A.R.M. LOXAHATCHEE NATIONAL WILDLIFE REFUGE

ENHANCED WATER QUALITY PROGRAM

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ACRONYMS AND ABBREVIATIONS

ACME Special Drainage District, Village of Wellington
acre-ft acre-feet (volume reported as one acre in area by one foot in depth)
cfs cubic feet per second
Cl chloride
cm centimeter
DBHYDRO SFWMD's web portal for water quality data
DCS depth from water surface to consolidated substrate
DOI US Department of Interior
EAA Everglades Agricultural Area
EVPA Federal Consent Decree compliance sampling network for Refuge
ft feet
FWM flow-weighted mean
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
NGVD National Geodetic Vertical Datum
NO_x total concentration as nitrogen of oxides of nitrogen, NO_2 + NO_3
Refuge A.R.M. Loxahatchee National Wildlife Refuge
s second
SFWMD South Florida Water Management District
SO_4 sulfate
STA Stormwater Treatment Area
Tdepth depth of clear water column
TN total nitrogen
TP total phosphorus
µg microgram
$\mu S\ cm^{-1}$ microSiemens per centimeter (measure of conductivity)
USACE U.S. Army Corps of Engineers
USFWS U.S. Fish and Wildlife Service
USGS U.S. Geological Survey
WCA Water Conservation Area

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EXECUTIVE SUMMARY

Congress appropriated funds to the U.S. Fish and Wildlife Service in 2004 which funded 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 monitored as a part of 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. The number of grab sample sites has reduced to 37 in recent years because two sites located near the canal were overrun with cattail making them inaccessible. Continuous measurements of conductivity additionally have been collected along seven transects, four of which extend from surface water discharge points in the canal into the interior. This report is the sixth annual report, with analyses focused on January through December 2009, and with comparisons made to the preceding years (2004 through 2008).

Water quality data and analyses of canal water intrusion into the Refuge marsh 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 2009 canal water intrusion analyses include:

- Canal water intruded into the marsh up to 2.1 km (1.30 miles) depending on timing and location.
- Rainfall in 2009 for the Refuge and contributing basins was similar to the historic average (1963 through 2009); regardless, inflows to the Refuge were lower than inflow volumes during average rainfall years (i.e., 2004). The reduction in canal water inflows was a result of management operations and not drought conditions as a substantial amount of water that was sent to tide (the east coast – Lake Worth Lagoon) likely should have been treated by the stormwater treatment areas adjacent to the Refuge.
- Intrusion into the marsh, particularly the southwestern Refuge, was sustained for a considerable period after inflows declined at the end of October. The extent of canal water intrusion into the marsh was maintained by the lack of water discharges from the Refuge during and after the high rate inflows from July through October. These conditions have been shown to exacerbate Consent Decree excursions as was observed in November 2008 during the total phosphorus (TP) excursion event which occurred after inflows during November

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

were reduced.

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, negative impacts to *Xyris* spp.in 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 impacts.

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. When combined with our understanding of canal water intrusion 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 of the long-term TP level, as defined by the Consent Decree, occurred in June 2009. Elevated inflows, rapid canal stage rise, and canal water intrusion were the environmental conditions leading to the June 2009 excursion. These conditions are consistent with most of the excursions that have occurred over the past five years.

The June 2009 excursion, coupled with the November 2008 excursion, is an exceedance of the long-term level. The TOC did not find that there was substantial evidence of error or extraordinary natural phenomena, therefore, this exceedance represents a violation of the Consent Decree's long-term level. Further, this exceedance is the first exceedance since the long-term level went into effect in 2007.

In 2009, we continued to investigate the growth and survival of native Florida apple snails (*Pomacea paludosa*) as a response to periphyton compositions from the Perimeter, Transition, and Interior Zones. We also continued to investigate how *P. paludosa* life histories are affected by water chemistry in the Northern Everglades. Analytical results will be available in the next annual report.

Refuge modeling progress in 2009 centered on the final meeting of the Refuge modeling Technical Advisory Panel (TAP) on May 11, 2009. After primary focus on development, calibration, and verification of the models, much of the modeling effort in 2009 was redirected toward model application and use. Refuge models have been used to analyze hydrologic impacts of the EAA Regional Feasibility Study, comparison of methods and results with the South Florida Water Management Model, comparison of alternative regulatory releases under the current regulation schedule, comparison of model water quality results using hourly rather than daily average inflows, analysis of potential impacts of a berm along the marsh bank of the L-40 Canal, and sensitivity of interior and peripheral marsh to changes in chloride, sulfate, and TP inflow concentrations. In the final months of 2009, a version of the aggregated model was applied in development, testing, and application of a high-stage hydrological performance measure for testing alternative water management scenarios.

SECTION A. REFUGE ENVIRONMENTAL CONDITIONS[2]

The objective of this section is to provide a general descriptive summary of environmental conditions, 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 2009 following approaches presented in previous annual reports (USFWS 2007a, b; USFWS 2009; USFWS 2011). Further, we compare results, particularly total phosphorus (TP), in 2009 to results presented in previous water quality reports covering the period from January 2004 through December 2008 (Harwell et al. 2005; USFWS 2007a, b; USFWS 2009; USFWS 2011). Thus, this chapter serves as an update to the 2008 annual report (USFWS 2011). This chapter briefly characterizes environmental conditions (e.g., rainfall, canal flows, and marsh and canal stages) associated with events of canal water intrusion into the marsh and water quality conditions during 2009. We also describe conditions of canal water intrusion during a Consent Decree excursion event in June 2009, which led to a Consent Decree violation.

Background

Prior to June 2004, water quality in the Refuge interior was monitored primarily using the 1992 Federal Consent Decree (Case No. 88-1886-CIV-MORENO) compliance network (EVPA). These 14 stations (**Figure 1**), monitored since 1978, characterize the central region of the interior marsh, leaving a relatively large region uncharacterized, predominantly in the outer, impacted fringe of the wetland (Harwell et al. 2005; USFWS 2007a, b; USFWS 2009). 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 marsh, 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 1**).

Water delivered to the Refuge originates as direct rainfall and canal water discharges from the surrounding basins. Stormwater treatment areas (STA) 1W and 1E treat the majority of water delivered to the Refuge via canals. Canal discharges are driven by rainfall in the surrounding basins, with a large volume delivered to the Refuge from the L-8 and S-5A basin (Burns and McDonnell Engineering Co, Inc. 2005). The L-8 basin discharges are generally a mixture of water from Lake Okeechobee and the S-5A and C-51 basins (Gary Goforth, Inc. 2006). The STA1E water control plan indicates that during this interim period (through 2015), water discharges to tide (east coast – Lake Worth Lagoon) should approach 150,000 acre-ft, while the remainder of the water should be treated and distributed throughout the Everglades Protection Area (Refuge south to Florida Bay). Stormwater Treatment Areas 1W ((180,000 acre-ft annually) and 1E (165,000 acre-ft annually) are to treat some of this water (Gary Goforth, Inc. 2006).

[2] Prepared by: Donatto D. Surratt, Matthew C. Harwell, Michael G. Waldon

Water levels in the Refuge are managed by the U.S. Army Corps of Engineers (USACE) based on the 1995 Water Regulation Schedule (USFWS 2000; USFWS 2007a, b; **Figure 2**).

Methods

Environmental Conditions. Rainfall, 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 September 20, 2010 (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 1**) were used as estimates of marsh stage values; canal stage data from the headwater gage of the G-94C outflow spillway structure (**Figure 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 1**). Data from G-338 also were considered, but the discharges 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 to represent Refuge rainfall (**Figure 1**). Rainfall for the C-51 is represented by S-5A and WPB AIRP, and Pahokee1 and Pahokee2 represent rainfall for the S5A basins. Flows to the east of the Refuge from the S-5A, C-51, and L-8 basins are represented by pump structure S-155A.

Intrusion Monitoring. We determined the spatial and temporal extent of high conductivity canal water intrusion into the Refuge under different hydrologic conditions with emphasis on six of seven total Refuge conductivity transects (**Figure 1**), where temperature-compensated conductivity is collected hourly using conductivity data loggers. Also, we related changes in the extent of intrusion to water management activities affecting canal stages and flows into the Refuge, and determined the influence of natural meteorological events and hydrologic mechanisms on intrusion of high conductivity canal water.

We used the six conductivity transects to track water movement between the canal and the first six kilometers of the marsh (**Figure 1**). Two transects (STA-1E and STA-1W) were established near the outflow of STA-1W and STA-1E discharge structures. Two of the remaining transects (ACME-2 and Southeast) were established on the east side of the Refuge south of the STA-1E discharge structure. We established the Southeast (SE) transect late in July 2007 to capture canal water intrusion in areas not previously characterized. The final two transects (S-6 and Extreme Southwest) were established on the west side of the Refuge south of the STA-1W discharge structure. The Extreme Southwest (ESW) transect also was established late in July 2007 to capture canal water intrusion signals in areas previously not characterized.

Conductivity acts as a conservative tracer of canal water; there are no biological or chemical processes in the surface water that significantly alter conductivity. Thus, these data can be used to track canal water intrusion into the marsh, which ultimately can be examined in relationship to water management operations.

Seventy-five percent of canal monthly conductivity values were greater than 620 µS cm^{-1} and the maximum was 1,148 µS cm^{-1}. Monthly Interior Zone conductivity levels remained below 210 µS cm^{-1} through 2009. Given this large difference in conductivity between the canal and the interior marsh, we use two conductivity levels, 350 and 500 µS cm^{-1}, to help identify the distance into the interior marsh that canal water penetrated. Tracking was done using isopleths of conductivity generated from the hourly conductivity data. Isopleths are lines connecting points of equal value for a given metric. Elevation contours on a topographic map are examples of isopleths.

The two isopleths (350 and 500 µS cm^{-1}) were chosen to sufficiently cover the conductivity gradient observed from the canal into the marsh. Further, laboratory and field studies have shown that high conductivity waters (>300 µS cm^{-1}) have adverse impacts on the ecosystem community structure (e.g., reduced growth rate of *Xyris* spp. (McCormick and Crawford 2006), shifts from sawgrass to cattail communities (Richardson 2010), altered periphyton community structure (Sklar et al. 2005)).

Marsh Water Quality and Water Quality Zone. As in past years, monthly water quality samples were collected from the EVPA and LOXA monitoring networks (**Figure 1**). The EVPA network consists of 14 interior marsh sites collected cooperatively with the South Florida Water Management District and Refuge staff. Refuge staff solely collect water samples from the 37 sites (five in the canal and 32 in the marsh) in the LOXA network. The number of grab sample sites has reduced from 39 to 37 in the last few years because two sites located near the canal were overrun with cattail, making them inaccessible for water quality sampling. Samples for both networks generally are analyzed for more than 20 water quality parameters. Sample collection is confounded by water depth and sample site accessibility. When clear water depths are between 10 and 20 cm (3.9 and 7.9 inches), only partial samples are collected and analyzed for 6 of the 29 water quality parameters, including: TP, chloride, sulfate, temperature, depth, and specific conductance. When the clear water depths are below 10 cm (3.9 inches), no samples are collected and no data are recorded. This report only presents TP data. **Appendix A** presents summary statistics for all water quality parameters measured in the LOXA network.

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; 2009; 2011. 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 – S-5A and C-51 Basins. The 2009 S-5A (544,099 acre-ft) and C-51 (486,782 acre-ft) basins' rainfall volumes were similar to the average annual volumes since 1963 for the two basins (538,666 and 483,740 acre-ft respectively – **Figure 3**). These rainfall volumes also were similar to average rainfall volumes in 2008 when S-5A and C-51 basin volumes were 539,164 and 496,238 acre-ft, respectively. Basin S-5A rainfall in 2009 was 14 and 25% higher than 2006 and 2007 volumes, while basin C-51 rainfall volume in 2009 was 15 and 10% higher than 2006 and 2007 volumes, respectively.

Since 2006, the first full year when the major inflow structures to STA1E were in operation, discharges through S-155A have been lower than the annual 150,000 acre-ft except in 2008 (160,996 acre-ft) and 2009 (221,081 acre-ft – **Figure 4**). The drought years, 2006 and 2007, had much lower deliveries through the S-155A at 92,239 and 17,003 acre-ft, respectively.

In 2006 and 2007, inflows to STA1E (**Figure 5a**) were lower than the treatment capacity (165,000 acre-ft yr^{-1}; Gary Goforth, Inc. 2006) at 116,440 and 103,828 acre-ft yr^{-1} respectively. In 2008, inflows to STA1E increased above the treatment capacity to 190,530 acre-ft, but in 2009, inflows to STA1E declined to 67,098 acre-ft, 41% of the treatment capacity.

In 2006 and 2007, inflows to STA1W (**Figure 5b**) were lower than the treatment capacity (180,000 acre-ft yr^{-1}; Gary Goforth, Inc. 2006) at 138,549 and 142,467 acre-ft yr^{-1}, respectively. In 2008, inflows to STA1W increased above the treatment capacity to 185,008 acre-ft, but in 2009, inflows to STA1W declined to 166,007 acre-ft.

Rainfall on the Refuge in 2009 was approximately 621,000 acre-ft, 10% lower than in 2008, 18% greater than in 2007, 13% greater than in 2006, 3% greater than in 2005, 20% greater than in 2004, and 5% lower than the historic (1963 through 2009) average (**Figure 6a**).

Canal inflow volume was approximately 239,000 acre-ft in 2009, only about 60,000 acre-ft more than during the drought year of 2007, similar to 2006 and 2005 inflow volumes, but much lower than in 2004 and 2008 - years when rainfall was similar to or greater than historic rainfall (**Figure 6b**). Daily inflow rates to the Refuge are presented in **Figure 7a and 8a**.

In 2009, canal stages were greater than 16.5 ft (5.03 m)and marsh stages were greater than 16.6 ft (5.06 m) 75% of the year (**Figure 7b and 8b**). The 2008 75^{th} percentile stages in the canal and marsh were 16.2 ft (4.94 m) and 16.5 ft (5.03 m), respectively. Canal stages were greater than 14.8 ft and marsh stages were greater than 15.9 ft (4.85 m) 75% of 2007. In 2006, canal stages were greater than 15.9 ft and marsh stages were greater than 16.1 ft (4.91 m) 75% of the year.

Intrusion Monitoring. In June 2009, intrusion extended 1.7 km (1.06 miles) into the marsh on the east and west sides of the Refuge, particularly in the northern sections

(**Figure 7c-e** and **8c-e**, respectively). This intrusion event was coincident with continuous elevated inflows (> 1,500 cfs (43 m^3 s^{-1})) for more than a week leading to the intrusion event and rising canal (0.08 ft d^{-1}; 0.24 cm d^{-1}) and marsh (0.01 ft d^{-1}; 0.12 cm d^{-1}) stage that rehydrated most of the dried-out marsh.

Maximum intrusion on the east side of the Refuge was observed in January 2009 with intrusion as much as 1.8 km (1.12 miles) into the marsh. Unlike intrusion events that generally result from elevated inflows and rapid stage rise, the January 2009 intrusion event on the east side of the Refuge likely was linked to legacy intrusion from August through December 2008. In general, intrusion on the east side of the Refuge in 2009 peaked more than 1.7 km (1.06 miles) during the June and July period and again from August through October (**Figure 7c-e**). This pattern of increased intrusion was observed in 2006, 2007, and 2008 over different extents.

On the west side of the Refuge, maximum intrusion extended into the marsh 1.9 km (1.18 miles) in the north and 2.1 km (1.30 miles) in the south at the beginning of September 2009 (**Figure 8c-e**). Inflows were greater than 1,000 cfs (28 m^3 s^{-1}) leading to the September intrusion event. Stage increased 0.3 ft (0.09 m) to 16.75 ft (5.11 m) over 13 days (0.02 ft d^{-1}; 0.6 cm d^{-1}). The inflows associated with the September 2009 intrusion event were much greater than outflows, which allowed the canal water to pour into the marsh instead of draining south and out of the canal. The pattern of intrusion was less extensive, but measurable, on the east side of the Refuge, with intrusion extending just beyond 0.5 km (0.31 miles) into the marsh.

Total Phosphorus and Intrusion Dynamics. Flow-weighted mean TP concentration discharged to the Refuge through 2009 were generally higher from STA1E (S362) than from STA1W (G251 and G310; **Figure 9a**). The FWM TP concentrations from STA1W ranged from 10 to 71 µg TP L^{-1}, while discharge from STA1E ranged from 40 to 131 µg TP L^{-1}. Canal TP concentrations generally followed STA1W patterns, but ranged from 16 to 95 µg L^{-1} (**Figure 9a**). Peak discharge from STA1E occurred in September at 131 µg TP L^{-1} and remained above 100 µg TP L^{-1} through the rest of the year. Discharges from STA1E and STA1W (G251) increased above 70 µg L^{-1} in May, leading to the maximum canal TP concentration (95 µg L^{-1}; June) of the year.

In 2009, Perimeter Zone TP concentrations ranged from 3 to 23 µg L^{-1}, Transition Zone TP concentrations ranged from 3 to 13 µg L^{-1}, and Interior Zone TP concentrations ranged from 5 to 12 µg L^{-1} (**Figure 6b**). Perimeter Zone TP concentrations increased above 20 µg L^{-1} in June when inflows increased above 2,000 cfs (4,893 ML) and marsh and canal stages were rising rapidly. This high TP concentration in the Perimeter Zone was coincident with the June intrusion event. In general, the Transition and Interior Zone TP concentrations followed the rise and fall patterns of the Canal and Perimeter Zones TP concentrations.

There was an excursion of the Consent Decree defined TP long-term level in June 2009. Elevated inflows, rapid canal stage rise, and canal water intrusion were the environmental conditions leading to the June 2009 sampling event. These conditions are consistent with most of the excursions that have occurred over that past five years.

The June 2009 excursion, coupled with the November 2008 excursion, is an exceedance of the long-term level. The Consent Decree defines an exceedance as two or more excursions occurring within any consecutive 12 sampling events. The TOC did not find substantial evidence of error or extraordinary natural phemonena, therefor, this exceedance represents a violation of the Consent Decree for the Refuge. Further, this violation represents the first violation since the long-term levels went into effect in 2007.

Discussion

The 2009 environmental conditions for the Refuge and contributing basins represent the second year of normal rainfall levels following the two-year drought (2006 through 2007). Inflows to the Refuge in 2009 were lower than any other year with normal rainfall since 2004. The STA1E interim operation plan (GG 2006) suggests that approximately 150,000 acre-ft (monitored at S-155A) of L-8 and C-51 basin runoff will be delivered to tide annually. In 2009, inflows to STA1E were only 41% of the treatment capacity, while flows to tide through S-155A were 47% greater than expected. Based on the reduction in water discharged to the Refuge and the volume of water discharged to tide, water management operations in 2009 reduced the volume of water delivered to the Refuge regardless of how much rain fell in the region. Outflows from the system also have been substantially reduced. While it is not clear why the 2009 water management strategy was implemented, it did not result in the avoidance of a Consent Decree violation.

All the observed excursions since 2005 have been coincident with intrusion events extending more than 1.5 km (0.93 miles) into the marsh. Our data continue to show that keeping canal water intrusion to less than 1 km (0.62 miles) during high inflow events reduces the risk of excursions of the long-term levels.

Previous annual reports for the Refuge (Harwell et al. 2005; USFWS 2007a, b; USFWS 2009; USFWS 2011) 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. In the 2005, 2006, 2007, and 2008 annual reports, we suggested that if canal water inflows were necessary, the inflow rate should be below 200 cfs (6 m^3 s^{-1}) and for a short duration (< five days). 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. The recommended timing, volume, or duration of outflows with respect to inflows was not extensively observed in 2009, similar to 2004 through 2007, and most of 2008. We continue to support the water management recommendation to reduce canal water intrusion as characterized here and in previous reports (USFWS 2007a, b; USFWS 2009). Some of these management recommendations include (**Table 1**):

- Refuge inflows should be short duration (≤ 5 days) pulses of < 200 cfs (6 $m^3 s^{-1}$) 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; 6 to 11 $m^3 s^{-1}$) 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).

- If Refuge inflows must be extended beyond short-duration pulses at high volumes and there is nowhere else to send water during these inflows, outflow should occur as soon as possible to moderate the extent of intrusion.

We have presented our recommendations at several forums to water managers and the various agencies responsible for making water management decisions. These forums include direct communication from Refuge managers, quarterly regional water coordination meetings, and periodic calls with the Corps of Engineers. The quarterly water coordination meetings focus on water management for the northern portion of the Everglades (from Lake Okeechobee down to Water Conservation Area 2) and consist of multiple agencies (e.g., U.S. Fish and Wildlife Service, National Park Service, Corps of Engineers, Lake Worth Drainage District, Florida Fish and Wildlife Conservation Commission, South Florida Water Management District). Periodic calls with the Corps of Engineers focus on water management under the various water regulation schedules for each of the Water Conservation Areas.

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Table 1. Evolution of water management recommendation based on water quality analysis since 2004.

Recommendation ID	Recommendation	2006	2007	2008	2009
1	Refuge inflows should be short duration (≤5 days) pulses of $<5655\ L\ s^{-1}$ (<200 cfs) when absolute canal /marsh stage difference is <0.1 m (<0.2 ft) and interior water depths are 0.2 m (<0.5 ft).	X	V	V	V
2	Refuge inflow rates can be moderate 5655 to 11,310 $L\ s^{-1}$ (200 to 400 cfs) for short durations if marsh stage is > 0.2 m (> 0.6 ft) higher than canal stage by and waters dept are <0.1 m (<0.3 ft).	X	V	V	V
3	Refuge inflows should be discontinued when the canal stage is > 0.1 m (> 0.2 ft) higher than marsh stage, unless the rainfall or outflow volumes are 3 to 4-times higher than t inflows.	X	U	Refined	
3.a	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.			X	V
4	If Refuge inflows must be extended beyond short-duration pulses, outflow should be greater than inflow and last several days longer.	X	U	Refined	
4.a	If Refuge inflows must be extended beyond short-duration pulses, outflow should be equal to or greater than inflow and last several days longer.			V	V
5	If Refuge inflows must be maintained at high rates, the S-10s and S-39 should be opene to create outflow 3 or 4-times higher than inflow.	X	U	Refined	
5.a	If Refuge inflows must be maintained at high rates, the S-10s and S-39 should be opene in conjunction with canal inflows to create outflow equal to higher than inflow.			X	V
6	If Refuge inflows must be extended beyond short-duration pulses at high volumes and there is nowhere to send water during these inflows, outflow should proceed as soon a practicable to moderate the extent of intrusion the marsh receives from the original inflows.				X

V = Analyses continue to verify this recommendation
X = Inflow and outflow operations were similar to recommendation
U = Environmental conditions did not allow for verification of the recommendations

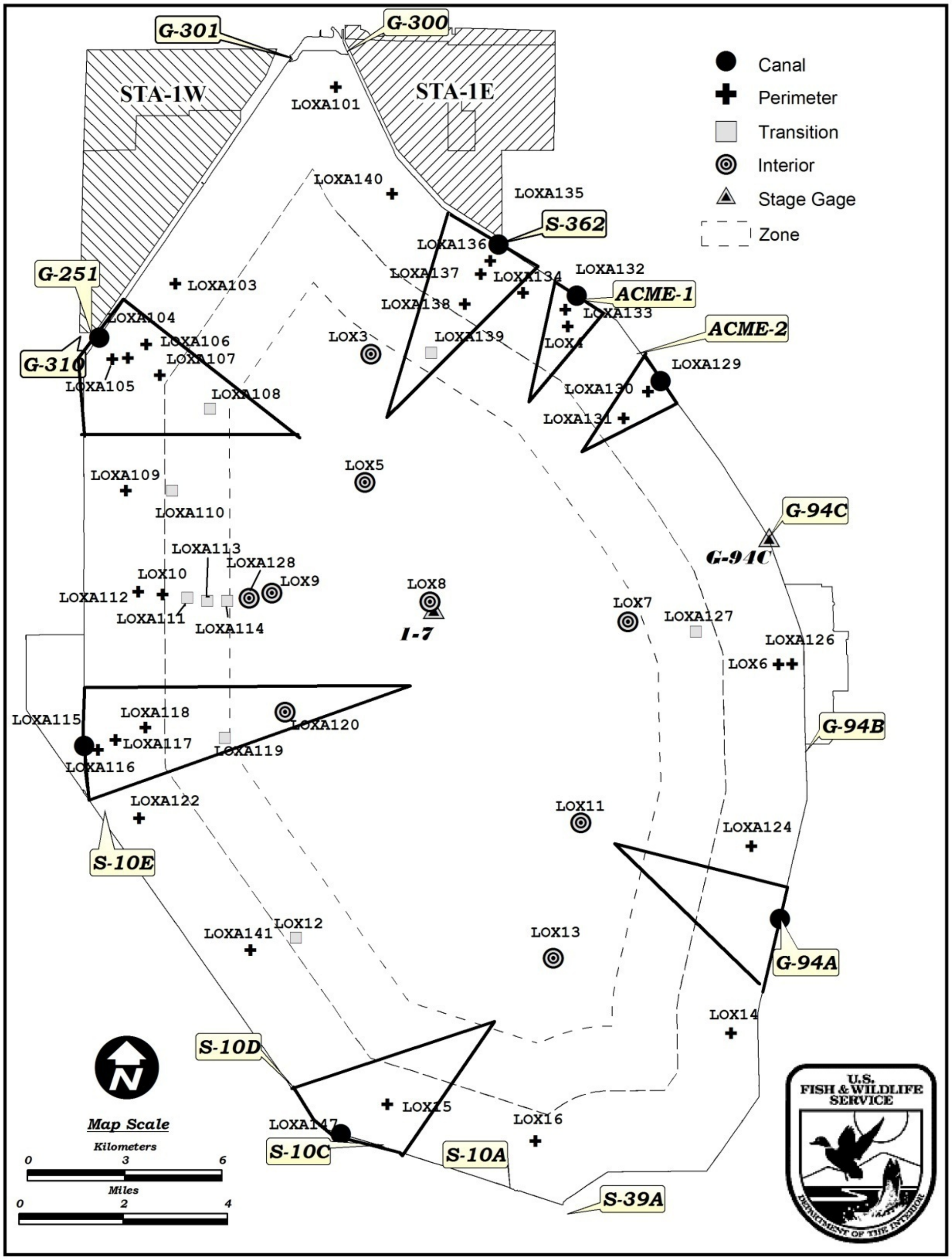
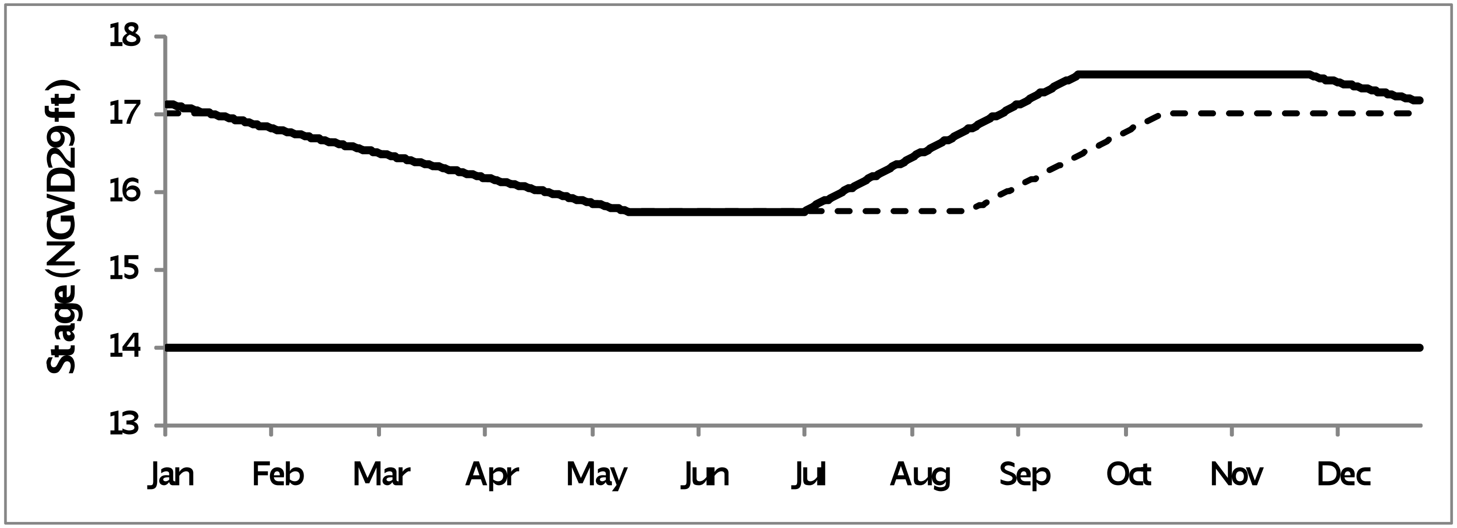


Figure 1. LOXA (LOXA###) and EVPA (LOX#) water quality monitoring sites, inflow and outflow structures, and canal and marsh stage gages used in this report. Solid polygons delineate transects, dashed polygons represent marsh zones.



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 is 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 2. Water Regulation Schedule for the Arthur R. Marshall Loxahatchee National Wildlife Refuge (USACE 1994).

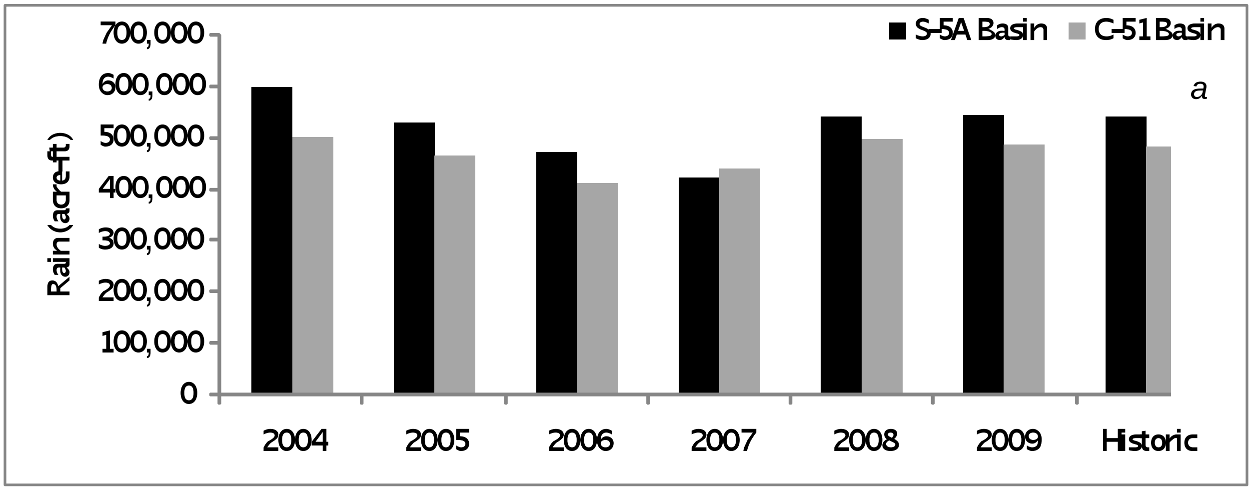


Figure 3. Total annual rainfall for the S-5A and C-51 basins. Historic rainfall was determined from 1963 through 2009.

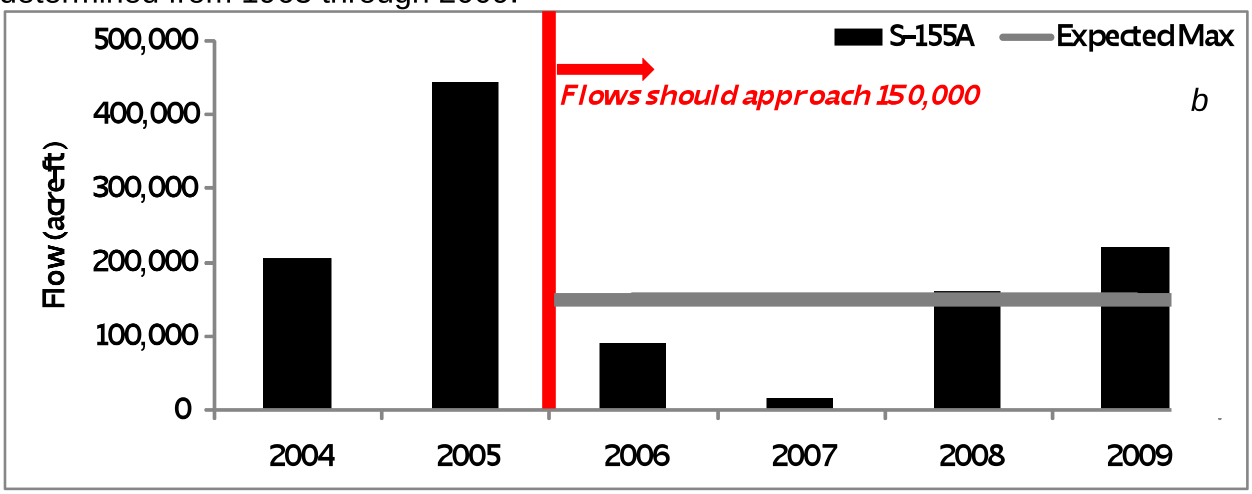


Figure 4. Total annual flows through the S-155A structure. The red vertical bar represents the period when flows through S-155A should approach 150,000 acre-ft as a mixture of L-8 and C-51 basin runoff (Gary Goforth, Inc. 2006). The horizontal grey bar represents the expected maximum (150,000 acre-ft) through S-155A.

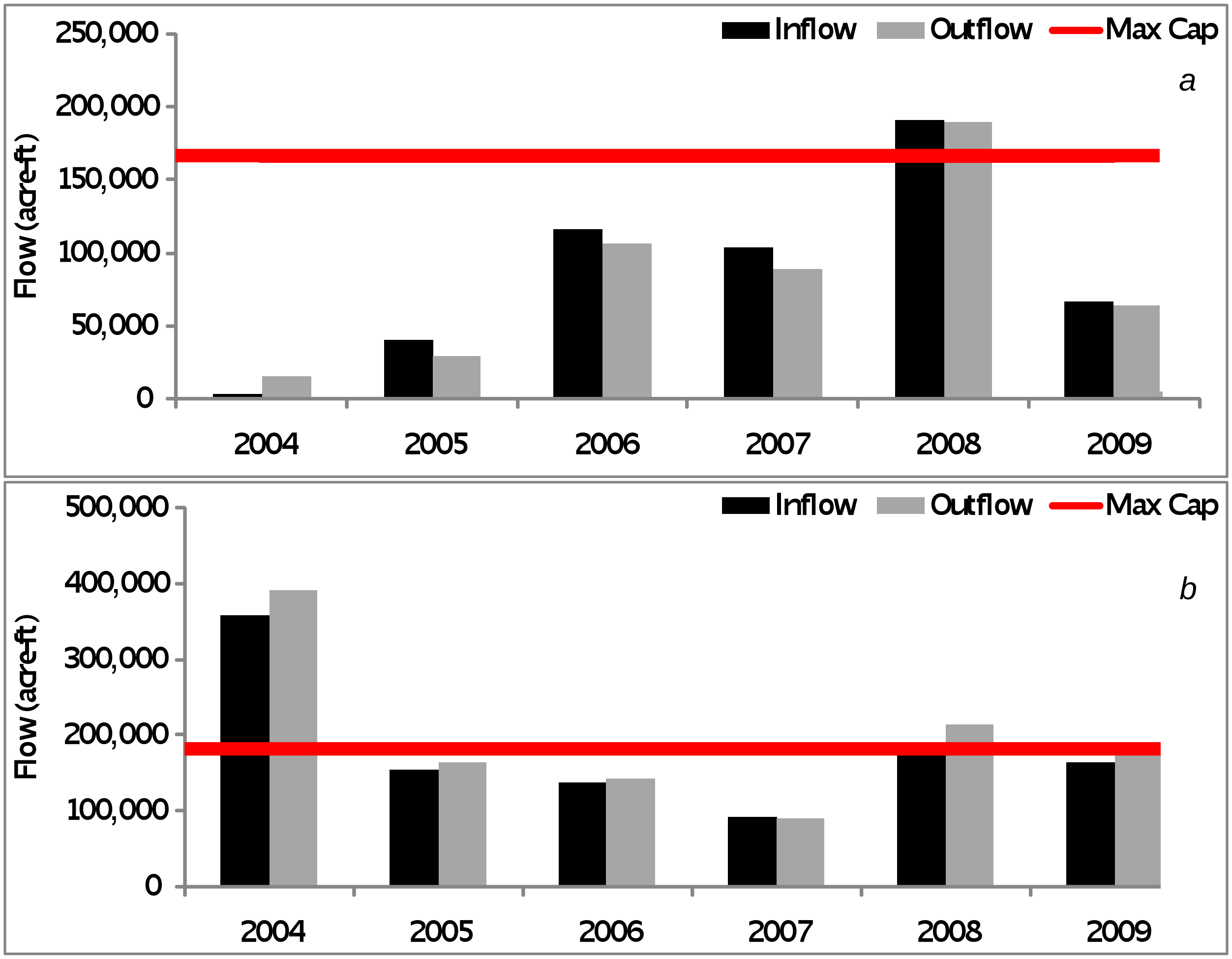


Figure 5. (a) STA1E and (b) STA1W annual inflow and outflow volumes. Horizontal red lines represent maximum treatment capacities for STA1E (165,000 acre-ft) and STA1W (180,000 acre-ft; Gary Goforth, Inc. 2006).

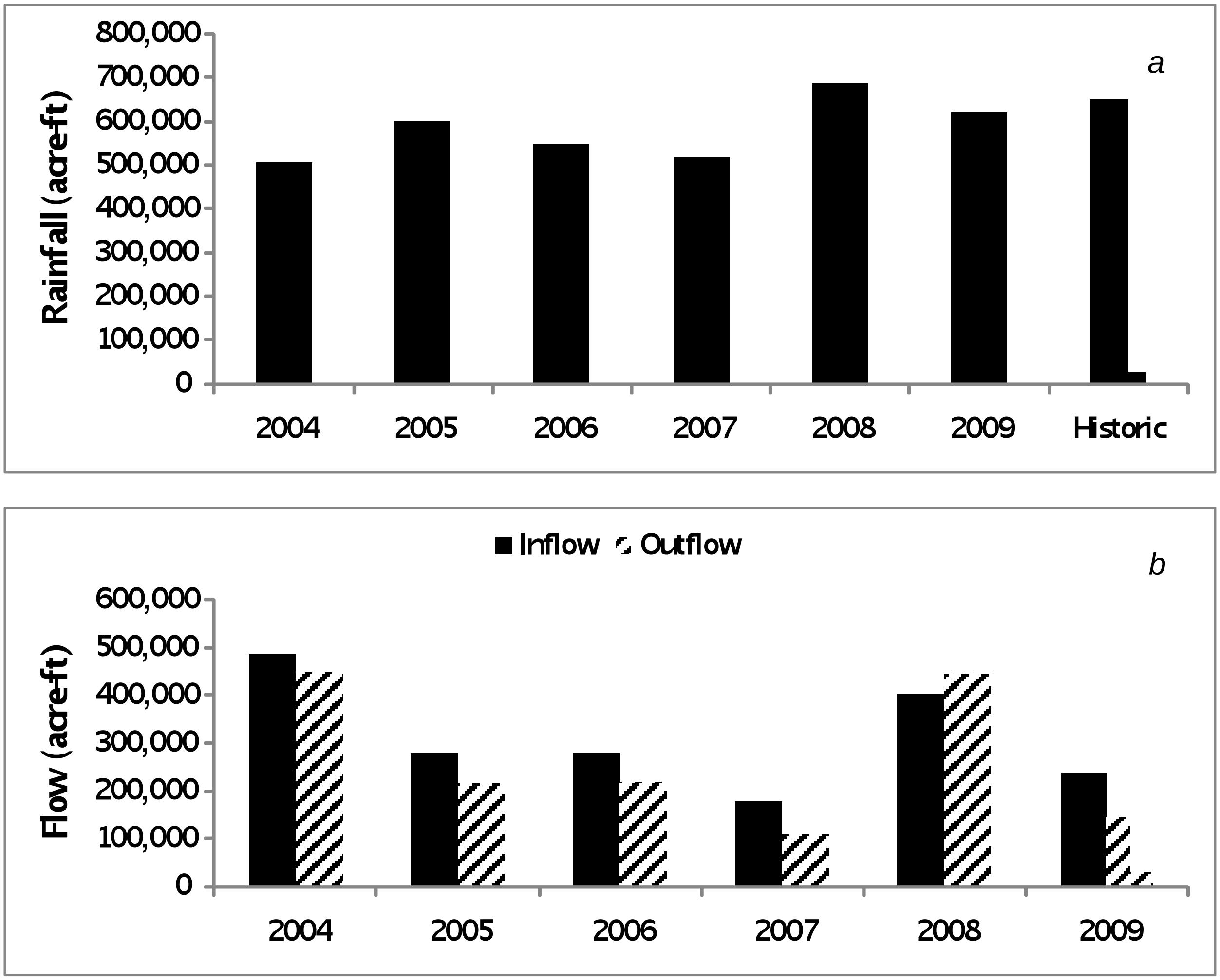


Figure 6. (*a*) Total annual rainfall and (*b*) inflow and outflow for the Refuge. Historic rainfall was determined from 1963 through 2009.

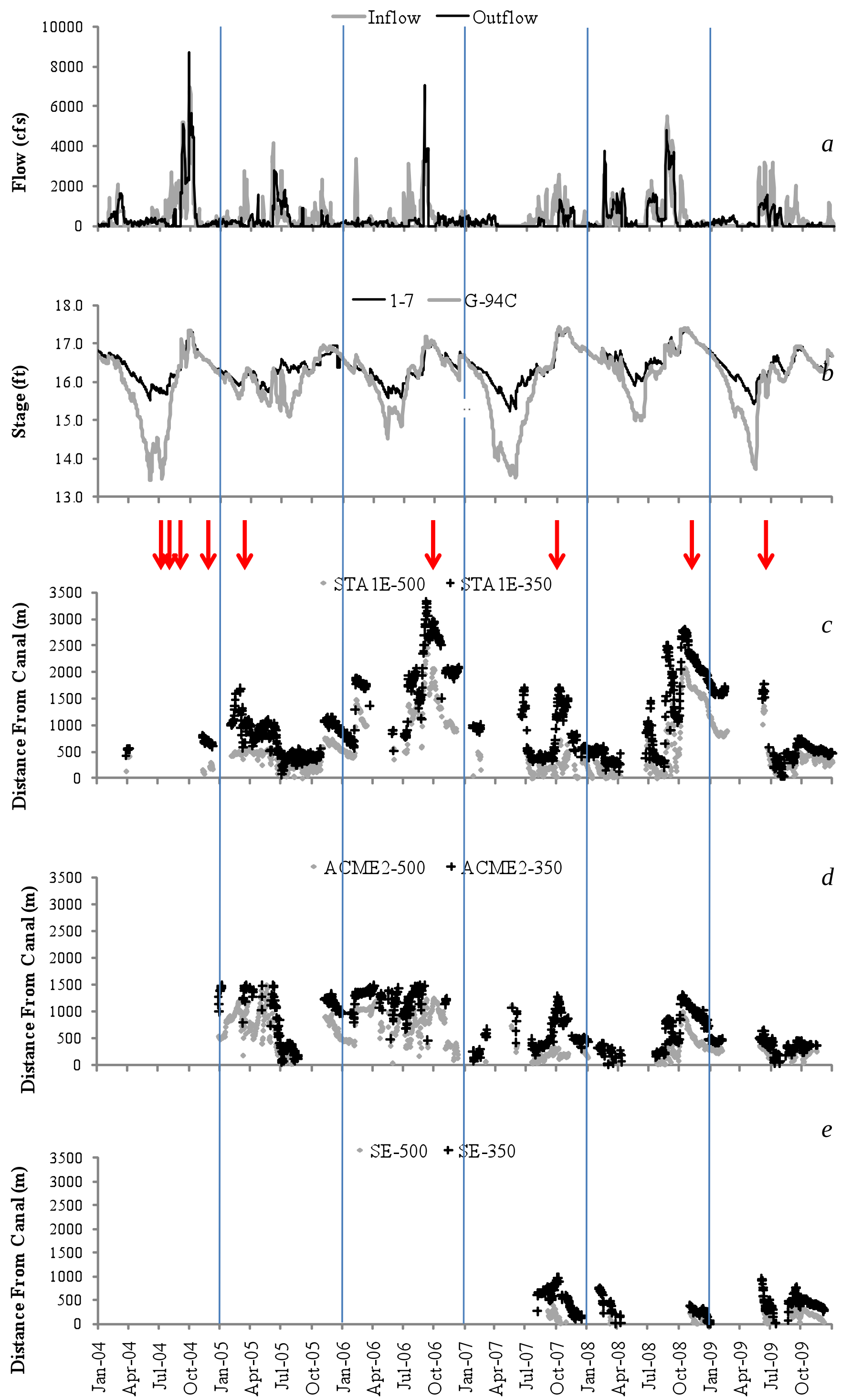


Figure 7. a) Inflow and outflow rates (cfs) summed for all structures from January 2004 to December 2009. b) Canal (G-94C) and marsh (1-7) stage levels (NGVD29). The 350 µS cm^{-1} and 500 µS cm^{-1} conductivity isopleths used to track canal water movement into and out of the marsh interior for: c) STA-1E, d) ACME-2, and e) SE transects. Red arrows indicate Consent Decree excursions.

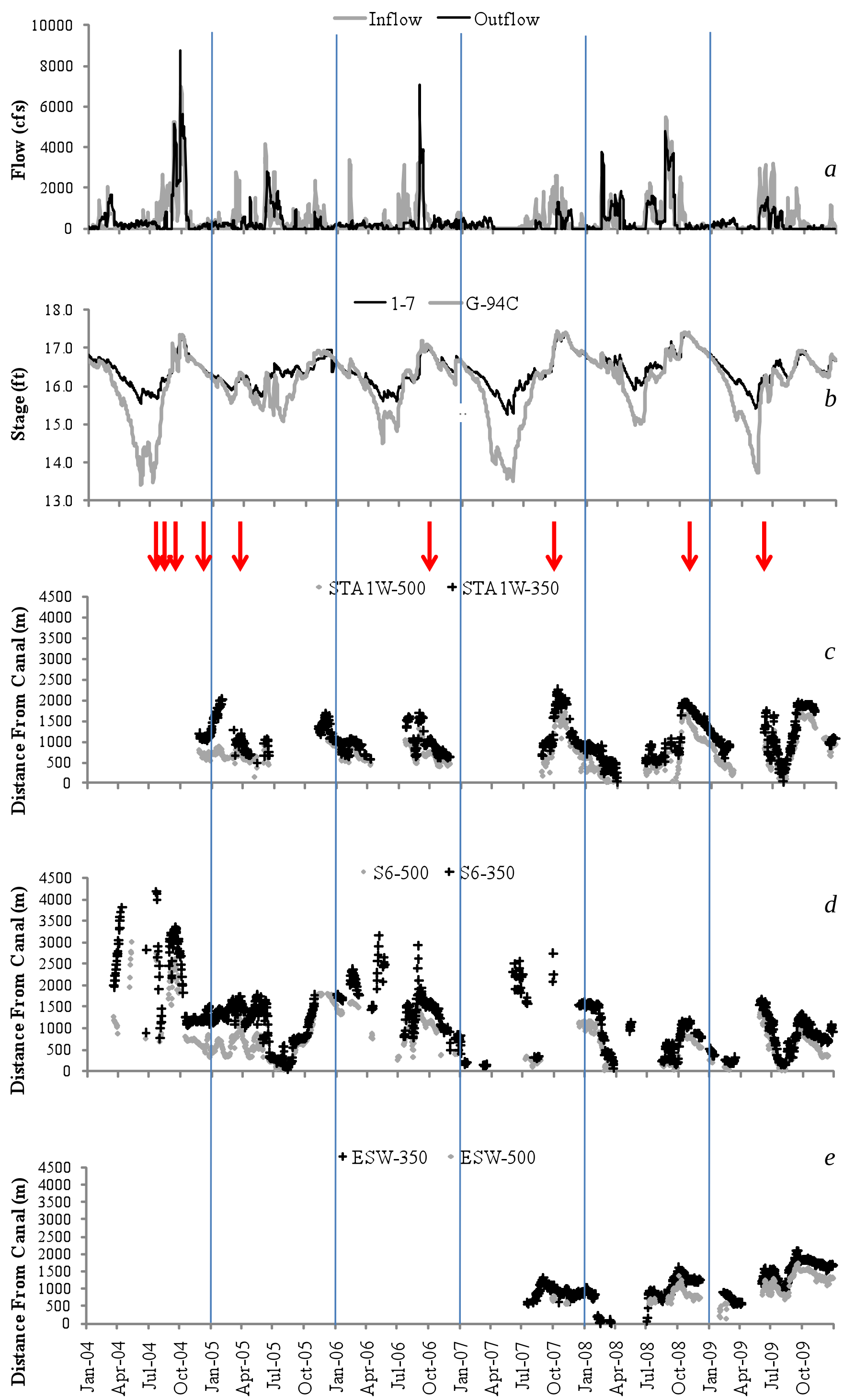


Figure 8. a) Inflow and outflow rates (cfs) summed for all structures from January 2004 to December 2009. b) Canal (G-94C) and marsh (1-7) stage levels (NGVD29). The 350 µS cm^{-1} and 500 µS cm^{-1} conductivity isopleths used to track canal water movement into and out of the marsh interior for: c) STA-1W, d) S-6, and e) the new ESW transects. Red arrows indicate Consent Decree excursions.

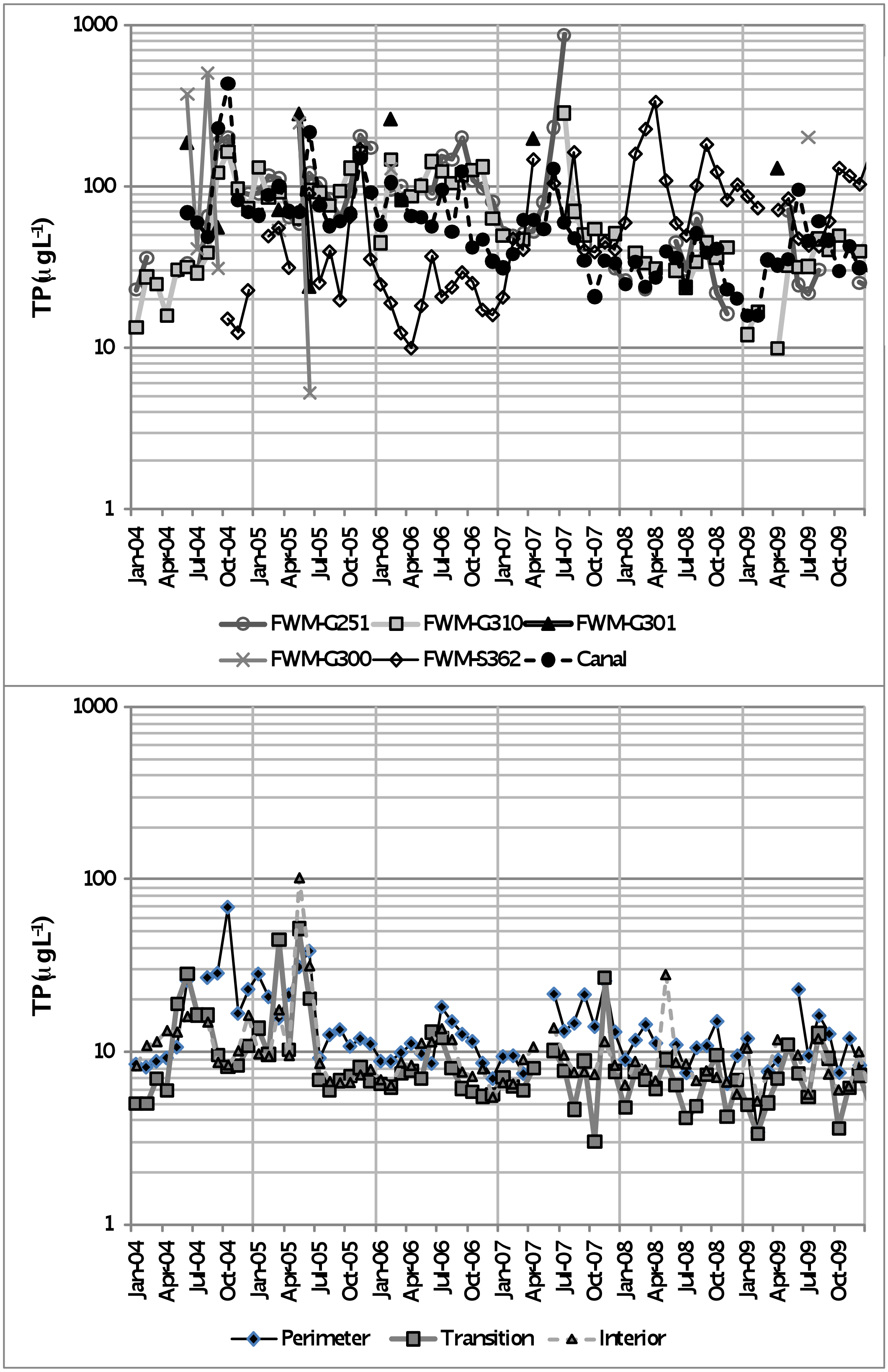


Figure 9. (a) Monthly TP FWM from Refuge inflow structures and TP concentration in the canal. (b) Monthly mean TP concentrations in marsh zones.

SECTION B. ECOLOGICAL IMPACT OF MINERAL ENRICHMENT[3]

An ecological effects program was initiated at the Refuge in September 2006 by the Everglades Program Team in association with the Enhanced Water Quality monitoring project. The focus of this program is to investigate and characterize the ecological impact of mineral enrichment that results from canal water intrusion into the Refuge interior. Much of 2009 was spent continuing data analyses from ongoing projects. No new projects were initiated in 2009. Multiple projects are planned for FY2010.

Projects updated in 2009 include:

- characterization of vegetation and topographic dynamics at existing water quality sites;
- germination of interior seed banks under different water quality and hydrology treatments; and
- an apple snail (*Pomacea paludosa)* grazing study.

Vegetation and Topographic Characterization Project

The vegetation and topographic characterization project was originally envisioned to answer questions about hydrologic and water quality dynamics that exist for each water quality site. Some marsh water quality sites appeared to be more protected from canal water influence than other sites even though these sites are in the direct vicinity of canal water intrusion. To better understand dynamics at the unusual sites (e.g., sites with unusually low TP concentrations near the canal, sites with unusually high TP concentrations at sites remote from the canal, etc.), we attempted to characterize vegetation and topographic resistance to water flow into and out of all the individual water quality sites.

Because vegetation at the water quality sites might be heavily impacted by physical disturbance (e.g., samplers stepping on and uprooting vegetation in the sampling area), vegetation sampling was established as linear, north-to-south transects (50 m) in sloughs adjacent (less than 100 m distance) to each water quality station (LOXA and EVPA). Percent cover for each plant species in a 1 m^2 quadrat was assessed at 5 m increments along the 50 m transect. Photos were taken of each transect from a standard northern position. The ends of each transect were marked permanently with 1/2”-diameter PVC poles. Additional data were collected in March and August 2009, and presently we have quantified vegetation as percent abundance for the various species and quantified topographic slopes to and from the center of each water quality site. Slope analysis did not indicate any significant impedance to surface water flow to and from the sites.

[3] Prepared by: Rebekah Gibble, Donatto D. Surratt, Marcie A. Dixson

Further analyses on existing data will be completed in 2010 and presented in the 7th Annual Report. Vegetation surveys are conducted bi-annually in alternating years and the next survey is scheduled for 2011.

Vegetation Germination Project
Changes in vegetation communities within the Refuge have been attributed to human-induced alterations in hydrology and water quality. Species such as cattail (*Typha domingensis)* have displaced sawgrass (*Cladium jamaicense*) and slough habitats in canal-influenced areas around the Refuge perimeter (Richardson 1990). Several other species such as *Xyris* spp. and some *Rhynchospora* spp. occur only in the Refuge interior (McCormick 2007). We performed an experiment to measure the effects of hydrology and water chemistry on plant community development from the seed bank in order to understand the drivers of observed plant community distributions within the Refuge. Results of these analyses have been presented in the 4th Annual Report (USFWS 2009), but presently a manuscript for journal submission is in preparation.

Apple Snail (*Pomacea paludosa*) Grazing Study
This study investigated the impact of water quality and periphyton communities on the growth and survival of native Florida apple snails *(P. paludosa)*. The 5th Annual Report (USFWS 2010) presents detailed information for the project. Data analysis and report preparation were initiated in 2009 and are ongoing in 2010. Manuscript preparation also will be completed in 2011.

Literature Cited

McCormick PV, 2007. White Paper: ecological effects of mineral enrichment on peatlands such as the Everglades. USGS, Leetown, WV.

Richardson JR, Bryant WL, Kitchens WM, Mattson JE, Pope KR, 1990. An evaluation of Refuge habitats and relationships to water quality, quantity, and hydroperiod. Florida Cooperative Fish and Wildlife Research Unit, University of Florida, Gainesville, FL.

USFWS, 2009. A.R.M. Loxahatchee National Wildlife Refuge - Enhanced Water Quality Program – 4th Annual Report – July 2009. LOXA09-007, U.S. Fish and Wildlife Service, Boynton Beach, FL. 106 pp.

SECTION C. MODELING UPDATE[4]

The Refuge has developed a suite of models simulating stage, and concentration of chloride, sulfate, and TP in the Refuge marsh and canals. Included in this suite is a complex spatially-explicit model, as well as spatially aggregated models. The spatially explicit model uses the MIKE-FLOOD software sold and supported by DHI[5]. Three spatially aggregated models with varying degrees of aggregation are in use or under development. These models were developed using the Berkeley-Madonna simulation software[6]. The aggregated models have 4, 9, or 39 water quality cells depending on the level of spatial aggregation. Further details of these models are available through the Refuge modeling web site[7] and at the USGS SOFIA site[8].

Refuge modeling progress in 2009 centered on the final meeting of the Refuge modeling Technical Advisory Panel (TAP) on May 11, 2009. This meeting followed three previous public modeling workshops. In addition to the TAP, this public meeting was attended by modelers, scientists, and managers from other agencies including the USGS, South Florida Water Management District, and universities. In addition to all of the presentations from that meeting, additional graphics that were not presented at the meeting because of time limitations are available on line through a linked version of the meeting agenda. Links to this and more information are available through links on the Refuge modeling web site (http://loxmodel.mwaldon.com).

After primary focus on development, calibration, and verification of the models, much of the modeling effort in 2009 was redirected toward model application and use. Refuge models have been used to analyze hydrologic impacts of the EAA Regional Feasibility Study, comparison of methods and results with the South Florida Water Management Model, comparison of alternative regulatory releases under the current regulation schedule, comparison of model water quality results using hourly rather than daily average inflows, analysis of potential impacts of a berm along the marsh bank of the L-40 Canal, and sensitivity of interior and peripheral marsh to changes in chloride, sulfate, and total phosphorus inflow concentrations. In the final months of 2009, a version of the aggregated model was applied in development, testing, and application of a high-stage hydrological performance measure for testing alternative water management scenarios.

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[4] Prepared by: Michael G. Waldon, Donatto D. Surratt, Matthew C. Harwell

[5] http://mikebydhi.com/sitecore/content/Microsites/MIKEbyDHI/Products/WaterResources/MIKEFLOOD.aspx

[6] http://www.berkeleymadonna.com/

[7] http://loxmodel.mwaldon.com/

[8] http://sofia.usgs.gov/lox_monitor_model/reports/

SECTION D. 2009 PRESENTATION, REPORTS, AND PUBLICATIONS

Presentations

Gibble R, 2009. Overview of current research in the Loxahatchee Refuge. Annual A.R.M. Loxahatchee National Wildlife Refuge Science Workshop, U.S. Fish and Wildlife Service, Boynton Beach, FL.

Harwell MC, 2009. Future science overview. Annual A.R.M. Loxahatchee National Wildlife Refuge Science Workshop, U.S. Fish and Wildlife Service, Boynton Beach, FL.

Harwell MC, 2009. System-wide science to improve planning and adaptive management. Independent Technical Advisory Panel: Hydrodynamic and water quality modeling. US Fish and Wildlife Service, Boynton Beach, FL.

Meselhe E, 2009. Spatially explicit (MIKE-FLOOD) model or refuge. Independent Technical Advisory Panel: Hydrodynamic and water quality modeling. US Fish and Wildlife Service, Boynton Beach, FL.

Surratt D, 2009. A.R.M. Loxahatchee National Wildlife Refuge – Water quality. Presentation to Chinese government delegates. U.S. Fish and Wildlife Service, Boynton Beach, FL.

Waldon MG, 2009. Refuge modeling – history, opportunities, and constraints. Independent Technical Advisory Panel: Hydrodynamic and water quality modeling. US Fish and Wildlife Service, Boynton Beach, FL.

Waldon MG, 2009. Refuge modeling – water quality modeling. Independent Technical Advisory Panel: Hydrodynamic and water quality modeling. US Fish and Wildlife Service, Boynton Beach, FL.

Waldon MG, 2009. Simple Refuge screening (SRSM) model for Refuge. Independent Technical Advisory Panel: Hydrodynamic and water quality modeling. US Fish and Wildlife Service, Boynton Beach, FL.

Waldon MG, 2009. Multi-compartment models. Independent Technical Advisory Panel: Hydrodynamic and water quality modeling. US Fish and Wildlife Service, Boynton Beach, FL.

Reports

Chen C, Meselhe EA, Waldon M, 2009. A.R.M. Loxahatchee National Wildlife Refuge hydrodynamic modeling with MIKE FLOOD (version 2.0.0). LOXA09-004, U.S. Fish and Wildlife Service, Boynton Beach, FL.

Chen C, Meselhe EA, Waldon M, 2009. A.R.M. Loxahatchee National Wildlife Refuge

modeling development and application – status report. LOXA09-005, U.S. Fish and Wildlife Service, Boynton Beach, FL.

Harwell M, Surratt D, Waldon M, 2009. Quarterly Update on Enhanced Water Quality Monitoring and Modeling Program for the A.R.M. Loxahatchee National Wildlife Refuge (January 2009). LOXA09-001, U.S. Fish and Wildlife Service, Boynton Beach, FL.

Harwell M, Surratt D, Waldon M, 2009. Quarterly Update on Enhanced Water Quality Monitoring and Modeling Program for the A.R.M. Loxahatchee National Wildlife Refuge (April 2009). LOXA09-008, U.S. Fish and Wildlife Service, Boynton Beach, FL.

Harwell M, Surratt D, Waldon M, 2009. Quarterly Update on Enhanced Water Quality Monitoring and Modeling Program for the A.R.M. Loxahatchee National Wildlife Refuge (July 2009). LOXA09-009, U.S. Fish and Wildlife Service, Boynton Beach, FL.

Harwell M, Surratt D, Waldon M, 2009. Quarterly Update on Enhanced Water Quality Monitoring and Modeling Program for the A.R.M. Loxahatchee National Wildlife Refuge (October 2009). LOXA09-010, U.S. Fish and Wildlife Service, Boynton Beach, FL.

Meselhe EA, Waldon MG, Roth W, 2009. A.R.M. Loxahatchee National Wildlife Refuge Simple Refuge Screening Model Version 4.00 User's Manual. University of Louisiana - Lafayette, Lafayette, Louisiana.

USFWS, 2009. A.R.M. Loxahatchee National Wildlife Refuge – Enhanced monitoring and modeling program annual report – July 2009. LOXA09-007, US Fish and Wildlife Service, Boynton Beach, FL, pg106.

Waldon M, 2009. A.R.M. Loxahatchee National Wildlife Refuge hydrodynamic modeling with MIKE FLOOD (version 2.0.0). LOXA09-004, U.S. Fish and Wildlife Service, Boynton Beach, FL.

Waldon MG, Meselhe EA, Roth W, Wang H, Chen C, 2009. A.R.M. Loxahatchee Refuge Water Quality Modeling - Rates, constants, and kinetic formulations. Report #LOXA009-003, University of Louisiana-Lafayette, in cooperation with the US Fish and Wildlife Service.

Publications

Meselhe E, Arceneaux JC, Waldon MG, submitted 2009. Water budget model for a remnant northern Everglades wetland. *Journal of Hydraulic Research*, v48, p100-105.

Wang H, Waldon MG, Meselhe EA, Arceneaux JC, Chen C, Harwell MC, 2009. Surface water sulfate dynamics in the northern Florida Everglades, USA. *Journal of Environmental Quality*, v38, p734-741.

APPENDIX A

Table A-1. Individual EVPA and LOXA station summary statistics of water quality data for calendar year 2009. Where values were below the minimum detection limits, one-half of the minimum detection limit is reported (Weaver et al. 2008). Previous summary statistics (2004 – 2008) can be found in the previous annual reports (USFWS 2007a, b, 2009, 2010).

	STAT	TEMP	DO	SPCOND	PH	TURB	TSUSSD	NOX	TKN	TN	OPO4	TP	SIO2	CA	CL	SO4	ALKALINITY	TDORGC	TDSSOL	TOTORC
	unit	Celcius	mg L^{-1}	$\mu S\ cm^{-1}$		NTU	mg L^{-1}	mg L^{-1}	mg L^{-1}	mg L^{-1}	$\mu g\ L^{-1}$	$\mu g\ L^{-1}$	mg L^{-1}	mg L^{-1}	mg L^{-1}	mg L^{-1}	mg L^{-1}	mg L^{-1}	mg L^{-1}	mg L^{-1}
A101	Count	9	9	9	9	3	9	2	3.0	5.0	2.0	9	3	3	8	9.00	3	3	3	3
	Mean	23	3	550	7	1	2	0.005	1.5	1.5	1.5	12	11	43	88	8.90	134	28	337	30
	StDev	4	2	243	0	0	1	0.000	0.6	0.5	0.0	9	3	22	41	13.89	50	8	178	10
	Min	18	1	276	7	0	1	0.005	0.9	0.9	1.5	3	8	24	31	1.20	81	21	180	21
	Max	28	7	918	7	1	4	0.005	2.0	2.0	1.5	32	14	67	150	45.00	180	37	530	41
A102	Count	6	6	6	6	1	6	1	1.0	1.0	0.0	6	1	1	5	6.00	1	1	1	1
	Mean	23	5	203	7	0	2	0.005	0.8	0.8	0.0	7	13	18	31	3.11	59	20	150	20
	StDev	4	2	53	0	NA	1	NA	NA	NA	0.0	3	NA	NA	5	4.38	NA	NA	NA	NA
	Min	17	3	102	6	0	1	0.005	0.8	0.8	0.0	2	13	18	23	0.74	59	20	150	20
	Max	28	9	242	7	0	5	0.005	0.8	0.8	0.0	10	13	18	34	12.00	59	20	150	20
A103	Count	8	8	8	8	2	8	1	2.0	5.0	1.0	8	2	2	7	8.00	2	2	2	2
	Mean	23	2	185	7	0	4	0.005	1.2	1.2	1.5	10	9	16	32	1.32	46	27	174	27
	StDev	4	1	86	0	0	2	NA	0.1	0.1	NA	5	11	10	16	0.98	29	1	108	2
	Min	15	1	94	6	0	1	0.005	1.1	1.1	1.5	2	1	9	15	0.50	25	26	97	25
	Max	28	5	357	7	1	9	0.005	1.3	1.3	1.5	20	17	23	62	3.50	66	28	250	28
A104	Count	12	12	12	12	12	12	12	12.0	12.0	10.0	12	12	12	11	10.00	12	11	12	11
	Mean	26	6	791	8	3	4	0.050	1.8	1.9	9.3	34	14	57	112	40.40	178	30	493	31
	StDev	4	2	220	0	3	2	0.058	0.3	0.3	8.3	13	8	13	38	22.51	40	6	148	6
	Min	19	3	488	8	1	2	0.005	1.3	1.3	1.5	10	3	41	59	18.00	130	20	300	21
	Max	31	8	1148	8	11	9	0.190	2.2	2.2	20.0	60	27	84	170	87.00	250	40	740	40
A105	Count	9	9	9	9	4	9	4	4.0	6.0	2.0	9	4	4	8	9.00	4	3	4	3
	Mean	24	4	664	7	1	2	0.006	1.8	1.8	31.8	14	21	57	112	21.27	185	36	515	36
	StDev	5	2	316	0	0	1	0.002	0.5	0.5	42.8	8	12	18	51	22.03	52	12	188	12
	Min	16	2	160	7	0	1	0.005	1.1	1.1	1.5	3	4	31	48	2.50	110	24	240	24
	Max	29	8	1015	8	1	4	0.009	2.2	2.2	62.0	28	30	68	170	58.00	230	48	660	48
A106	Count	7	7	7	7	3	7	3	3.0	5.0	2.0	7	3	3	6	7.00	3	2	3	2
	Mean	26	4	493	7	1	2	0.005	1.6	1.6	5.1	12	26	46	86	12.37	153	33	457	34
	StDev	3	1	249	0	0	1	0.000	0.2	0.2	3.0	7	6	3	38	13.96	21	3	49	4
	Min	22	3	123	6	0	1	0.005	1.4	1.4	3.0	2	19	43	27	1.40	130	31	400	31
	Max	31	6	779	7	1	4	0.005	1.8	1.8	7.2	21	30	49	130	35.00	170	35	490	36
A107	Count	4	4	4	4	0	4	0	0.0	4.0	1.0	4	0	0	3	4.00	0	0	0	0
	Mean	26	2	143	6	0	1	0.000	0.0	NA	3.0	12	0	0	22	1.40	0	0	0	0
	StDev	3	0	33	0	0	1	0.000	0.0	NA	NA	5	0	0	4	1.80	0	0	0	0
	Min	21	2	99	6	0	1	0.000	0.0	0.0	3.0	5	0	0	19	0.37	0	0	0	0
	Max	29	3	179	7	0	3	0.000	0.0	0.0	3.0	17	0	0	27	4.10	0	0	0	0
A108	Count	5	5	5	5	2	5	2	2.0	5.0	1.0	5	2	2	4	5.00	2	2	2	2
	Mean	27	4	117	7	1	3	0.005	0.9	0.9	1.5	5	4	5	25	0.02	11	21	83	21
	StDev	4	1	34	0	0	2	0.000	0.1	0.1	NA	1	1	0	8	0.00	2	1	0	1
	Min	21	3	85	6	1	1	0.005	0.9	0.9	1.5	4	3	4	16	0.02	10	20	83	20
	Max	29	5	163	7	1	5	0.005	1.0	1.0	1.5	7	5	5	33	0.02	13	22	83	22

	STAT	TEMP	DO	SPCOND	PH	TURB	TSUSSD	NOX	TKN	TN	OPO4	TP	SIO2	CA	CL	SO4	ALKALINITY	TDORGC	TDSSOL	TOTORC
	unit	Celcius	mg L^{-1}	$\mu S\ cm^{-1}$		NTU	mg L^{-1}	mg L^{-1}	mg L^{-1}	mg L^{-1}	$\mu g\ L^{-1}$	$\mu g\ L^{-1}$	mg L^{-1}	mg L^{-1}	mg L^{-1}	mg L^{-1}	mg L^{-1}	mg L^{-1}	mg L^{-1}	mg L^{-1}
A109	Count	9	9	9	9	9	9	9	9.0	9.0	8.0	9	9	9	8	9.00	9	8	9	8
	Mean	25	3	221	7	1	1	0.006	1.2	1.2	9.1	7	6	17	35	5.23	48	22	156	22
	StDev	4	2	98	0	0	1	0.004	0.2	0.2	18.2	5	3	9	15	8.81	14	1	55	2
	Min	18	1	108	6	0	1	0.002	1.0	1.0	1.5	2	1	7	17	0.58	25	20	110	20
	Max	29	6	440	7	1	3	0.016	1.5	1.5	54.0	15	10	33	66	28.00	75	24	280	25
A110	Count	8	8	8	8	4	8	4	4.0	6.0	3.0	8	4	4	7	8.00	4	3	4	3
	Mean	27	6	107	7	1	2	0.005	1.4	1.4	1.5	7	6	7	22	0.27	18	20	103	21
	StDev	4	2	39	0	0	2	0.000	0.4	0.4	0.0	4	5	1	5	0.19	5	2	17	3
	Min	19	3	29	6	1	1	0.005	1.0	1.0	1.5	2	1	5	14	0.02	12	18	81	18
	Max	31	10	143	7	1	5	0.005	1.8	1.8	1.5	14	12	8	28	0.60	23	21	120	24
A111	Count	8	8	8	8	5	8	5	5.0	6.0	4.0	8	5	5	7	8.00	5	4	5	4
	Mean	25	4	110	7	0	2	0.005	1.0	1.0	1.5	5	3	7	16	0.37	25	14	78	15
	StDev	4	2	22	0	0	2	0.000	0.3	0.3	0.0	4	1	1	4	0.09	4	2	15	2
	Min	20	2	77	6	0	1	0.005	0.7	0.7	1.5	2	1	6	9	0.25	20	12	58	12
	Max	29	7	142	7	0	7	0.005	1.4	1.4	1.5	14	5	9	22	0.48	30	15	92	16
A112	Count	9	9	9	9	8	9	8	8.0	8.0	7.0	9	8	8	8	9.00	8	7	8	7
	Mean	25	3	140	7	1	1	0.005	1.1	1.1	10.0	8	5	11	21	2.49	36	18	115	18
	StDev	5	1	59	0	0	1	0.002	0.2	0.2	17.1	6	2	2	8	5.44	5	3	33	3
	Min	18	2	47	6	0	1	0.002	0.9	0.9	1.5	2	3	8	12	0.39	26	16	79	15
	Max	30	5	257	7	1	3	0.009	1.6	1.6	48.0	19	9	17	38	17.00	40	24	190	23
A113	Count	8	8	8	8	3	8	3	3.0	6.0	2.0	8	3	3	7	8.00	3	2	3	2
	Mean	25	4	102	7	1	2	0.005	0.9	0.9	1.5	8	3	6	17	0.23	18	14	72	14
	StDev	4	2	22	0	0	1	0.000	0.4	0.4	0.0	6	2	1	4	0.14	5	4	19	4
	Min	18	2	69	6	0	1	0.005	0.5	0.5	1.5	2	2	6	9	0.02	13	11	53	11
	Max	29	8	140	7	1	4	0.005	1.2	1.2	1.5	17	5	8	22	0.39	23	16	91	16
A114	Count	9	9	9	9	4	9	4	4.0	6.0	4.0	8	4	4	8	9.00	4	4	4	4
	Mean	25	4	105	7	1	2	0.006	1.0	1.0	14.6	5	3	6	19	0.09	14	17	77	18
	StDev	4	2	27	0	0	1	0.002	0.2	0.2	23.7	4	2	1	6	0.10	2	4	18	5
	Min	18	1	67	6	0	1	0.005	0.7	0.7	1.5	2	2	5	9	0.02	11	12	52	12
	Max	28	7	154	7	1	4	0.009	1.2	1.2	50.0	13	5	7	28	0.24	16	21	94	23
A115	Count	11	11	11	11	12	12	12	12.0	12.0	11.0	12	12	12	11	11.00	12	11	12	11
	Mean	25	5	758	8	3	3	0.040	1.8	1.8	9.1	28	18	56	107	53.09	173	30	487	30
	StDev	4	2	281	0	2	2	0.031	0.4	0.3	7.5	16	9	16	46	25.86	49	7	175	8
	Min	18	1	401	7	0	1	0.005	1.3	1.3	1.5	4	5	36	47	16.00	110	19	250	18
	Max	30	7	1133	8	9	8	0.120	2.2	2.2	19.0	64	32	80	170	83.00	240	40	720	41
A116	Count	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA
	Mean	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA
	StDev	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA
	Min	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA
	Max	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA

	STAT	TEMP	DO	SPCOND	PH	TURB	TSUSSD	NOX	TKN	TN	OPO4	TP	SIO2	CA	CL	SO4	ALKALINITY	TDORGC	TDSSOL	TOTORC
	unit	Celcius	mg L^{-1}	μS cm^{-1}		NTU	mg L^{-1}	mg L^{-1}	mg L^{-1}	mg L^{-1}	μg L^{-1}	μg 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}
A117	Count	8	8	8	8	7	9	7	7.0	7.0	7.0	9	7	7	8	9.00	7	6	7	6
	Mean	23	2	276	7	1	1	0.004	1.2	1.2	10.6	13	10	28	46	9.03	88	23	241	23
	StDev	5	2	126	0	0	1	0.001	0.4	0.4	15.6	9	3	10	25	13.45	29	4	101	5
	Min	16	1	158	6	0	1	0.002	0.8	0.8	1.5	3	5	15	21	1.50	43	17	120	17
	Max	28	7	456	7	1	3	0.005	1.9	1.9	43.0	31	15	43	91	43.00	120	30	420	30
A118	Count	9	9	9	9	9	10	9	9.0	9.0	9.0	10	9	9	9	10.00	9	8	9	8
	Mean	23	3	122	7	1	2	0.007	0.8	0.8	5.9	8	7	10	20	1.51	29	17	104	17
	StDev	4	1	22	0	0	2	0.008	0.2	0.2	10.9	6	2	1	8	1.72	5	2	27	2
	Min	18	1	101	6	0	1	0.002	0.6	0.6	1.5	2	3	8	13	0.74	25	14	75	14
	Max	28	5	173	7	1	7	0.027	1.3	1.3	35.0	21	10	13	37	6.40	40	19	170	20
A119	Count	9	9	9	9	9	10	9	9.0	9.0	9.0	10	9	9	9	10.00	8	8	9	8
	Mean	24	4	116	7	1	2	0.007	1.1	1.1	7.4	7	10	8	19	0.26	31	19	105	19
	StDev	4	2	29	0	0	1	0.007	0.3	0.3	14.5	3	3	1	7	0.21	11	3	26	3
	Min	18	1	75	6	0	1	0.002	0.8	0.8	1.5	3	5	6	9	0.02	20	14	69	14
	Max	29	6	171	7	2	4	0.025	1.7	1.7	46.0	15	15	11	31	0.72	55	26	140	25
A120	Count	10	10	10	10	10	11	10	10.0	10.0	10.0	11	10	10	10	10.00	10	9	10	9
	Mean	25	6	123	7	1	2	0.009	1.1	1.1	155.5	9	4	6	24	0.06	19	17	90	17
	StDev	4	2	59	1	0	2	0.007	0.2	0.2	472.5	10	1	3	13	0.08	6	4	25	4
	Min	20	2	66	6	0	1	0.002	0.9	0.9	1.5	2	2	0	10	0.02	13	12	61	11
	Max	29	8	262	8	2	6	0.023	1.5	1.5	1500.0	30	6	10	54	0.24	30	25	140	24
A122	Count	8	8	8	8	7	9	7	7.0	7.0	7.0	9	7	7	8	9.00	7	6	7	6
	Mean	23	3	349	7	1	1	0.006	1.3	1.3	4.4	18	12	37	55	10.29	108	25	283	25
	StDev	5	3	142	0	0	1	0.005	0.3	0.3	3.4	18	3	13	28	11.81	37	4	101	4
	Min	17	1	208	7	0	1	0.002	0.9	0.9	1.5	3	7	17	26	1.90	51	21	160	21
	Max	28	9	562	7	1	5	0.018	1.9	1.9	11.0	62	16	51	105	37.00	160	31	450	32
A124	Count	9	9	9	9	8	10	7	8.0	8.0	8.0	10	8	8	9	10.00	8	7	8	7
	Mean	23	3	177	7	1	2	0.007	1.1	1.1	3.4	14	7	16	33	0.87	36	20	140	21
	StDev	4	2	43	0	0	2	0.004	0.2	0.2	3.3	10	3	8	10	1.26	12	3	38	2
	Min	17	2	131	6	0	1	0.005	0.8	0.8	1.5	3	3	9	21	0.03	21	18	93	18
	Max	29	9	265	7	2	7	0.016	1.5	1.5	11.0	37	13	33	49	4.20	56	26	200	25
A126	Count	8	8	8	8	6	9	5	6.0	7.0	6.0	9	6	6	8	9.00	6	5	6	5
	Mean	23	9	371	7	1	2	0.006	1.3	1.3	2.3	10	11	34	66	10.21	89	22	275	22
	StDev	5	12	211	0	0	1	0.002	0.3	0.3	1.4	5	6	18	35	12.71	47	3	127	3
	Min	17	2	142	7	1	1	0.005	0.9	0.9	1.5	2	1	11	19	0.26	35	17	97	16
	Max	30	39	604	7	1	3	0.009	1.7	1.7	4.8	18	18	54	98	37.00	140	26	390	25
A127	Count	6	6	6	6	5	7	4	5.0	7.0	6.0	7	5	5	6	7.00	5	4	5	4
	Mean	27	6	120	7	1	3	0.005	1.4	1.4	4.4	10	7	8	19	0.04	20	20	108	20
	StDev	4	2	32	0	0	1	0.000	0.2	0.2	7.1	7	1	1	7	0.07	3	2	18	1
	Min	22	3	92	7	0	1	0.005	1.2	1.2	1.5	2	6	7	10	0.02	17	18	85	18
	Max	32	8	173	7	1	4	0.005	1.7	1.7	19.0	21	9	9	27	0.21	23	22	130	21

	STAT	TEMP	DO	SPCOND	PH	TURB	TSUSSD	NOX	TKN	TN	OPO4	TP	SIO2	CA	CL	SO4	ALKALINITY	TDORGC	TDSSOL	TOTORC
	unit	Celcius	mg L^{-1}	μS cm^{-1}		NTU	mg L^{-1}	mg L^{-1}	mg L^{-1}	mg L^{-1}	μg L^{-1}	μg 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}
A128	Count	6	6	6	6	2	7	2	2.0	4.0	2.0	7	2	2	6	7.00	2	2	2	2
	Mean	26	4	94	6	1	3	0.005	1.1	1.1	4.5	7	3	5	18	0.04	14	18	70	17
	StDev	3	2	19	0	0	2	0.000	0.0	0.0	4.2	12	1	1	5	0.05	2	4	18	5
	Min	21	2	69	6	1	1	0.005	1.1	1.1	1.5	2	2	5	10	0.02	12	15	57	13
	Max	30	7	118	7	1	8	0.005	1.1	1.1	7.4	33	4	6	25	0.14	15	20	83	20
A129	Count	11	12	12	12	12	12	11	12.0	12.0	12.0	12	12	12	11	11.00	12	11	12	11
	Mean	24	4	681	7	3	7	0.057	1.7	1.8	9.7	45	10	53	106	27.20	158	24	418	25
	StDev	4	2	184	0	2	4	0.109	0.4	0.5	18.0	32	6	15	25	18.69	40	5	111	4
	Min	17	0	302	7	1	1	0.005	1.1	1.1	1.5	11	1	24	65	7.50	71	17	210	18
	Max	30	7	1001	8	8	12	0.380	2.5	2.7	64.0	130	19	83	140	75.00	230	30	630	29
A130	Count	8	9	9	9	7	9	6	7.0	7.0	7.0	9	7	7	8	9.00	7	6	7	6
	Mean	24	3	240	7	1	2	0.004	1.2	1.2	4.9	12	8	19	33	3.32	59	20	154	19
	StDev	5	1	72	0	0	1	0.001	0.3	0.3	5.8	5	3	3	14	4.88	9	1	36	1
	Min	16	1	137	6	0	1	0.002	0.9	0.9	1.5	3	5	15	15	0.90	46	18	110	18
	Max	30	4	355	7	1	5	0.005	1.7	1.7	16.0	17	13	24	51	16.00	70	21	220	21
A131	Count	8	9	9	9	7	9	6	7.0	7.0	7.0	9	7	7	8	9.00	7	6	7	6
	Mean	24	5	143	7	1	2	0.004	1.2	1.2	5.8	7	6	10	22	0.82	31	18	103	18
	StDev	4	2	50	0	0	1	0.001	0.2	0.2	7.4	5	3	1	11	1.09	5	3	17	2
	Min	17	3	92	7	0	1	0.002	0.9	0.9	1.5	2	1	9	10	0.22	25	13	69	13
	Max	30	7	232	7	1	3	0.005	1.6	1.6	20.0	17	12	12	39	3.70	39	20	120	20
A132	Count	11	12	12	12	12	12	11	12.0	12.0	12.0	12	12	12	11	11.00	12	11	12	11
	Mean	25	4	715	7	4	11	0.063	1.8	1.9	14.2	48	10	55	111	28.82	165	27	438	27
	StDev	4	2	145	0	6	16	0.106	0.5	0.5	21.4	31	6	13	20	17.75	34	4	96	3
	Min	17	1	446	7	1	3	0.005	1.1	1.1	1.5	12	0	31	78	15.00	93	20	280	21
	Max	30	7	996	8	22	61	0.370	2.6	2.9	74.0	130	19	88	140	74.00	240	32	640	32
A133	Count	5	6	6	6	3	6	2	3.0	5.0	3.0	6	3	3	5	6.00	3	2	3	2
	Mean	24	3	254	7	2	5	0.005	1.5	1.5	7.7	49	8	23	38	5.35	71	20	220	20
	StDev	2	1	154	0	0	4	0.000	0.7	0.7	10.7	47	3	11	29	10.61	24	4	140	4
	Min	22	1	143	6	2	1	0.005	1.0	1.0	1.5	16	6	16	17	0.66	57	17	120	17
	Max	27	4	560	7	2	11	0.005	2.3	2.3	20.0	140	11	35	90	27.00	99	23	380	22
A134	Count	8	9	9	9	6	9	5	6.0	7.0	6.0	9	6	6	8	9.00	6	5	6	5
	Mean	24	4	291	7	1	1	0.005	1.3	1.3	1.7	14	7	19	44	4.73	81	19	164	18
	StDev	4	1	175	0	0	1	0.000	0.4	0.4	0.4	9	2	10	33	8.46	62	2	113	2
	Min	18	2	132	7	0	1	0.005	1.0	1.0	1.5	3	5	11	13	1.10	36	17	94	17
	Max	31	6	590	8	1	3	0.005	2.1	2.1	2.5	29	11	39	99	27.00	200	22	390	22
A135	Count	11	12	12	12	12	12	11	12.0	12.0	10.0	12	12	12	11	11.00	12	11	12	11
	Mean	25	4	726	8	4	7	0.082	1.9	1.9	15.8	49	11	56	109	30.00	163	27	453	28
	StDev	4	2	105	0	4	4	0.131	0.3	0.3	24.2	29	6	9	18	15.72	21	4	72	4
	Min	17	1	618	7	2	3	0.005	1.3	1.3	1.5	14	1	47	87	14.00	140	20	370	21
	Max	30	7	942	8	15	17	0.460	2.2	2.6	76.0	130	22	71	140	60.00	210	34	610	34

	STAT	TEMP	DO	SPCOND	PH	TURB	TSUSSD	NOX	TKN	TN	OPO4	TP	SIO2	CA	CL	SO4	ALKALINITY	TDORGC	TDSSOL	TOTORC
	unit	Celcius	mg L^{-1}	µS cm^{-1}		NTU	mg L^{-1}	mg L^{-1}	mg L^{-1}	mg L^{-1}	µg L^{-1}	µg 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}
A136	Count	7	8	8	8	5	8	5	5.0	8.0	4.0	8	5	5	7	8.00	5	4	5	4
	Mean	23	2	413	7	1	2	0.015	1.4	1.2	2.0	21	10	36	65	9.81	110	25	292	25
	StDev	4	1	227	0	0	2	0.021	0.4	0.7	1.0	15	3	19	35	18.10	56	4	148	4
	Min	16	1	164	6	0	1	0.005	0.9	0.1	1.5	3	8	16	23	0.96	45	21	140	22
	Max	28	3	844	7	2	4	0.052	2.0	2.0	3.5	51	16	66	120	54.00	190	29	520	30
A137	Count	8	9	9	9	5	9	4	5.0	6.0	4.0	9	5	5	8	9.00	5	4	5	4
	Mean	23	3	259	7	1	2	0.005	1.3	1.3	1.5	13	7	19	41	5.11	53	20	165	20
	StDev	4	2	162	0	0	2	0.000	0.4	0.4	0.0	8	2	12	30	11.25	25	2	121	2
	Min	17	1	112	6	0	1	0.005	0.9	0.9	1.5	3	4	10	13	0.67	28	17	92	17
	Max	29	7	569	7	1	5	0.005	2.0	2.0	1.5	27	9	39	93	35.00	95	22	380	21
A138	Count	7	8	8	8	3	8	2	3.0	6.0	2.0	8	3	3	7	8.00	3	2	3	2
	Mean	24	4	145	7	1	3	0.005	1.2	1.2	1.5	13	5	8	22	0.54	23	17	97	17
	StDev	5	2	62	0	0	2	0.000	0.4	0.4	0.0	13	2	2	11	0.23	8	2	20	2
	Min	16	2	78	6	0	1	0.005	0.9	0.9	1.5	2	4	7	10	0.36	14	15	83	15
	Max	29	7	282	8	1	5	0.005	1.7	1.7	1.5	44	7	10	44	1.10	30	18	120	18
A139	Count	5	6	6	6	2	6	2	2.0	5.0	1.0	6	2	2	5	6.00	2	2	2	2
	Mean	26	4	90	7	1	2	0.005	1.1	1.1	1.5	9	4	5	15	0.02	10	18	72	18
	StDev	4	2	24	0	0	2	0.000	0.2	0.2	NA	4	1	1	4	0.00	3	1	7	1
	Min	20	2	59	7	1	1	0.005	0.9	0.9	1.5	5	3	5	10	0.02	8	17	67	17
	Max	29	8	128	7	1	5	0.005	1.2	1.2	1.5	14	5	5	21	0.02	12	19	77	19
A140	Count	7	8	8	8	2	8	1	2.0	5.0	2.0	8	2	2	7	8.00	2	1	2	1
	Mean	24	5	157	7	1	3	0.005	1.4	1.4	2.5	13	4	14	24	1.10	36	20	139	20
	StDev	4	2	57	0	0	2	NA	0.6	0.6	1.3	4	1	6	13	1.35	11	NA	73	NA
	Min	17	2	93	7	1	1	0.005	1.0	1.0	1.5	9	3	9	10	0.41	28	20	87	20
	Max	29	7	262	7	1	6	0.005	1.8	1.8	3.4	20	5	18	48	4.40	43	20	190	20
A141	Count	9	10	10	10	9	10	9	9.0	9.0	9.0	10	9	9	9	10.00	9	8	9	8
	Mean	23	3	286	7	1	2	0.007	1.1	1.1	4.7	9	10	24	41	7.12	77	20	202	21
	StDev	4	2	143	0	1	1	0.008	0.2	0.2	6.6	6	4	10	21	9.30	31	3	87	3
	Min	18	1	152	7	0	1	0.002	0.9	0.9	1.5	2	5	13	21	0.64	36	18	110	18
	Max	28	6	519	8	3	3	0.028	1.5	1.5	22.0	22	14	39	71	26.00	120	25	340	26
LOX10	Count	9	8	8	9	5	5	4	5.0	6.0	5.0	9	5	5	9	9.00	5	5	3	5
	Mean	24	3	133	7	1	3	0.005	1.0	1.2	0.8	8	4	9	17	0.64	31	16	87	16
	StDev	5	1	26	0	0	0	0.000	0.1	0.5	1.1	3	1	1	6	0.89	4	3	47	3
	Min	15	1	96	6	1	3	0.005	0.8	0.8	0.0	5	3	7	10	0.20	26	11	50	12
	Max	29	5	173	7	1	3	0.005	1.2	2.2	2.0	15	6	10	25	3.00	37	19	140	20
LOX11	Count	10	10	10	10	8	8	8	8.0	9.0	8.0	10	8	8	10	10.00	8	8	8	8
	Mean	24	3	110	6	1	2	0.007	1.1	1.4	1.0	7	4	7	18	0.07	13	20	83	20
	StDev	4	1	32	0	1	1	0.003	0.2	0.4	0.9	3	2	2	6	0.04	5	5	34	5
	Min	17	1	66	6	0	1	0.003	0.9	0.9	0.0	4	1	4	11	0.02	8	14	44	13
	Max	29	5	169	7	2	3	0.011	1.5	2.0	2.0	14	6	10	30	0.10	24	26	136	27

	STAT	TEMP	DO	SPCOND	PH	TURB	TSUSSD	NOX	TKN	TN	OPO4	TP	SIO2	CA	CL	SO4	ALKALINITY	TDORGC	TDSSOL	TOTORC
	unit	Celcius	mg L^{-1}	$\mu S\ cm^{-1}$		NTU	mg L^{-1}	mg L^{-1}	mg L^{-1}	mg L^{-1}	$\mu g\ L^{-1}$	$\mu g\ L^{-1}$	mg L^{-1}	mg L^{-1}	mg L^{-1}	mg L^{-1}	mg L^{-1}	mg L^{-1}	mg L^{-1}	mg L^{-1}
LOX12	Count	11	11	11	11	11	11	11	11.0	11.0	10.0	11	11	11	11	11.00	11	11	11	11
	Mean	25	4	143	7	1	2	0.008	0.9	1.1	1.0	9	5	10	19	0.32	33	16	98	16
	StDev	4	2	37	0	0	1	0.012	0.2	0.4	0.9	4	1	3	7	0.39	8	3	22	3
	Min	18	2	98	6	0	1	0.003	0.6	0.7	0.0	4	4	7	13	0.02	23	13	66	13
	Max	31	8	228	7	1	3	0.045	1.4	1.7	2.0	17	8	16	35	1.40	51	21	141	22
LOX13	Count	10	10	10	10	8	8	8	8.0	9.0	8.0	10	8	8	10	10.00	8	8	8	8
	Mean	25	4	119	6	1	2	0.005	1.2	1.3	0.9	7	5	7	20	0.07	18	19	105	19
	StDev	4	1	21	0	1	1	0.002	0.2	0.4	0.8	2	2	3	5	0.04	5	3	35	3
	Min	18	2	89	6	1	1	0.003	0.9	0.9	0.0	5	4	0	14	0.02	12	15	70	15
	Max	31	6	155	7	3	3	0.011	1.5	2.2	2.0	12	9	11	29	0.10	25	24	153	23
LOX14	Count	10	10	10	10	10	10	10	9.0	10.0	10.0	10	10	10	10	10.00	10	10	10	10
	Mean	25	4	168	7	1	2	0.005	0.9	1.0	1.0	7	5	14	25	2.17	39	17	119	17
	StDev	5	1	50	0	0	1	0.002	0.2	0.5	0.9	3	2	4	8	3.73	10	2	60	2
	Min	17	2	122	6	0	1	0.003	0.7	0.0	0.0	3	2	10	16	0.20	26	15	30	14
	Max	30	6	295	7	1	3	0.009	1.3	1.8	2.0	12	8	24	45	12.40	58	20	234	21
LOX15	Count	10	10	10	10	10	10	10	10.0	10.0	10.0	10	10	10	10	10.00	10	10	10	10
	Mean	25	4	392	7	1	2	0.005	1.3	1.6	1.0	7	11	28	53	13.92	90	21	257	21
	StDev	5	2	209	0	1	1	0.001	0.3	0.5	0.9	2	7	14	30	12.08	44	5	121	5
	Min	17	2	136	6	0	1	0.003	0.9	0.9	0.0	4	2	10	19	0.80	35	15	110	15
	Max	30	8	675	7	3	3	0.008	1.7	2.5	2.0	11	19	48	92	33.30	152	28	437	28
LOX16	Count	10	10	10	10	10	10	10	10.0	10.0	10.0	10	10	10	10	10.00	10	10	10	10
	Mean	24	3	118	6	1	2	0.005	0.8	0.9	1.4	8	3	10	16	0.44	28	15	79	15
	StDev	5	1	26	0	0	1	0.001	0.1	0.4	1.5	2	1	2	4	0.77	8	1	25	1
	Min	17	1	87	6	0	1	0.005	0.6	0.6	0.0	5	2	7	11	0.02	17	13	36	12
	Max	30	5	169	7	1	3	0.008	1.0	1.7	5.0	11	4	15	21	2.60	45	17	117	17
LOX3	Count	6	5	5	6	1	1	1	1.0	4.0	1.0	6	1	1	6	6.00	1	1	1	1
	Mean	26	4	115	7	1	3	0.005	1.7	3.4	2.0	8	4	5	19	0.09	10	26	81	26
	StDev	3	1	18	1	NA	NA	NA	NA	NA	NA	1	NA	NA	5	0.03	NA	NA	NA	NA
	Min	21	3	90	6	1	3	0.005	1.7	3.4	2.0	6	4	5	13	0.03	10	26	81	26
	Max	29	5	131	8	1	3	0.005	1.7	3.4	2.0	9	4	5	25	0.10	10	26	81	26
LOX4	Count	9	8	8	9	6	6	5	6.0	7.0	6.0	9	6	6	9	9.00	6	6	5	6
	Mean	25	4	254	7	1	3	0.005	1.2	1.4	0.9	13	7	20	35	3.14	62	25	186	25
	StDev	5	1	101	0	0	1	0.000	0.4	0.6	1.0	6	2	8	20	6.05	20	8	98	7
	Min	15	1	147	6	1	1	0.005	0.9	0.9	0.0	5	5	13	15	0.60	44	17	85	17
	Max	30	5	410	7	1	3	0.005	2.0	2.3	2.0	25	11	30	64	19.20	98	38	306	37
LOX5	Count	6	5	5	6	0	0	0	0.0	3.0	0.0	5	0	0	6	6.00	0	0	0	0
	Mean	27	4	106	6	0	0	0.000	0.0	NA	0.0	7	0	0	18	0.09	0	0	0	0
	StDev	3	1	14	0	0	0	0.000	0.0	NA	0.0	1	0	0	4	0.03	0	0	0	0
	Min	21	3	86	6	0	0	0.000	0.0	0.0	0.0	6	0	0	14	0.03	0	0	0	0
	Max	30	5	119	7	0	0	0.000	0.0	0.0	0.0	7	0	0	23	0.10	0	0	0	0

	STAT	TEMP	DO	SPCOND	PH	TURB	TSUSSD	NOX	TKN	TN	OPO4	TP	SIO2	CA	CL	SO4	ALKALINITY	TDORGC	TDSSOL	TOTORC
	unit	Celcius	mg L^{-1}	μS cm^{-1}		NTU	mg L^{-1}	mg L^{-1}	mg L^{-1}	mg L^{-1}	μg L^{-1}	μg 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}
LOX6	Count	9	9	8	9	7	7	7	7.0	7.0	7.0	9	7	7	9	9.00	7	7	7	6
	Mean	24	3	304	7	1	3	0.005	1.6	2.0	0.8	8	14	23	45	5.01	66	23	213	23
	StDev	5	1	139	0	0	2	0.000	0.4	0.8	1.0	6	4	9	25	7.19	30	3	77	3
	Min	15	2	135	7	0	1	0.005	1.2	1.2	0.0	4	9	13	20	0.02	37	19	112	18
	Max	30	4	503	7	1	6	0.006	2.5	3.4	2.0	22	21	35	79	22.20	110	27	296	27
LOX7	Count	11	10	10	11	10	10	8	10.0	10.0	10.0	11	10	10	11	11.00	10	10	8	9
	Mean	25	4	125	6	1	2	0.011	1.3	1.5	1.0	9	6	6	20	0.08	15	22	88	23
	StDev	5	2	39	0	0	1	0.014	0.2	0.4	0.9	3	1	1	7	0.06	3	5	42	4
	Min	16	2	87	6	1	1	0.005	1.2	1.2	0.0	5	4	5	12	0.02	9	16	44	16
	Max	30	6	210	7	1	3	0.045	1.7	2.2	2.0	18	8	8	33	0.20	22	30	179	30
LOX8	Count	11	10	10	11	11	11	10	11.0	11.0	11.0	11	11	11	11	11.00	11	11	9	11
	Mean	24	4	119	6	1	2	0.009	1.4	1.7	1.0	12	5	5	20	0.06	11	23	101	24
	StDev	5	2	31	0	1	1	0.013	0.3	0.5	0.9	4	1	2	6	0.04	3	5	38	5
	Min	17	1	88	6	1	1	0.003	1.2	1.2	0.0	9	4	4	14	0.02	8	17	32	17
	Max	30	8	189	7	3	4	0.045	2.0	2.6	2.0	20	7	9	30	0.10	17	33	140	33
LOX9	Count	9	8	8	9	5	5	4	5.0	5.0	5.0	9	5	5	9	9.00	5	5	3	5
	Mean	25	4	122	6	1	3	0.005	1.3	1.6	0.8	7	4	6	20	0.07	17	18	66	18
	StDev	5	1	18	0	0	0	0.000	0.3	0.7	1.1	2	1	1	6	0.04	3	3	45	3
	Min	15	2	92	6	0	3	0.005	1.0	1.0	0.0	4	2	5	12	0.02	13	13	22	13
	Max	30	5	146	7	1	3	0.005	1.7	2.8	2.0	10	5	7	31	0.10	22	21	111	22

APPENDIX B

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

Canal	LOXA104, LOXA115, LOXA129, LOXA132, LOXA135
Perimeter (<2.5 km; <1.6 miles)	LOX4, LOX6, LOX10, LOX14, LOX15, LOX16, LOXA101, LOXA102, LOXA103, LOXA105, LOXA106, LOXA107, LOXA109, LOXA112, LOXA116, LOXA117, LOXA118, LOXA122, LOXA124, LOXA126, LOXA130, LOXA131, LOXA133, LOXA134, LOXA136, LOXA137, LOXA138, LOXA140
Transition (2.5 - 4.5 km; 1.6 - 2.8 miles)	LOX12, LOXA108, LOXA110, LOXA111, LOXA113, LOXA114, LOXA119, LOXA127, LOXA139
Interior(>4.5 km;> 2.8 miles)	LOX3, LOX5, LOX7, LOX8, LOX9, LOX11, LOX13, LOXA120, LOXA128

APPENDIX C

Table A-3. Monthly summary statistics (Count = # of samples, Mean = arithmetic mean, StDev = one standard deviation, Min = minimum, Max = maximum) for calendar year 2009. Previous summary statistics (2004 – 2008) can be found in the previous annual reports.

	Zone	STAT	Jan-09	Feb-09	Mar-09	Apr-09	May-09	Jun-09	Jul-09	Aug-09	Sep-09	Oct-09	Nov-09	Dec-09
TP ($\mu g L^{-1}$)	C	Count	5	5	5	5	5	5	5	5	5	5	5	5
	C	Mean	15.8	15.9	35.2	32.6	35.6	95.2	46.0	60.6	46.4	30.0	42.8	31.4
	C	StDev	4.9	8.7	6.8	9.2	17.5	49.1	15.7	18.1	6.2	5.5	12.8	5.0
	C	Min	11.0	3.6	25.0	19.0	11.0	26.0	30.0	41.0	42.0	25.0	24.0	28.0
	C	Max	22.0	24.0	42.0	44.0	58.0	130.0	64.0	80.0	57.0	36.0	57.0	40.0
	P	Count	21	21	7	3	0	28	28	28	28	28	26	26
	P	Mean	12.0	3.4	7.7	9.0	0.0	23.0	9.5	16.2	12.7	7.6	12.0	8.4
	P	StDev	11.8	0.9	7.4	1.7	0.0	25.3	6.4	9.2	7.0	5.4	10.0	3.4
	P	Min	3.7	3.0	1.5	8.0	0.0	5.0	1.5	0.0	4.4	1.5	5.0	3.8
	P	Max	62.0	6.0	22.0	11.0	0.0	140.0	30.0	44.0	37.0	25.0	56.0	19.0
	T	Count	5	3	2	1	1	9	9	9	9	9	8	7
	T	Mean	4.9	3.3	5.1	7.0	11.0	7.5	5.5	12.8	9.1	3.6	6.2	7.3
	T	StDev	2.3	0.6	1.3	NA	NA	4.2	4.6	5.5	4.1	2.8	1.9	5.1
	T	Min	3.0	3.0	4.1	7.0	11.0	3.3	1.5	0.0	5.0	1.5	3.8	1.5
	T	Max	8.5	4.0	6.0	7.0	11.0	14.0	17.0	21.0	19.0	9.0	9.0	17.0
	I	Count	6	6	5	5	0	7	9	9	9	9	9	6
	I	Mean	10.5	5.2	7.4	11.7	0.0	9.6	5.7	11.9	7.4	6.0	6.3	10.0
	I	StDev	9.9	2.0	4.3	5.8	0.0	6.7	2.8	8.3	1.1	2.7	1.4	8.5
	I	Min	3.0	3.0	3.2	7.0	0.0	1.5	1.5	7.0	5.0	1.5	3.6	4.0
	I	Max	30.0	9.0	13.0	18.0	0.0	20.0	10.0	33.0	9.0	9.0	9.0	27.0
TN ($mg L^{-1}$)	C	Count	5	5	5	5	5	5	5	5	0	0	5	5
	C	Mean	1.5	1.5	1.6	1.6	1.8	2.5	1.5	2.3	0.0	0.0	2.1	1.8
	C	StDev	0.1	0.1	0.3	0.2	0.3	0.3	0.5	0.3	0.0	0.0	0.2	0.2
	C	Min	1.4	1.3	1.3	1.5	1.5	2.1	1.1	2.0	0.0	0.0	1.9	1.5
	C	Max	1.6	1.7	2.0	1.9	2.0	2.9	2.2	2.6	0.0	0.0	2.4	2.0
	P	Count	10	7	3	3	0	25	20	14	1	0	12	9
	P	Mean	1.1	0.8	0.6	1.2	0.0	1.7	1.4	1.4	0.6	0.0	1.1	1.1
	P	StDev	0.3	0.4	0.5	0.2	0.0	0.4	0.6	0.7	NA	0.0	0.2	0.2
	P	Min	0.7	0.1	0.0	1.0	0.0	0.9	0.9	0.8	0.6	0.0	0.9	0.8
	P	Max	1.5	1.2	1.0	1.3	0.0	2.5	2.6	3.4	0.6	0.0	1.4	1.6
	T	Count	2	1	2	1	1	6	9	2	2	0	3	1
	T	Mean	1.0	0.7	1.3	1.1	1.4	1.5	1.1	1.3	0.8	0.0	1.2	1.1
	T	StDev	0.2	NA	0.6	NA	NA	0.2	0.3	0.5	NA	0.0	0.3	NA
	T	Min	0.9	0.7	0.8	1.1	1.4	1.2	0.9	0.9	0.8	0.0	1.0	1.1
	T	Max	1.1	0.7	1.7	1.1	1.4	1.8	1.7	1.7	0.8	0.0	1.5	1.1
	I	Count	4	5	5	3	0	4	7	4	2	0	1	1
	I	Mean	1.1	1.2	1.5	1.7	0.0	1.4	2.3	2.0	0.9	0.0	1.1	1.0
	I	StDev	0.1	0.1	0.2	0.3	0.0	0.3	0.7	0.6	0.0	0.0	NA	NA
	I	Min	1.0	1.1	1.3	1.5	0.0	1.2	1.0	1.1	0.9	0.0	1.1	1.0
	I	Max	1.2	1.4	1.7	2.0	0.0	1.8	3.4	2.6	0.9	0.0	1.1	1.0

	Zone	STAT	Jan-09	Feb-09	Mar-09	Apr-09	May-09	Jun-09	Jul-09	Aug-09	Sep-09	Oct-09	Nov-09	Dec-09
COND ($\mu S\ cm^{-1}$)	C	Count	5	5	5	5	5	4	5	5	5	5	5	5
	C	Mean	660.0	673.9	572.5	536.4	581.4	936.4	623.0	939.4	903.2	881.2	810.9	726.8
	C	StDev	23.9	77.5	105.2	84.9	98.7	78.8	247.8	214.4	186.5	107.8	111.3	163.7
	C	Min	629.4	555.2	435.3	401.2	440.0	834.4	301.8	633.7	650.9	782.6	682.5	532.7
	C	Max	683.0	766.7	677.1	626.1	656.1	1001.0	925.9	1148.0	1080.0	1065.0	982.9	897.6
	P	Count	21	21	7	3	0	23	25	25	28	28	26	26
	P	Mean	282.4	280.1	152.6	169.6	0.0	391.4	152.5	184.0	301.6	312.3	284.8	268.8
	P	StDev	174.1	197.1	29.3	20.5	0.0	241.6	90.1	91.1	232.4	230.2	198.8	156.1
	P	Min	113.6	123.6	109.3	145.9	0.0	110.1	77.6	89.0	92.3	102.3	46.7	118.8
	P	Max	814.8	918.4	197.3	182.4	0.0	865.5	438.9	499.8	966.1	1015.0	929.9	818.0
	T	Count	5	3	2	1	1	7	9	8	10	9	8	8
	T	Mean	132.2	138.5	147.0	164.5	227.8	109.3	83.7	91.2	84.1	116.0	131.2	136.9
	T	StDev	10.6	14.3	33.6	NA	NA	25.8	12.4	25.5	15.6	25.1	20.9	14.8
	T	Min	116.4	126.7	123.2	164.5	227.8	84.0	59.1	29.0	67.1	89.7	108.3	115.6
	T	Max	142.4	154.4	170.7	164.5	227.8	164.1	106.0	106.7	105.9	164.4	173.1	162.7
	I	Count	7	6	5	5	0	5	4	9	9	9	9	6
	I	Mean	113.1	121.4	147.2	197.0	0.0	135.2	84.1	101.2	86.0	96.2	116.9	125.3
	I	StDev	16.5	20.2	23.5	41.7	0.0	20.0	12.0	15.0	15.0	15.6	10.3	10.0
	I	Min	87.7	96.5	125.6	155.3	0.0	99.9	76.3	75.0	66.1	82.6	99.1	111.6
	I	Max	131.8	146.0	179.9	261.7	0.0	148.9	102.0	123.0	102.1	133.7	131.2	138.4
SO_4 ($mg\ L^{-1}$)	C	Count	5	5	5	0	5	5	5	5	4	5	5	5
	C	Mean	20.8	21.2	19.0	0.0	23.8	67.6	31.3	52.4	53.8	45.4	34.4	27.9
	C	StDev	9.4	6.1	2.4	0.0	5.3	7.8	22.3	29.3	23.1	19.4	19.1	21.1
	C	Min	14.0	14.0	16.0	0.0	17.0	57.0	7.5	24.0	30.0	34.0	21.0	8.7
	C	Max	36.0	27.0	22.0	0.0	30.0	75.0	62.0	87.0	83.0	80.0	68.0	61.0
	P	Count	21	21	7	3	0	28	28	25	28	28	26	26
	P	Mean	2.6	1.5	0.4	0.6	0.0	21.0	1.8	1.8	9.1	5.2	3.2	2.3
	P	StDev	3.0	1.7	0.4	0.6	0.0	16.5	3.2	1.8	14.1	8.3	5.0	3.5
	P	Min	0.3	0.0	0.0	0.2	0.0	1.1	0.1	0.2	0.4	0.2	0.2	0.2
	P	Max	11.0	7.2	1.0	1.3	0.0	56.0	16.9	8.1	58.0	32.0	22.9	16.2
	T	Count	5	3	2	1	1	9	9	8	10	9	8	8
	T	Mean	0.1	0.1	0.2	0.0	0.1	0.4	0.1	0.2	0.2	0.2	0.2	0.1
	T	StDev	0.1	0.1	0.3	NA	NA	0.4	0.1	0.1	0.1	0.2	0.2	0.2
	T	Min	0.0	0.0	0.0	0.0	0.1	0.0	0.0	0.0	0.0	0.0	0.0	0.0
	T	Max	0.3	0.2	0.4	0.0	0.1	1.4	0.3	0.3	0.4	0.6	0.5	0.5
	I	Count	7	6	5	4	0	7	9	9	9	9	9	6
	I	Mean	0.0	0.0	0.0	0.0	0.0	0.1	0.1	0.1	0.0	0.1	0.0	0.0
	I	StDev	0.0	0.1	0.0	0.0	0.0	0.1	0.0	0.0	0.0	0.2	0.0	NA
	I	Min	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
	I	Max	0.0	0.2	0.0	0.0	0.0	0.2	0.1	0.1	0.0	0.2	0.0	0.0
Tdepth (m)	C	Count	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA
	C	Mean	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA
	C	StDev	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA
	C	Min	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA
	C	Max	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA
	P	Count	21	21	7	25	0	14	28	28	28	28	26	26
	P	Mean	0.2	0.2	0.2	0.0	0.0	0.3	0.3	0.2	0.4	0.3	0.3	0.3
	P	StDev	0.1	0.1	0.1	0.1	0.0	0.1	0.1	0.1	0.1	0.2	0.2	0.2
	P	Min	0.1	0.1	0.1	0.0	0.0	0.1	0.1	0.1	0.1	0.1	0.1	0.1
	P	Max	0.4	0.6	0.4	0.4	0.0	0.6	0.7	0.5	0.7	0.9	0.9	0.7
	T	Count	5	3	2	9	1	6	9	9	10	9	8	8
	T	Mean	0.2	0.3	0.4	0.0	0.3	0.3	0.3	0.2	0.4	0.3	0.3	0.2
	T	StDev	0.1	0.3	0.2	0.1	NA	0.2	0.2	0.2	0.2	0.2	0.2	0.2
	T	Min	0.2	0.1	0.2	0.0	0.3	0.2	0.2	0.1	0.2	0.2	0.1	0.1
	T	Max	0.3	0.6	0.5	0.4	0.3	0.6	0.7	0.6	0.8	0.8	0.7	0.7
	I	Count	7	6	5	6	0	5	9	9	9	9	9	6
	I	Mean	0.2	0.3	0.3	0.2	0.0	0.2	0.3	0.2	0.3	0.4	0.2	0.2
	I	StDev	0.1	0.1	0.0	0.1	0.0	0.1	0.1	0.1	0.1	0.1	0.1	0.1
	I	Min	0.1	0.1	0.2	0.0	0.0	0.1	0.2	0.1	0.2	0.2	0.1	0.1
	I	Max	0.4	0.4	0.3	0.3	0.0	0.3	0.5	0.3	0.5	0.6	0.4	0.4