEPTH	DEPTH	cm		FIELD
DISSOLVED OXYGEN	DO	mg L^{-1}		FIELD
DISSOLVED ORGANIC CARBON	DOC	mg L^{-1}	1.0	EPA 415.1
DEPTH TO CONSOLIDATED SUBSTRATE	DCS	Cm		FIELD
NITRATES and NITRITES as N	NOX	mg L^{-1}	0.006	SM4500NO3F
PHOSPHATE, ORTHO as P	OPO_4	mg L^{-1}	0.004	SM4500PF
pH	pH	UNITS		FIELD
SILICA	SiO_2	mg L^{-1}	0.05	SM4500SID (MODIFIED)
SULFATE	SO_4	mg L^{-1}	0.1	EPA 300.0
SP CONDUCTANCE	SpCond	μS cm^{-1}		FIELD
TOTAL DISSOLVED SOLIDS	TDS	mg L^{-1}	22	SM2540C
TEMPERATURE	TEMP	Deg. C		FIELD
KJELDAHL NITROGEN, TOTAL	TKN	mg L^{-1}	0.05	EPA 351.2-MOD
CARBON, TOTAL ORGANIC	TOC	mg L^{-1}	1	EPA 415.1
PHOSPHATE, TOTAL AS P	TPO_4	mg L^{-1}	0.002	SM4500PF
TOTAL DEPTH	TDEPTH	cm		FIELD
TOTAL SUSPENDED SOLIDS	TSS	mg L^{-1}	3	EPA 160.2
TURBIDITY	TURB	NTU	0.1	SM2130B

[1] ID is the descriptor used in Appendix 2-1

Table 2-3. Summary statistics of wet deposition concentrations for TP, TN, Cl, and SO_4, for calendar years 2004, 2005, 2006, and 2007. Data from ENRWET station (**Figure 2-1**).

Atmospheric Deposition Chemistry								
Parameter	**Year**	**n**	**Mean**	**Std**	**Max**	**Min**	**C.V.**	**Median**
TP ($\mu g\ L^{-1}$)	2004	12	33.3	77.8	276.0	2.0	2.3	6.6
	2005	10	14.7	17.7	58.0	2.0	1.2	8.0
	2006	20	3.8	42.0	14.0	1.0	11.2	3.0
	2007	25	23.4	77.0	391.0	2.0	3.3	6.0
TN ($mg\ L^{-1}$)	2004	11	0.5	0.3	1.3	0.2	0.7	0.4
	2005	10	0.3	0.2	0.8	0.2	0.5	0.3
	2006	18	0.4	0.4	1.5	0.1	1.1	0.3
	2007	27	0.6	0.7	3.5	0.1	1.2	0.4
Cl ($mg\ L^{-1}$)	2004	11	1.1	1.0	3.0	0.2	0.9	0.9
	2005	11	2.1	3.1	11.3	0.5	1.5	1.0
	2006	18	1.3	1.9	8.6	0.1	1.5	0.6
	2007	25	1.8	2.8	12.1	0.1	1.5	0.8
SO_4 ($mg\ L^{-1}$)	2004	11	1.1	0.7	3.0	0.6	0.6	0.8
	2005	11	1.0	0.6	2.4	0.6	0.6	0.8
	2006	19	0.9	0.8	2.6	0.1	0.9	0.6
	2007	24	1.0	0.7	2.7	0.2	0.7	0.8

C.V. = coefficient of variation
Max = maximum
Min = minimum
n = number samples
* parameter specific summary statistics for the period 1999-2005 were aggregated to annual monthly values and then aggregated again to 12 months for comparison to 2004 and 2005

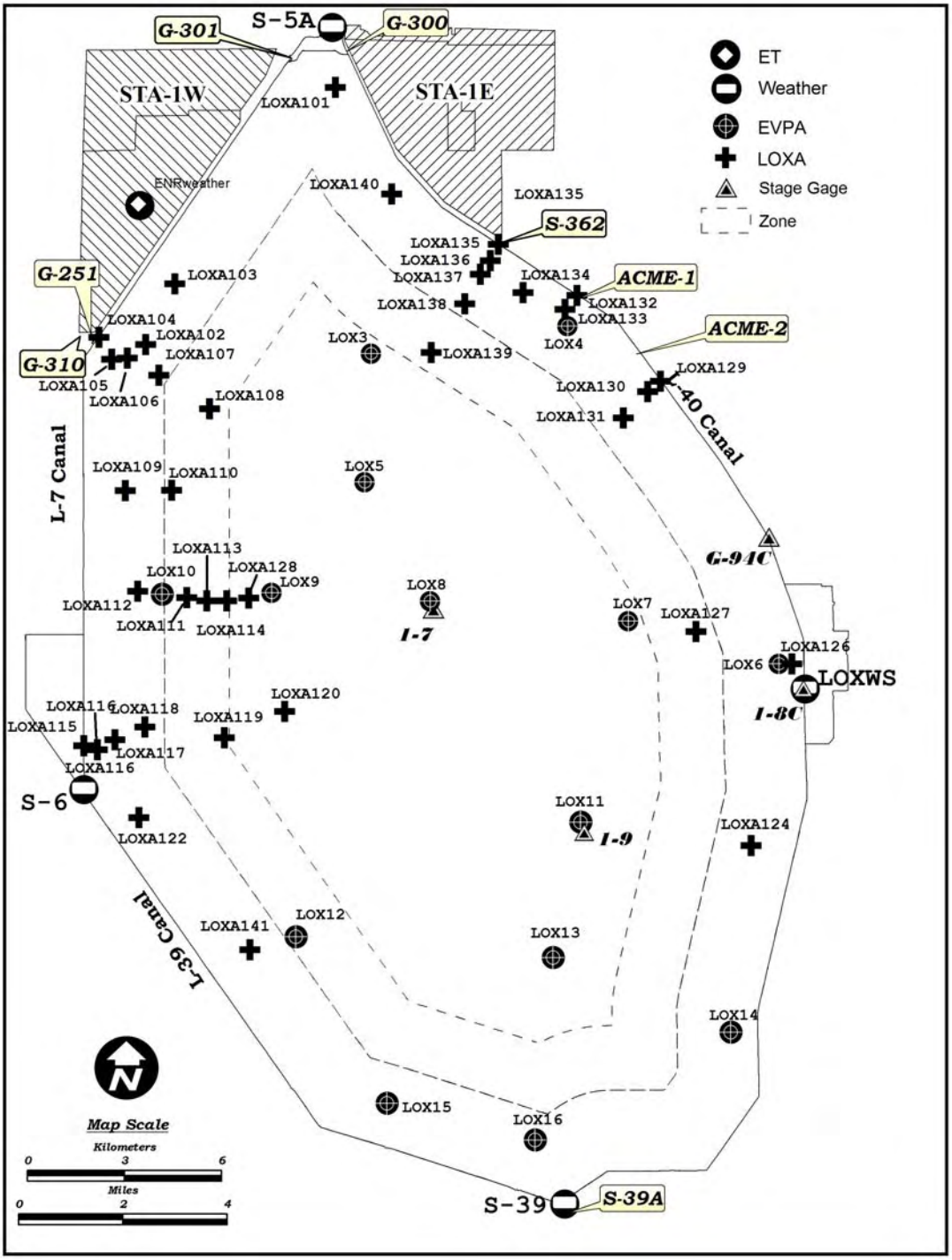

Figure 2-1. Water quality stations and operational structures in the A.R.M. Loxahatchee National Wildlife Refuge.

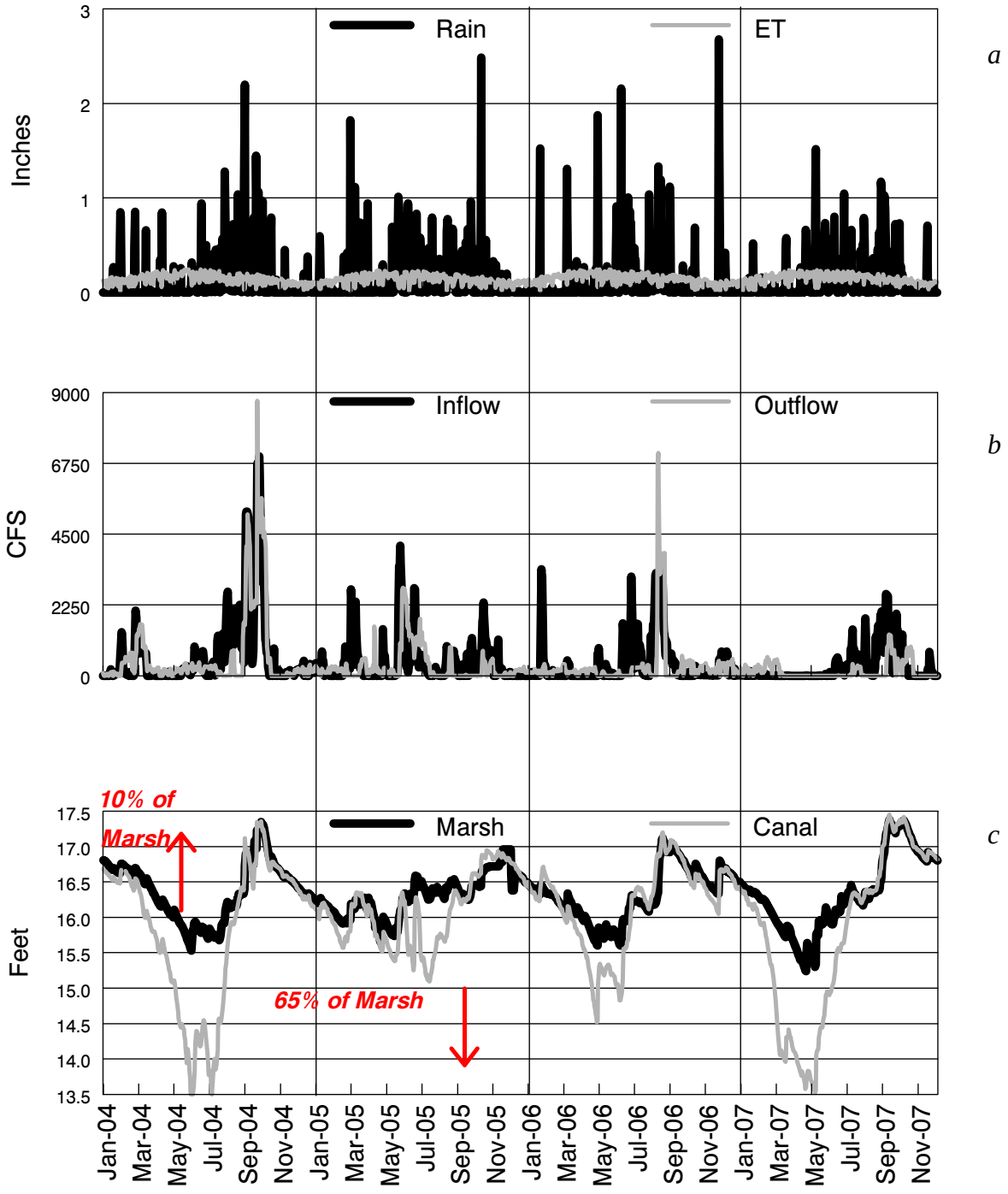

Figure 2-2. Daily (*a*) rainfall and ET, (*b*) canal inflow and outflow, and (*c*) marsh and canal stages for the period January 2004 through December 2007.

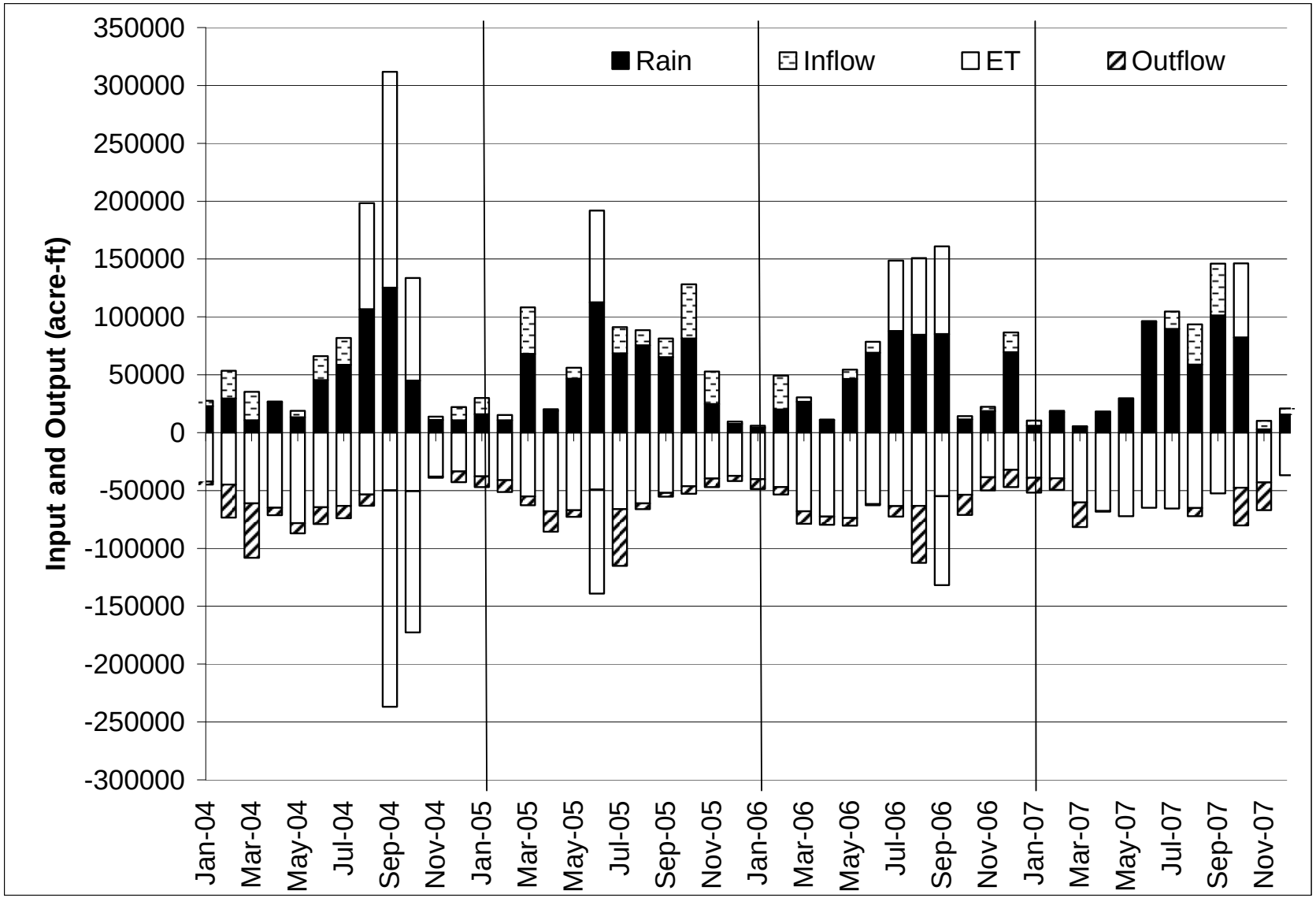
Rain
Inflow
ET
Outflow
Input and Output (acre-ft)
350000
300000
250000
200000
150000
100000
50000
0
-50000
-100000
-150000
-200000
-250000
-300000
Jan-04
Mar-04
May-04
Jul-04
Sep-04
Nov-04
Jan-05
Mar-05
May-05
Jul-05
Sep-05
Nov-05
Jan-06
Mar-06
May-06
Jul-06
Sep-06
Nov-06
Jan-07
Mar-07
May-07
Jul-07
Sep-07
Nov-07

Figure 2-3. Total monthly water inputs (rainfall and canal inflows) and outputs (evapotranspiration and canal outflows) for the Refuge from January 2004 to December 2007. Rainfall was the average of four weather stations (S-5A, S-6, LOXWS, and the S-39) summed for each month. Canal inflows were the daily sum from all the inflow structures (STA-1W: G-251 and G-310, STA-1E: S-362, bypass: G-300 and G-310, and ACME-1 and ACME-2) summed over each month. Evapotranspiration was the monthly total determined from the ENRWET station. Canal outflows were the daily sum from all the outflow structures (bypass: G-300 and G-301, S-10A, S-10C, S-10D, G-94A, G-94B, ACME-1 and ACME-2) summed over each month. Stations and structures shown in **Figure 2-1**.

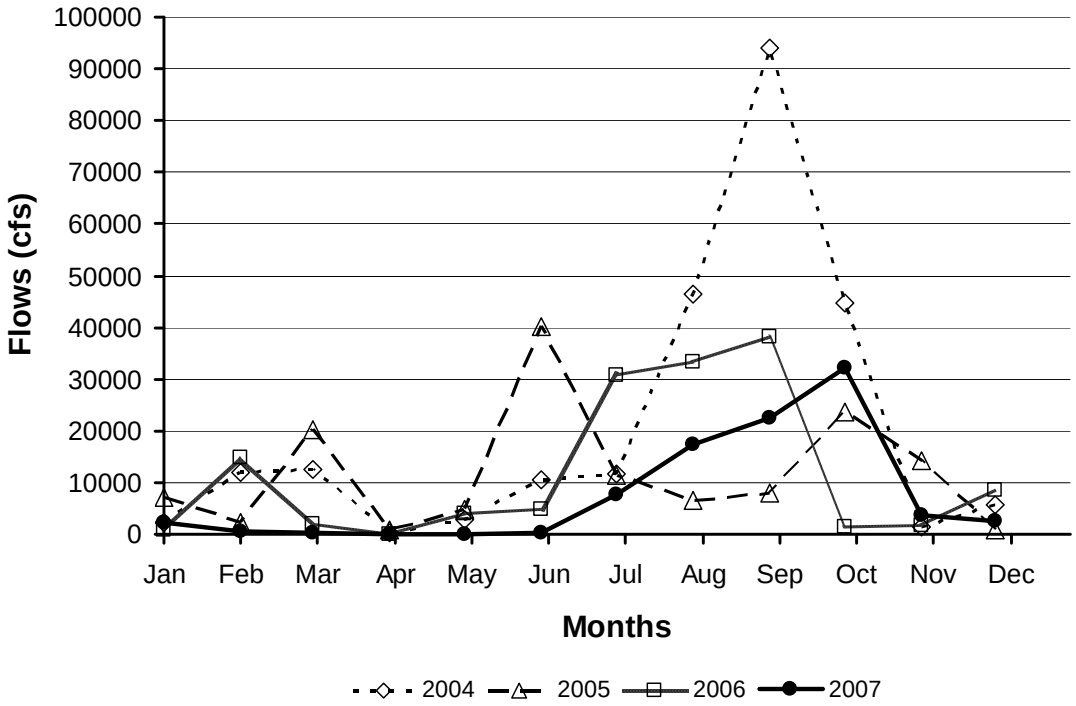

Figure 2-4. Average monthly inflow rates for 2004, 2005, 2006, and 2007.

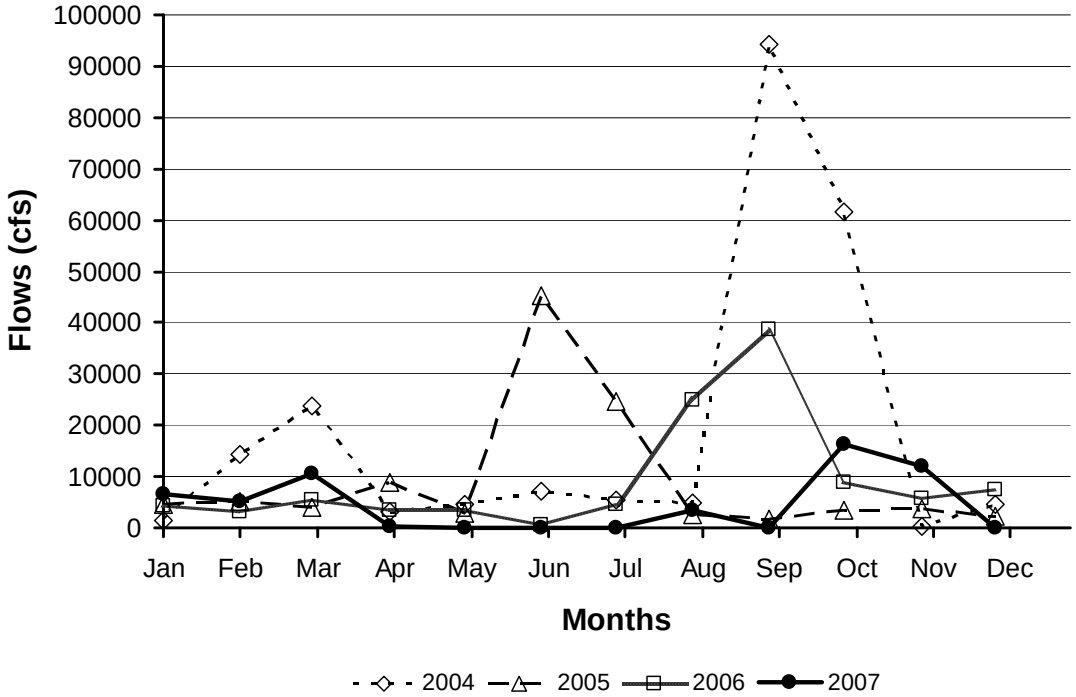

Figure 2-5. Average monthly outflow rates for 2004, 2005, 2006, and 2007.

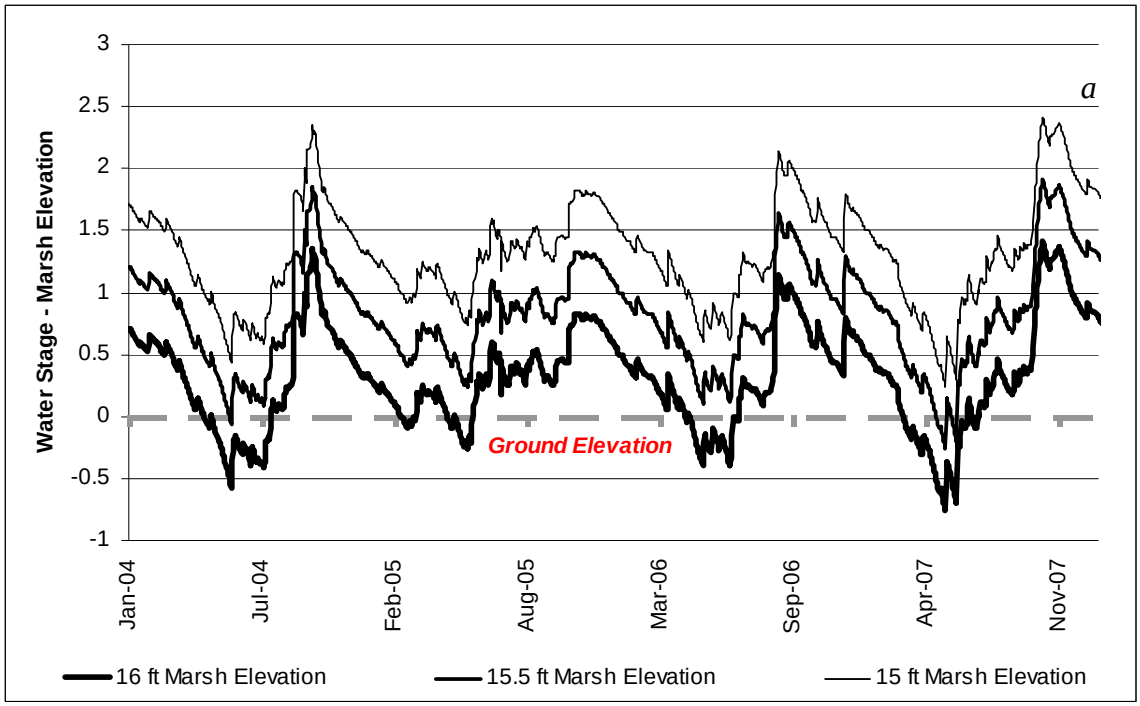

Figure 2-6a. Marsh hydroperiods represented as the difference between surface water stage (1-7 stage gage) and marsh elevations (16, 15.5, and 15 ft; 4.88, 4.72 and 4.57 m, respectively).

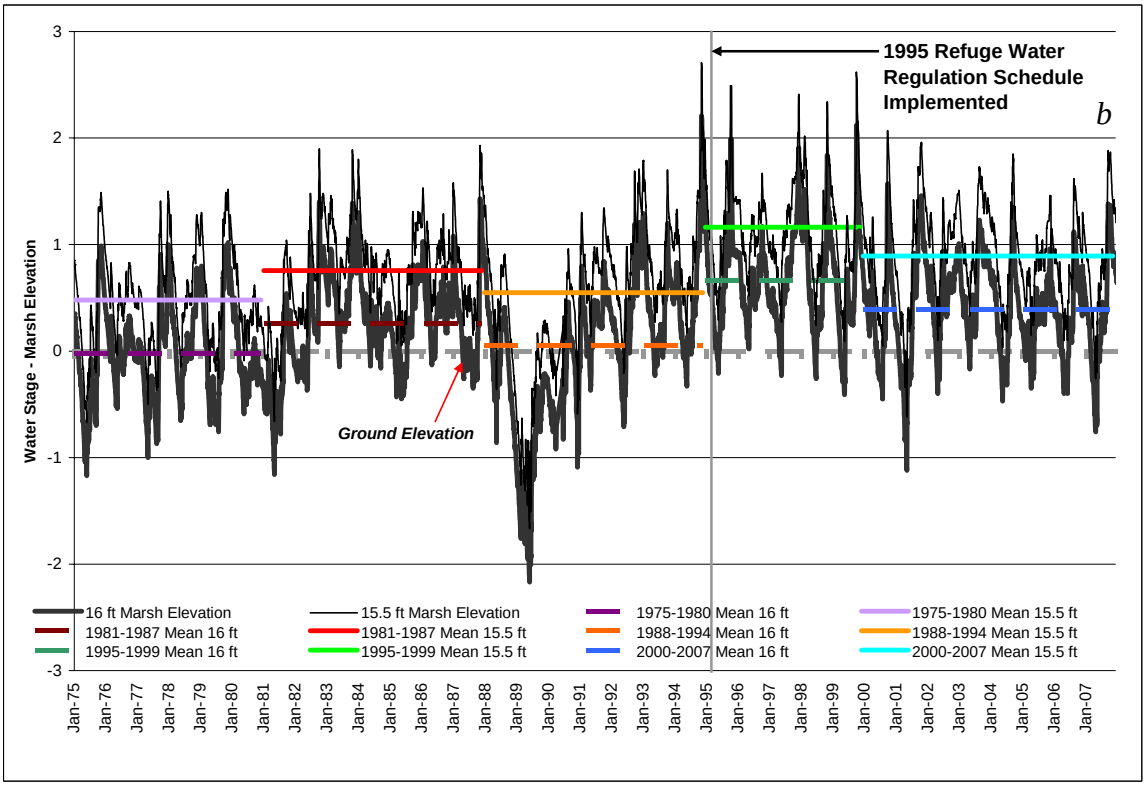

Figure 2-6b. Marsh hydropatterns represented as stage (1-7 stage gage) and marsh elevations (16, 15.5, and 15 ft; 4.88, 4.72 and 4.57 m, respectively) differences since 1975. Mean hydroperiods are presented for visually identified breaks in hydropatterns.

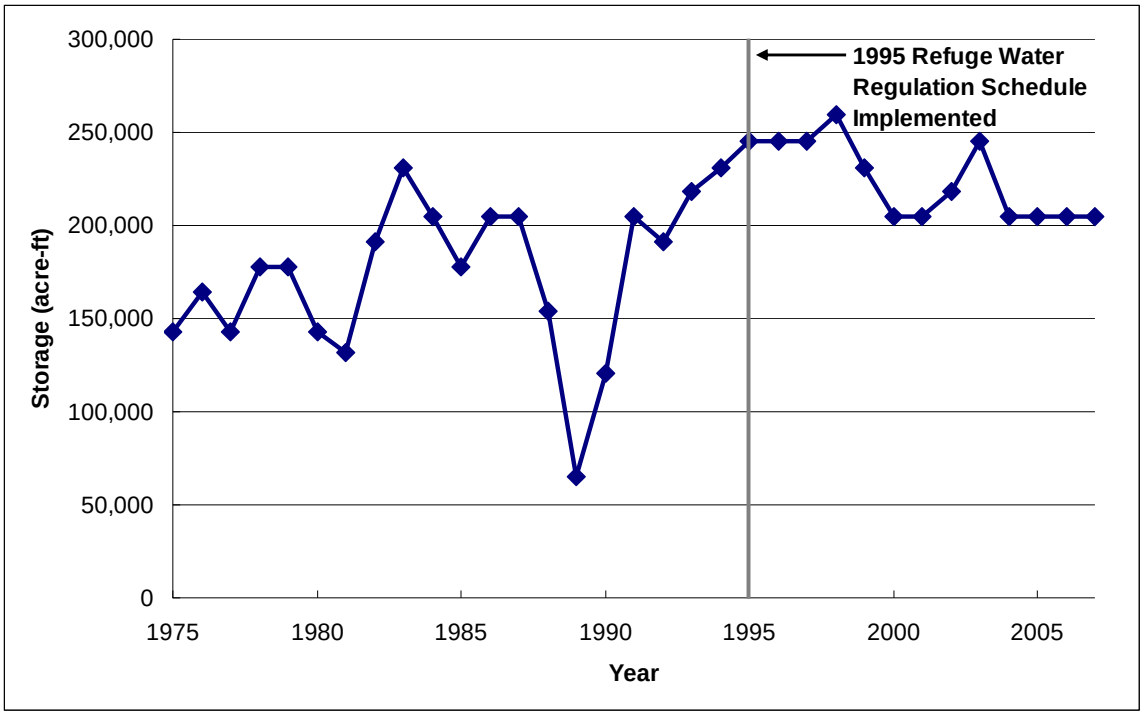

Figure 2-7. Marsh storage based on the stage to storage relationship developed by the U.S. Army Corps of Engineers as determined from mean annual stages from the 1-7 stage gage as the annual mean.

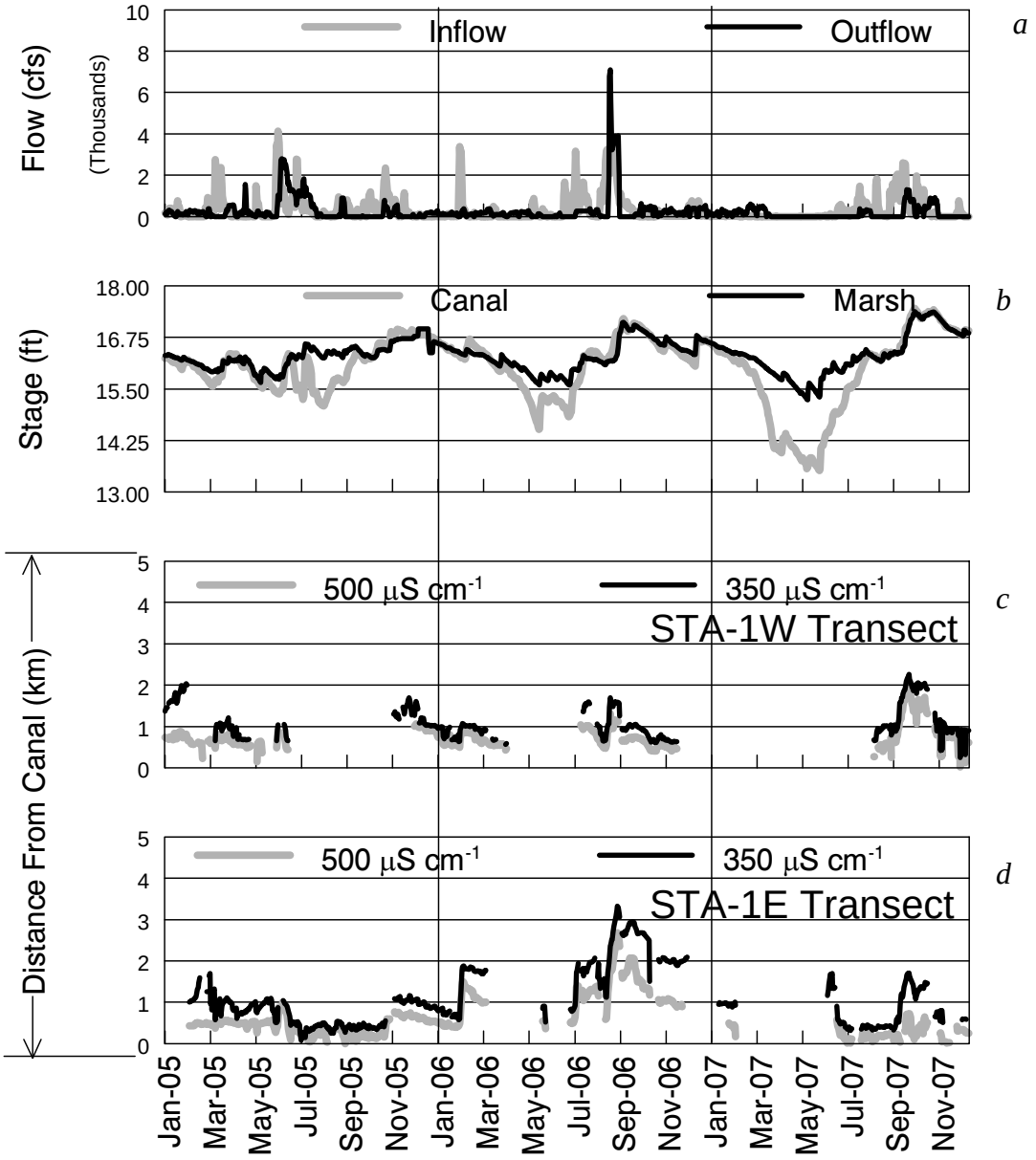

Figure 2-8. *a*) Inflow and outflow rates (cfs) summed for all structures. *b*) Marsh and canal stage reading from the 1-7 and G-94C stage gages, respectively. The 500 and 350 μS cm^{-1} conductivity isopleths used to track canal water movement into and out of the marsh interior for: *c*) STA-1W and *d*) STA-1E transects.

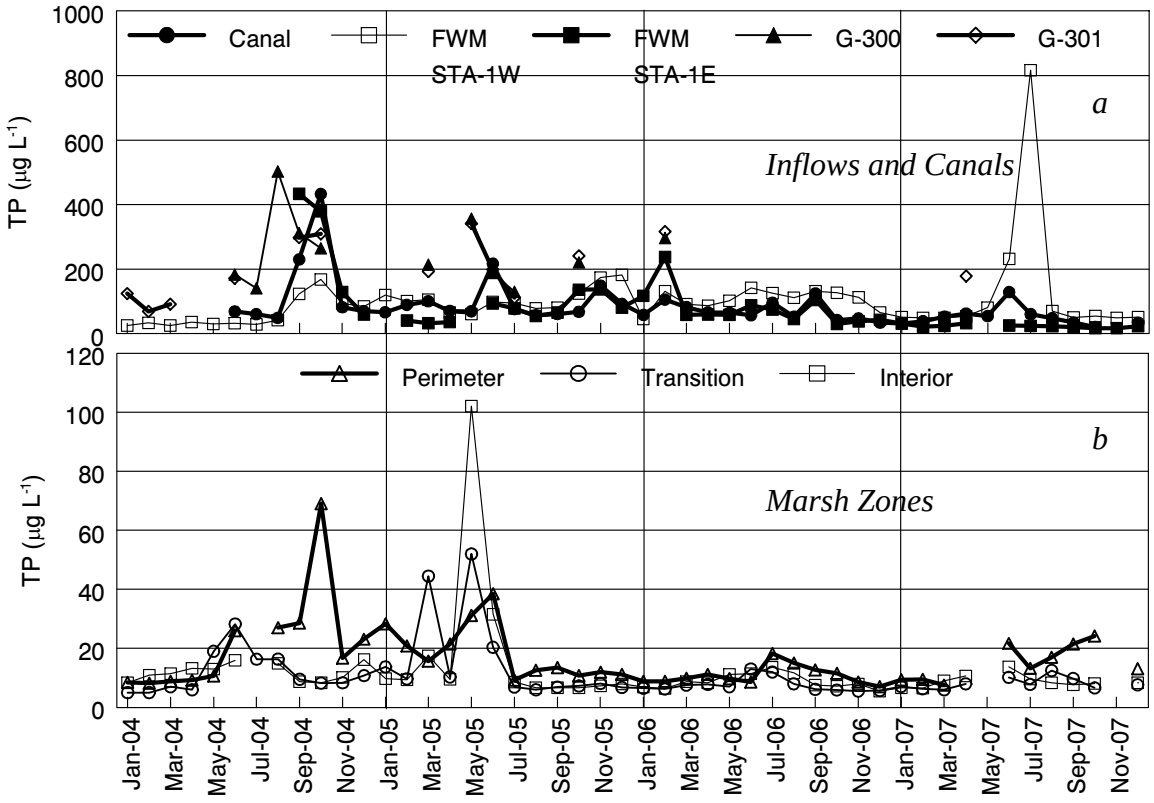

Figure 2-9. (a) Mean TP in the Canal Zone, flow-weighted mean (FWM) TP concentration (µg L^{-1}) over time for STA-1W outflows (G-251 plus G-310), STA-1E outflows (S-362), G-300, and G-301. (b) Monthly arithmetic mean TP concentration (µg L^{-1}) for the Perimeter Zone, Transition Zone, and Interior Zone of the Refuge. Monthly values are summarized in Appendix 2-2.

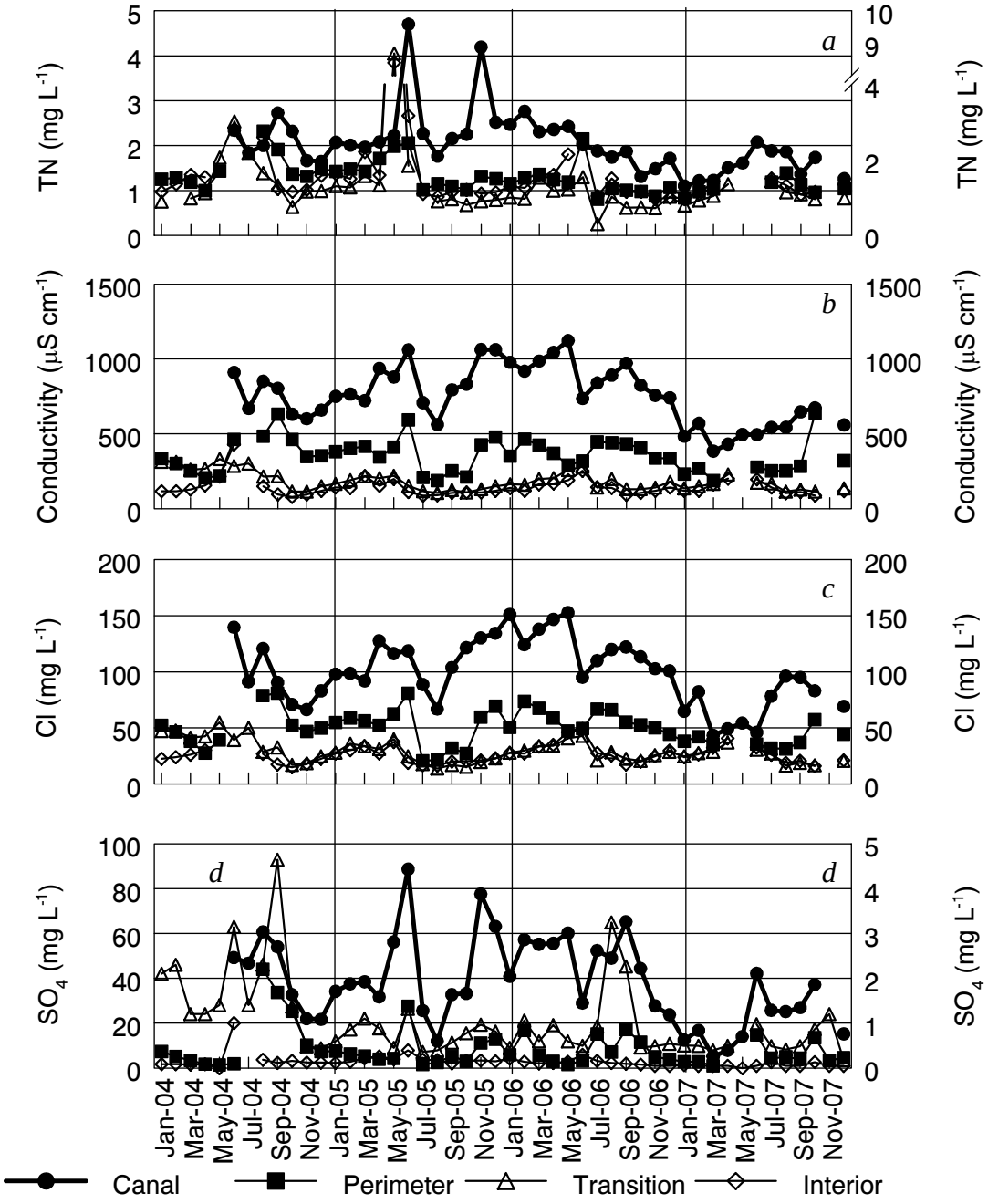

Figure 2-10. Mean of all stations in each zone through time for a) TN (mg L^{-1}); b) conductivity (µS cm^{-1}); c) Cl (mg L^{-1}); and d) SO_4 (mg L^{-1}). Canal and Perimeter Zone parameters are presented on the left axis, while Transition and Interior Zone parameters are presented on the right axis. Refuge Canal, Perimeter, Transition, and Interior Zone values are presented for each parameter in the individual panels.

CHAPTER 3. ECOLOGICAL EFFECTS[4]

Abstract

The A.R.M. Loxahatchee National Wildlife Refuge (Refuge) is one of the last remnants of the Everglades to retain soft-water, rainfall-driven chemistry. Intrusion of mineral-rich canal water into the Refuge periodically elevates surface-water conductivity through enrichment with elements such as calcium, magnesium, and sulfur. These water-quality changes translate into persistent chemical gradients in the soil that can result in ecological changes including shifts in the composition of periphyton and macrophyte communities, which can lead to effects at higher trophic levels. An ecological effects program was initiated in conjunction with an enhanced water-quality-monitoring program to further investigate and characterize the impacts of mineral enrichment within the Refuge. Soil and vegetation sampling at established monitoring sites examine chemical-ecological relationships that are being further tested using controlled field and laboratory experiments. The taxonomic and chemical composition of the Refuge periphyton community has been shown to change in response to increased mineral loading. An investigation regarding the impact of these altered periphyton communities on a critical primary consumer (Florida apple snail) was initiated. In addition to field characterization of macrophyte communities at existing water quality sampling sites, the relative influence of water quality and hydrology on macrophyte germination and seedling survival was investigated.

This chapter provides methods and preliminary results for multiple projects designed to characterize the ecological effects of mineral enrichment in the Refuge. Information gained from these studies will support ongoing hydrologic and ecological modeling efforts and enhance the scientific basis for wetland management strategies that minimize effects of mineral enrichment on Refuge resources.

Introduction

The A.R.M. Loxahatchee National Wildlife Refuge (Refuge) historically was an oligotrophic, rainfall-driven wetland with low nutrient and mineral concentrations. Regional water management and land-use changes have altered the hydrology and chemistry of the Refuge in a manner similar to other parts of the Everglades. Canal waters entering the Refuge contain elevated concentrations of nutrients such as phosphorus (P) and minerals such as calcium (Ca) that can impact wetland ecology (USFWS 2007a, b; Harwell et al. 2008). Canal-water intrusion toward the Refuge interior has altered hydrology and soil chemistry, resulting in a gradient of soil/water chemistry extending from the Refuge perimeter towards the less impacted interior

[4] Prepared by Rebekah Gibble and Matthew C. Harwell

(McCormick 2007). Because ecological interactions and relationships within the Refuge are only partially understood, an ecological effects program was initiated as part of the Refuge's Enhanced Water Quality Monitoring and Modeling program. The focus of this program is to investigate and characterize the ecological impact of mineral-rich canal water intrusion into the Refuge.

A number of major research projects have been implemented since the inception of the ecological effects program and include collaborations with various inter- and intra-agency researchers. These projects were designed to probe mineral enrichment effects at multiple and critical trophic levels. Projects include:

- vegetation and topographic characterization of existing water quality sites,
- germination of interior seed banks under different water quality and hydrology treatments, and
- initiation of a grazing study using Florida apple snails (*Pomacea paludosa* Say).

In future work, we will expand the vegetation characterization beyond water quality sites, continue the apple snail grazing study, and develop a periphyton econiche model.

Projects

Characterization of Water Quality Sites

The overall objective of this study is to characterize factors beyond just distance from the canal that influence local surface water quality at established water quality sites within the Refuge. This project has four specific objectives aimed at providing information to improve our understanding of how various physical and biological factors may be influencing water quality:

1. Describe the topography of each site by determining the elevation at the site and at surrounding points relative to the USGS 1-7 gage located near the center of the Refuge.
2. Characterize vegetation patterns at each site.
3. Summarize the physical and biological site characteristics of each site by characterizing major plant communities, habitat conditions as they pertain to wildlife, and other notable features of each site.
4. Determine whether there are differences other than water quality among sites categorized in the Perimeter (2.5 km from the canal into the marsh), Transition (2.5 km to 4.5 km into the marsh), and Interior (>4.5 km into the marsh) Zones.

Initial sampling for this project took place in January 2006 and was conducted by collaborators and Refuge staff. Vegetation community composition and density data were collected as percent cover in 1 m^2 plots in the center of each site and in each cardinal direction at 50 and 100 m. The site center was defined as the central point between the poles marking the boundaries of each site. Site specific elevations (water stage at the 1-7 gage minus water depth) were determined at the center and 50 m in each

cardinal and intermediate direction. Slopes based on relative elevation were determined between each direction and center of each site to estimate any potentially influence micro-scale topography may have on water movement in and out of the site. Cluster analysis of surrounding slopes as a whole did not explain observed water quality trends (data not shown). Future analyses will examine slopes in each water quality zone of the Refuge individually.

Seed Bank Germination – Water Quality and Hydrologic Influences[5]

Changes in vegetation communities within the Refuge have been attributed to anthropogenic alterations in hydrology and water quality (Childers et al. 2003; Richardson et al. 1990). Species such as cattail (*Typha domingensis*) have displaced sawgrass (*Cladium jamaicense*) and slough habitats in canal-influenced areas (Richardson et al. 1990). Several other species such as *Xyris* spp. and some *Rhynchospora* spp. occur only in the Refuge interior (McCormick 2007). The objective of this experiment was to measure the relative importance of soil chemistry and hydrology as determinants of changes in Refuge plant community composition in response to canal-water intrusion.

This experiment was conducted at Refuge headquarters in the northern Everglades (**Figure 3-1**). Surface soils were collected from multiple randomly-selected habitats across the Refuge interior that had emergent macrophyte communities indicative of non-impacted areas. These soils were cleaned of large roots and debris and homogenized. The resulting soil was used as the experimental seed bank. In addition, soils were also collected from bare (non-vegetated) peat pop-ups in the Refuge interior. These soils were also cleaned of large roots and debris, homogenized, and then distributed among 24 plastic tubs 1 ft x 2 ft (30 cm x 60 cm) each filled to a depth of 0.66 ft (20 cm). This soil served as a substrate for seedling germination. Seed bank (as described above) was then evenly distributed to each replicate by spreading a thin (3 cm) layer of seed bank on top of the substrate soil. Experimental units were placed in a water bath (inflatable pool) to regulate temperature and were shielded from rainfall (**Figure 3-2**). Soils from 12 tubs were enriched with calcium in the form of finely ground limestone (180 g/replicate) and phosphorus in the form of triple superphosphate (4 g/replicate; 45% P_2O_5; Bonide Products, Oriskany, NY) to achieve concentrations representative of canal-impacted soils near the Refuge perimeter. Final calcium and phosphorus concentrations in enriched treatments were 32.6 g/kg and 1,460 mg/kg, respectively. The other 12 tubs were not enriched and were representative of the relatively nonimpacted Refuge interior with final concentrations of 11.0 g/kg of calcium and 347 mg/kg of phosphorus. These values are consistent with concentrations of calcium and phosphorus previously reported in soil samples collected from established water quality zones within the Refuge (Chang et al. 2009; Newman 1997). Four tubs from each enrichment treatment were subjected to one of three hydrologic treatments (flooded, saturated, or drained). Hydrology treatments were initially achieved and subsequently hydrated using water from the L-40 canal (enriched treatment) or Refuge interior (unenriched treatment) until specific conductivity

[5] Coauthored by Dr. Paul McCormick when he was affiliated with the USGS. Dr. McCormick presently is affiliated with the SFWMD - pmccormi@sfwmd.gov

reached predetermined levels (1,000 and 200 µS cm-1, respectively), after which rainwater was used in order to prevent excessive addition of minerals and maintain target treatments. Drained treatments were allowed to partially dry before rehydrating and saturated treatments remained wet but without standing water throughout the entire experiment. Flooded treatments had a clear water column above the consolidated soil material of 0.78 to 1.18 inches (2 to 3 cm), but the soil material was not as consolidated as in other treatments. Control tubs containing commercial potting soil were hydrated with canal water to confirm that this water was not a propagule source.

Temperature (°C), pH, and specific conductivity (µS/cm) of soil pore water were monitored weekly in each replicate and were representative of conditions along the water quality gradient within the Refuge (**Table 3-1**). Refuge water quality data were accessed from the South Florida Water Management District data web portal, DBHYDRO (http://my.sfwmd.gov/dbhydroplsql/show_dbkey_info.main_menu).

Seedling emergence was tracked weekly for nine weeks. Each week, new seedlings were labeled with color-coded markers and the number of dead seedlings from previous weeks were recorded If shoots from seedlings were found to consistently die-off in unenriched treatments, successive shoots were transplanted to separate containers of enriched soil and grown to an identifiable size. At the end of the experiment, living plants were identified to genus or species, species abundances were recorded, and the above ground portion of each plant was removed. Plant material was grouped by species, placed in brown paper sacks, dried at 70 °C for 48 hours, and weighed to 0.001 mg. A non-parametric method (Kruskal-Wallace) was used to identify differences in percent abundance and biomass metrics. Total germination and total survival were tested for differences between treatments using MANOVA.

More seedlings germinated in unenriched treatments ($p < 0.01$, $n = 12$) but survival rates were highest in enriched treatments ($p < 0.01$, $n = 12$) (**Table 3-2**). The fewest seedlings germinated in flooded treatments ($p < 0.01$, $n = 8$), but this treatment had the greatest rate of seedling survival ($p < 0.05$, $n = 8$).

A total of 18 species were present across all treatments at the end of the experiment (**Table 3-3**). Species such as *Xyris* spp. and *Utricularia* spp. failed to germinate in enriched treatments, while *Cyperus* spp., *Pluchea* spp., and *Ludwigia* spp. did not germinate in unenriched treatments (**Table 3-3**). Other species such as *Mikania scandens* and *Typha domingensis* germinated in both treatments, but died off in the unenriched treatments during the course of the experiment. *Cladium jamaicense* was notably missing from our treatments. The absence of this defining species is most likely because of a tendency of this species towards asexual reproduction. Sexual reproduction of *C. jamaicense* under natural conditions is considered negligible because of typically low seed production and viability (Alexander 1971; Steward and Ornes 1975). Therefore, the absence of *C. jamaicense* was attributed to a lack of viable seeds present in the seed bank.

Although many species were present in all treatments, enrichment treatments ultimately developed different communities as measured by species richness (**Table 3-4**), percent

abundance (**Table 3-5** and **Figure 3-3**) and biomass per plant (**Table 3-6**) of those species present at the end of the 9-week experiment. There was also a visible and significant difference in total biomass ($p < 0.01$, $n = 12$) (**Figure 3-4 and 3-5**).

Although the flooded treatments were confounded by non-compacted soils, hydrology treatments yielded differences in abundance and biomass per plant for some species, independent of enrichment (e.g., *M. scandens*, *J. megacephalus*). There was no hydrology effect on total biomass ($p = 0.4227$, $n = 8$) (data not shown).

Rhynchospora spp. and *Xyris* spp. are characteristic of softwater, nonimpacted wet prairie habitats (Richardson et al. 1990; McCormick 2007). In the current study, these species were present in both enrichment treatments but were significantly more abundant in unenriched treatments ($p < 0.01$, $n = 12$ and $p <0.01$, $n = 12$, respectively) (**Table 3-5** and **Figure 3-3**). Additionally, different weekly germination patterns were observed in unenriched treatments between *Rhynchospora* and *Xyris* spp. (**Figure 3-6**). Relative to *Xyris*, *Rhynchospora* seedlings germinated early in the experiment (week 1) and at a relatively constant rate after an initial peak in number of seedlings per week. *Xyris* seedlings were slower to appear and the number of newly germinating seedlings steadily increased over the 9 week experiment. These results demonstrate germination requirements and timing of two typical northern Everglades wetland species, which may ultimately influence macrophyte community composition.

Our findings have important implications for efforts to restore and maintain native Everglades plant communities. Specifically, our results suggest that:

- while hydrology is a critical factor affecting Everglades vegetation, soil and surface-water chemistry can exert strong independent effects on plant communities as demonstrated by the significant differences observed in seedling germination, survival, and biomass resulting from the nutrient enrichment experiment;

- soil and water chemistry is a determinant of differences in plant communities between the relatively unenriched Refuge interior and enriched areas near the perimeter as similar communities to those found in the field developed from a single seed bank maintained under controlled, environmentally relevant conditions; and

- effects of soil chemistry on plant community development can occur within a single growing season after disturbances such as droughts, when vegetative cover is reduced and plant establishment from the seed bank may be important.

<u>Initiation of Apple Snail Grazing Experiment</u>

As secondary producers, Florida apple snails (*Pomacea paludosa* Say) are a critical component of the Everglades food web (Darby et al. 1999). Apple snails are the principal food source for the Limpkin (*Aramus guarauna*), which is a listed species of

special concern (FFWCC 2006) and are nearly the exclusive food source for the critically endangered Everglade Snail Kite (*Rostrhamus sociabilis*) (Sykes et al. 1995). Wading birds (e.g., White Ibis; *Eudocimus albus*), alligators (*Alligator missippienisis*), fish, amphibians, and turtles also prey on apple snails (referenced in Darby et al. 1999; Shuford et al. 2005). Although a number of sites in the Refuge were sampled to test hypotheses regarding the effects of hydrology and habitat structure on apple snail density (Darby et al. 2006; Karunaratne et al. 2006) no empirical data have been collected over time to indicate current trends. However, the Refuge has been shown to support relatively low densities compared to other wetlands in South Florida (Karunaratne et al. 2006) and anecdotal reports from Refuge staff indicate populations have been in decline since the 1970s (Brandt 2006).

Factors known to influence apple snail abundance include hydrology (Darby et al. 2004), habitat structure (Karunaratne et al. 2006), food availability (Shuford et al. 2005; Sharfstein and Steinman 2001), food web interactions (Browder et al. 1994), parasites (Hanning 1979), and water quality (Glass 2007). The influence of food quality (i.e., periphyton composition) on snail fitness (e.g., apple snail growth and survival) has not been investigated previously.

The primary objective of this study is to characterize how apple snail growth and survival is impacted by available food resources as a function of water quality. Laboratory-raised apple snails are used in *in situ* feeding trials that incorporate different water quality-driven periphyton assemblages as treatments. This project has two specific objectives:

1. Associate growth rates of snails exposed *in situ* to different water chemistry-driven assemblages of periphyton found within the Everglades ecosystem.

2. Describe the nutritional value of periphyton collected from areas with characterized differences in algal communities and water quality conditions.

A pilot study to determine the feasibility of a snail grazing study was initiated in December 2007. Egg clusters were collected from the Refuge interior (**Figure 3-1**) and allowed to hatch in aquaria containing 5 – 10 gallons of aerated surface water (~350 µS/cm) housed in a constructed greenhouse at the Refuge headquarters. Water was collected from a small impoundment adjacent to the EPT building at the Refuge headquarters. Snails were fed romaine lettuce *ad libitum* daily. Leftover food from the previous day was removed at each feeding. Half of the water in each aquarium was replaced three times weekly to remove waste and maintain water quality. Snails were grown in aquaria for approximately 60 days (reaching an average shell length of 15 mm and average wet mass of 1.5 g) prior to use in the field experiments. Individual snails were marked with brightly-colored nail polish before release to facilitate relocating them during sampling.

Snails were transplanted to four sites within the Refuge interior and exposed the local water quality from December 2007 through January 2008. Site selection was based on capturing water quality gradients within the interior while maintaining consistent

hydrology. At each site, 15 randomly selected snails were placed into one of six replicate cages constructed of nylon mesh (1/16" x 1/16") around a 1 m^3 PVC frame. Additionally, periphyton and associated *Utricularia* spp. (3 L wet volume) was placed within each replicate cage to serve as a food source and provide habitat structure. The periphyton used at each site was locally collected so that snails at each site were provided a different, site-dependent food source.

Snails remained in cages for eight weeks and selected endpoints (aperture length, shell length, and survival) were measured at Weeks 0, 4 and 8. Additionally, water quality conditions (specific conductivity [µS/cm], dissolved oxygen [mg/L], temperature, [°C], pH, total phosphorus, calcium, and sulfate) were monitored at each sampling event.

The preliminary exposure demonstrated the feasibility of the described experimental design. Additional exposures are planned for 2008. Results from this research will provide insight into the ecological requirements and external influences regulating apple snail populations in the Refuge. Further, the results can be used to guide management of habitats in order to provide adequate conditions for apple snail growth and survival. Management of habitat to provide adequate conditions for growth, survival, and reproduction of apple snails will indirectly promote conservation of other species of concern, such as the Everglades Snail Kite and Limpkin.

Summary

Intrusion of mineral-rich canal water into the Refuge periodically elevates surface-water conductivity through enrichment with elements such as phosphorus, calcium, magnesium, and sulfur. These water-quality changes are associated with persistent chemical gradients in the soil and ecological changes including shifts in periphyton and macrophyte species composition. The ecological effects program employs several approaches to examine the impacts of mineral enrichment within the Refuge. Investigations include the effects of altered water chemistry on multiple trophic levels including macrophytes, periphyton, and secondary production. Information gained will support hydrologic and ecological modeling efforts and provide the scientific basis for wetland management strategies that minimize effects on Refuge resources caused by mineral enrichment.

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Table 3-1. Water quality conditions of enriched and unenriched (control) treatments. Means, averages and minimums and maximums are presented for each enrichment. treatment.

	Unenriched			Enriched			
Variable	**n**	**Mean**	**SE**	**Min-Max**	**Mean**	**SE**	**Min-Max**
Specific Conductivity (µS/cm)	9	247	8	100-520	610	20	240-1110
Temperature (°C)	9	26.9	0.3	23.2-38.3	26.8	0.2	23.3-31.2
pH	9	5.97	0.04	5.71-6.18	6.82	0.02	6.70-6.91

Table 3-2. Average number of seedlings and percent survival (±SE) for each enrichment and hydrology treatments. Means with different letters within treatments are significantly different as detected by MANOVA.

	Enrichment		Hydrology		
Variable	**Unenriched**	**Enriched**	**Drained**	**Saturated**	**Flooded**
Total Germination	57.75 ± 4.78^{a}	27.97 ± 3.11^{b}	45.38 ± 6.99^{c}	52.50 ± 8.21^{c}	30.63 ± 4.50^{d}
Total Survival	71.31 ± 3.28^{e}	87.15 ± 3.62^{f}	73.85 ± 4.19^{g}	79.12 ± 4.11^{h}	84.71 ± 6.36^{h}

$^{a,b}p<0.0001$, $^{c,d}p=0.0018$, $^{e,f}0.0005$, $^{g,h}p=0.0233$. Significant interaction between enrichment and hydrology was also detected for total survival (p=0.0256).

Table 3-3. Germinated plant species in each enrichment and hydrology treatment.

Plant Species	Treatment Hydrology					
	Unenriched Drained	Unenriched Flooded	Unenriched Saturated	Enriched Drained	Enriched Flooded	Enriched Saturated
Rhynchospora inundata	X		X			
Rhynchospora tracyi	X	X	X			X
Rhynchospora* spp. *A	X	X	X	X	X	X
Rhynchospora* spp. *B	X	X	X	X	X	X
Rhynchospora.* spp. *X	X	X	X	X	X	X
***Xyris* spp.**	X	X	X			X
***Nymphaea* spp.**	X	X	X	X	X	X
***Cyperus* spp.**				X		X
***Typha* spp.**	X[a]	X[a]	X[a]	X	X	X
***Utric* spp.**		X	X			X
***Ludwigia* spp.**				X	X	X
***Pluchea* spp.**				X		X
***Eleocharis* spp.**	X	X	X	X		X
***Pontederia* spp.**					X	
Mikania scandens		X[a]	X[a]		X	X
Juncus megacephalus	X		X	X		X
***Eriocaulon* spp.**	X					
***Salix* spp.**				X		
Unk Monocot	X	X	X	X	X	X
Unk Dicot	X	X	X	X	X	X

[a]seedlings died off during experiment

Table 3-4. Species richness values for each level of enrichment and hydrology treatments. Levels within each treatment were compared using ANOVA. Values denoted with different letters within a treatment are significantly different. Significant p-values are shown in **bold**.

Treatment	Level	Species Richness (SE)	p-value
Enrichment	Enriched	1.83 (0.18)[a]	**0.0018**
	Unenriched	2.67 (0.19)[b]	
Hydrology	Drained	2.30 (0.20)[c]	**0.0001**
	Saturated	2.94 (0.28)[c]	
	Flooded	1.52 (0.17)[d]	

Table 3-5. Results (p-values) for the abundances major species present. Species abundance in each treatment was tested using the Kruskal-Wallace non-parametric test. Significant differences ($p < 0.05$) are shown in **bold**.

Species	Enrichment	Hydrology
Rhynchospora spp.	**0.0053**	**0.002**
Xyris spp.	**<0.0001**	0.451
Nymphaea spp.	0.066	0.338
Cyperus spp.	**0.015**	0.189
Typha spp.	**0.001**	0.189
Utricularia spp.	**0.002**	**0.038**
Ludwigia spp.	**0.003**	0.636
Pluchea spp.	0.071	0.336
Eleocharis spp.	0.85	0.062
Pontederia spp.	0.317	0.368
Mikania scandens	0.18	**0.044**
Juncus megacephalus	0.313	**<0.0001**
Eriocaulon spp.	0.071	0.305
Salix caroliniana Michx.	0.149	0.124
Unknown monocot	0.817	0.871
Unknown dicot	0.643	0.477
Dead seedlings	**0.006**	0.461

Table 3-6. Results (p-values) for biomass per plant (mg) of species present. Biomass per plant in each treatment was tested using the Kruskal-Wallace non-parametric test. Significant differences ($p < 0.05$) are shown in **bold**. Species occurring in both enriched and unenriched (control) treatments are marked with asterisks.

Species	Enrichment	Hydrology
Rhynchospora spp.*	0.204	0.219
Xyris spp.*	**0.017**	**0.02**
Nymphaea spp.*	**0.007**	0.84
Cyperus spp.	**0.006**	0.142
Typha spp.*	**0.001**	0.369
Ludwigia spp.	**0.003**	0.86
Pluchea spp.	0.071	0.366
Eleocharis spp.*	0.388	0.11
Pontederia spp.	0.317	0.368
Mikania scandens	**0.037**	**0.029**
*Juncus megacephalus**	0.59	**0.001**
Eriocaulon spp.	0.317	0.368
Salix caroliniana Michx.	0.149	0.124
Unknown monocot	0.86	0.214
Unknown dicot	0.449	0.063

Figure 3-1. Map of A.R.M. Loxahatchee National Wildlife Refuge apple snail experimental sites and Refuge headquarters (HQ).

Figure 3-2. Outdoor experimental mesocosm used for seed germination experiment at A.R.M. Loxahatchee National Wildlife Refuge headquarters.

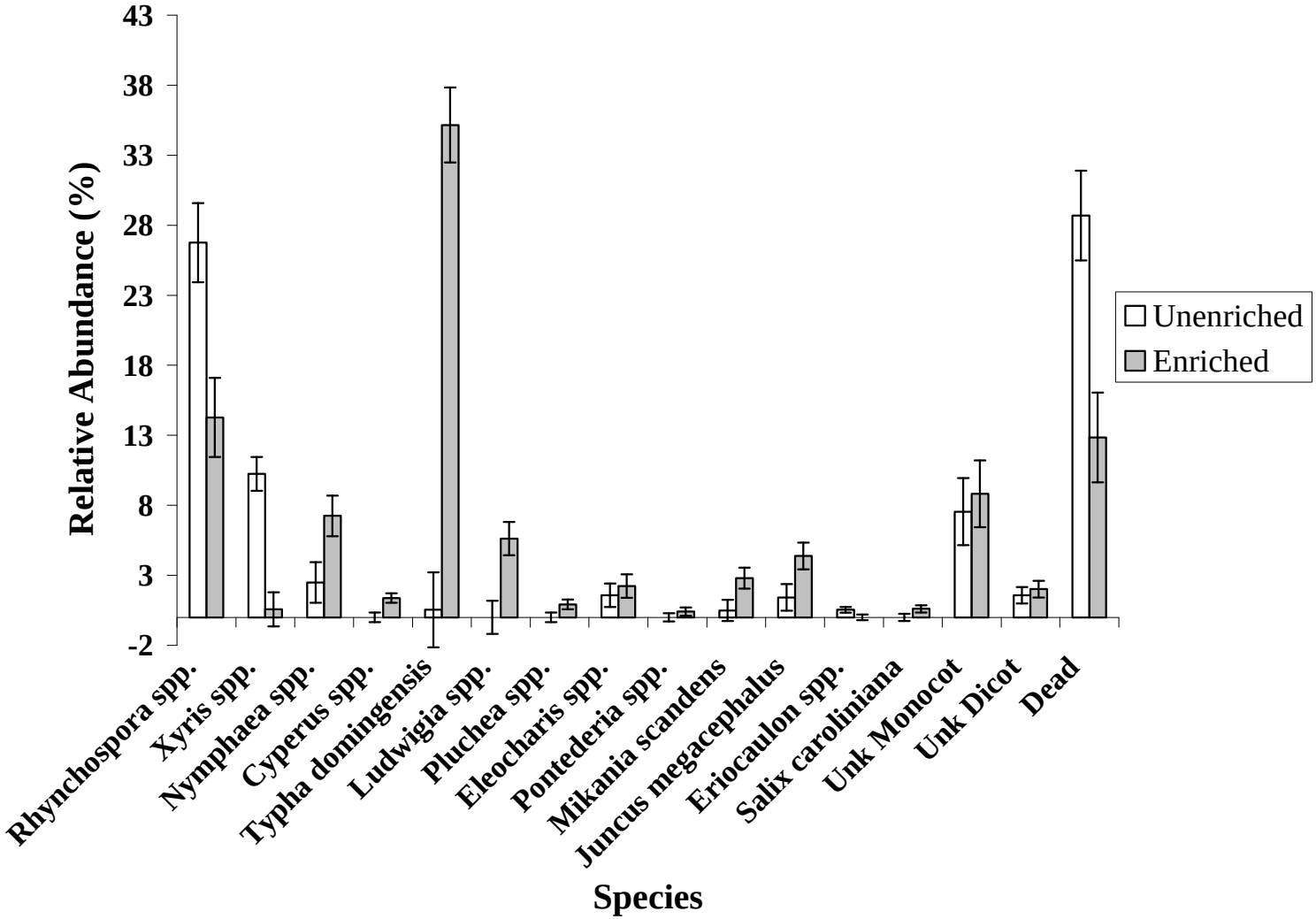


Figure 3-3. Abundances (%) for plants present in unenriched and enriched treatments. Error bars represent standard errors.

Figure 3-4. Final plant communities of nutrient enrichment (enriched and unenriched) and hydrology (drained, saturated, and flooded) treatments. Enriched treatments are presented in the left panel (A) and unenriched treatments are pictured in the right panel (B). Hydrology treatments were randomly dispersed among tubs for each enrichment treatment.

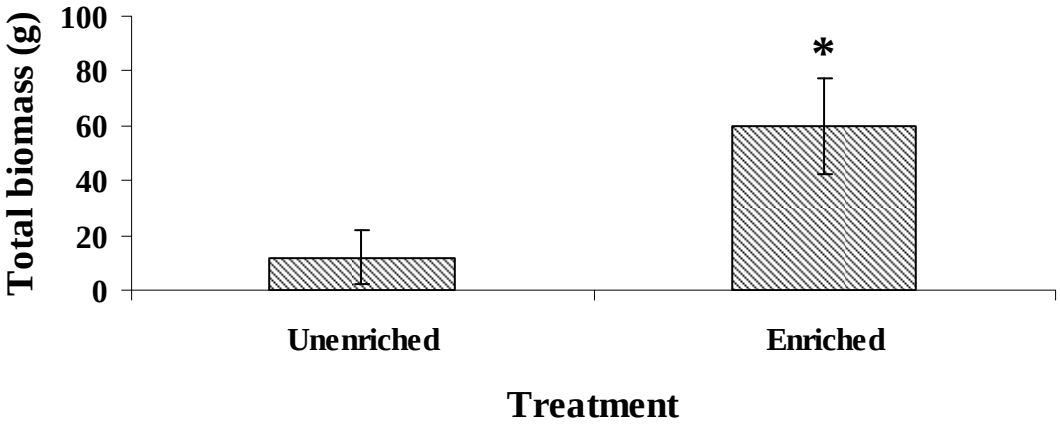
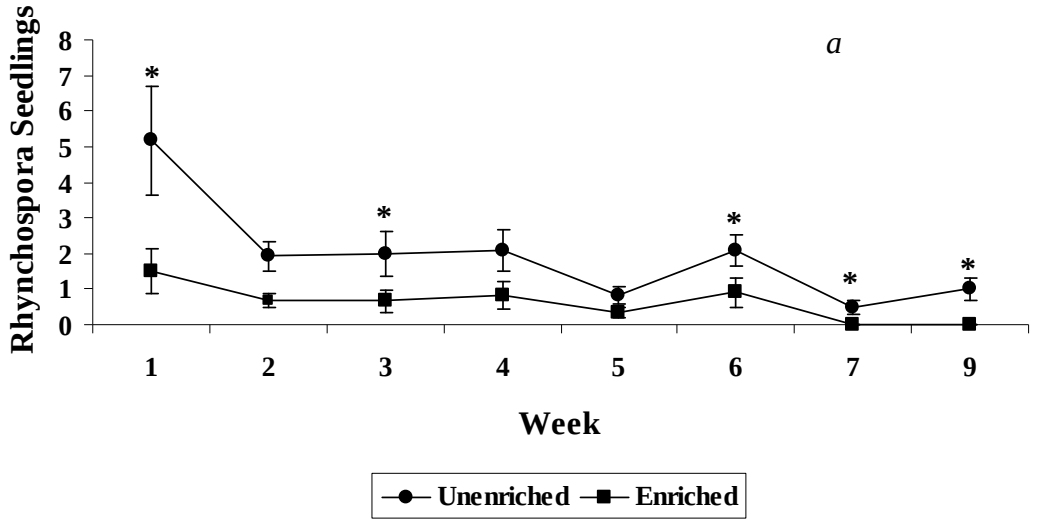


Figure 3-5. Total biomass for unenriched and enriched treatments. Error bars represent standard deviation. Unenriched treatments had significantly less biomass than the enriched treatment (p=<0.0001; n-12).



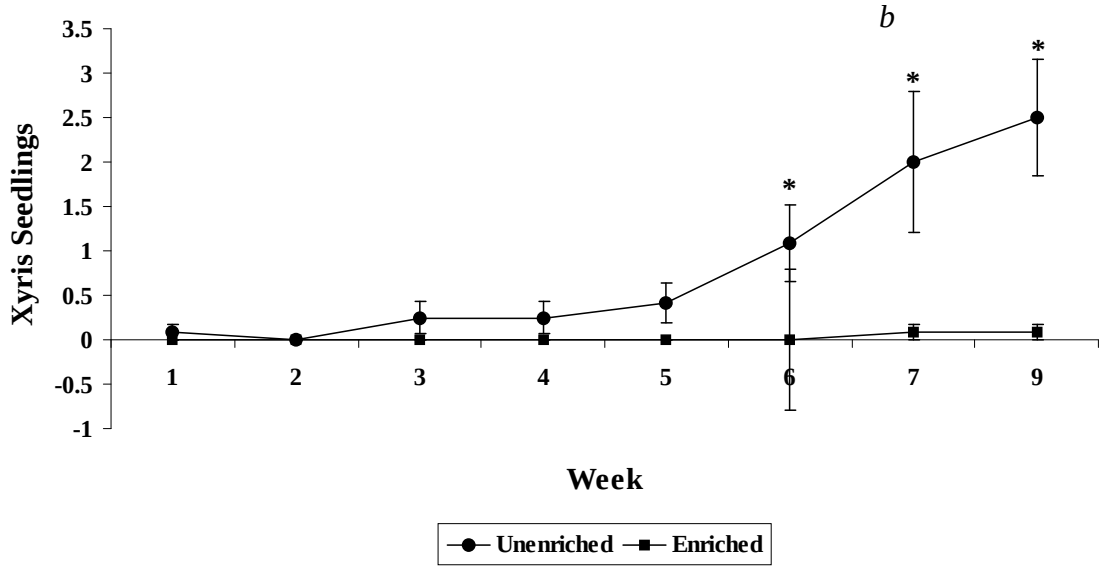


Figure 3-6. Weekly germination of *Rhynchospora* spp. seedlings (*a*) and *Xyris* spp. seedlings (). Error bars represent standard deviations. Points marked with asterisks are significantly different (95% confidence; MANOVA).

CHAPTER 4. HYDRODYNAMIC AND WATER QUALITY MODELING[6]

Abstract

This chapter is a status report through December 2007 on an ongoing project to model water and water quality in the Arthur R. Marshall Loxahatchee National Wildlife Refuge. This report is a snapshot of modeling approaches and available results. More detailed modeling results[7] are published or will be published in other reports.

Hydrodynamic, hydrologic and water budget models coupled with water quality and mass balance models are valuable tools that provide predictions of movement of water and associated transport and transformation of constituents. Models provide a basis for answering questions about the hydrodynamic and water quality conditions occurring under historic and hypothetical management scenarios. Predictions of hydrologic and water quality conditions can, in turn, if the relationship of ecologic indicators to hydrology and water quality are known, support predictions of ecologic processes and conditions. In this way, models can support more reliable decision making.

The complexity and spatial resolution needed in a model are dependent on the specific hydrological and ecological system under study, and the nature of the questions being addressed. We have therefore pursued the development of two modeling approaches with two levels of spatial complexity. We document the development of water budget, hydrodynamic, and constituent models that will be used to provide a quantitative framework for screening management decisions related to inflow and outflow quantities, timing, and water quality.

Efforts of the modeling team in 2007 focused on model implementation, calibration, testing, and communication and training provided through two modeling workshops. The simpler compartmental model for water stage and flow was ported from an Excel spreadsheet to the STELLA simulation system (www.iseesystems.com), and then to the Berkeley Madonna simulation modeling program (www.berkeleymadonna.com). The modeling team found that both STELLA and Berkeley Madonna have straightforward user interfaces, and usually ran the models quickly. Berkeley Madonna was the preferred platform for simulation because of its speed, ability to run longer simulations, and lower cost. The simple constituent model was also ported from WASP to Berkeley Madonna. Both the stage model and the constituent models gave very similar results in Berkeley Madonna when compared to the previous Excel and WASP models, respectively.

In 2007, the spatially explicit MIKE-FLOOD model continued to evolve and improve. By the end of 2007, the model was providing excellent agreement with historical stage data, and promising agreement with chloride concentration, and total phosphorus data throughout a 5-year calibration period. Sulfate concentration simulation has been implemented in the model, but little effort has been expended to calibrate this variable beyond that used in earlier WASP modeling.

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[7] See loxmodel.mwaldon.com

In 2007, two modeling workshops were hosted by the Refuge to communicate progress on Refuge modeling and encourage communication and cooperation among interested parties. These workshops were held in South Florida on June 18, and August 27, 2007. In 2007, the water budget model was also applied in investigations of Refuge water needs by a work group of the Technical Oversight Committee. The model was successful in screening and comparing alternatives water management strategies.

Future applications of the completed models will examine the impacts, both positive and negative, of management and structural alternatives. The hydrological and water quality models could, for example, examine operational strategies that would minimize intrusion of canal water into the Refuge interior. An understanding of any ecological tradeoff between an optimal hydrologic regimen and avoidance of intrusion of the currently high-nutrient canal water is a priority need for management in the short-term until the water quality of Stormwater Treatment Area effluent is good enough to cause no imbalance of Refuge flora and fauna.

Introduction

Although previous efforts directed at modeling hydrology and water quality of the Refuge have been of value (Lin 1979; MacVicar et al. 1984; Lin and Gregg 1988; Richardson et al. 1990; Fitz and Sklar 1999; MacVicar and Lindahl 2000; Raghunathan et al. 2001; Munson et al. 2002; Welter 2002), none of these modeling efforts adequately address some of the current Refuge modeling needs. The Refuge is impacted by changes in water flow and stage (Brandt et al. 2000; USFWS 2000; Brandt 2006), excessive nutrient loading (Newman et al. 1997; USFWS 2000), and altered dissolved mineral concentrations including chloride (Swift 1981; Swift 1984; Swift and Nicholas 1987; Browder et al. 1991; Browder et al. 1994; McCormick and Crawford 2006). Hydrodynamic and water quality models have the potential to provide needed management and scientific support related to these concerns.

The goal of the modeling program (Brandt et al. 2004) is to provide best available technical support for management decisions related to Refuge inflow and outflow water quantity, timing, and quality. A water budget model and a two-dimensional hydrodynamic and water quality model for the Refuge were developed to provide a quantitative framework for these management decisions. These models also predict water movement and water quality resulting from alternative operation scenarios, Stormwater Treatment Area (STA) performance, climatic variation, and structural changes within the Refuge.

Models can assist managers in decision-making, but alone are not sufficient. Objectives and alternatives must first be defined before alternatives can be compared. When fully calibrated and validated, the models described here should assist in answering questions such as (Brandt et al. 2004):

- What is the impact of different management scenarios on the water distribution inside the Refuge?
- What is the impact of the management scenarios on the hydroperiod?
- Does the water depth (duration and frequency) satisfy the needs of plant communities and associated wildlife?
- What are the spatial and temporal distributions of total phosphorus (TP) concentrations within the Refuge?
- What are the impacts of management decisions and strategies on the water quality?
- What are the impacts of alternative regulation schedules on the water quantity (stage) and quality (TP, chloride (Cl), and possibly other constituents such as sulfate (SO_4)) in the Refuge?
- How does (and what are the effects of) surface and ground water interactions in the Refuge?
- What was the impact of moving the location of inflows?
- How do new inflow volume and concentration boundary conditions representing STA design alternatives impact the Refuge hydrology and water quality?

These models will provide a needed tool supporting investigation of these and other questions, but, for most questions, these Refuge models are not sufficient alone to answer these questions. Questions related to ecological change require a definition of how water quality and quantity impact Refuge communities (**see Chapter 3**). For example, the models may predict water depths and flows, and nutrient concentrations, but prediction of changes in distribution of species such as cattail or sawgrass may require further research, assumptions, or modeling. Similarly, the Refuge models can only predict the effects on the Refuge of changes happening outside of the

model's domain (Water Conservation Area 1) through the changed boundary flows and concentrations that result from outside changes. These changes in model boundary conditions must be defined by other models or by clearly-delineated assumptions. The Refuge models can predict effects of external changes if appropriate altered boundaries are input to the Refuge model. Project analyses using the Refuge models will necessarily require predictions from other models of project-related impacts to the Refuge model boundaries. For example, analyses of impacts to the Refuge from the EAA Feasibility Study alternatives (A.D.A. Engineering and SFWMD 2005; Arceneaux 2007b) require specification of quantity and quality of inflow to the Refuge under each alternative scenario.

It is a priority for the Refuge to ensure appropriate structure operations within the water regulation schedule that will produce maximum benefits for fish and wildlife, flood control and water supply. It is also a priority to better understand and to minimize the impact of excessive nutrient loading. The main goal of this modeling effort is to provide a quantitative framework for management decisions related to water quality, quantity and timing. This goal is being accomplished through the development of two models: (a) a water budget and constituent mass balance model, and (b) a complex hydrodynamic-water quality model. This chapter provides a status update from the 3rd Annual Report (USFWS 2007) on the lumped compartmental and the more complex spatially explicit modeling approaches. This chapter provides a brief overview of the status of the modeling program. For detailed information about specific modeling aspects, the reader is directed to the reports cited herein, as well as future reports which will be posted to appropriate internet sites (including: http://loxmodel.mwaldon.com and http://sofia.usgs.gov/lox_monitor_model/).

An independent technical review panel of environmental hydrodynamic and water quality modeling experts has been tasked with advising the Refuge modeling team during model selection, critically reviewing the modeling progress, reviewing documents, and recommending any needed changes. The panel – established independent of the modeling program – is also tasked with providing any technical comments or recommendations that they feel are appropriate and are of value in improving the modeling project. The panel was charged with answering specific questions compiled by the panel chair, Dr. Vincent Neary, Tennessee Technological University (TTU). Dr. Neary established the membership of this panel, including Dr. John A. McCorquodale, University of New Orleans, and Dr. Malcolm L. Spaulding, University of Rhode Island. In order to maintain their complete independence, DOI funding of costs for committee members' participation was funded separately from the modeling support agreement with UL. Funding of the panel was provided through a Cooperative Ecosystems Studies Unit (CESU) agreement between the U.S. Fish and Wildlife Service and TTU.

The panel initially met on January 28, 2005 at the Palm Beach Community College in West Palm Beach to receive input from Refuge staff and other interested agencies and individuals. The panel held its second meeting in Lafayette, Louisiana, on October 27, 2006. At this second meeting, in addition to Dr. Meselhe, Dr. Michael Waldon, Jeanne Arceneaux, and Dr. Alonso Griborio gave presentations on the progress of the Refuge modeling project. The panel again provided many specific technical recommendations to the modeling team. Further recommendations from the advisory panel were considered and documented in the advisory panel report that was provided in 2007 following their 2006 meeting. Throughout 2007, the panel chair and members provided reviews of draft manuscripts and other documents. In 2007, the cooperative agreement with TTU was extended and provided with added funding to insure the continued advice and oversight of the panel.

In 2007, two modeling workshops were held to present modeling status and results (Meselhe et al. 2007b; Meselhe et al. 2007c). The first workshop in 2007, held on June 18, 2007, was attended by more than two dozen people across multiple state and federal agency representatives, university researchers, and others. The workshop covered the water budget and simple constituents modeling efforts, as well as some preliminary information on the complex hydrodynamic modeling. The second workshop was held on August 27, 2007, and covered the updates on the water budget and simple constituents modeling efforts, as details on the complex hydrodynamic modeling. Workshop presentations are currently available at http://loxmodel.mwaldon.com.

Compartmental Modeling

Water budget modeling

A completely-mixed flow (CMF) water budget model was developed for the Refuge (Arceneaux et al. 2006; Arceneaux 2007a; Arceneaux et al. 2007; Meselhe et al. 2007a; Roth 2007) and is now available for use (model and documentation can currently be downloaded at: http://loxmodel.mwaldon.com/). The model was initially developed as an Excel spreadsheet (version 1), but was then ported to the STELLA model simulation program (version 2), and then to Berkeley Madonna modeling program (version 3). These models simulate water volume and stage in the marsh and canal. Model predictions of the spreadsheet and simulation software versions are very similar (**Table 4-1**), but STELLA and Berkeley Madonna add an improved user interface and are more easily adapted. Berkeley Madonna was selected to replace STELLA – based upon recommendations from Dr. Carl Fitz, attendee at one of the previous modeling workshops – for future development because of its speed, lower cost, and ability to simulate longer time periods. This model predicts canal and marsh stages from observed inflow, outflow, precipitation, and evapotranspiration (**Figure 4-1**). The simplified water budget model was developed to predict temporal variations of water levels in the canal and in the marsh based on user-specified inflow and outflow conditions of the boundary hydraulic structures.

Application of the water budget model

As part of a Technical Oversight Committee sub-team to evaluate the "water needs" of the Refuge, the Refuge water balance model was applied to better understand the Refuge inflow component to this question that focuses on identifying a strategy that considers net inflow, timing of inflows, temporal and spatial distribution of inflows, and antecedent conditions in the Refuge for operations. The model was applied to simulate Refuge stage, first under inflow conditions, then under conditions of a hypothetical controlled diversion, and finally under a fixed diversion scenario (described in further detail at *https://my.sfwmd.gov/pls/portal/url/ITEM/4D326CFFCFCFC51EE040E88D485246EA)*. One value of this model is the ability to examine the sensitivity of components of the water budget such as water supply withdrawals and regulator releases that cannot easily be examined by other models. This model application, concluded in early 2008, was successful in helping identify the inflow volumes required to meet the Refuge's water needs[8].

Annual constituent loads as basis for chloride and total phosphorus modeling

[8] More details of this effort is available at www.waterneeds.mwaldon.com.

Annual mass loads for Cl and TP were calculated to gain improved understanding of the processes affecting Refuge water quality. Chloride mass loads provide a useful insight into water movement because chloride uptake or release by biological or chemical processes in surface water is insignificant in relation to surface water concentrations. Thus, chloride acts as a natural conservative tracer of water flow. Unlike water inflow and outflow volumes, chloride annual inflow load was found to consistently exceed outflow load over the period 1995-2004 (**Figure 4-2**). We conclude that significant quantities of chloride, and presumably other constituents, are discharged from the Refuge through groundwater flow.

Total phosphorus annual load has a pattern similar to that exhibited by Cl (**Figure 4-3**), but TP typically exhibits a more reduced outflow load relative to inflow loads (**Figure 4-4**). We interpret this as showing that while some TP is lost through groundwater flow, a significant portion of the TP load is also sequestered within the Refuge. Calendar year 2004 is exceptional, having more TP discharged through outflow than entering through inflow (**Figure 4-4 and 4-5**). It is conjectured that this net TP export in 2004 resulted from the multiple hurricanes that affected the Refuge through direct impact and runoff in September 2004 (Waldon 2006). The observed average canal concentration greatly exceeded modeled concentration that month (Arceneaux et al. 2007) suggesting a mechanism was active at that time that was not represented in the model structure. It is conjectured here that this mechanism was entrainment of canal sediments from water velocity and wind induced turbulence.

Compartmental chloride and phosphorus modeling

The 4-compartment constituent model has been applied to Cl, SO_4, and TP in the Refuge (Arceneaux 2007a; Arceneaux et al. 2007). The spatial conceptualization of the model is mapped in **Figure 4-6**, and the model structure is diagrammed in **Figure 4-7**. Flows driving the constituent model are imported from the water budget model. The water budget and the constituent model were ported from Excel and WASP, respectively, into Berkeley Madonna. In the constituent model, flows between marsh compartments are calculated assuming a flat-pool. Despite data limitations for Cl, current modeling results for Cl (Figure 4-8) are encouraging. Total phosphorus was originally modeled in WASP using a simple k-c* formulation that was not expected to match transient TP concentrations observed in the marsh (**Figure 4-9**). Modeling for TP in the Madonna model has been augmented by a second approach using a more reliable model structure analogous to that used in the DMSTA model (www.wwwalker.net; Waldon 2007b). Preliminary sulfate modeling results are encouraging.

Model improvements are currently under investigation. One improvement suggested by the modeling Technical Advisory Panel is to provide a more quantitative basis for compartment mapping, as well as for the number of compartments utilized. Cluster analysis of observed data is being applied to suggest a new compartmental model structure.

The WASP model has proven to be a convenient and user friendly platform for initial constituent model implementation. A need was recognized for added flexibility in testing new model structure. In particular, increasing the number of compartments in both the water budget and constituent models, and testing alternative constituent dynamics for SO_4 and TP will be considered. The Berkeley Madonna simulation platform will be used to implement these new model structures.

Fully-Dynamic Spatially-Explicit Modeling

Many management needs require a higher spatial resolution than is available through compartmental modeling. Although relatively flat, spatial topographic detail can affect water constituent patterns (**Figure 4-10**). Model prediction of higher resolution spatial variations of stage, flow, and constituent concentrations can be only obtained using a spatially explicit (two-dimensional) numerical model and it is necessary to use a dynamic spatially-variable numerical model. These spatially complex models, however, require much longer time to compute results, are more difficult to operate because of their more complex input and output, and their results are less easily presented and interpreted. We are therefore pursuing a mixed modeling strategy, implementing complex dynamic spatially explicit models to complement development and application of compartmental models. These models form a synergistic suite of tools available to improve our understanding of the Refuge ecosystem.

Hydrodynamic and constituent modeling

The MIKE FLOOD model is a widely-used proprietary set of linked modeling modules that are relatively user friendly when compared to other similarly complex models. The MIKE 21 model uses a structured Cartesian grid; MIKE11 simulates branched one-dimensional channels. MIKE-FLOOD integrates modeling programs, including MIKE-11 and MIKE-21 modules, to simulate hydrodynamic (DHI Water & Environment 2005c), advection/dispersion (DHI Water & Environment 2005b), and ecological (DHI Water & Environment 2005a) processes. The MIKE FLOOD model for the Refuge (Meselhe 2007) has been calibrated for the 5-year period from 2000 to 2004 (**Table 4-2**). The model was validated for the 5-year period from 1995-1999, and 2-year period 2005-2006. Bias, root mean square error (RMSE), correlation coefficient (R), variance reduction, and the Nash Sutcliffe efficiency (Nash and Sutcliffe 1970) were performed for the calibration (**Table 4-2**) and validation periods. Full calibration and validation statistics will be reported in future reports. Calibration of the advection-dispersion module used Cl as conservative tracer. A current simulation of central Refuge stage at the 1-7 gage is presented in **Figure 4-11** as an example of model results.

In 2007, the spatially explicit MIKE-FLOOD model continued to evolve and improve. By the end of 2007, the model was providing good agreement with historical stage, chloride concentration, and total phosphorus data throughout a 5-year calibration period. Constituents are modeled using the DHI ECO-Lab module (DHI Water & Environment 2005a). Sulfate concentration simulation has been implemented in the model, but little effort has been expended to calibrate this variable beyond the parameterization developed in the compartmental model.

Chloride is being modeled as a conservative constituent; TP is modeled using the DMSTA differential equations (Waldon 2007b). This modeling was implemented using the DHI ECO Lab software which links the MIKE FLOOD advection dispersion module results to the constituent dynamics. Example results for Cl are presented in **Figure 4-12**.

2007 Efforts Summary

Initial modeling efforts of the Refuge have been completed. Two modeling workshops demonstrating the results of modeling research have been completed in 2007 and additional workshops are planned. The models described here provide insight into the spatial and temporal variation of flow conditions (stage and velocity), and constituent transport and transformation

within the marsh and in the perimeter canal. These models provide a valuable tool supporting Refuge management.

The modeling effort began with an in-depth review of important hydrodynamic and water quality processes occurring in the Refuge, historic publications on Refuge and Everglades modeling, and data availability. Significant early efforts were directed at model selection, with a final strategy, supported by the modeling Technical Advisory Panel, to utilize a dual modeling approach. This approach combines efforts to develop a completely-mixed flow (CMF) water budget and constituent mass balance model (otherwise termed a box or compartmental model), with development of an implementation of a MIKE-FLOOD/ECO Lab spatially explicit model. The CMF model is efficient, providing excellent spatially-averaged marsh and rim-canal projections for water stage and Cl. This research has applied sound scientific principles and approaches to the setup of both the CMF and MIKE FLOOD models. Initial CMF simulations helped identify model data needs and knowledge gaps. The dual modeling approach increases overall confidence in numerical predictions.

It is recognized that data availability constraints limit rigorous model calibration and validation. Despite specific data deficiencies, potential performance of the hydrodynamic and phosphorous fate and transport models is good. It is imperative to identify additional monitoring data needs to support future modeling efforts. A future challenge is to also find ways to make available model output and aggregated statistics for management and other research uses.

These models are not regional in scope, and can project the response of the natural system inside the Refuge's boundaries to external management alterations through imposed changes in boundary flows and concentrations. These models can provide detailed information about the response of the Refuge to regional management changes and alterations. However, the impact of regional changes on the Refuge model boundary conditions must be assumed or obtained from regional modeling efforts (e.g., the SFWMM).

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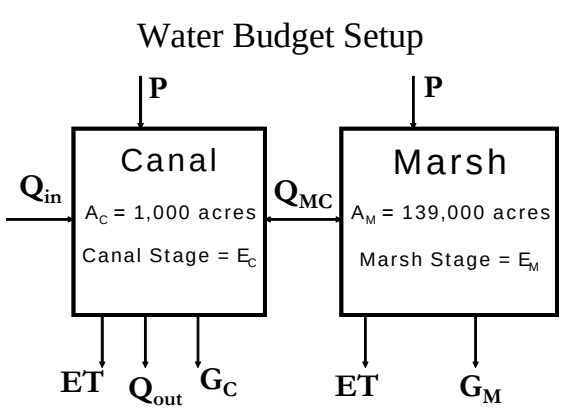
Statistics (1995-2004)	Excel Marsh	STELLA Marsh
Bias	-0.020	-0.021
RMSE	0.079	0.079
SD Observed	0.148	0.148
SD Model	0.171	0.171
SD Error	0.077	0.076
n, sample #	3653	3653
Variance reduction	73%	74%
R (Correl Coef)	0.894	0.897
r^2 (coefficient of determination)	0.800	0.805
Nash-Sutcliffe Eff	0.713	0.719

Table 4-1. Comparison of calibration statistics for the Excel (version 1) and STELLA (version 2) Completely-Mixed Flow models (Roth 2007). Stage units are meters.

Calibration Statistics

Stage Calibration Statistics - Year 2000 to 2004						
Parameter	**North**	**1-7**	**1-8T**	**1-9**	**South**	**1-8C**
Bias (ft)	**-0.075**	**-0.001**	**0.157**	**-0.086**	**0.007**	**0.089**
RMSE (ft)	**0.315**	**0.260**	**0.346**	**0.278**	**0.357**	**0.491**
Variance reduction	**36%**	**66%**	**79%**	**74%**	**75%**	**72%**
R (Correl Coef)	**0.841**	**0.876**	**0.890**	**0.894**	**0.870**	**0.851**
Nash-Sutcliffe Eff	**0.675**	**0.765**	**0.664**	**0.783**	**0.732**	**0.560**

Table 4-2. MIKE-FLOOD stage calibration statistics (Meselhe et al. 2007c).



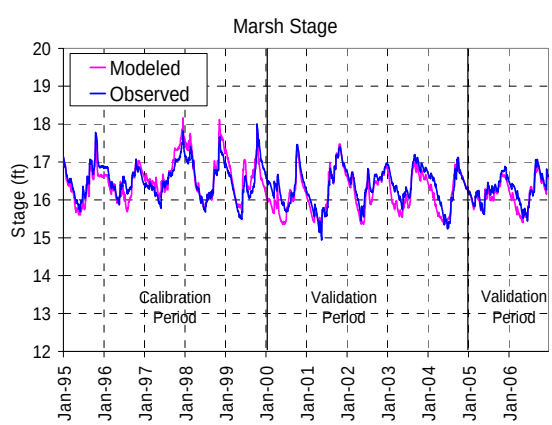


Figure 4-1. Refuge 2-box Completely-Mixed Flow water budget model structure (Arceneaux et al. 2007). Left – structure of the water budget model; Right – example of model output on water levels in the Refuge interior.

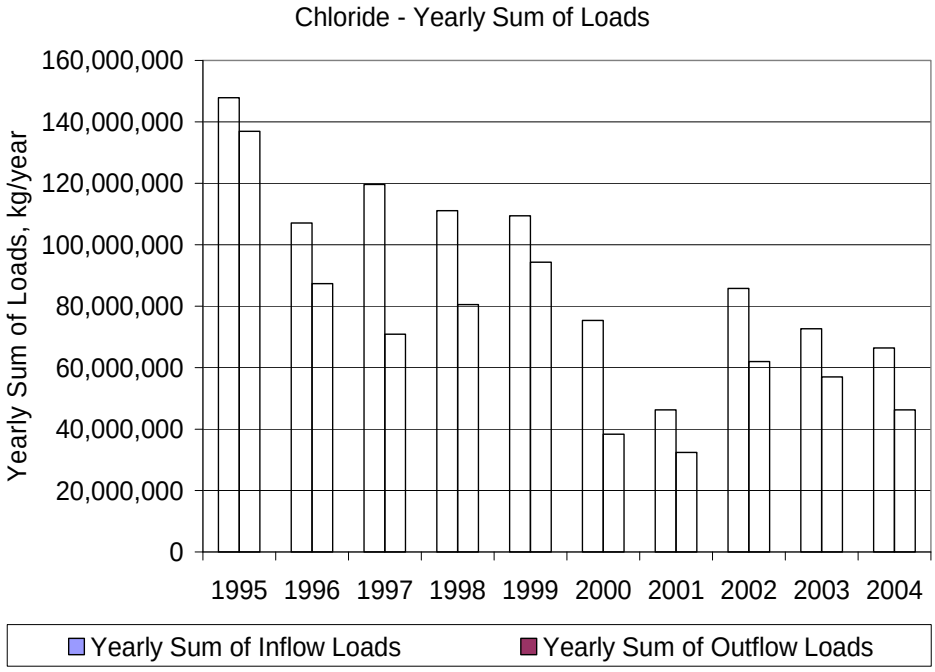


Figure 4-2. Annual (calendar year) Refuge chloride inflow and outflow loads estimated from observed data.

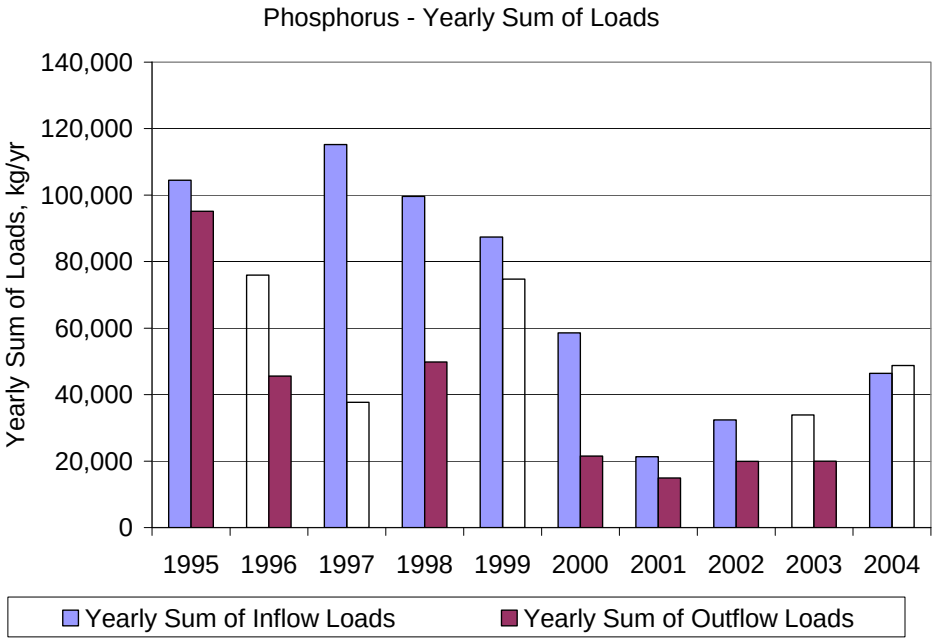


Figure 4-3. Annual (calendar year) Refuge total phosphorus inflow and outflow loads estimated from observed data.

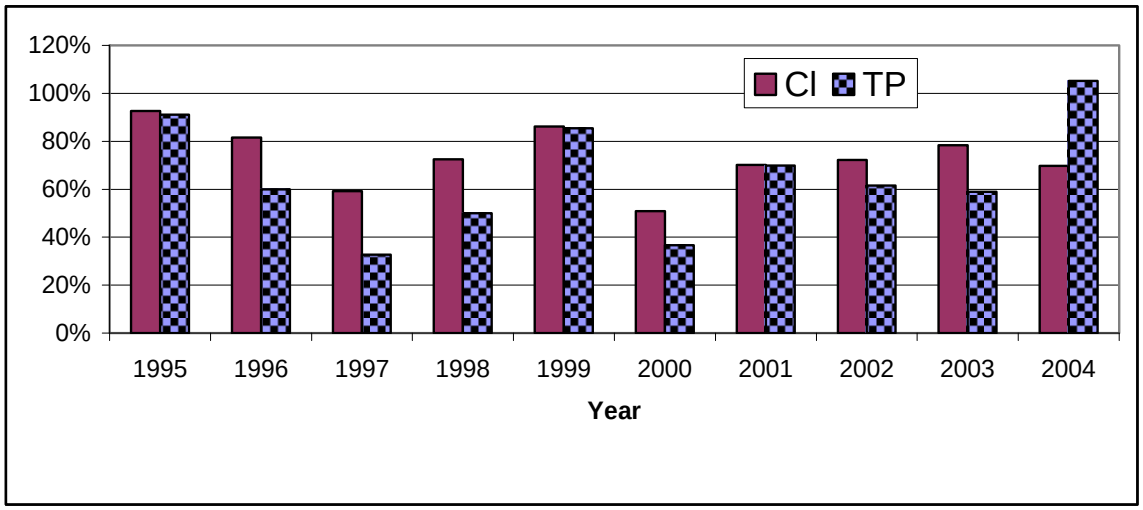


Figure 4-4. Total annual (calendar year) observed outflow load as a percent of inflow load for chloride and total phosphorus.

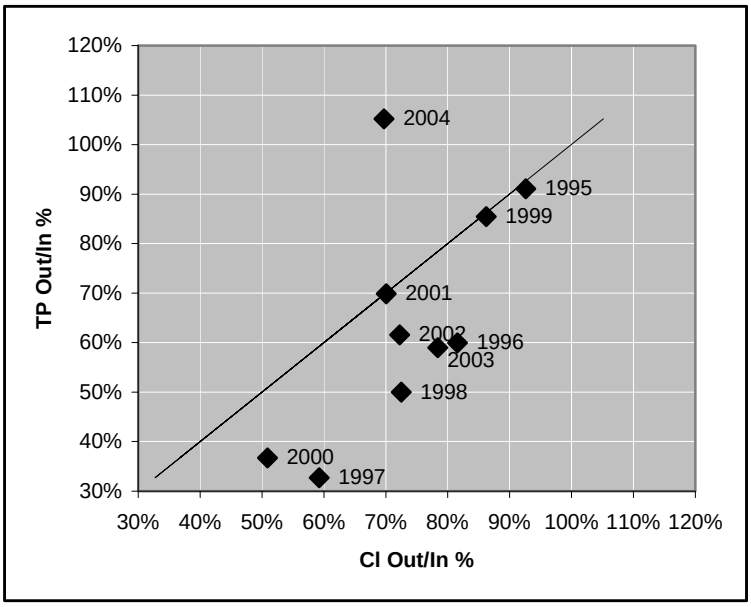


Figure 4-5. Total annual outflow loads as a percentage of inflow loads for total phosphorus are plotted against chloride for the calendar years of study 1995-2004. The line traces a 1:1 ratio between the percentages.

- Divide the Refuge into four cells
  - Canal = 996 acres
  - Cell 1 = 22,072 acres
  - Cell 2 = 55,353 acres
  - Cell 3 = 60,901 acres
- Observed Data – aggregated monthly
  - XYZ
  - EVPA
  - Outflow Hydraulic Structures

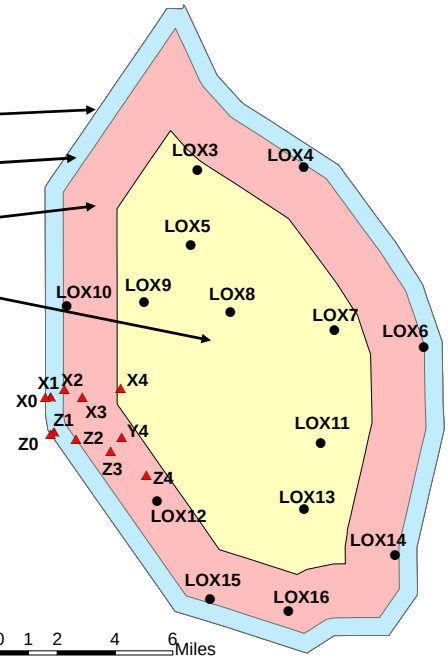


Figure 4-6. Compartment structure of the Refuge 4-compartment constituent model. The locations of water quality monitoring sites (XYZ = X0-X4, Y0, Z0-Z4; EVPA = LOX2-LOX16) used in calibration are shown. Additional stations (not shown) were used for the 2004-2006 validation period.

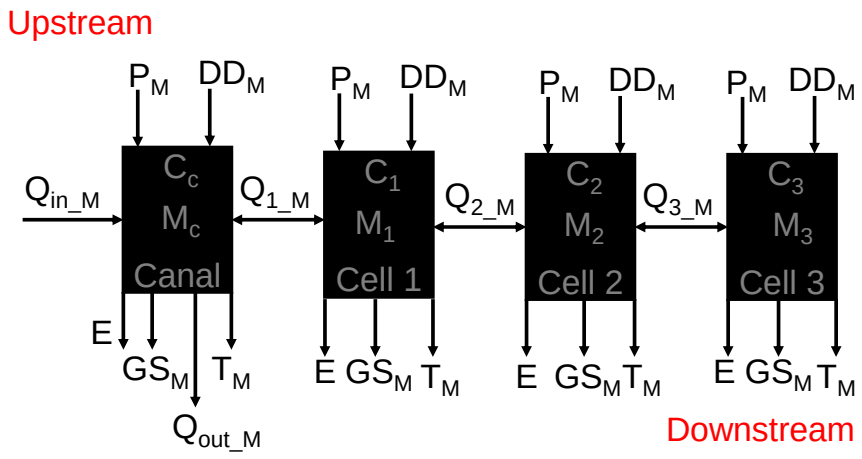


Figure 4-7. Constituent model structure is a one-dimensional series of compartments including a canal (left) and marsh cells. Precipitation (P) and dry deposition (DD) contribute mass while groundwater recharge (G) and transpiration driven flow (T) remove mass. Mass is assumed to not be transported with evaporation (E) flow. Flow between cells, Inflow, and outflow (Q) are imported from the water budget model.

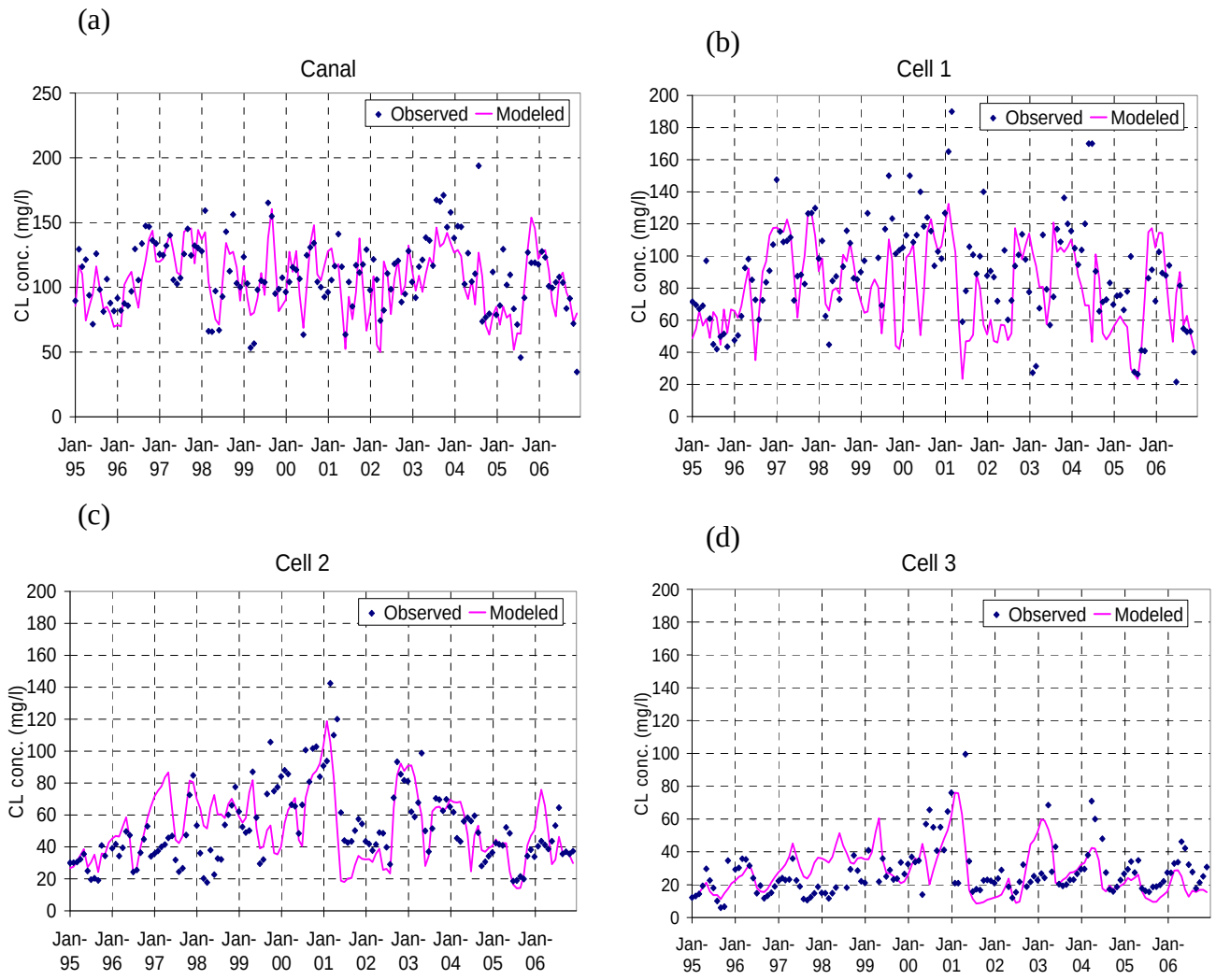


Figure 4-8. Chloride model results are compared with observed average values in each cell as described in Fig. 4-8.

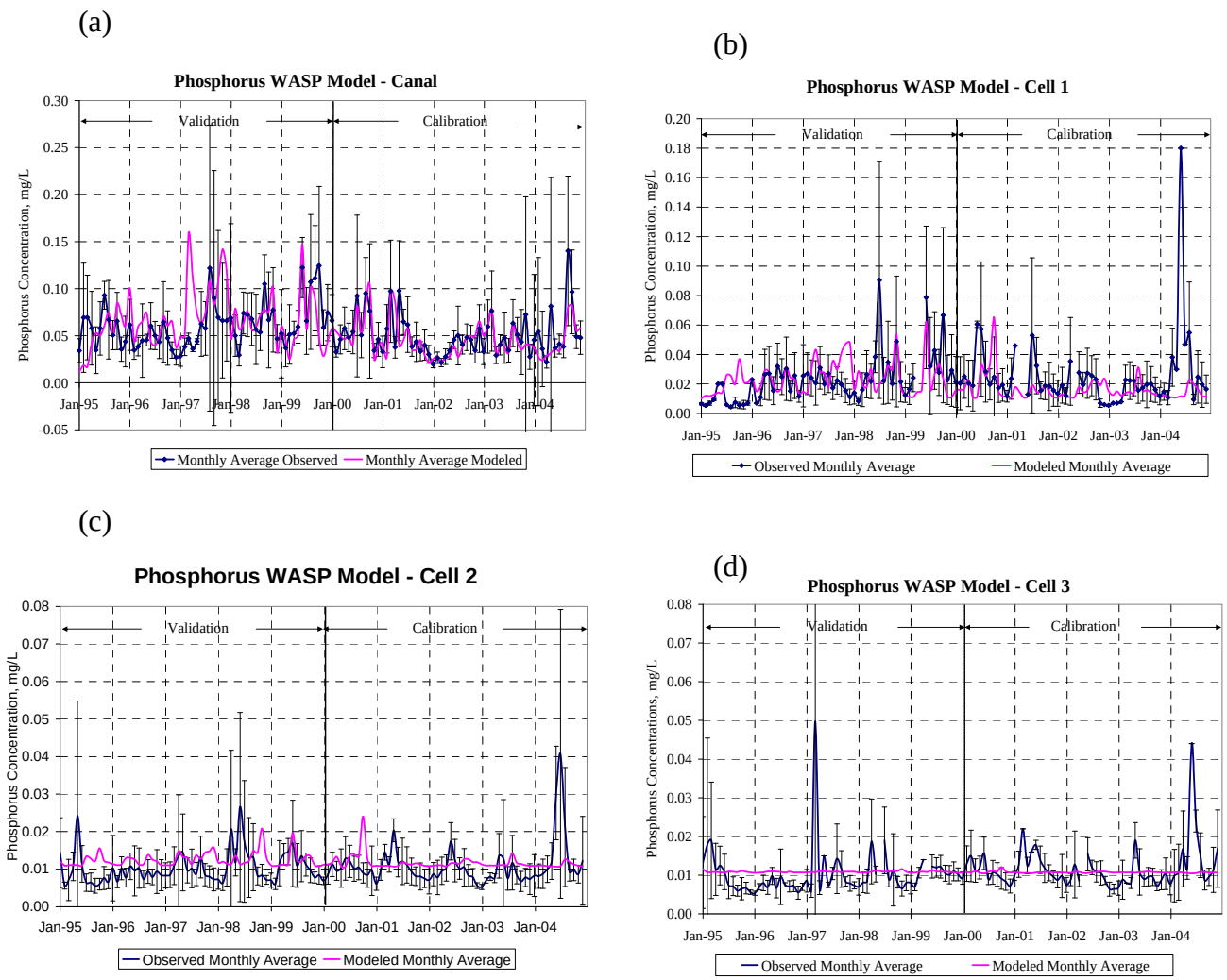


Figure 4-9. Model results for TP compared with observed mean values and standard deviation in each cell described in Figure 4-8.

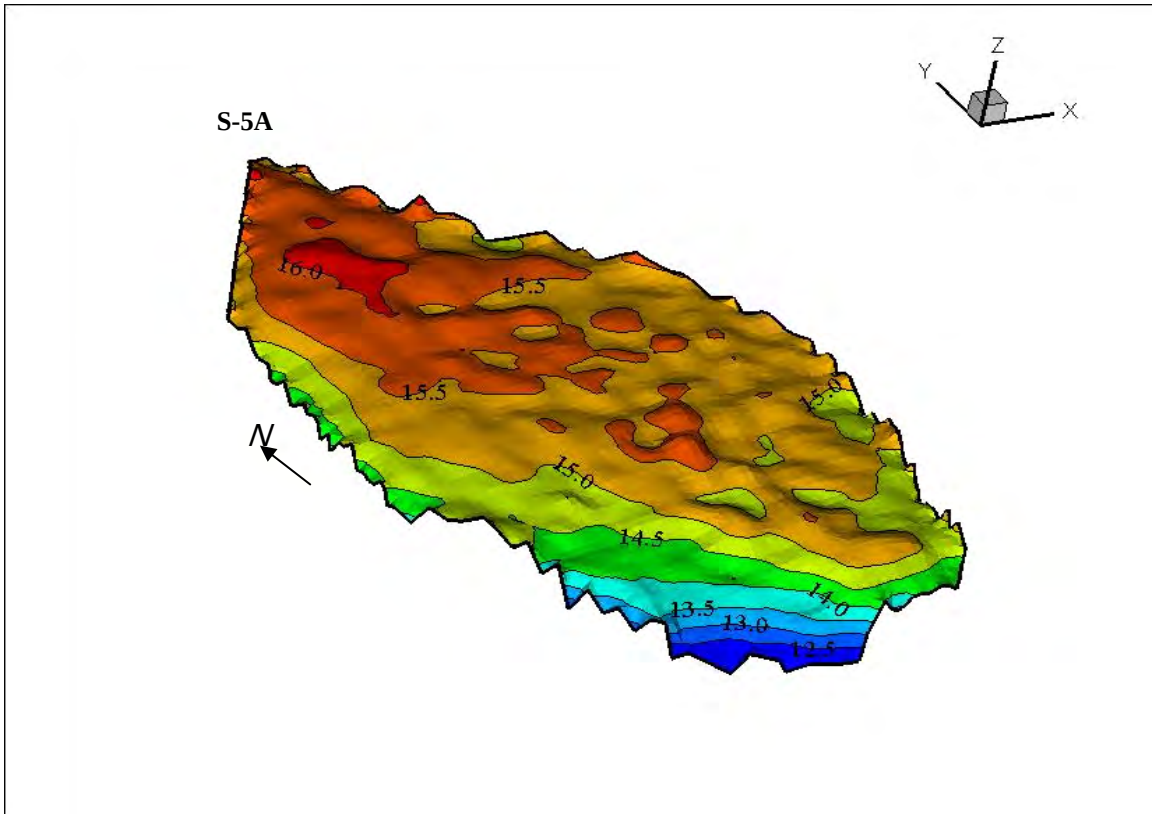


Figure 4-10. Topography of the Refuge (in feet NGVD 1929), based on USGS published (Desmond 2003) elevations, are illustrated in 0.5 ft increments. For reference, a north arrow, and the S5-A inflow pump at the northern boundary of the Refuge are shown.

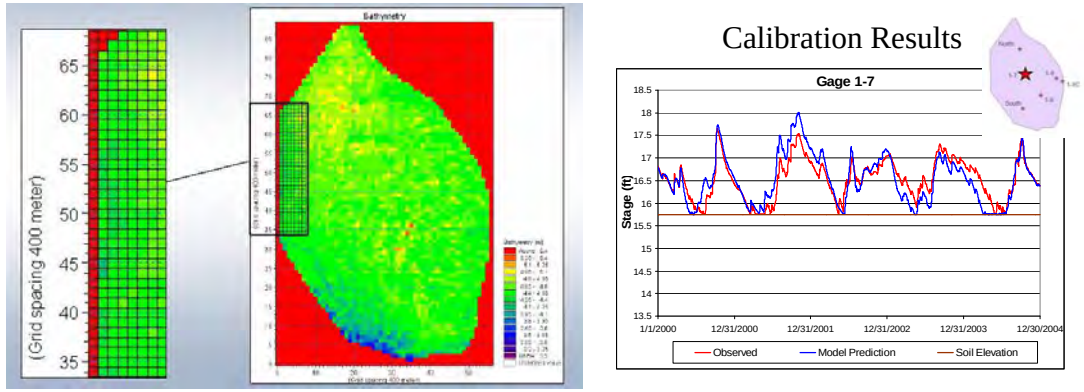


Figure 4-11. Left – 400m grid of complex hydrodynamic model of the Refuge. This is consistent with the USGS high accuracy elevation and EDEN grids. Right – example of initial model output on water levels in the Refuge interior.

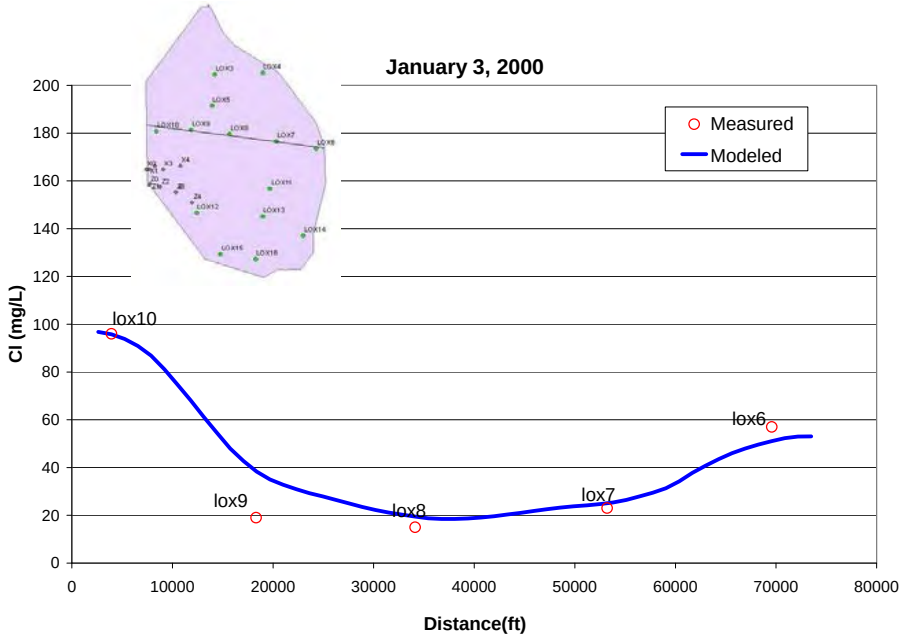


Figure 4-12. Simulation of chloride across a Refuge MIKE-21 (M21) marsh transect (shown by the line in the inset map) is compared here to observed values (Waldon 2007a).

CHAPTER 5: SYNTHESIS OF FINDINGS[9]

Background

The general purposes of the Refuge's enhanced water quality monitoring and modeling program are to improve the scientific understanding of Refuge water quality and to provide an improved scientific foundation for water management decisions to protect Refuge resources. In this program, we improved our understanding of: (1) canal-marsh water movement dynamics; (2) water quality characteristics in the Refuge; (3) water quality impacts on marsh ecology; and (4) hydrologic and water quality dynamics during the different stages of model development.

Canal-Marsh Water Movement Dynamics

This study enhanced our understanding of environmental condition and water management operation influences on canal water intrusion (movement of water from the perimeter canal into the marsh interior) by addressing two water management questions related to intrusion:

- Under what operational or environmental conditions does canal water intrude into the marsh and how far does it intrude?
- How does relative flow through different structures affect water flow and water quality within the interior marsh?

Canal water intrusion continued to be documented near the stormwater treatment area (STA) outflows despite limited discharges during the period of record. Analysis of intrusion dynamics focused on a number of events and associated hydrological conditions. Important insights gained from 2007 data analyses include:

- Canal water intruded into the marsh from 0.5 to 2.3 km (0.3 to 1.4 miles) depending on timing and location.
- Intrusion was not as extensive as in previous years, likely because the Refuge received less canal inflows than in previous years.
- Overall meteorological drought conditions in South Florida began in 2005 and persisted through 2007. Although the Refuge received less rain and canal water inflows, outflows were reduced significantly when compared to previous years, and this operation likely reduced the potential for an extended hydrologic drought for the Refuge. However, 2007 hydroperiods for areas of the marsh greater than 15.5 ft were shorter than during the period from 2004 through 2006.
- In October 2007, canal inflow rates exceeded 2,500 cfs (4,959 acre-ft; 6,114 ML^{-1}), maximum outflow rates were less than half the inflow rates, and canal and marsh stage increased above 17 ft (5.18 m) , resulting in intrusion extending up to 2 km into the marsh.
- Elevated STA outflow flow-weighted mean TP concentrations, elevated canal inflow rates, increased canal and marsh stages, and extended distances of canal water intrusion into the marsh in October 2007 were coincident with a Consent Decree excursion that month.

[9] Prepared by Donatto Surratt, Matthew C. Harwell, Nicholas G. Aumen

Overall insights from the analysis of intrusion information over the history of the Refuge's enhanced water quality program include:

- The relative difference between marsh and canal stages is an important driver of water movement and intrusion.
- Intrusion varies by location and was influenced by canal and marsh stage differences, inflow and outflow rates, and rainfall conditions.
- When canal stage was higher than marsh stage, intrusion occurred under all conditions of inflow and outflow.
- Intrusion across the Refuge increased when inflows occurred (low, moderate, and high rates) and canal-marsh stage difference was small.
- Intrusion is most extensive during elevated inflow and rising stage.
- When rainfall is high and last for several days, canal water intrusion can be buffered or reduced.
- While following water movement does not provide direct information about phosphorus dynamics because phosphorus is taken up by marsh flora, tracking water movement does provide an idea of when and where to expect higher levels of phosphorus in the marsh fringe.

To reduce the frequency and extent of canal water intrusion some of the major implications from these finds include:

- Refuge inflows should be short duration (≤ 5 days) pulses of < 200 cfs (<5,665 L s^{-1}) when absolute canal/marsh stage difference is < 0.2 ft (< 0.1 m) and interior water depths are < 0.5 ft (< 0.2 m).

- Refuge inflow rates can be moderate (200 to 400 cfs; 5,655 to 11,310 L s^{-1}) for short durations if marsh stage is > 0.6 ft (> 0.2 m) higher than canal stage and waters depths are < 0.3 ft (< 0.1 m).

One of our previous recommendations (USFWS 2007a) suggested that outflows needed to be up to 3 – 4 times greater than inflows to minimize canal water intrusion. The addition of 2007 information to data from 2004 through 2006 suggests that the difference between outflows and inflows may not need to be as great. Thus, several earlier management recommendations have been further refined:

- Refuge inflows should be discontinued when the canal stage is > 0.2 ft (> 0.1 m) higher than marsh stage, unless the rainfall or outflow volumes are equal to or greater than inflows.

- If Refuge inflows must be extended beyond short-duration pulses, outflow should be equal to or greater than inflow and last several days longer.

- If Refuge inflows must be maintained at high rates, the S-10s and S-39 should be opened in conjunction with canal inflows to create outflow equal to higher than inflow.

Water Quality Characteristics of the Refuge

The Refuge marsh was classified for analyses based upon conductivity data variability and changes in overall conductivity with perpendicular distance from the perimeter canal into the marsh interior (USFWS 2007a). Drought and inflow operations in 2007 decreased marsh stages for more extensive periods of time relative to previous years, with conditions drying many areas of the Refuge. Regardless of decreased inflows and stages, generally, water quality data for 2007 continued to indicate that the Perimeter Zone (extending from the canal up to 2.5 km (1.6 miles) into the Refuge marsh) is subject to canal water intrusion. In addition, canal water occasionally was observed in the Transition Zone (extending from 2.5 to 4.5 km (1.6 to 2.8 miles) into the marsh). These findings are of concern because of poor water quality and resulting ecological impacts. Average 2007 TP concentrations in the Perimeter Zone (13 $\mu g\ L^{-1}$, or ppb) were lower than canal concentrations (51 $\mu g\ L^{-1}$), but higher than the Transition (7 $\mu g\ L^{-1}$) and Interior Zones (9 $\mu g\ L^{-1}$). Average values of other water quality parameters in 2007 continue to show a decreasing gradient from the canal into the interior marsh even though canal water total nitrogen, sulfate, and chloride concentrations were lower than those observed from 2004 through 2006. Conductivity in the Perimeter Zone consistently was greater than conductivity in the Interior Zone (defined as the marsh area farther than 4.5 km (2.8 miles) from the perimeter canals).

Water Quality Impacts on the Marsh Ecology

From a management perspective, we have begun to tease the influence of water quality apart from other hydrologic and environmental factors on vegetation dynamics. Ecologically, marsh exposure to nutrient and mineral-enriched canal waters has negative consequences to vegetation dynamics, with the Perimeter Zone of the marsh most susceptible to canal water influence. Seed bank germination research conducted in 2007 shows that species such as *Xyris* spp. and *Utricularia* spp. fail to germinate when marsh soils are exposed to canal waters, while *Cyperus* spp., *Pluchea* spp., and *Ludwigia* spp. do not germinate in areas exposed to rain water. Other species such as *Mikania scandens* and *Typha domingensis* germinate under exposure to canal or rain water, but die off in the rain water exposure, likely a response to the lower nutrient concentrations. Observation of *Typha* spp. in the western marsh fringe based on the 2004 vegetation map supports the findings of this research. Particularly, *Typha* spp. is densely distributed up to 1.5 km into the marsh from the canal on the west side of the Refuge, where canal water has been shown to intrude. Beyond 1.6 km into the marsh from the canal, *Typha* spp. density drops rapidly. Further, *Typha* spp. stands can be found throughout the marsh, mostly near alligator and bird nesting sites, where nutrient concentrations tend to be elevated. Result from our seed germination research may provide a possible explanation to these *Typha* spp. dynamics. Other vegetative species observed in the 2007 study were not clearly delineated in the 2004 vegetation map as they were generally classified in one submerged aquatic vegetation group. Future investigations into the site characterization work will be used to field-test results from the seed bank germination study, furthering our understanding of canal water influence on marsh ecology.

Hydrologic and Water Quality Dynamics Modeling

The hydrodynamic and water quality models under development will be used to address the influences of water depths, flow, and water quality under different water management scenarios. The first version of the water budget model (period of record from 1995-2006) is available and has already been used. This model predicts canal and marsh stages from observed inflow, outflow, precipitation, and evapotranspiration. Initial chloride, sulfate, and TP mass balance

models are completed and future revisions have been identified. Because the mass balance models can be run very quickly, a wide range of inputs can be examined for initial screening purposes. The more complex dynamic model then can be used to evaluate a subset of those scenarios.

As part of a Technical Oversight Committee sub-team to evaluate the "water needs" of the Refuge, the Refuge water balance model was applied to better understand the Refuge inflow components to include: net inflow, timing of inflows, temporal and spatial distribution of inflows, and antecedent conditions in the Refuge for operations. The model was applied to simulate Refuge stage, first under inflow conditions, then under conditions of a hypothetical controlled diversion, and finally under a fixed diversion scenario (described in further detail at *https://my.sfwmd.gov/pls/portal/url/ITEM/4D326CFFCFCFC51EE040E88D485246EA)*. One value of this model is the ability to examine the sensitivity of components of the water budget such as water supply withdrawals and regulator releases that cannot easily be examined by other models. This model application, concluded in early 2008, was successful in helping identify the inflow volumes required to meet the Refuge's water needs.

Conclusion

Water management operations affect patterns of intrusion and the frequency and extent of marsh dry-downs, which ultimately affect Refuge ecology. Interpretation of analytical results in this report provides ways to minimize canal water intrusion by adjusting inflow and outflow rates, depending on relative marsh and canal stages. Data analyses presented in this, and previous reports (e.g., USFWS 2007a, b), coupled with future scenario analyses using the models, will allow us to more fully develop water management recommendations. In addition to recommending operational strategies, these data and scenario analyses will provide information to identify potential linkages between canal water intrusion and any future high TP events. A few of the questions we will answer include:

- If there are potential negative impacts of pump, structure, or STA operations, how can they be minimized or eliminated?
- When water supply releases from the eastern Refuge boundary are made up by increased Refuge inflows, what is the optimal pattern of structure operations? Should we continue to require that all make-up water be provided prior to water supply releases?
- When canal stages are below the interior marsh elevation, what are the impacts of water supply releases on interior surface water and groundwater conditions?

Beyond managing canal water intrusion into the marsh, the frequency and extent of marsh dry-downs has an impact on flora and fauna in the Refuge. Previous research in the Everglades (Trexler and Loftus 2001; Trexler et al. 2004; Brandt 2006) suggest there are ideal dry-down and wetting frequencies necessary to maintain healthy habitats for native fauna (e.g., small fish, apple snails). Because a major objective of the U.S. Fish and Wildlife Service is to protect the fish and wildlife and their habitats in the Refuge, it is important to understand these frequencies of hydrologic conditions in the Refuge. Hydrologic conditions in 2007 represent the fourth consecutive year of dry-downs at areas greater than 15.5 ft (34% of the Refuge marsh). The literature suggest that dry-down frequencies should be limited to between no more than three to five consecutive years of dry-down and that it takes three consecutive years of hydrated

conditions for some fauna to recover to pre-dry-down conditions. Thus, in addition to ameliorating canal water intrusion, a reduction in frequency and extent of dry-downs appears to be necessary for the next few years. Both goals of reducing canal water intrusion and frequency and extent of marsh dry-downs aim to restore ecosystem functionality; our enhanced water quality monitoring and modeling program has shown that these two management goals are not incompatible.

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Trexler JC, Loftus WF, Tarboton KC, 2004. Chapter 6: Fish Habitat suitability index. Habitat suitability indices for evaluating water management alternatives, K. C. Tarboton and others, eds., South Florida Water Management District, Office of Modeling, West Palm Beach, FL.

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APPENDICES

App. 2-1. Individual EVPA and LOXA station summary statistics of water quality data for calendar year 2007.

App. 2-2. Monthly water quality data summary statistics by zone for calendar year 2007.

Appendix 2-1

Individual EVPA and LOXA station summary statistics of water quality data for calendar year 2007. Where values were below the minimum detection limits, one half of the minimum detection limit is reported (sensu Weaver et al. 2008). Previous summary statistics (2004 – 2006) can be found in the previous annual reports (USFWS 2007a, b).

Site	STAT	ALK	Ca	Cl	COLOR	D-O	DOC	HARD	K	Mg	NO2	NO3	Na	NH4	NOX	OPO4	Ph_F	SiO2	SO4	SpC	T_PO4	TDKN	TDS	TEMP	TKN	TOC	TSS	TURB
		mg L^{-1}	mg L^{-1}	mg L^{-1}	PCU	mg L^{-1}	mg L^{-1}	mg L^{-1}	mg L^{-1}	mg L^{-1}	mg L^{-1}	mg L^{-1}	mg L^{-1}	mg L^{-1}	mg L^{-1}	µg L^{-1}	units	mg L^{-1}	mg L^{-1}	µS cm^{-1}	µg L^{-1}	mg L^{-1}	mg L^{-1}	Deg. C	mg L^{-1}	mg L^{-1}	mg L^{-1}	mg L^{-1}
LOX3	Count	2.0	2.0	6.0	2.0	5.0	2.0	2.0	2.0	2.0	2.0000	2.0000	2.0	2.0000	2.0000	2.0	5.0	2.0	6.0	5.0	7.0	2.0	2.0	6.0	2.0	2.0	2.0	2.0
	Average	8.0	4.8	20.0	115.0	3.2	23.3	19.0	0.8	1.7	0.0040	0.0025	11.3	0.0205	0.0038	3.0	6.1	3.7	0.1	111.5	9.1	1.3	114.5	24.8	1.4	23.7	2.3	0.7
	StdDev	1.4	0.2	4.4	29.7	0.7	0.2	0.6	0.1	0.0	0.0014	0.0000	0.9	0.0049	0.0018	0.0	0.2	0.8	0.0	27.5	1.1	0.1	4.9	3.3	0.1	0.4	1.1	0.1
	Min	7.0	4.6	16.6	94.0	2.5	23.1	18.5	0.7	1.7	0.0030	0.0025	10.6	0.0170	0.0025	3.0	5.9	3.1	0.1	89.1	8.0	1.3	111.0	21.5	1.4	23.4	1.5	0.6
	Max	9.0	4.9	27.5	136.0	4.4	23.4	19.4	0.9	1.7	0.0050	0.0025	11.9	0.0240	0.0050	3.0	6.4	4.3	0.1	145.0	11.0	1.4	118.0	28.9	1.5	23.9	3.0	0.7
LOX4	Count	6.0	6.0	9.0	6.0	8.0	6.0	6.0	6.0	6.0	6.0000	5.0000	6.0	6.0000	5.0000	6.0	8.0	6.0	9.0	7.0	9.0	6.0	6.0	9.0	6.0	6.0	6.0	6.0
	Average	74.8	23.0	45.2	171.7	4.0	25.5	82.6	3.0	6.2	0.0057	0.0025	27.7	0.0248	0.0052	3.2	6.6	10.0	2.5	301.0	11.7	1.2	231.7	24.7	1.2	26.0	1.8	0.7
	StdDev	16.9	5.4	14.5	51.6	2.0	4.8	18.8	0.8	1.4	0.0016	0.0000	8.3	0.0095	0.0026	0.4	0.2	4.0	2.4	65.3	3.7	0.2	50.0	4.5	0.2	4.8	0.6	0.3
	Min	57.0	18.0	25.0	111.0	2.0	18.4	64.4	1.9	4.7	0.0040	0.0025	18.4	0.0110	0.0025	3.0	6.4	4.4	0.8	227.0	7.0	1.0	173.0	18.1	1.0	18.4	1.5	0.4
	Max	100.0	31.7	67.4	236.0	7.1	31.0	111.1	4.0	7.8	0.0080	0.0025	38.0	0.0370	0.0080	4.0	6.8	13.6	7.7	415.3	17.0	1.4	313.0	31.1	1.5	31.2	3.0	1.0
LOX5	Count	3.0	3.0	7.0	3.0	6.0	3.0	3.0	3.0	3.0	3.0000	3.0000	3.0	3.0000	3.0000	3.0	6.0	3.0	7.0	6.0	8.0	3.0	3.0	7.0	3.0	3.0	3.0	3.0
	Average	7.3	5.0	24.3	82.3	4.1	24.0	19.9	0.8	1.8	0.0033	0.0037	14.3	0.0197	0.0052	3.0	6.1	4.4	0.1	113.1	8.3	1.5	117.3	24.3	1.6	24.2	1.5	1.0
	StdDev	1.2	0.7	3.4	20.6	1.4	2.1	2.5	0.1	0.2	0.0006	0.0020	2.3	0.0015	0.0024	0.0	0.3	0.6	0.1	11.4	1.3	0.2	18.2	4.3	0.2	2.1	0.0	0.3
	Min	6.0	4.6	19.8	68.0	2.4	22.5	18.4	0.8	1.7	0.0030	0.0025	12.2	0.0180	0.0025	3.0	5.9	3.8	0.1	98.8	7.0	1.3	101.0	17.5	1.4	22.7	1.5	0.7
	Max	8.0	5.8	29.0	106.0	6.1	26.4	22.8	0.9	2.0	0.0040	0.0060	16.8	0.0210	0.0070	3.0	6.7	4.9	0.4	132.0	11.0	1.7	137.0	29.7	1.8	26.6	1.5	1.3
LOX6	Count	8.0	8.0	9.0	8.0	8.0	8.0	8.0	8.0	8.0	8.0000	8.0000	8.0	8.0000	8.0000	8.0	9.0	8.0	9.0	8.0	9.0	8.0	8.0	9.0	8.0	8.0	8.0	8.0
	Average	59.8	20.5	43.1	72.8	4.1	17.5	71.1	2.1	4.9	0.0024	0.0039	27.9	0.0166	0.0044	3.3	7.0	10.0	3.6	274.3	6.6	1.1	213.1	23.3	1.2	17.7	1.5	0.6
	StdDev	20.1	7.1	15.7	26.1	1.7	3.9	24.0	0.8	1.5	0.0007	0.0027	9.9	0.0136	0.0027	0.5	0.4	7.6	3.1	101.8	2.1	0.3	57.5	5.0	0.3	3.8	0.0	0.2
	Min	34.0	11.2	23.6	53.0	1.6	14.0	39.7	1.0	2.8	0.0020	0.0025	15.0	0.0045	0.0025	3.0	6.5	0.5	0.2	146.4	4.0	0.8	128.0	15.6	0.8	14.0	1.5	0.4
	Max	88.0	30.4	62.4	131.0	6.6	24.2	103.7	3.0	6.7	0.0040	0.0100	39.2	0.0480	0.0100	4.0	7.6	17.6	9.1	405.1	10.0	1.7	286.0	30.1	1.8	24.4	1.5	0.8
LOX7	Count	9.0	9.0	9.0	9.0	8.0	9.0	9.0	9.0	9.0	9.0000	8.0000	9.0	9.0000	8.0000	9.0	8.0	9.0	9.0	7.0	9.0	9.0	9.0	9.0	9.0	9.0	9.0	9.0
	Average	13.1	6.7	22.3	100.3	5.6	23.0	24.4	0.7	1.8	0.0032	0.0056	13.7	0.0162	0.0074	3.2	6.3	4.8	0.1	100.5	8.6	1.3	121.2	25.0	1.3	23.6	1.5	0.9
	StdDev	5.9	1.9	6.3	24.6	1.2	3.1	5.6	0.2	0.3	0.0008	0.0052	3.5	0.0100	0.0048	0.4	0.3	2.5	0.1	13.4	1.1	0.2	29.4	5.1	0.2	3.2	0.0	0.6
	Min	9.0	5.4	12.9	74.0	4.0	19.0	20.0	0.4	1.5	0.0020	0.0025	8.7	0.0045	0.0025	3.0	6.0	1.5	0.1	78.3	7.0	1.0	78.0	17.4	1.1	20.0	1.5	0.6
	Max	28.0	11.2	33.0	155.0	7.6	27.4	37.2	1.0	2.4	0.0040	0.0180	19.5	0.0350	0.0180	4.0	6.8	7.9	0.2	116.6	10.0	1.6	158.0	31.8	1.7	29.1	1.5	2.4
LOX8	Count	8.0	8.0	9.0	8.0	9.0	8.0	8.0	8.0	8.0	8.0000	7.0000	8.0	8.0000	7.0000	8.0	9.0	8.0	9.0	8.0	10.0	8.0	8.0	10.0	8.0	8.0	8.0	8.0
	Average	9.9	5.3	21.1	70.0	5.3	20.8	20.1	0.5	1.7	0.0028	0.0069	12.1	0.0148	0.0076	3.3	6.2	3.0	0.1	104.6	9.4	1.2	103.5	24.9	1.3	21.1	1.5	0.8
	StdDev	5.3	1.2	5.5	12.9	1.7	2.0	3.8	0.1	0.2	0.0007	0.0053	2.2	0.0051	0.0049	0.5	0.4	1.3	0.0	34.7	2.4	0.2	14.4	4.7	0.1	2.2	0.0	0.2
	Min	6.0	4.2	14.9	50.0	3.0	17.8	16.1	0.3	1.4	0.0020	0.0025	9.3	0.0045	0.0025	3.0	5.8	1.0	0.1	78.2	7.0	1.0	83.0	17.4	1.1	17.8	1.5	0.6
	Max	22.0	8.0	32.6	88.0	7.0	23.2	28.2	0.6	2.0	0.0040	0.0160	15.9	0.0200	0.0160	4.0	7.2	4.4	0.1	187.0	15.0	1.5	124.0	30.3	1.6	24.8	1.5	1.2
LOX9	Count	3.0	3.0	8.0	3.0	7.0	3.0	3.0	3.0	3.0	3.0000	3.0000	3.0	3.0000	3.0000	3.0	7.0	3.0	8.0	7.0	8.0	3.0	3.0	8.0	3.0	3.0	3.0	3.0
	Average	16.7	5.8	27.7	64.3	4.4	20.0	23.7	1.1	2.2	0.0027	0.0025	13.4	0.0160	0.0025	3.0	6.3	6.0	0.1	135.2	7.9	1.3	100.7	25.4	1.3	20.4	1.5	0.7
	StdDev	6.4	1.1	7.6	6.8	1.3	1.8	4.3	0.1	0.4	0.0006	0.0000	1.9	0.0026	0.0050	0.0	0.1	0.7	0.0	26.8	2.0	0.1	26.1	4.4	0.1	1.3	0.0	0.2
	Min	13.0	5.0	17.0	59.0	2.9	18.3	20.4	1.1	1.9	0.0020	0.0025	11.5	0.0140	0.0025	3.0	6.1	5.5	0.1	98.3	5.0	1.2	76.0	17.1	1.2	19.3	1.5	0.5
	Max	24.0	7.1	38.8	72.0	6.1	21.8	28.6	1.2	2.6	0.0030	0.0025	15.2	0.0190	0.0025	3.0	6.5	6.7	0.1	183.4	11.0	1.4	128.0	30.4	1.4	21.8	1.5	0.9
LOX10	Count	6.0	6.0	7.0	6.0	7.0	6.0	6.0	6.0	6.0	6.0000	6.0000	6.0	6.0000	6.0000	6.0	7.0	6.0	7.0	7.0	7.0	6.0	5.0	7.0	6.0	6.0	6.0	6.0
	Average	52.7	15.1	29.1	80.5	4.0	18.9	58.1	2.9	4.9	0.0028	0.0048	20.2	0.0206	0.0053	3.2	6.8	9.8	1.7	191.8	8.4	1.1	180.2	24.3	1.1	18.9	1.5	0.7
	StdDev	15.1	4.5	13.7	44.2	1.6	3.2	17.5	1.2	1.6	0.0012	0.0055	8.2	0.0099	0.0054	0.4	0.3	3.9	1.5	89.2	3.1	0.1	50.8	4.1	0.2	3.2	0.0	0.1
	Min	30.0	9.2	17.8	52.0	2.8	15.0	36.0	1.4	3.1	0.0020	0.0025	12.8	0.0045	0.0025	3.0	6.3	3.1	0.8	94.1	6.0	0.9	106.0	17.3	0.8	15.0	1.5	0.5
	Max	76.0	22.6	53.9	168.0	7.0	24.3	87.5	4.8	7.5	0.0050	0.0160	33.9	0.0320	0.0160	4.0	7.2	15.2	5.0	351.7	15.0	1.2	241.0	29.4	1.3	24.0	1.5	0.9
LOX11	Count	8.0	8.0	11.0	8.0	10.0	8.0	8.0	8.0	8.0	8.0000	8.0000	8.0	8.0000	8.0000	8.0	10.0	8.0	11.0	9.0	12.0	8.0	8.0	11.0	8.0	8.0	8.0	7.0
	Average	11.1	6.2	21.2	64.9	4.4	17.8	21.1	0.3	1.4	0.0026	0.0038	11.1	0.0158	0.0042	3.3	6.2	2.0	0.1	104.8	7.8	1.0	104.3	22.7	1.1	18.3	1.5	0.7
	StdDev	4.5	1.2	7.5	22.0	2.0	2.6	3.6	0.1	0.2	0.0007	0.0029	2.2	0.0101	0.0030	0.5	0.3	0.8	0.0	35.5	2.4	0.1	19.9	5.6	0.1	2.3	0.0	0.2
	Min	7.0	4.9	14.4	44.0	1.4	13.4	17.8	0.2	1.2	0.0020	0.0025	8.5	0.0045	0.0025	3.0	5.8	0.6	0.1	77.7	4.0	0.8	80.0	14.7	0.9	13.7	1.5	0.5
	Max	20.0	8.3	39.0	105.0	7.5	21.1	28.1	0.4	1.8	0.0040	0.0110	14.7	0.0360	0.0110	4.0	6.9	3.0	0.1	192.0	13.0	1.2	143.0	29.8	1.3	20.6	1.5	1.2
LOX12	Count	10.0	10.0	10.0	10.0	9.0	10.0	10.0	10.0	10.0	10.0000	9.0000	10.0	9.0000	9.0000	10.0	10.0	10.0	10.0	9.0	10.0	10.0	10.0	10.0	10.0	10.0	10.0	9.0
	Average	42.5	12.7	26.2	63.1	4.8	17.5	48.5	1.2	4.1	0.0024	0.0031	17.4	0.0262	0.0031	3.2	6.8	6.4	0.8	173.4	8.5	1.0	148.6	23.3	1.1	17.6	1.5	0.7
	StdDev	5.8	1.8	5.6	19.9	1.6	1.5	7.0	0.3	0.6	0.0005	0.0011	3.8	0.0348	0.0011	0.4	0.3	3.7	0.4	29.5	2.6	0.2	26.0	5.5	0.2	1.5	0.0	0.3
	Min	34.0	9.9	17.7	40.0	2.4	15.9	37.4	0.8	3.1	0.0020	0.0025	11.6	0.0025	0.0025	3.0	6.5	1.8	0.4	124.8	5.0	0.9	116.0	15.7	0.9	16.0	1.5	0.4
	Max	53.0	16.3	37.3	89.0	7.6	20.9	62.2	1.7	5.2	0.0030	0.0060	25.0	0.1070	0.0060	4.0	7.3	11.9	1.4	230.1	13.0	1.3	206.0	30.7	1.5	21.2	1.5	1.6
LOX13	Count	8.0	8.0	10.0	8.0	9.0	8.0	8.0	8.0	8.0	8.0000	7.0000	8.0	8.0000	7.0000	8.0	9.0	8.0	10.0	8.0	10.0	8.0	8.0	10.0	8.0	8.0	8.0	8.0
	Average	15.5	7.3	19.8	59.5	4.6	16.1	23.6	0.4	1.3	0.0023	0.0039	10.1	0.0104	0.0039	3.3	6.3	2.8	0.1	99.0	8.2	1.0	103.9	23.6	1.0	16.5	1.5	0.7
	StdDev	5.1	1.6	7.2	18.9	1.6	2.1	4.8	0.1	0.2	0.0007	0.0014	2.2	0.0060	0.0014	0.5	0.3	1.2	0.0	30.5	2.9	0.2	30.9	6.4	0.2	2.3	0.0	0.1
	Min	8.0	4.7	11.9	43.0	2.4	12.2	15.9	0.2	1.0	0.0010	0.0025	7.0	0.0025	0.0025	3.0	6.0	1.8	0.1	63.5	6.0	0.8	72.0	15.4	0.8	12.5	1.5	0.5
	Max	21.0	9.1	31.7	96.0	7.6	18.9	29.5	0.4	1.7	0.0030	0.0060	13.2	0.0190	0.0060	4.0	6.8	5.4	0.1	158.3	16.0	1.2	173.0	36.0	1.2	20.0	1.5	0.9
LOX14	Count	9.0	9.0	10.0	9.0	9.0	9.0	9.0	9.0	9.0	9.0000	9.0000	9.0	9.0000	8.0000	9.0	10.0	9.0	10.0	8.0	10.0	9.0	9.0	10.0	9.0	9.0	9.0	8.0
	Average	43.1	14.7	27.7	78.9	4.3	15.6	50.2	1.2	3.3	0.0026	0.0030	17.6	0.0114	0.0034	3.2	6.7	4.8	2.1	189.2	7.4	0.8	142.8	24.3	0.8	15.8	1.5	0.5
	StdDev	13.5	5.2	9.0	24.0	2.0	2.4	17.4	0.7	1.1	0.0009	0.0011	5.6	0.0091	0.0014	0.4	0.1	3.3	2.6	62.6	2.0	0.2	45.4	5.0	0.2	2.6	0.0	0.1
	Min	32.0	10.4	17.0	54.0	1.6	13.6	34.8	0.8	2.1	0.0020	0.0025	11.1	0.0025	0.0025	3.0	6.5	0.9	0.4	144.5	4.0	0.6	90.0	15.9	0.7	13.5	1.5	0.4
	Max	76.0	27.3	50.4	124.0	7.3	20.5	92.2	3.1	5.8	0.0040	0.0060	30.9	0.0290	0.0060	4.0	6.9	9.0	9.0	331.0	11.0	1.1	245.0	30.2	1.2	20.9	1.5	0.7
LOX15	Count	9.0	9.0	9.0	9.0	8.0	9.0	9.0	9.0	9.0	9.0000	8.0000	9.0	9.0000	8.0000	9.0	9.0	9.0	9.0	8.0	9.0	9.0	9.0	9.0	9.0	9.0	9.0	8.0
	Average	72.6	23.2	32.6	54.1	5.1	16.8	83.7	1.6	6.3	0.0023	0.0079	22.9	0.0340	0.0079	3.2	7.2	5.8	7.7	262.3	8.0	1.1	198.4	24.4	1.1	17.2	1.5	0.6
	StdDev	14.3	6.4	4.6	22.2	1.7	1.1	18.7	0.3	0.8	0.0007	0.0051	3.3	0.0417	0.0051	0.4	0.2	3.0	5.5	38.8	1.2	0.1	24.2	4.9	0.1	1.4	0.0	0.1
	Min	53.0	14.5	25.4	39.0	2.4	14.7	55.7	1.1	4.7	0.0020	0.0025	18.1	0.0025	0.0025	3.0	7.0	0.7	1.8	205.3	7.0	0.9	173.0	16.3	1.0	15.1	1.5	0.5
	Max	102.0	35.1	41.6	111.0	7.1	18.2	118.8	1.9	7.6	0.0040	0.0160	28.8	0.1250	0.0160	4.0	7.5	9.2	17.9	324.3	11.0	1.3	244.0	30.9	1.3	19.7	1.5	0.8

Site	STAT	ALK	Ca	Cl	COLOR	D-O	DOC	HARD	K	Mg	NO2	NO3	Na	NH4	NOX	OPO4	Ph_F	SiO2	SO4	SpC	T_PO4	TDKN	TDS	TEMP	TKN	TOC	TSS	TURB
		mg L^{-1}	mg L^{-1}	mg L^{-1}	PCU	mg L^{-1}	mg L^{-1}	mg L^{-1}	mg L^{-1}	mg L^{-1}	mg L^{-1}	mg L^{-1}	mg L^{-1}	mg L^{-1}	mg L^{-1}	µg L^{-1}	units	mg L^{-1}	mg L^{-1}	µS cm^{-1}	µg L^{-1}	mg L^{-1}	mg L^{-1}	Deg. C	mg L^{-1}	mg L^{-1}	mg L^{-1}	mg L^{-1}
LOX16	Count	9.0	9.0	9.0	9.0	8.0	9.0	9.0	9.0	9.0	9.0000	9.0000	9.0	9.0000	9.0000	9.0	9.0	9.0	9.0	8.0	9.0	9.0	9.0	9.0	9.0	9.0	9.0	8.0
	Average	53.7	18.3	36.4	78.8	2.7	16.7	63.3	1.9	4.3	0.0027	0.0039	22.9	0.0188	0.0039	3.2	6.6	6.3	4.3	241.0	8.6	0.9	176.4	23.6	0.9	17.1	1.5	0.6
	StdDev	14.6	6.3	13.0	23.5	1.6	2.8	21.2	0.9	1.3	0.0010	0.0016	7.6	0.0128	0.0016	0.4	0.2	3.5	5.4	86.1	2.7	0.2	49.9	5.1	0.2	2.9	0.0	0.2
	Min	34.0	10.5	20.5	56.0	0.6	13.3	36.1	0.6	2.4	0.0020	0.0025	12.9	0.0025	0.0025	3.0	6.4	1.6	0.3	127.2	5.0	0.7	108.0	16.0	0.7	14.0	1.5	0.4
	Max	80.0	30.6	59.5	119.0	5.7	21.0	103.4	3.3	6.6	0.0050	0.0070	35.9	0.0380	0.0070	4.0	6.8	10.4	17.6	382.0	13.0	1.3	262.0	30.1	1.3	21.8	1.5	1.0
A101	Count	3.0	3.0	7.0		7.0	3.0								2.0000	3.0	7.0	3.0	7.0	7.0	7.0		3.0	7.0	3.0	3.0	5.0	3.0
	Average	114.7	43.0	95.1		2.2	28.3								0.0020	17.9	7.4	11.8	13.0	573.7	11.0		366.7	23.2	1.5	28.3	3.2	0.4
	StdDev	18.6	15.6	33.5		1.2	7.5								0.0000	22.6	0.3	4.8	9.5	248.4	5.9		141.5	4.1	0.2	9.0	0.9	0.1
	Min	94.0	33.0	52.0		0.8	21.0								0.0020	4.3	7.2	7.5	2.7	162.4	4.3		280.0	18.4	1.3	19.0	2.0	0.4
	Max	130.0	61.0	130.0		4.5	36.0								0.0020	44.0	7.8	17.0	27.0	826.6	20.0		530.0	29.1	1.7	37.0	4.0	0.5
A102	Count	3.0	3.0	3.0		3.0	3.0								2.0000	3.0	3.0	3.0	3.0	3.0	3.0		3.0	3.0	3.0	3.0	2.0	3.0
	Average	43.0	12.3	17.3		3.7	21.7								0.0020	38.4	7.2	14.6	1.3	150.3	6.6		126.7	22.1	0.9	22.0	0.8	0.6
	StdDev	10.0	2.6	2.1		0.6	0.6								0.0000	47.6	0.7	4.6	0.6	28.5	2.1		20.8	3.7	0.1	0.0	0.0	0.2
	Min	33.0	9.9	15.0		3.3	21.0								0.0020	4.7	6.7	9.9	0.7	121.9	5.1		110.0	19.2	0.9	22.0	0.8	0.5
	Max	53.0	15.0	19.0		4.3	22.0								0.0020	72.0	8.0	19.0	2.0	178.8	8.1		150.0	26.3	1.0	22.0	0.8	0.8
A103	Count	3.0	3.0	5.0		5.0	3.0								2.0000	3.0	5.0	3.0	5.0	5.0	5.0		3.0	5.0	3.0	3.0	3.0	3.0
	Average	43.3	11.7	22.8		2.4	26.3								0.0020	40.5	7.0	15.1	1.1	166.0	6.7		140.0	21.8	1.2	26.3	2.3	0.5
	StdDev	7.6	1.2	7.7		0.9	2.9								0.0000	46.0	0.8	7.1	0.4	26.7	3.2		17.3	3.5	0.4	3.8	1.4	0.2
	Min	38.0	11.0	16.0		1.5	23.0								0.0020	7.9	6.5	9.2	0.7	135.9	4.0		130.0	18.2	0.9	22.0	0.8	0.3
	Max	52.0	13.0	36.0		3.8	28.0								0.0020	73.0	8.2	23.0	1.7	204.4	11.0		160.0	26.0	1.6	29.0	3.5	0.6
A104	Count	12.0	12.0	11.0		12.0	12.0								9.0000	10.0	12.0	12.0	11.0	12.0	12.0		12.0	12.0	12.0	12.0	12.0	12.0
	Average	152.5	49.0	82.0		5.2	25.1								0.0387	21.5	7.7	9.8	25.4	581.8	119.6		390.0	25.5	1.7	25.2	6.6	6.5
	StdDev	30.2	11.5	30.9		1.3	5.3								0.0376	22.0	0.3	6.2	16.1	200.6	277.6		118.2	3.9	0.5	5.0	4.3	6.2
	Min	110.0	32.0	44.0		2.0	19.0								0.0020	4.9	7.3	2.2	7.4	292.3	24.0		200.0	20.5	1.2	19.0	0.8	2.0
	Max	200.0	70.0	120.0		6.8	34.0								0.1000	61.0	8.1	20.0	60.0	924.6	1000.0		580.0	31.5	2.8	33.0	14.0	19.0
A105	Count	3.0	3.0	7.0		7.0	3.0								2.0000	3.0	7.0	3.0	7.0	7.0	7.0		3.0	7.0	3.0	3.0	6.0	3.0
	Average	166.7	52.3	61.6		2.7	28.7								0.0090	30.5	7.4	17.0	13.0	475.4	21.2		453.3	23.7	1.8	28.7	3.9	1.0
	StdDev	28.9	12.1	29.0		1.6	4.7								0.0099	38.9	0.6	3.6	15.1	228.0	15.4		100.7	4.1	0.6	4.7	4.2	0.5
	Min	150.0	43.0	32.0		0.6	25.0								0.0020	3.0	6.8	13.0	2.6	229.6	7.5		360.0	17.7	1.3	25.0	0.8	0.5
	Max	200.0	66.0	110.0		5.0	34.0								0.0160	58.0	8.4	20.0	45.0	859.2	52.0		560.0	28.3	2.4	34.0	12.0	1.5
A106	Count	3.0	3.0	6.0		6.0	2.0								2.0000	3.0	6.0	3.0	6.0	6.0	6.0		3.0	6.0	3.0	3.0	5.0	3.0
	Average	101.7	31.0	42.8		2.9	25.5								0.0150	27.0	7.4	12.7	7.3	341.0	17.5		290.0	24.9	1.4	22.7	1.9	0.6
	StdDev	37.5	13.0	25.4		1.3	3.5								0.0184	33.9	0.7	6.0	10.0	166.4	22.1		125.3	3.4	0.6	4.5	1.2	0.2
	Min	65.0	18.0	22.0		1.0	23.0								0.0020	3.0	6.9	6.2	1.5	196.1	4.8		160.0	20.2	0.9	18.0	0.8	0.5
	Max	140.0	44.0	87.0		4.6	28.0								0.0280	51.0	8.6	18.0	27.0	620.7	56.0		410.0	29.1	2.0	27.0	3.5	0.8
A107	Count	2.0	2.0	3.0		3.0	2.0								1.0000	2.0	3.0	2.0	3.0	3.0	3.0		2.0	3.0	2.0	2.0	3.0	2.0
	Average	65.0	12.6	23.3		2.2	20.0								0.0040	88.0	6.6	16.5	1.0	164.5	24.3		147.0	22.0	1.1	20.0	1.2	0.4
	StdDev	49.5	4.8	9.1		0.3	1.4								0.0000	0.0	0.3	12.0	0.3	51.1	29.4		75.0	3.6	0.2	1.4	0.7	0.1
	Min	30.0	9.2	15.0		2.0	19.0								0.0040	88.0	6.3	8.0	0.7	120.3	4.0		94.0	18.6	1.0	19.0	0.8	0.3
	Max	100.0	16.0	33.0		2.5	21.0								0.0040	88.0	6.8	25.0	1.3	220.5	58.0		200.0	25.7	1.3	21.0	2.0	0.5
A108	Count	3.0	3.0	3.0		3.0	3.0								2.0000	3.0	3.0	3.0	3.0	3.0	3.0		3.0	3.0	3.0	3.0	3.0	3.0
	Average	17.7	5.7	19.3		4.7	23.3								0.0020	13.0	6.9	5.8	0.1	114.5	4.4		101.0	22.1	1.4	24.7	2.4	0.7
	StdDev	4.5	0.4	2.5		1.1	3.5								0.0000	14.1	0.8	1.2	0.2	12.2	0.6		8.5	4.0	0.1	4.5	1.4	0.1
	Min	13.0	5.2	17.0		3.4	20.0								0.0020	3.0	6.4	4.4	0.1	105.3	4.0		93.0	19.2	1.3	20.0	0.8	0.6
	Max	22.0	6.0	22.0		5.6	27.0								0.0020	23.0	7.9	6.5	0.3	128.3	4.8		110.0	26.7	1.4	29.0	3.5	0.8
A109	Count	6.0	6.0	7.0		7.0	6.0								2.0000	6.0	7.0	6.0	7.0	7.0	7.0		6.0	7.0	5.0	6.0	7.0	6.0
	Average	57.3	17.2	31.4		3.0	22.0								0.0163	37.9	7.1	11.1	3.4	237.0	15.4		166.2	25.2	1.3	21.5	2.2	0.8
	StdDev	20.8	7.4	15.5		1.5	1.9								0.0061	35.6	0.3	4.3	4.8	99.3	13.5		63.2	3.2	0.4	1.4	0.7	0.2
	Min	34.0	12.0	20.0		1.2	20.0								0.0120	5.6	6.6	2.5	1.1	143.6	5.4		87.0	20.5	0.8	19.0	0.8	0.5
	Max	96.0	32.0	66.0		4.8	25.0								0.0206	85.0	7.6	14.0	14.0	445.9	41.0		280.0	28.3	1.8	23.0	3.0	1.1
A110	Count	3.0	3.0	6.0		6.0	3.0								2.0000	3.0	6.0	3.0	6.0	6.0	5.0		3.0	6.0	3.0	3.0	5.0	3.0
	Average	24.0	7.7	20.2		4.4	20.7								0.0090	47.0	7.1	10.5	0.3	126.7	18.3		113.7	24.9	1.3	20.3	2.0	0.7
	StdDev	4.0	0.2	4.5		3.2	3.2								0.0099	2.8	0.6	4.9	0.2	12.0	21.5		20.3	3.2	0.1	2.1	1.2	0.2
	Min	20.0	7.5	16.0		1.4	17.0								0.0020	45.0	6.4	6.6	0.1	105.1	4.0		91.0	19.7	1.2	18.0	0.8	0.6
	Max	28.0	7.9	29.0		10.2	23.0								0.0160	49.0	7.8	16.0	0.5	136.8	43.0		130.0	27.5	1.4	22.0	3.5	0.9
A111	Count	3.0	3.0	7.0		7.0	3.0								2.0000	3.0	7.0	3.0	7.0	7.0	6.0		3.0	7.0	3.0	3.0	5.0	3.0
	Average	37.7	11.3	20.9		4.3	17.3								0.0060	28.0	7.1	11.3	0.6	149.2	16.4		130.0	24.7	1.1	17.3	2.8	0.6
	StdDev	2.5	0.6	2.5		2.6	1.5								0.0057	19.8	0.6	2.9	0.5	21.8	14.5		20.0	3.1	0.1	1.5	1.2	0.0
	Min	35.0	11.0	18.0		1.2	16.0								0.0020	14.0	6.3	8.0	0.2	108.9	7.3		110.0	20.0	1.0	16.0	0.8	0.5
	Max	40.0	12.0	24.0		8.4	19.0								0.0100	42.0	8.1	13.0	1.7	175.8	38.0		150.0	27.8	1.1	19.0	4.0	0.6
A112	Count	4.0	4.0	7.0		7.0	4.0								1.0000	4.0	7.0	4.0	7.0	7.0	7.0		4.0	7.0	4.0	4.0	7.0	4.0
	Average	63.3	20.0	37.4		3.2	20.8								0.0020	49.3	7.3	10.2	3.6	275.1	7.4		187.5	25.2	1.3	20.8	2.3	1.0
	StdDev	29.9	7.3	23.5		1.7	1.5								0.0000	39.9	0.5	2.5	4.2	169.5	3.8		69.5	3.4	0.3	1.7	1.0	0.6
	Min	30.0	14.0	16.0		1.6	20.0								0.0020	4.0	6.5	7.0	1.2	131.1	4.0		130.0	19.8	1.0	19.0	0.8	0.5
	Max	100.0	30.0	71.0		6.4	23.0								0.0020	79.0	7.9	13.0	13.0	561.7	14.0		270.0	28.4	1.7	23.0	4.0	1.5

Site	STAT	ALK	Ca	Cl	COLOR	D-O	DOC	HARD	K	Mg	NO2	NO3	Na	NH4	NOX	OPO4	Ph_F	SiO2	SO4	SpC	T_PO4	TDKN	TDS	TEMP	TKN	TOC	TSS	TURB
		mg L^{-1}	mg L^{-1}	mg L^{-1}	PCU	mg L^{-1}	mg L^{-1}	mg L^{-1}	mg L^{-1}	mg L^{-1}	mg L^{-1}	mg L^{-1}	mg L^{-1}	mg L^{-1}	mg L^{-1}	µg L^{-1}	units	mg L^{-1}	mg L^{-1}	µS cm^{-1}	µg L^{-1}	mg L^{-1}	mg L^{-1}	Deg. C	mg L^{-1}	mg L^{-1}	mg L^{-1}	mg L^{-1}
A113	Count	3.0	3.0	9.0		9.0	3.0								2.0000	3.0	9.0	3.0	8.0	9.0	7.0		3.0	9.0	3.0	3.0	7.0	3.0
	Average	31.7	8.8	22.6		5.0	17.7								0.0051	31.0	7.2	12.0	0.4	144.4	15.0		109.7	26.8	1.0	17.3	2.2	0.5
	StdDev	3.8	0.4	7.2		2.5	4.5								0.0044	15.6	0.6	4.0	0.3	32.7	13.1		27.0	5.0	0.1	3.1	1.1	0.1
	Min	29.0	8.4	14.0		1.5	13.0								0.0020	20.0	6.5	8.1	0.1	108.1	6.1		79.0	20.2	0.9	14.0	0.8	0.5
	Max	36.0	9.1	37.0		8.5	22.0								0.0082	42.0	8.1	16.0	0.8	200.3	38.0		130.0	37.8	1.1	20.0	3.5	0.6
A114	Count	3.0	3.0	8.0		8.0	3.0								2.0000	3.0	8.0	3.0	3.0	8.0	7.0		3.0	8.0	3.0	3.0	6.0	3.0
	Average	29.0	7.2	21.1		3.5	19.7								0.0059	22.6	7.0	12.1	0.2	127.2	13.8		113.3	25.0	1.0	19.0	2.6	0.6
	StdDev	1.7	0.6	4.4		1.2	4.2								0.0055	24.7	0.6	2.5	0.3	14.2	17.2		5.8	3.3	0.3	2.6	1.7	0.1
	Min	27.0	6.8	15.0		1.9	15.0								0.0020	5.1	6.3	9.2	0.1	105.2	4.2		110.0	19.6	0.7	16.0	0.8	0.5
	Max	30.0	7.9	29.0		5.5	23.0								0.0098	40.0	7.8	14.0	0.6	145.0	44.0		120.0	28.5	1.2	21.0	5.5	0.7
A115	Count	12.0	12.0	12.0		12.0	12.0								10.0000	11.0	12.0	12.0	12.0	12.0	12.0		12.0	12.0	12.0	12.0	11.0	12.0
	Average	144.4	46.0	71.7		4.6	23.9								0.0322	17.5	7.6	8.1	24.8	563.5	35.3		361.7	25.8	1.5	23.9	4.1	3.3
	StdDev	28.3	13.0	29.6		1.8	5.0								0.0600	16.5	0.3	6.5	17.1	201.3	14.3		129.3	3.3	0.4	5.5	2.3	2.6
	Min	120.0	31.0	40.0		1.4	19.0								0.0020	3.7	7.2	2.1	5.7	343.0	14.0		220.0	20.5	0.9	17.0	0.8	1.0
	Max	210.0	74.0	120.0		6.8	34.0								0.2000	53.0	8.0	20.0	62.0	966.6	57.0		620.0	30.0	2.1	34.0	8.5	10.0
A116	Count	6.0	5.0	6.0		6.0	5.0								3.0000	6.0	6.0	6.0	6.0	6.0	8.0		6.0	6.0	6.0	6.0	6.0	6.0
	Average	150.8	44.0	82.5		1.1	29.6								0.0027	41.8	7.0	16.0	25.2	623.0	92.4		413.3	23.3	2.3	29.5	19.8	6.4
	StdDev	61.8	17.3	37.2		0.8	6.5								0.0012	25.6	0.4	7.8	16.2	266.8	37.4		166.3	3.8	0.9	6.4	11.6	5.5
	Min	65.0	23.0	35.0		0.3	20.0								0.0020	3.8	6.7	6.0	8.4	280.1	20.0		170.0	19.3	0.8	18.0	2.5	0.8
	Max	220.0	64.0	120.0		2.2	37.0								0.0041	80.0	7.8	23.0	52.0	944.1	130.0		600.0	28.1	3.3	36.0	36.0	15.0
A117	Count	6.0	6.0	7.0		7.0	6.0								3.0000	5.0	7.0	6.0	7.0	7.0	7.0		6.0	7.0	6.0	6.0	4.0	6.0
	Average	103.5	32.2	52.9		1.7	27.8								0.0034	39.5	6.8	15.2	11.5	393.7	22.6		293.3	22.4	1.3	27.5	2.0	0.8
	StdDev	40.6	14.2	31.7		0.9	6.1								0.0025	39.8	0.5	9.5	9.8	210.0	28.5		139.7	3.5	0.3	6.3	1.4	0.2
	Min	61.0	17.0	21.0		0.6	20.0								0.0020	7.5	6.2	4.7	3.6	193.2	4.6		150.0	17.8	0.8	18.0	0.8	0.6
	Max	150.0	50.0	95.0		2.7	35.0								0.0063	84.0	7.7	26.0	30.0	685.0	86.0		450.0	26.9	1.6	34.0	3.5	1.0
A118	Count	7.0	7.0	7.0		7.0	7.0								4.0000	6.0	7.0	7.0	7.0	7.0	7.0		7.0	7.0	7.0	7.0	5.0	7.0
	Average	60.6	15.9	30.1		2.8	20.4								0.0031	28.7	6.8	11.6	4.0	215.0	18.8		159.6	23.6	0.9	20.4	2.1	0.6
	StdDev	22.6	5.6	14.4		0.8	3.6								0.0017	27.1	0.7	7.7	2.1	88.9	23.0		59.2	3.6	0.2	3.7	1.2	0.2
	Min	40.0	10.0	15.0		1.9	17.0								0.0020	5.9	6.1	2.8	2.5	131.3	4.1		100.0	18.7	0.6	16.0	0.8	0.4
	Max	100.0	24.0	53.0		4.4	25.0								0.0055	68.0	8.1	22.0	8.2	349.4	65.0		240.0	28.7	1.3	26.0	3.0	0.9
A119	Count	6.0	6.0	7.0		7.0	6.0								4.0000	5.0	7.0	6.0	7.0	7.0	7.0		6.0	7.0	6.0	6.0	4.0	6.0
	Average	25.8	8.3	18.1		3.4	19.5								0.0031	39.0	6.4	11.9	0.9	119.6	16.1		95.8	24.4	0.9	19.0	1.5	0.7
	StdDev	9.3	1.3	3.7		1.0	2.0								0.0014	32.5	0.3	6.8	0.5	16.5	20.6		22.9	3.1	0.1	1.8	0.9	0.4
	Min	12.0	6.5	14.0		2.3	17.0								0.0020	16.0	6.0	5.1	0.4	98.2	4.2		61.0	20.8	0.6	17.0	0.8	0.5
	Max	40.0	9.7	24.0		4.9	23.0								0.0048	62.0	7.0	22.0	1.8	137.9	58.0		120.0	28.3	1.0	22.0	2.5	1.5
A120	Count	9.0	9.0	11.0		11.0	9.0								6.0000	6.0	11.0	9.0	4.0	11.0	10.0		9.0	11.0	9.0	9.0	10.0	9.0
	Average	25.4	7.8	28.8		5.4	20.8								0.0036	14.8	6.9	5.8	0.2	158.0	12.3		117.9	25.8	1.4	20.4	3.2	0.8
	StdDev	9.5	2.2	11.6		1.6	4.1								0.0027	11.9	0.6	1.6	0.2	55.8	8.8		34.0	2.8	0.5	3.8	1.8	0.4
	Min	17.0	5.9	15.0		2.7	16.0								0.0020	3.0	6.3	3.7	0.1	92.4	4.5		76.0	22.1	0.8	16.0	0.8	0.5
	Max	47.0	13.0	51.0		7.6	31.0								0.0089	28.0	7.9	8.4	0.5	255.0	34.0		200.0	29.4	2.3	30.0	7.5	1.8
A122	Count	6.0	6.0	7.0		7.0	6.0								1.0000	4.0	7.0	6.0	7.0	7.0	7.0		6.0	7.0	6.0	6.0	3.0	6.0
	Average	125.0	38.7	51.6		1.5	26.2								0.0020	55.0	7.0	10.5	12.2	1380.0	11.0		291.7	24.1	1.3	26.3	1.6	0.6
	StdDev	42.3	15.4	27.9		0.6	4.2								0.0000	39.6	0.5	6.5	11.4	2659.3	3.6		132.7	3.6	0.3	4.5	0.7	0.3
	Min	60.0	19.0	20.0		0.7	21.0								0.0020	27.0	6.5	4.0	4.7	200.4	5.9		150.0	18.9	0.9	21.0	0.8	0.3
	Max	170.0	59.0	99.0		2.4	31.0								0.0020	83.0	7.8	19.0	37.0	7403.9	15.0		480.0	27.8	1.8	31.0	2.0	1.2
A124	Count	7.0	7.0	9.0		9.0	7.0								5.0000	5.0	9.0	7.0	8.0	9.0	8.0		7.0	9.0	7.0	7.0	6.0	7.0
	Average	52.7	16.9	33.6		2.8	19.1								0.0064	23.3	6.8	7.2	1.9	206.4	12.3		168.7	24.1	1.0	19.6	2.6	0.6
	StdDev	21.7	5.8	14.5		1.8	3.3								0.0027	16.5	0.5	4.6	3.0	88.7	6.5		66.7	3.4	0.4	4.3	1.0	0.2
	Min	29.0	10.0	19.0		0.7	15.0								0.0021	3.0	5.8	1.5	0.2	118.2	5.6		92.0	18.5	0.5	15.0	0.8	0.5
	Max	88.0	28.0	61.0		6.6	24.0								0.0089	42.0	7.4	14.0	9.2	377.1	24.0		290.0	28.2	1.7	26.0	4.0	1.1
A126	Count	7.0	7.0	8.0		8.0	7.0								4.0000	5.0	8.0	7.0	8.0	8.0	8.0		7.0	8.0	7.0	7.0	5.0	7.0
	Average	77.9	26.6	50.0		3.2	17.7								0.0088	28.5	6.9	8.2	7.4	338.9	8.8		226.9	24.7	1.0	18.3	2.1	0.8
	StdDev	27.0	9.9	18.8		1.2	3.5								0.0116	19.0	0.2	5.4	5.6	119.7	3.9		76.5	4.0	0.4	4.3	1.3	0.4
	Min	40.0	13.0	25.0		1.5	15.0								0.0020	3.0	6.7	0.7	0.7	168.4	4.0		120.0	19.1	0.6	15.0	0.8	0.4
	Max	110.0	38.0	75.0		4.9	24.0								0.0260	49.0	7.1	13.0	17.0	468.8	14.0		320.0	29.2	1.9	25.0	3.5	1.5
A127	Count	5.0	5.0	7.0		7.0	5.0								3.0000	5.0	7.0	5.0	3.0	7.0	6.0		5.0	7.0	5.0	5.0	4.0	5.0
	Average	23.0	7.7	23.3		3.7	20.8								0.0074	22.3	6.5	8.3	0.2	125.3	7.7		106.4	24.9	1.3	22.0	2.0	0.9
	StdDev	12.0	1.0	6.5		1.4	2.2								0.0068	14.5	0.2	1.4	0.2	21.8	3.9		10.5	4.0	0.5	2.1	1.7	0.4
	Min	12.0	6.5	19.0		1.9	18.0								0.0020	3.0	6.3	5.9	0.1	103.8	4.0		93.0	19.6	0.9	20.0	0.8	0.6
	Max	42.0	8.8	35.0		5.4	23.0								0.0150	38.0	6.8	9.7	0.4	160.0	13.0		120.0	30.4	2.1	25.0	4.5	1.5
A128	Count	3.0	3.0	7.0		7.0	3.0								2.0000	3.0	7.0	3.0	3.0	6.0	6.0		3.0	7.0	3.0	3.0	4.0	3.0
	Average	18.0	6.1	23.7		3.9	21.3								0.0020	25.0	6.5	8.4	0.2	133.2	6.9		102.3	25.7	1.2	21.3	2.3	0.6
	StdDev	4.4	0.7	5.3		2.5	3.8								0.0000	11.3	0.4	3.2	0.2	19.0	4.5		16.6	2.4	0.4	3.8	1.2	0.2
	Min	15.0	5.4	16.0		0.3	17.0								0.0020	17.0	6.2	5.9	0.1	109.1	4.2		87.0	22.6	0.8	17.0	0.8	0.4
	Max	23.0	6.7	31.0		8.3	24.0								0.0020	33.0	7.4	12.0	0.4	151.0	15.0		120.0	29.0	1.4	24.0	3.5	0.7

Site	STAT	ALK	Ca	Cl	COLOR	D-O	DOC	HARD	K	Mg	NO2	NO3	Na	NH4	NOX	OPO4	Ph_F	SiO2	SO4	SpC	T_PO4	TDKN	TDS	TEMP	TKN	TOC	TSS	TURB
		mg L^{-1}	mg L^{-1}	mg L^{-1}	PCU	mg L^{-1}	mg L^{-1}	mg L^{-1}	mg L^{-1}	mg L^{-1}	mg L^{-1}	mg L^{-1}	mg L^{-1}	mg L^{-1}	mg L^{-1}	µg L^{-1}	units	mg L^{-1}	mg L^{-1}	µS cm^{-1}	µg L^{-1}	mg L^{-1}	mg L^{-1}	Deg. C	mg L^{-1}	mg L^{-1}	mg L^{-1}	mg L^{-1}
A129	Count	12.0	12.0	12.0		12.0	12.0								10.0000	11.0	12.0	12.0	12.0	12.0	12.0		12.0	12.0	12.0	12.0	12.0	12.0
	Average	137.5	51.3	62.7		3.4	19.3								0.0185	35.3	7.3	6.4	18.2	513.2	69.3		322.9	25.5	1.4	19.5	6.5	4.4
	StdDev	31.9	11.6	16.9		1.7	3.3								0.0145	54.2	0.3	2.3	14.4	80.3	69.4		57.3	3.3	0.5	3.5	3.8	2.9
	Min	110.0	36.0	43.0		1.2	13.0								0.0020	3.0	6.8	1.6	4.1	375.7	13.0		215.0	20.1	0.7	13.0	3.0	1.1
	Max	210.0	76.0	98.0		6.1	24.0								0.0440	180.0	7.9	9.9	58.0	620.0	270.0		390.0	30.5	2.3	24.0	16.0	11.0
A130	Count	7.0	7.0	8.0		8.0	7.0								5.0000	6.0	8.0	7.0	8.0	8.0	8.0		7.0	8.0	7.0	7.0	5.0	7.0
	Average	85.1	28.4	43.8		1.7	20.6								0.0054	24.2	6.7	8.6	4.8	328.6	10.2		226.0	24.5	1.0	20.9	1.5	0.6
	StdDev	12.5	6.2	10.1		0.5	5.3								0.0022	24.2	0.1	4.5	5.0	71.0	4.6		34.3	3.5	0.4	6.2	0.7	0.2
	Min	65.0	22.0	25.0		1.0	15.0								0.0034	3.0	6.6	2.4	1.6	220.5	4.8		180.0	18.9	0.6	15.0	0.8	0.5
	Max	100.0	37.0	61.0		2.4	30.0								0.0090	62.0	6.8	15.0	16.0	446.8	20.0		280.0	28.7	1.6	31.0	2.0	0.9
A131	Count	5.0	5.0	8.0		8.0	5.0								3.0000	5.0	8.0	5.0	8.0	8.0	8.0		5.0	8.0	5.0	5.0	5.0	5.0
	Average	51.2	15.2	29.1		4.2	20.8								0.0047	20.5	6.8	9.6	1.1	204.6	6.3		154.0	25.0	1.2	21.8	2.4	0.8
	StdDev	6.3	2.2	6.4		1.7	3.6								0.0046	12.8	0.3	1.4	0.6	33.1	2.0		15.2	3.7	0.5	4.1	1.0	0.5
	Min	42.0	13.0	20.0		2.6	16.0								0.0020	3.0	6.5	8.6	0.3	162.3	4.0		130.0	19.2	0.6	17.0	0.8	0.4
	Max	58.0	18.0	36.0		7.1	24.0								0.0100	33.0	7.4	12.0	2.3	254.1	9.7		170.0	29.8	1.8	26.0	3.5	1.5
A132	Count	11.0	11.0	12.0		12.0	11.0								9.0000	9.0	12.0	11.0	12.0	12.0	12.0		11.0	12.0	11.0	11.0	12.0	11.0
	Average	124.2	47.1	65.3		3.9	19.5								0.0191	36.1	7.3	6.5	18.8	507.8	57.8		318.2	25.8	1.4	20.7	8.2	4.3
	StdDev	13.0	7.7	16.9		1.8	3.4								0.0146	47.6	0.4	2.1	15.1	68.1	49.4		43.3	3.4	0.5	6.5	7.0	2.9
	Min	96.0	38.0	43.0		1.2	15.0								0.0020	3.0	6.2	3.6	3.4	375.2	13.0		240.0	20.1	0.9	15.0	2.5	1.9
	Max	140.0	63.0	98.0		5.9	24.0								0.0500	150.0	7.9	11.0	61.0	637.8	200.0		380.0	30.6	2.3	38.0	27.0	11.0
A133	Count	3.0	3.0	6.0		6.0	3.0								2.0000	3.0	6.0	3.0	6.0	6.0	7.0		3.0	6.0	3.0	3.0	6.0	3.0
	Average	102.3	33.7	46.8		1.9	19.7								0.0041	32.3	6.8	9.7	4.6	377.3	60.3		260.0	23.3	1.4	19.7	4.3	2.4
	StdDev	22.5	10.1	14.3		0.7	3.8								0.0029	25.4	0.2	2.2	4.9	63.7	42.5		36.1	3.4	0.2	4.6	2.1	0.6
	Min	77.0	22.0	22.0		0.9	17.0								0.0020	3.0	6.5	7.7	1.5	299.8	17.0		220.0	18.6	1.3	17.0	2.5	1.7
	Max	120.0	40.0	63.0		2.9	24.0								0.0061	48.0	7.2	12.0	14.0	466.6	120.0		290.0	28.2	1.7	25.0	8.0	2.8
A134	Count	7.0	7.0	9.0		9.0	7.0								4.0000	6.0	9.0	7.0	9.0	9.0	9.0		7.0	9.0	7.0	7.0	6.0	7.0
	Average	68.4	25.9	37.5		2.0	23.0								0.0043	23.0	6.8	8.8	8.8	309.3	13.7		231.4	24.9	1.4	23.4	2.9	0.9
	StdDev	20.0	6.9	20.1		1.0	6.5								0.0045	17.6	0.3	3.3	16.2	93.9	12.2		61.8	3.2	0.7	7.0	0.2	0.4
	Min	43.0	18.0	1.4		0.7	16.0								0.0020	3.0	6.5	3.4	0.4	175.5	6.1		160.0	19.3	0.8	17.0	2.5	0.6
	Max	100.0	37.0	62.0		3.7	36.0								0.0110	46.0	7.2	13.0	51.0	430.6	44.0		340.0	29.2	2.9	37.0	3.0	1.7
A135	Count	11.0	12.0	12.0		12.0	12.0								10.0000	9.0	12.0	12.0	12.0	12.0	12.0		12.0	12.0	11.0	12.0	11.0	11.0
	Average	128.9	48.8	71.1		3.9	19.7								0.0264	21.9	7.5	6.2	28.9	534.5	46.9		585.7	25.2	1.4	19.7	7.5	4.9
	StdDev	27.1	7.0	24.3		2.5	3.4								0.0306	24.5	0.3	2.5	32.1	86.2	32.7		888.2	3.4	0.6	3.5	6.6	4.9
	Min	68.0	39.0	43.0		0.3	14.0								0.0020	4.2	7.1	2.8	4.1	385.9	8.8		208.0	20.6	0.8	14.0	0.8	1.2
	Max	170.0	63.0	130.0		8.5	26.0								0.1000	68.0	7.9	11.0	120.0	727.6	130.0		3400.0	30.2	3.2	26.0	25.0	16.0
A136	Count	4.0	4.0	8.0		8.0	4.0								3.0000	4.0	8.0	4.0	8.0	8.0	8.0		4.0	8.0	4.0	4.0	5.0	4.0
	Average	100.3	34.3	48.4		2.1	21.3								0.0039	25.0	6.9	9.8	5.3	355.4	21.0		257.5	24.0	1.1	21.3	2.3	0.8
	StdDev	25.7	8.6	19.4		1.8	4.8								0.0032	36.4	0.3	3.4	5.9	112.7	7.4		54.4	3.5	0.1	5.6	1.6	0.2
	Min	70.0	23.0	22.0		0.5	17.0								0.0020	3.0	6.6	6.1	0.8	212.1	13.0		180.0	19.6	1.0	16.0	0.8	0.6
	Max	130.0	41.0	67.0		5.1	28.0								0.0076	67.0	7.4	14.0	17.0	486.7	37.0		300.0	28.8	1.2	29.0	4.5	1.0
A137	Count	6.0	6.0	9.0		9.0	6.0								4.0000	5.0	9.0	6.0	9.0	9.0	9.0		5.0	9.0	6.0	6.0	6.0	5.0
	Average	81.5	22.0	39.4		2.4	22.7								0.0033	24.3	6.8	9.5	4.5	276.5	11.2		208.0	24.6	1.3	22.3	2.6	0.6
	StdDev	33.3	5.5	13.6		1.3	3.1								0.0015	23.8	0.4	4.4	4.8	79.1	4.8		42.1	3.9	0.2	2.7	0.7	0.2
	Min	51.0	16.0	20.0		0.8	19.0								0.0020	3.0	6.5	1.3	1.3	170.7	5.0		160.0	19.6	1.0	19.0	2.0	0.4
	Max	140.0	31.0	53.0		4.8	26.0								0.0049	50.0	7.6	13.0	16.0	392.2	20.0		260.0	29.9	1.6	25.0	3.5	0.9
A138	Count	3.0	3.0	9.0		9.0	3.0								2.0000	3.0	9.0	3.0	9.0	9.0	8.0		3.0	9.0	3.0	3.0	6.0	3.0
	Average	37.7	12.6	27.6		3.5	20.3								0.0020	21.5	7.0	12.4	1.3	179.1	8.2		136.7	24.7	1.2	21.0	2.5	0.6
	StdDev	10.8	3.1	10.4		1.4	3.2								0.0000	26.2	0.5	4.1	1.4	47.9	4.6		30.6	3.9	0.2	3.6	1.6	0.2
	Min	30.0	9.9	16.0		1.6	18.0								0.0020	3.0	6.4	9.1	0.4	124.7	2.8		110.0	18.2	1.0	18.0	0.8	0.4
	Max	50.0	16.0	45.0		6.0	24.0								0.0020	40.0	7.9	17.0	4.9	241.7	16.0		170.0	29.2	1.4	25.0	5.5	0.8
A139	Count	3.0	3.0	6.0		6.0	3.0								2.0000	3.0	6.0	3.0	5.0	6.0	6.0		3.0	6.0	3.0	3.0	6.0	3.0
	Average	15.3	6.2	17.2		3.7	23.7								0.0020	15.5	6.8	4.9	0.4	106.1	9.0		90.7	24.3	1.3	23.7	3.0	0.7
	StdDev	5.9	0.8	4.2		1.7	4.2								0.0000	17.7	0.6	2.2	0.6	24.0	3.1		5.9	4.0	0.2	4.0	0.8	0.1
	Min	11.0	5.3	12.0		1.8	19.0								0.0020	3.0	6.3	3.1	0.1	80.6	5.1		84.0	17.7	1.0	19.0	2.5	0.5
	Max	22.0	6.7	24.0		6.0	27.0								0.0020	28.0	7.9	7.3	1.5	149.3	12.0		95.0	28.6	1.4	26.0	4.5	0.8
A140	Count	4.0	4.0	7.0		7.0	4.0								3.0000	4.0	7.0	4.0	7.0	7.0	7.0		4.0	7.0	4.0	4.0	5.0	4.0
	Average	42.0	13.5	30.7		4.4	34.8								0.0045	16.5	7.1	7.7	1.0	208.8	16.3		155.0	24.4	1.5	31.8	2.3	0.9
	StdDev	5.6	1.7	11.4		1.3	9.6								0.0043	19.5	0.7	4.6	0.3	55.5	18.1		25.2	3.3	0.4	8.9	1.0	0.9
	Min	37.0	12.0	21.0		2.8	26.0								0.0020	3.9	6.5	3.1	0.5	156.4	5.5		130.0	19.3	1.2	26.0	0.8	0.5
	Max	50.0	16.0	50.0		6.8	44.0								0.0094	39.0	8.0	14.0	1.4	313.0	53.0		190.0	28.9	2.0	45.0	3.5	2.2
A141	Count	8.0	8.0	9.0		9.0	8.0								3.0000	6.0	9.0	7.0	9.0	9.0	9.0		8.0	9.0	6.0	8.0	6.0	8.0
	Average	106.8	27.8	40.8		2.3	22.8								0.0057	27.8	6.9	10.4	8.7	352.9	13.4		240.0	24.3	1.4	22.8	2.4	0.8
	StdDev	34.4	10.2	22.0		1.9	2.9								0.0047	25.5	0.4	4.2	8.3	140.2	10.7		86.8	3.3	0.1	3.3	1.0	0.4
	Min	44.0	14.0	13.0		0.3	18.0								0.0020	4.5	6.4	6.2	2.1	170.6	5.6		130.0	20.6	1.2	18.0	0.8	0.2
	Max	160.0	42.0	85.0		6.0	26.0								0.0110	55.0	7.6	17.0	27.0	595.9	34.0		370.0	28.5	1.6	26.0	3.3	1.4

Appendix 2-2

Monthly water quality data summary statistics by zone for calendar year 2007.

Table A2-2-1. EVPA and LOXA sites classified into zones for analyses.

Zone	Sites
Canal	LOXA104, LOXA115, LOXA129, LOXA132, LOXA135
Perimeter (<2.5 km)	LOX4, LOX6, LOX10, LOX14, LOX15, LOX16, LOXA101, LOXA102, LOXA103, LOXA105, LOXA106, LOXA107, LOXA109, LOXA112, LOXA116, LOXA117, LOXA118, LOXA121, LOXA122, LOXA123, LOXA124, LOXA126, LOXA130, LOXA131, LOXA133, LOXA134, LOXA136, LOXA137, LOXA138, LOXA140
Transition (2.5 - 4.5 km)	LOX12, LOXA108, LOXA110, LOXA111, LOXA113, LOXA114, LOXA119, LOXA127, LOXA139
Interior (>4.5 km)	LOX3, LOX5, LOX7, LOX8, LOX9, LOX11, LOX13, LOXA120, LOXA128

Table A2-2-2. Monthly summary statistics (Mean = arithmetic mean, Count = # of sites, 95% CI Up = 95% upper arithmetic mean confidence interval, 95% CI Low = 95% lower arithmetic mean confidence interval) for calendar year 2007. Previous summary statistics (2004 – 2006) can be found in the previous annual reports (USFWS 2007a, b).

		Jan-07	Feb-07	Mar-07	Apr-07	May-07	Jun-07	Jul-07	Aug-07	Sep-07	Oct-07	Nov-07	Dec-07
TP (µg L^{-1})	Canal - Mean	31.4	38.4	242.2	61.8	54.4	128.6	60.2	48.0	34.6	20.8		33.6
	Canal - Count	5.0	5.0	5.0	5.0	5.0	5.0	5.0	5.0	5.0	5.0		5.0
	Canal - 95% CI Up	37.9	45.6	614.0	79.7	68.8	224.8	91.1	60.1	41.6	31.9		40.6
	Canal - 95% CI Low	24.9	31.2	-129.6	43.9	40.0	32.4	29.3	35.9	27.6	9.7		26.6
	Perimeter - Mean	9.4	9.5	7.5	0.0	0.0	21.7	13.2	17.0	21.5	24.2	6.4	13.1
	Perimeter - Count	27.0	20.0	6.0	0.0	0.0	5.0	17.0	26.0	27.0	32.0	5.0	29.0
	Perimeter - 95% CI Up	12.0	14.5	9.4			33.9	15.6	24.4	33.0	36.2	7.7	20.3
	Perimeter - 95% CI Low	6.8	4.5	5.6			9.5	10.8	9.6	10.1	12.3	5.1	5.9
	Transition - Mean	7.1	6.3	6.0	8.0	0.0	10.2	7.8	12.5	9.8	6.6	6.0	7.7
	Transition - Count	4.0	3.0	1.0	1.0	0.0	2.0	3.0	8.0	8.0	9.0	1.0	9.0
	Transition - 95% CI Up	8.0	9.4				11.8	13.0	13.0	10.9	8.8		9.7
	Transition - 95% CI Low	6.2	3.2				8.6	2.5	12.0	8.7	4.4		5.6
	Interior - Mean	6.6	6.5	9.0	10.7	0.0	13.8	9.6	8.4	7.7	8.1	7.7	8.3
	Interior - Count	9.0	6.0	5.0	3.0	0.0	4.0	8.0	8.0	10.0	9.0	3.0	9.0
	Interior - 95% CI Up	7.6	7.8	11.1	15.9		15.9	10.2	9.4	8.6	9.2	9.0	9.6
	Interior - 95% CI Low	5.7	5.2	6.9	5.4		11.6	8.9	7.4	6.7	6.9	6.4	7.0
TN (mg L^{-1})	Canal - Mean	1.1	1.2	1.2	1.5	1.6	2.1	1.9	1.9	1.4	1.5		1.3
	Canal - Count	4.0	5.0	5.0	5.0	4.0	5.0	5.0	5.0	5.0	5.0		5.0
	Canal - 95% CI Up	1.2	1.5	1.4	1.7	1.6	2.7	2.3	2.2	1.7	2.3		1.5
	Canal - 95% CI Low	1.0	1.0	1.1	1.3	1.6	1.4	1.6	1.6	1.0	0.7		1.0
	Perimeter - Mean	0.8	1.0	1.0	0.0	0.0	2.9	1.3	1.5	1.3	1.3	0.9	1.2
	Perimeter - Count	14.0	12.0	4.0	0.0	0.0	1.0	4.0	19.0	19.0	29.0	5.0	28.0
	Perimeter - 95% CI Up	1.0	1.1	1.4				1.6	1.7	1.6	1.5	1.1	1.3
	Perimeter - 95% CI Low	0.7	0.8	0.7				1.0	1.4	1.1	1.1	0.7	1.0
	Transition - Mean	0.8	0.9	1.0	1.4	0.0	0.0	1.5	1.4	1.1	1.0	0.9	1.2
	Transition - Count	2.0	1.0	1.0	1.0	0.0	0.0	1.0	3.0	3.0	9.0	1.0	9.0
	Transition - 95% CI Up	1.1							2.1	1.3	1.2		1.3
	Transition - 95% CI Low	0.5							0.7	0.9	0.9		1.0
	Interior - Mean	1.0	1.1	1.4	0.0	0.0	0.0	1.6	1.6	1.2	1.1	1.1	1.3
	Interior - Count	5.0	5.0	4.0	0.0	0.0	0.0	4.0	4.0	5.0	9.0	3.0	8.0
	Interior - 95% CI Up	1.1	1.2	1.7				1.9	2.0	1.4	1.2	1.5	1.5
	Interior - 95% CI Low	0.9	1.0	1.2				1.3	1.1	0.9	0.9	0.8	1.1
Conductivity (µS cm^{-1})	Canal - Mean	485.1	570.8	384.8	432.6	496.8	495.3	543.2	544.2	647.6	673.7		560.7
	Canal - Count	5.0	5.0	5.0	5.0	5.0	5.0	5.0	5.0	5.0	5.0		5.0
	Canal - 95% CI Up	529.8	729.0	413.9	503.6	580.6	543.0	617.0	670.5	708.5	892.2		657.1
	Canal - 95% CI Low	440.5	412.6	355.8	361.6	413.0	447.6	469.4	417.8	586.7	455.2		464.3
	Perimeter - Mean	231.5	269.9	188.7	0.0	0.0	277.5	253.4	253.6	284.1	640.0	271.4	321.0
	Perimeter - Count	27.0	23.0	5.0	0.0	0.0	4.0	12.0	26.0	26.0	29.0	5.0	29.0
	Perimeter - 95% CI Up	261.4	329.9	239.2			407.7	317.7	306.3	336.7	1119.3	338.4	384.5
	Perimeter - 95% CI Low	201.6	210.0	138.1			147.3	189.1	200.9	231.4	160.7	204.3	257.6
	Transition - Mean	136.0	150.1	167.5	230.1	0.0	174.8	169.8	115.7	129.5	116.0	196.8	138.4
	Transition - Count	7.0	6.0	1.0	1.0	0.0	2.0	2.0	8.0	8.0	9.0	1.0	9.0
	Transition - 95% CI Up	154.0	162.0				224.8	220.8	127.8	139.4	133.5		152.6
	Transition - 95% CI Low	118.0	138.2				124.8	118.8	103.6	119.7	98.5		124.3
	Interior - Mean	121.8	122.3	165.1	201.8	0.0	195.8	142.8	103.6	114.1	89.2	91.6	118.5
	Interior - Count	9.0	8.0	3.0	3.0	0.0	2.0	1.0	8.0	7.0	9.0	3.0	8.0
	Interior - 95% CI Up	135.3	135.9	253.3	257.3		212.9		120.2	145.6	98.2	96.0	133.3
	Interior - 95% CI Low	108.3	108.7	77.0	146.2		178.6		87.0	82.6	80.1	87.1	103.7
Cl (mg L^{-1})	Canal - Mean	65.0	82.2	43.4	49.2	54.4	46.2	78.4	96.2	95.0	83.2		69.3
	Canal - Count	5.0	5.0	5.0	5.0	5.0	5.0	5.0	5.0	5.0	5.0		4.0
	Canal - 95% CI Up	74.8	110.6	45.2	55.1	61.0	49.8	99.1	104.4	104.9	112.8		83.7
	Canal - 95% CI Low	55.2	53.8	41.6	43.3	47.8	42.6	57.7	88.0	85.1	53.6		54.8
	Perimeter - Mean	38.3	42.2	35.4	0.0	0.0	35.6	32.2	31.3	37.0	57.3	40.8	44.3
	Perimeter - Count	27.0	23.0	6.0	0.0	0.0	5.0	17.0	26.0	26.0	29.0	5.0	29.0
	Perimeter - 95% CI Up	46.3	51.8	48.7			47.8	38.2	39.0	44.3	67.7	52.9	53.6
	Perimeter - 95% CI Low	30.3	32.7	22.1			23.4	26.2	23.7	29.7	47.0	28.6	35.1
	Transition - Mean	24.8	27.8	28.7	37.3	0.0	30.5	27.3	16.6	19.0	16.7	27.9	20.8
	Transition - Count	7.0	6.0	1.0	1.0	0.0	2.0	3.0	8.0	8.0	9.0	1.0	9.0
	Transition - 95% CI Up	27.8	31.1				43.2	30.7	17.8	19.7	18.8		22.1
	Transition - 95% CI Low	21.8	24.5				17.8	23.8	15.3	18.4	14.6		19.6
	Interior - Mean	24.2	26.8	32.4	40.6	0.0	32.9	26.2	19.0	20.7	16.0	17.5	21.3
	Interior - Count	9.0	8.0	5.0	3.0	0.0	2.0	8.0	8.0	8.0	9.0	3.0	9.0
	Interior - 95% CI Up	26.9	29.6	40.4	51.6		37.0	30.8	22.1	26.2	17.4	19.6	24.0
	Interior - 95% CI Low	21.6	24.0	24.4	29.5		28.8	21.6	15.8	15.1	14.6	15.4	18.5
SO4 (mg L^{-1})	Canal - Mean	12.5	16.8	5.1	7.9	14.1	42.2	25.8	25.2	27.0	37.2		15.2
	Canal - Count	5.0	5.0	5.0	5.0	5.0	5.0	5.0	5.0	5.0	5.0		4.0
	Canal - 95% CI Up	16.9	24.6	6.5	11.1	17.2	63.2	30.4	35.5	31.7	56.3		26.9
	Canal - 95% CI Low	8.1	9.1	3.8	4.7	11.0	21.2	21.2	14.9	22.3	18.1		3.6
	Perimeter - Mean	2.8	2.9	1.0	0.0	0.0	14.8	4.3	5.2	4.0	13.6	3.9	4.8
	Perimeter - Count	27.0	23.0	6.0	0.0	0.0	5.0	17.0	25.0	26.0	29.0	5.0	29.0
	Perimeter - 95% CI Up	4.0	4.2	1.6			33.3	6.2	7.8	5.8	18.6	5.9	7.2
	Perimeter - 95% CI Low	1.7	1.6	0.3			-3.7	2.3	2.7	2.2	8.7	1.8	2.4
	Transition - Mean	0.5	0.5	0.4	0.5	0.0	1.0	0.7	0.6	0.7	0.9	1.2	0.2
	Transition - Count	4.0	4.0	1.0	1.0	0.0	2.0	2.0	6.0	5.0	9.0	1.0	9.0
	Transition - 95% CI Up	0.8	0.7				2.0	0.9	0.8	1.2	1.3		0.3
	Transition - 95% CI Low	0.2	0.3				0.0	0.5	0.3	0.3	0.5		0.0
	Interior - Mean	0.1	0.1	0.1	0.1	0.0	0.1	0.1	0.1	0.1	0.1	0.1	0.1
	Interior - Count	7.0	6.0	4.0	2.0	0.0	1.0	8.0	6.0	6.0	9.0	3.0	9.0
	Interior - 95% CI Up	0.1	0.1	0.1	0.1			0.2	0.1	0.1	0.3	0.1	0.1
	Interior - 95% CI Low	0.0	0.0	0.1	0.1			0.0	0.0	0.0	0.0	0.0	0.0
Tdepth (in.)	Canal - Mean	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA
	Canal - Count	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA
	Canal - 95% CI Up	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA
	Canal - 95% CI Low	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA
	Perimeter - Mean	0.2	0.2	0.1	0.0	0.0	0.1	0.2	0.3	0.3	0.6	0.8	0.4
	Perimeter - Count	30.0	26.0	18.0	9.0	0.0	13.0	23.0	28.0	28.0	29.0	5.0	30.0
	Perimeter - 95% CI Up	0.3	0.3	0.2	0.1		0.1	0.2	0.3	0.4	0.6	1.1	0.5
	Perimeter - 95% CI Low	0.2	0.2	0.0	0.0		0.1	0.1	0.2	0.3	0.5	0.6	0.4
	Transition - Mean	0.2	0.2	0.2	0.1	0.0	0.1	0.1	0.2	0.3	0.5	1.0	0.4
	Transition - Count	9.0	8.0	5.0	5.0	1.0	8.0	9.0	9.0	9.0	9.0	1.0	9.0
	Transition - 95% CI Up	0.3	0.4	0.5	0.2		0.1	0.2	0.4	0.5	0.6		0.5
	Transition - 95% CI Low	0.1	0.0	-0.1	0.0		0.0	0.0	0.1	0.1	0.4		0.3
	Interior - Mean	0.3	0.3	0.2	0.1	0.1	0.1	0.2	0.2	0.2	0.5	0.6	0.4
	Interior - Count	9.0	8.0	5.0	3.0	1.0	5.0	9.0	8.0	10.0	9.0	3.0	14.0
	Interior - 95% CI Up	0.4	0.4	0.3	0.2		0.2	0.3	0.3	0.3	0.6	0.9	0.5
	Interior - 95% CI Low	0.2	0.2	0.2	0.0		0.1	0.1	0.2	0.2	0.4	0.3	0.3

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