Work Plan: Water Quality Monitoring and Modeling for the A.R.M. Loxahatchee National Wildlife Refuge: 2004-2006

Draft February 2, 2004

Introduction

<u>Refuge *Comprehensive Conservation Plan*</u>
A multi-year effort was undertaken in the late 1990s to develop a comprehensive 15-year plan for the refuge. The final plan, titled *Arthur R. Marshall Loxahatchee National Wildlife Refuge Comprehensive Conservation Plan*, or CCP, was approved in 2000 after incorporating revisions that followed extensive review by the public, the State of Florida, and other federal agencies (USFWS 2000). The plan identifies long-term goals for the refuge including the need to have a better understanding of the extent and potential influence of canal water intruding into the relatively unimpacted refuge interior. The CCP describes activities such as increased water quality monitoring, and development of a hydrodynamic and water quality model to aid in refuge management decisions, and to provide a better understanding of the potential impacts of altered Everglades hydrology on the ecosystem. In 2003, these goals were further defined in the *Arthur R. Marshall Loxahatchee National Wildlife Refuge Water Quality Monitoring Plan* (USFWS 2003). Specifically, the CCP identified these goals relevant to this project:

> *Goal 1 (Wildlife Habitat and Population Management):*
> Restore and conserve the natural diversity, abundance, and ecological function of refuge flora and fauna.

1. Continue to partner with the South Florida Water Management District and the Army Corps of Engineers to restore and maintain healthy water regimes and appropriate hydropatterns for 143,238 acres (Water Conservation Area 1) of the refuge as part of the northern Everglades.
    - Evaluate and monitor hydrologic conditions on the refuge
    - Review and improve the existing hydrologic model for the refuge to more closely predict wildlife population and vegetative community response to changes in water levels and water delivery
    - Assess the impacts of the previous, current, and future water regulation schedules regarding quality, quantity, delivery, and timing of water on native and exotic and invasive species and habitats.

2. Expand water quality monitoring to include pesticides, fertilizers, and elemental contaminant levels in the cypress swamp, compartments, Strazulla Marsh, below inflow water structures, and other pertinent locations.
    - Continue to monitor nutrient levels and add new monitoring sites at all water inflows to the refuge not currently being monitored.
    - Develop a Water Quality Monitoring Plan by 2002 (USFWS 2003).

8. Manage and maintain diverse native habitats and viable wildlife populations consistent with sound biological principles and other objectives of this plan.
    - Identify habitat needs through data collection and analyses.
    - Monitor changes and trends in wildlife, fish, and habitat.

To address these CCP goals and initiate related plan activities, this Work Plan presents a combination of projects totaling approximately $1M for:
- a 2-year enhanced monitoring study of water quality
- a new monitoring network recording conductivity at a number of fixed sites
- evaluation of current conductivity patterns near surface water inflows
- a 2-year monitoring study mapping refuge conductivity patterns
- development and application of a hydrodynamic/water quality model of the refuge

Current budget projections by major project are summarized below:

Project	Total Project Cost
1: Water quality sampling	$400,500
2: Conductivity mapping	224,484
3: Modeling	300,000
Support for other efforts (USGS)	73,150
TOTAL	$998,134

The research effort by the USGS cited above will address hydrological and ecological questions outside the scope of the projects described here. Funding for these other projects will primarily come from the USGS. Costs budgeted above for the USGS project cover only FWS staff time for sampling assistance and airboat operational costs.

These project activities are critical to help resource managers:
- Identify potential threats to refuge resources
- Keep unimpacted areas from becoming impacted
- Maximize the potential for the recovery of impacted areas
- Better understand the hydrology and ecology of the refuge

Management information needs that these projects will support include:

- When canal stages are below typical interior marsh elevation, what are the impacts of water supply release on interior surface water and groundwater conditions?
- How does selection of relative flow through each of the S-10 gates (gates A, C, D, and E) affect water flow and water quality within the interior?
- When water supply releases from the eastern refuge boundary are made-up by water deliveries, what is the optimal pattern of structure operations? Should we continue to require that all make-up water first be provided prior to water supply releases?
- During water year 2003 , the Everglades Consolidated Report (Weaver and Payne 2004) states that "sulfate concentrations at interior marsh stations in the Refuge (median = 11.0 mg/L) were substantially elevated above both the long-term, historic median (3.6 mg/L) and the previous water year (2.3 mg/L)." What operational or environmental conditions are causing this apparent increased impingement of canal water into the interior?
- How will reduced water supply demands from the refuge that are anticipated to result from the CERP Site 1 Reservoir and Hillsboro ASR projects improve water quality within the refuge and change interior water flow patterns?
- How will the "Loxahatchee National Wildlife Refuge Internal Canal Structures" (CERP project KK) change water flows, hydroperiods, and water quality within the refuge?
- How will changes in refuge inflow timing resulting from planned CERP water storage projects upstream of the refuge change projected water flows, hydroperiods, and water quality within the refuge?
- If there are potential negative impacts of pump, structure, or STA operations, how can they be minimized/eliminated?
- What impacts of STA-1E on refuge water quality and ecological resources are projected?
- How can consent decree related exceedances be eliminated?

<u>Previous Study: Florida Cooperative Fish and Wildlife Research Unit, 1990</u>
In 1990 researchers at the University of Florida Cooperative Fish and Wildlife Research Unit reported on a multi-year study of the refuge that included extensive spatial water quality sampling, data analysis, land cover analysis, and a hydrodynamic model of the refuge (Richardson *et al.* 1990). For over a decade, this study has provided the only comprehensive information to support many of the refuge management decisions and plans. This study provided a foundation supporting the initial CERP plan and the refuge CCP. Numerous changes in inflow volumes and water quality have occurred since the report was issued, and there is a clear need to now revisit questions addressed by Richardson *et al.* as well as new questions not anticipated in their study.

<u>Potential influence of future projects</u>

New projects include Storm Water Treatment Area 1 East (STA-1E) and several Comprehensive Everglades Restoration Plan (CERP) projects (US Army Corps of Engineers and South Florida Water Management District 1999) that will come on line in the next two to ten years. Schedules for the Everglades Construction Project (ECP) and non-ECP projects can be found in the 2004 Everglades Consolidated Report (SFWMD 2004). For a complete list of CERP project starting dates see http://www.evergladesplan.org/pm/projects/project_list.cfm. Many of these projects could change timing of flows into the refuge, location of inflows, and water flow patterns within the refuge resulting in changes in the movement of high-phosphorus and high-conductivity water into the refuge interior. Such intrusions would likely result in significant changes to refuge flora and fauna. An understanding of what controls these processes in the refuge interior is critical to understanding potential benefits and impacts of future CERP projects.

Monitoring downstream of STA discharges has been identified as critical to determine whether there is intrusion of contaminated water into the refuge interior from STA operations. Currently, no monitoring is being conducted immediately downstream from STA-1W discharges, and the permitting process has not been concluded for any potential STA-1E discharge monitoring.

Complementary recommendations of the Technical Oversight Committee

The 1991 Federal Settlement Agreement (Case No. 88-1886-CIV-HOEVELER) specified interim and long-term concentration levels for phosphorus (P) in the Arthur R. Marshall Loxahatchee National Wildlife Refuge (refuge). Interim levels have been in effect in the refuge since February 1999. Geometric mean concentrations at consent decree compliance sites within the refuge have been larger than the calculated interim levels in nine monthly sampling sets since February 1999. The long-term levels that go into effect December 31, 2006 are more stringent than interim levels and there is concern that the frequency of geometric means being above applicable levels will increase. To date, there is not a clear consensus on the causes of these exceedances and hypotheses for their occurrence range from natural variation to the movement of high phosphorus water from the canals into the interior.

The Technical Oversight Committee (TOC) originated from the Settlement Agreement as a mechanism for technical review and conflict resolution to support the Everglades Program begun by the Agreement and continued in the 1994 Everglades Forever Act (373.4592 F.S.). At the July 24, 2003 meeting of the TOC, the committee discussed the occurrence of the most recent exceedance of Settlement Agreement interim phosphorus levels within the refuge. Resulting from this discussion, the TOC unanimously agreed to forward recommendations to the consent decree principals dealing with (A) Controlling Phosphorus loads to the refuge, (B) Enhancing Monitoring of the refuge, and (C) Modeling of the refuge (http://www.sfwmd.gov/org/ema/toc/archives_mtgs.html). Implementing these recommendations will improve understanding and help provide a better consensus on the factors responsible for any future exceedances. Practical and cost-effective management plans that protect the resource and eliminate exceedances can be developed. These actions parallel those previously identified by the refuge in the CCP described above.

Work plan structure

This work plan is divided into three sections corresponding to separate but closely related projects:

I. Collection of additional water quality samples at new sampling sites between the canals and the existing interior marsh network.

II. Determination of conductivity patterns from canals into the interior marsh adjacent to discharge locations.

III. Development and application of a hydrodynamic/water quality model for the refuge.

Each section is designed as a single project or series of smaller projects that together will begin to address the questions outlined above. Each project has the following information:

Title of project/subproject
Project dates
Background
Objectives
Tasks
Results and implications
Resources needed
Project schedule
Implementation

I. Collection of additional water quality samples between the canals and the existing monthly sampling network

Project dates: 2004-2006

Background:
Three existing monitoring networks operated by the South Florida Water Management District regularly monitor water quality within the refuge (Figure 1):

- Monthly compliance monitoring is performed at 14 stations that are located in the marsh interior. These stations, designated as LOX3-LOX16, are the basis of the Settlement Agreement compliance tests.

- Volume of flow and water quality are monitored at inflow and outflow structures (G-300, G-301, G-251, G-310, S-10E, S-10D, S-10C, S-10A, S-39, G-94A, G-94B, G-94C, G-94D, and Acme #1 PS). Data from these sites are used to compute cumulative mass (loads) of phosphorus and other materials passing through the structures, but are also valuable in characterizing the water quality of the boundary canal waters impacting the refuge wetlands.

- Eleven stations along two transects (X0-X4, Y4, and Z0-Z4) in the southwestern refuge are monitored monthly to characterize water quality across the phosphorus-enriched impacted region of the refuge. These transect stations are designated as the X and Z transects, with one added interior site designated Y4 located between the most interior X and Z sites.

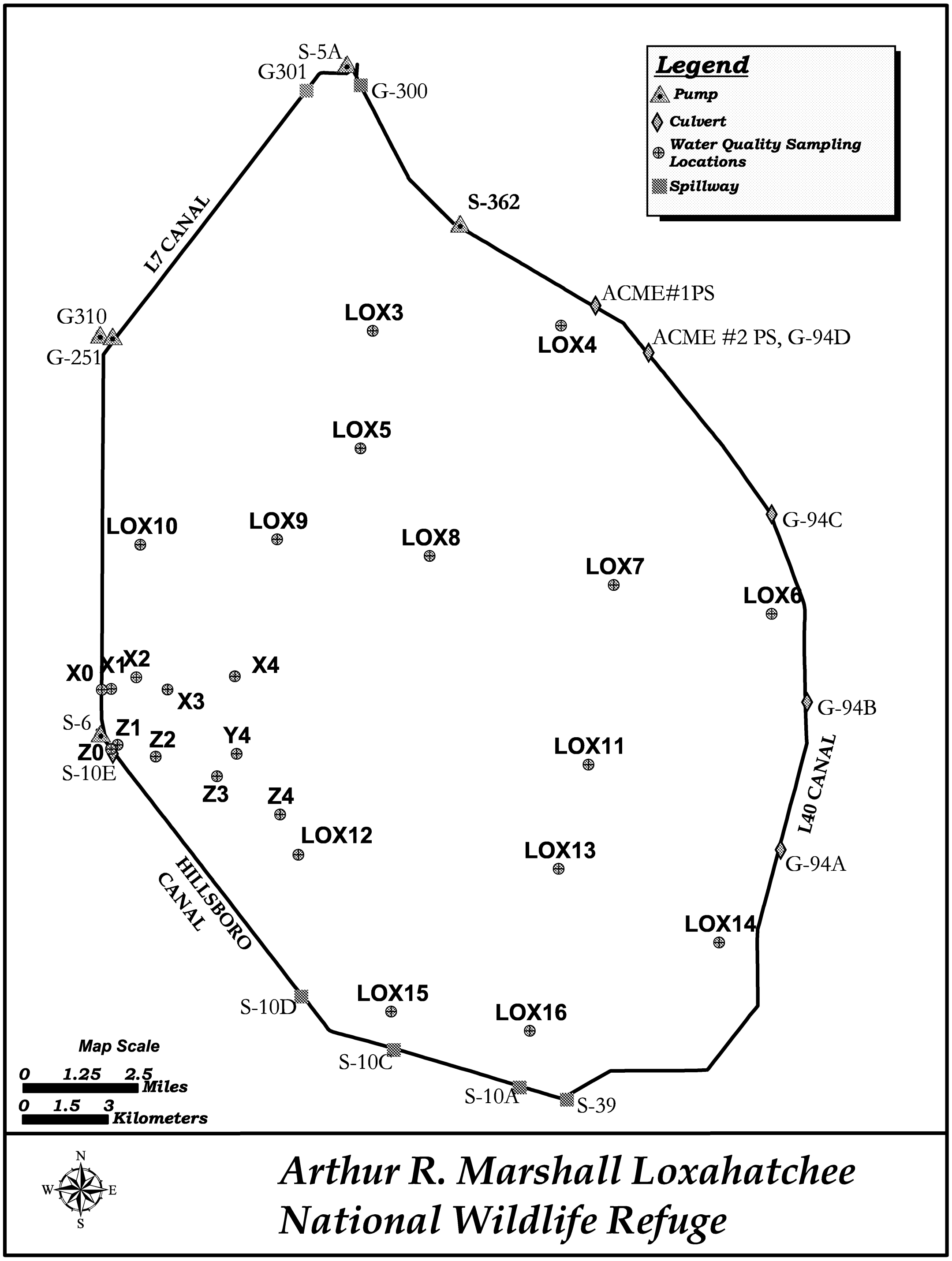

Figure 1: Map showing stations where existing water quality (and supporting information) is monitored.

Objective:
The objective of the proposed 2-year monitoring study is to support management decision-making related to water quantity, timing of inflows, and water quality, through the development and implementation of an enhanced monitoring network that increases the spatial coverage of water quality samples, especially in areas adjacent to discharges and the rim canal.
This work will also provide data in support of the modeling effort described in Section III (*Hydrodynamic and water quality modeling*) below.

Tasks:
Initial, year-one monitoring may occupy as many as 40 additional stations. This spatial density will be greatly reduced in the second project year using an adaptive process that will include consultation with other interested parties.

Task 1: Establish spatial pattern for additional stations
Location of additional monitoring sites will be determined through analysis of past data from the existing marsh monitoring stations and other relevant studies (Childers et al. 2003; Richardson et al. 1990; Scheidt et al. 2000) and the results of the synoptic conductivity sampling outlined in *Part II. Determination of conductivity patterns from canals into the interior marsh adjacent to discharge locations* below. Initially up to 40 new stations will sited, with this number being adaptively reduced as data become available. Samples will be analyzed for the same suite of parameters currently monitored at refuge interior (LOX) sites. Where appropriate, compatibility with anticipated future monitoring by CERP (Adaptive Assessment Team 2003) and other projects will be considered in sampling site selection.

Task 2: Implement sampling at new stations
PVC pipe will be placed at each new sampling location and each new station will be assigned an identification number that is consistent with other samples taken in the refuge. Sampling will be conducted via helicopter and follow procedures defined in the South Florida Water Management District's Water Quality Sampling protocol (SFWMD 2002). When practical, this monthly sampling will occur on days just prior to sampling of the current interior (LOX) sites in order to maximize the compatibility of the two sampling efforts.

Task 3: Sample analysis
Samples will be analyzed according to accepted procedures for analyzing other water quality samples in the Everglades. For the best ability to examine results from this project with the existing monitoring, described above, it is desirable for the samples to be analyzed by a lab participating in the Everglades laboratory round-robin, and most optimally be analyzed by the same lab that is currently doing the existing 14-station network (SFWMD).

Task 4: Develop QA/QC for sample collection, analysis, and management
An overall QA/QC document will be adopted and/or developed for all aspects of the sample collection and analysis. Protocols will be consistent with other Everglades monitoring efforts.

Task 5: Quarterly summary report
Quarterly summary reports will be prepared that present all of the raw data and simple parametric statistics over the reporting period. Narrative in the report will cite any other available water quality sampling data for that period. Report narrative will integrate the findings with information on STA operation, water level conditions, and other water management activities that occur during the reporting period. The report will be prepared and distributed to all interested parties.

Task 6: Annual report
The first annual report will summarize and synthesize the water quality data from this and other studies and make recommendations on which stations to retain in year 2 for continued monitoring. The year-two annual report will synthesize year 1 and 2 data in the context of water management and present a discussion of monitoring needs incompletely met by this study. The annual reports will, as far as possible, analyze spatial and temporal patterns and hypothesize underlying causes.

Results and implications:

Resources needed:

Water Quality Sampling (from the air)	Year 1	Year 2	Total
Helicopter (40 stations- 10 per day- 5 hours flight time, once a month using FWS ship)	$ 84,000		
Helicopter (30 stations- 10 per day- 5 hours flight time, once a month using FWS ship)		$ 63,000	$ 147,000
Sample analysis estimate from SFWMD for suite analyzed for 14 stations plus 25% for QA/QC	$115,000	$ 86,000	201,000
Staff time based on estimates for time for Lox flights ($15000 for 2.5 days each month)	$ 30,000	$ 22,500	52,500
	$229,000	**$171,500**	**$ 400,500**

Project schedule:

January-February 2004	Analyze existing data and select additional sites
January-March 2004	Work out contract agreement with laboratory for sample analysis and reporting

January-March 2004	Work out arrangements for helicopter
March 2004	Develop project QA/QC plan
April 2004	Initiate sampling
July, Oct 2004, Jan 2005	Quarterly reports due
April 2005	Annual report due with recommendation on reduction/changes to sampling sites
July, Oct 2005, Jan 2006	Quarterly reports due
April 2006	Final report due with recommendations on long-term monitoring sites

Implementation:
In order to implement this project, helicopter time, sample collection personnel, and a sample analysis lab must be identified and the appropriate contractual mechanisms must be put in place.

Helicopter time is expected to be available through the use of the FWS helicopter based at Merritt Island, Florida. The details of getting this ship assigned for refuge use 4 days each month will need to be worked out.

Monthly sampling can be conducted by personnel who already work at the refuge (0.13 FTEs/year), but whose positions are unfunded or only partially funded for FY04/FY05.

Someone will need to be assigned/hired to write the quarterly and annual reports. Ideally, this could be the same person who is responsible for the Hydrolab network and coordination with the ecological studies and modeling efforts.

A contract with a laboratory for analysis of samples needs to be developed prior to any sampling. This contract should include number of samples, what will be analyzed, when results will be available, storage of data (in DB Hydro if available to this project), and QA/QC information. The laboratory must meet QA and detection limits compatible with Everglades water quality sampling currently underway.

II. Determination of conductivity patterns from canals into the interior marsh adjacent to discharge locations

Project dates: 2004-2006

Background:
Much of the Everglades developed over the past 5000 years as a rainfall-driven system with surface waters low in nutrients and inorganic ions such as chloride, sodium, and calcium. This ion-depleted or "soft-water" condition was undoubtedly a major determinant of historic ecosystem structure and function. The ecological impacts associated with increased surface-water phosphorus (P) concentrations in the Everglades are by now well recognized (Payne and Weaver 2004). The ecological effects of elevated inorganic ion concentrations in the Everglades are also well established but less widely recognized.

Information from the refuge and other wetlands indicates that increases in the concentration of major inorganic ions may elicit undesirable ecological changes in the Everglades biota and should be avoided. Canal construction and associated wetland drainage and soil loss during the last century disrupted both the surface and groundwater hydrology of south Florida and initiated a slow but persistent movement of ancient seawater from the Floridian aquifer and into canals and subsided lands surrounding the remnant Everglades (Flora and Rosendahl 1982). These hydrologic changes have increased concentrations of major ions in surface waters by several-fold across large portions of the Everglades that are affected by canal discharges (Flora and Rosendahl 1982).

The refuge represents one of the last vestiges of the historic soft-water Everglades (Richardson et al. 1990). This condition is evidenced by the low conductivity (a simple but accurate measure of major ion concentrations, in the refuge an excellent estimate of chloride concentration can be made from conductivity) of surface water in the marsh interior (100 μS) compared with that in the canal surrounding the refuge (1000-1500 μS). Low-conductivity waters in the refuge interior are associated with a characteristic soft-water periphyton community, wetland plant species that may also be adapted to the soft-water conditions, and lower rates of key ecosystem processes (e.g., decomposition) than in areas of the Everglades impacted by canal discharges (Browder et al. 1991; Browder et al. 1994; Gleason 1974; Swift and Nicholas 1987). These effects continue to be a subject of study (S. Newman, pers. com.). While it has long been known that the fringes of the refuge are affected by high conductivity canal water, recent evidence indicates a trend towards increased intrusion of this water into the refuge interior with likely impacts of water chemistry on sensitive biota (Childers et al. 2003; Walker and Kadlec 2003; Weaver and Payne 2004). Both scientists and managers have expressed concern over the spread of such impacts and their relationship to water management structures and operations.

Factors controlling the extent of canal-water intrusion into the refuge interior are not well understood, but may be related to both natural hydrologic changes and water management activities. For example, several major pump stations control water flow and stage in the canal surrounding the refuge. Recent changes in the location and schedule of these pumping activities may be promoting increased intrusion of canal water into the marsh interior (http://www.sfwmd.gov/org/ema/toc/archives/docs/refuge_compliance.pdf). Additional water management changes associated with Everglades restoration have the potential to further exacerbate this problem. It is also possible that water management strategies could be altered in the future to alleviate, rather than exacerbate, water quality problems. Therefore, it is critical that causal relationships between water management activities and canal water intrusion into the refuge be developed quickly to ensure that current and proposed restoration programs do not result in the degradation of water quality within the refuge. These relationships can only be determined by monitoring surface-water conductivity across the refuge.

Restoration efforts associated with the Everglades Construction Project and the Comprehensive Everglades Restoration Plan include proposed changes in the location and operation of water control structures that regulate canal flows and stages around the outer rim of the refuge and other construction projects that may increase movement of canal water across the refuge in some areas, and decrease it in others. In addition to conveying existing sources of water into the refuge, the creation of Stormwater Treatment Area 1E (STA-1E) in the northeast corner of the refuge will introduce 100,000 acre-feet of new water into the Everglades Protection Area through discharges into the rim canals of the refuge. This new water, composed of treated water from a combination of agricultural and urban runoff basins, exhibits high conductivity relative to interior marsh locations. Current (though limited) water quality modeling tools suggest that more than 6,000 acres of interior marsh might be impacted by higher-than-background levels of phosphorus-rich water from STA-1E discharges, with a greater area of impact from dissolved constituents that are not taken up as rapidly as phosphorus. Treatment of Acme B basin Stormwater by STA-1E and the reduction of backwater flooding from the L-40 due to diversion of inflow from the S-6 pump may in some measure reduce these impacts.

As the refuge is an Outstanding Florida Water body (with anti-degradation provisions), it is important to characterize potential impacts of new sources of water with high conductivity levels. In order to assess current impacts of STA-1W and potential impacts of STA-1E discharges, baseline conductivity maps of this area of the refuge interior need to be developed for a series of different hydrological and water management conditions.

Objectives:

The proposed investigation has three primary objectives:

1. Document the spatial and temporal extent of intrusion of high conductivity canal water into the refuge under different hydrologic conditions with emphasis on areas directly interior from STA-1E and STA-1W;
2. Develop foundation for permanent monitoring adjacent to STA-1E prior to initiation of discharge;
3. Relate changes in the extent of intrusion to water management activities affecting canal stages and flows into the refuge.

4. Determine the influence of natural meteorological events and hydrologic mechanisms on intrusion of high conductivity canal water.

This work will also provide data supporting the modeling effort described in Section III (*Hydrodynamic and water quality modeling*) below.

Tasks:

Task 1: Synoptic sampling around STA-1E and STA-1W discharges

The northeast region of the refuge near the STA-1E discharge pump station (including the existing LOX3 and LOX4 stations) and the northwest region of the refuge near the STA-1W discharge pump station will be sampled with a modified square grid to develop a series of synoptic conductivity maps (Figure 2). The maps will be developed with a sampling grid starting at the canal and extending 5 km toward the interior at a resolution of no less than 500 m.

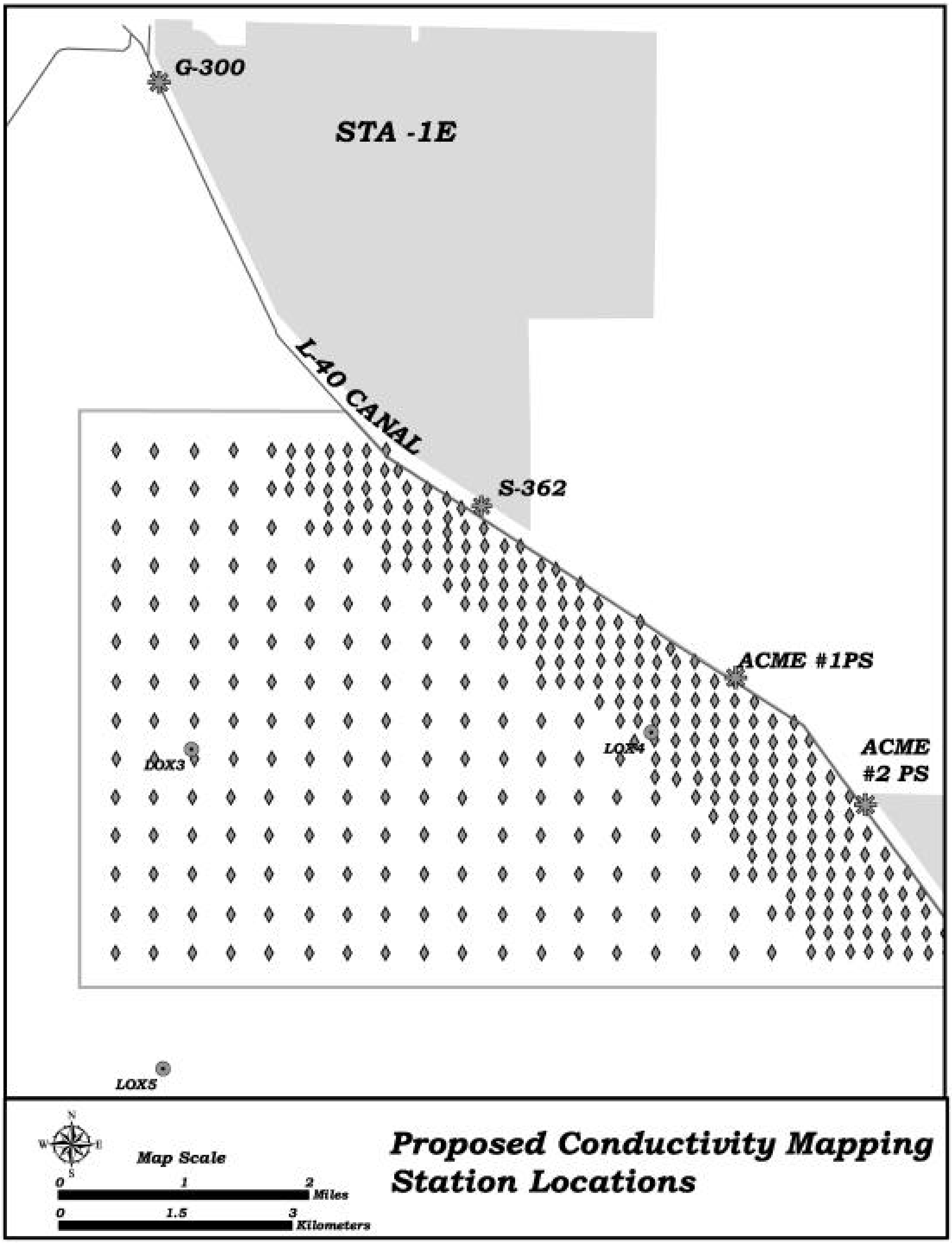

Figure 2: Proposed conductivity mapping grid for STA-1E downstream area in the refuge interior.

Sampling will occur when average canal stage is above average marsh stage. Some level of baseline sampling to provide a control condition will also be required. The initial sampling should occur as early as possible in the project schedule to facilitate location of the Hydrolab transects (see Task 3). Analysis of existing conductivity data taken during airboat surveys by refuge personnel indicates that conductivity in the northeastern portion of the refuge has been fairly low and stable (about 200 μS) since September 2003. Initial synoptic sampling will occur when conductivity at the currently monitored stations begins to increase. A two-person crew will sample each grid via helicopter in a 2-day window to get a "snapshot" picture of water column conductivity. Samples will be taken with a hand-held, temperature-compensated probe. The probe will be inserted mid-depth into the water column and the conductivity measured when the values equilibrate. At the beginning and end of each day, all conductivity meters will be calibrated using known standards.

After examining the data for quality assurance/quality control (e.g., outlier removal), a spatial map of surface water conductivity levels at the stations sampled will be generated. Appropriate geostatistical approaches will be explored to develop contoured maps.

A similar sampling grid is currently envisioned for conductivity mapping of the region downstream of STA-1W.

<u>Task 2: Event based synoptic sampling around STA-1E and STA-1W discharges</u>
After examining the first preliminary synoptic sampling exercise described in Task 1, a modified version of the synoptic sampling grid will be developed for use in conducting event-based sampling. While the extent of sampling effort will be less intensive than that for the synoptic sampling, it is important to develop a baseline understanding of what potential large-scale events might translate into in terms of water penetration into the refuge interior. It is anticipated that those events deemed of interest to sample will be evaluated on short notice. The sampling approach will mirror that of the synoptic sampling as best possible given logistical constraints with short notice. Sampling will occur during, or shortly after the event (rapid increase in canal level above marsh level due to rainfall and/or discharges), as well as several weeks after the event has concluded (to determine if it is possible to trace the return of high conductivity waters back towards the canal). This event based sampling scheme will be adaptively modified as more is learned concerning water movement.

Both the SFWMD and the USGS have ongoing monitoring programs that will provide the necessary hydrologic information (e.g., marsh and canal stage, pumping volumes and duration) to identify events and relate changes in marsh conductivity to changes in canal flows and stages. These data will be retrieved and used in combination with conductivity data to evaluate the strength of statistical relationships between specific water management activities and canal water intrusion into different parts of the refuge.

<u>Task 3: Network for long-term monitoring of conductivity patterns</u>
A permanent Hydrolab transect will be established adjacent to STA-1E, STA-1W discharges and along the SFWMD’s X transect in the southwest portion of the refuge.

These stations will allow for continuous monitoring of surface-water conductivity in the marsh (9 stations) and the rim canal (3 stations). A field datalogger and conductivity probe will be mounted to a pole at each station with the probe's sensor secured 10 cm above the sediment surface. Dataloggers will record site conductivity as frequently as required (possibly hourly) to insure that even the most rapidly changing transients are well characterized. Each station will be visited on a monthly or bimonthly basis to download accumulated data and perform calibration and routine maintenance.

These loggers will be arranged in transects generally perpendicular to the canal to measure the rate and extent of canal water intrusion into the refuge. Exact placement of Hydrolabs will depend on the examination of existing data and results from the synoptic survey. Generally, transects will span the area from the canal to a relatively pristine area in the interior.

Results and implications:
Previous data (mostly point samples) collected by refuge staff and SFWMD indicate that high conductivity water can intrude more than 4 km into the refuge in certain locations (Walker and Kadlec 2003). Assuming a 4-km wide impacted zone circumscribing the refuge, over half of the refuge may currently be affected by potentially harmful increases in constituents related to surface-water conductivity. The monitoring proposed here will allow refuge staff to conduct a more accurate assessment of the extent of exposure and the frequency of occurrence of different conductivity levels throughout the refuge. Analysis of these data in relationship to hydrological information will indicate hydrologic conditions and water management activities that promote intrusion of canal water into the refuge and, therefore, will suggest management solutions to this potentially serious environmental problem.

This monitoring project will not identify conductivity levels that are associated with significant ecological change in the refuge. This determination is critical to quantifying the ecological effects of canal-water intrusion into the marsh. This question will be addressed by complementary studies by other parties including the USGS.

Intrusion of high conductivity canal water is one of the most widespread water quality changes that human activities have on the refuge, and this project will identify the spatial and temporal extent of this intrusion. Furthermore, by providing an understanding of key hydrologic conditions that affect canal-water intrusion, the results of this work will allow refuge staff to work with the SFWMD and the Army Corp of Engineers to identify and implement alternative water management strategies that minimize flows of canal waters into the marsh while still achieving other water management objectives. Restoration efforts associated with the Everglades Construction Project and the Comprehensive Everglades Restoration Plan (CERP) include proposed changes in the location and operation of water control structures that regulate canal flows and stages around the outer rim of the refuge and other construction projects that may increase movement of canal water across the refuge. An improved understanding of the factors governing interactions between canal waters and the marsh is critical in order to predict the effects of these activities on canal-water intrusion and to modify them accordingly to minimize water quality impacts to the refuge.

Resources needed:

Determination of Conductivity Patterns	Year 1	Year 2	Total
Synoptic sampling			
Helicopter time for 4 events taking 4 days each, assuming FWS ship available	$ 44,800	$ 44,800	$ 89,600
Staff time- GS 7 for ground and aerial sampling (0.33 FTE + benefits)	13,333	13,333	26,666
Staff time- GS 11 for project coordination/data analysis and report writing (0.50 FTE plus benefits)	29,375	29,375	58,750
Conductivity meters	10,000		10,000
Hydrolabs (not covered by CESI request, see note below)	18,568		18,568
Field computer for downloading data	3,500		3,500
Supplies (for mounting Hydrolabs, calibration, etc)	1,500	1,500	3,000
Airboat time for monthly checks of Hydrolab network ($200/day includes fuel and maintenance)	7,200	7,200	14,400
	$ 128,276	**$ 96,208**	**$ 224,484**

Note: The CESI program previously provided funding for purchase of some of the Hydrolab conductivity dataloggers to be used in this study. Cost in this budget is for additional units.

Project schedule:

January-February 2004	Analyze existing data and determine locations for initial transects and design of synoptic sampling grid including criteria for an event
January-March 2004	Work out arrangements for helicopter
January-February 2004	Develop position description for GS11 ecologist/hydrologist and GS7 BioTech and send to regional office
January-February 2004	Order conductivity meters and field computer
February 2004	Install Hydrolabs
February 2004-	Watch for events and conduct event sampling as water moves into the interior (events will include natural fluctuations in water levels due to rainfall,

	and fluctuations caused by water management, e.g., discharges from STA-1E)
March 2004-March 2006	Monthly Hydrolab downloads
May 2004	GS11 on board
July, Oct, Jan,	Quarterly reports on conductivity data and synoptic sampling due (corresponds with reports for other water quality sampling)
April 2005 and April 2006	Annual and final report due

Implementation:
In order to implement this project, helicopter time must be secured. Helicopter time may be available through the use of the FWS helicopter based at Merritt Island. The details of getting this ship assigned for refuge use will need to be worked out. Ideally, four days would be needed in a row; however, two sets of two days within two weeks probably would work. Less than one weeks notice might be all we could give for event sampling.

Two additional personnel are needed for this project: one 0.33 FTE time GS7 for sampling and one 0.5 FTE time GS11 for project coordination, data analysis, and report writing. The GS11 would also prepare the reports for the additional water quality sampling and be responsible for ensuring that the additional sampling, conductivity sampling, and ecological studies were coordinated and on schedule. The refuge will have to develop a position description and get it approved and advertised through the Atlanta regional office.

III. Hydrodynamic and water quality modeling

Project dates: 2004-2006

Background:
The Arthur R. Marshall Loxahatchee National Wildlife Refuge is impacted by altered hydrology, impingement of high-conductivity canal water into the interior marsh, and elevated concentrations of nutrients, particularly phosphorus. A priority for the refuge is to better understand and minimize these impacts. Hydrodynamic and water quality models have the potential to provide needed management and scientific support related to these concerns. Information developed in the enhanced water quality monitoring project and conductivity project will be of value in model development and evaluation.

Although previous efforts directed at modeling hydrology and water quality of the refuge (alone or as a part of the greater Everglades) have been of value (Fitz and Sklar 1999; Lin 1979; Lin and Gregg 1988; MacVicar and Lindahl 2000; MacVicar et al. 1984; Munson et al. 2002; Raghunathan et al. 2001; Richardson et al. 1990), none of the these past modeling efforts adequately address current refuge needs. This project will utilize the understanding and experience of previous modeling studies to implement a working model that will address refuge needs. In order to minimize cost and ensure timely completion, it is anticipated that this project will not develop new computer modeling computer programs, but will utilize available computer programs (likely with some modification) for hydrodynamic and water quality modeling.

This modeling project shares some objectives with other Federal projects. Effort will be made throughout this project to maximize cooperation and information exchange with other Federal projects that are developing models of similar ecosystems. The Restoration Coordination and Verification (RECOVER) Water Quality Team has compiled a listing of 67 project related modeling efforts related to the Comprehensive Everglades Restoration Plan (CERP) implementation (Water Quality Team 2002b). The Water Quality Team has also inventoried some of the available water quality models of potential vale to CERP project teams in their project level water quality assessments (Water Quality Team 2002a). The CERP Everglades Agricultural Area (EAA) storage reservoir project design team has inventoried available models for analysis of hydrodynamics and phosphorus removal in proposed water storage reservoirs (Kimberly-Horn and Associates 2002; Kimberly-Horn and Associates 2003). These reservoirs are expected to often have little water or be dry. Several of the hydrology and water quality models considered by this team may also be applicable to refuge modeling. Support for water quality model review and selection has also been developed by the Southwest Florida Feasibility Study through contracted assistance (Ash Engineering and Engineering and Applied Science 2003). Model selection support documents produced by these and other teams and contractors will be consulted during this project model selection task.

This project also will build on the understanding of phosphorus dynamics in South Florida wetlands that has been established through the development of the DMSTA model (Walker and Kadlec 2002). The US DOI has primarily funded development of DMSTA. DMSTA has been calibrated or tested using data from over seventy wetland sites in South Florida. Initial modeling of phosphorus in this project will use kinetics and parameter ranges established by DMSTA modeling.

This modeling project will also provide a better understanding and support the development of a consensus on causes of historic and future exceedances of Settlement Agreement mandated phosphorus concentration levels. This project is consistent with recommendations of the Technical Oversight Committee (TOC).

This modeling project will also interact with other efforts to assess flows and water quality in the refuge. In particular, interaction and cooperation with efforts by the SFWMD, the EPD, and the USACOE will be actively pursued.

Objectives:
The goal of this modeling is to provide best available technical support for management decisions related to refuge inflow and outflow quantity, timing, and quality. This modeling effort will provide projections of water movement and water quality resulting under alternative scenarios of structure operation, STA performance, and structural changes within the refuge.

Tasks:
This project will involve ten tasks divided into two phases. Phase 1 will collect and organize the information needed to support model implementation, and Phase 2 will perform the model implementation and application. Although the deliverable information from Phase 1 will be necessary for completion of Phase 2, some of the tasks in Phase 2 can be initiated prior to completion of all tasks in Phase 1. Task scheduling will be designed to minimize overall project completion time within the constraints of total personnel resources available.

Documentation is a vital part of any modeling, and will be incorporated as a requirement for every task and contract deliverable. Metadata documentation requirements will also be established to assure that sources of data and transformations of data are available to future users and reviewers. All project documentation and modeling will be made available to interested parties. At this time, there is no facility available to the refuge to make these documents and files directly available on-line through a dedicated web page. This information will, at a minimum, be provided through email requests to the investigators.

PHASE I: PREPARATION OF DATA
<u>Task 1: Data acquisition and processing</u>

1.1: Select candidate constituents for modeling

There are a number of reasons that a particular water quality constituent might be selected for modeling: (1) Constituents that are of direct interest or directly affect performance measures must be modeled; (2) Constituents that are assumed to directly affect those in the first category must also be simulated; and, (3) Other constituents that add to the model quality assurance or credibility of calibration by providing added constraint or testing should be modeled. Modeling additional constituents reduces the likelihood that the model is “under-constrained” by the calibration data. At a minimum, a conservative constituent, probably chloride, and total phosphorus will be selected for modeling.

1.2: Select period-of-record

An ideal period-of-record (POR) covers a large number of years with periods of extreme meteorological and hydrological conditions that adequately calibrate and test model performance. It is also of value to have a POR that includes major structural changes (*e.g.* diversion of S-6 pump, STA-1E operation) because this further tests the models ability to project such changes. It is desirable to select a POR ending as close as practical to the present. The period of record for model calibration and possible verification should consider data availability, and quality. This task will require a preliminary review of data from various sources.

1.3: Types of data

A number of classes of data must be compiled to support model development. Many of these datasets are spatial (e.g., elevation), some are time series for specific sites (e.g., TP at monitoring sites), and some are both temporally and spatially variable (e.g., rainfall). Data sources must be identified for all data types required.

1.4: Geographic data – elevation, base map –

Most past and current modeling efforts have used soil surface elevation values collected under by the Florida Coop Fisheries and Wildlife Unit (Richardson et al. 1990). Newer topographic data may become available in time to be used in this study. Canal cross-section data have been measured by IFAS (Daroub et al. 2002)

1.5: Hydraulic data – stages and structure flows –

Stage observations and flows are publicly available through the SFWMD DBHYDRO database system. Other sources include refuge observations, and discharger reports.

1.6: Meteorological data – rainfall, temperature, ET –

Rainfall and temperature data recorded at nearby stations are available through DBHYDRO. ET observations within the refuge have been performed by the USGS over limited time periods, and these data can be used to test equations that predict ET from other meteorological parameters.

1.7: Water quality data – inflow, within, and outflow –

Water quality data are available in DBHYDRO, and from other sources.

1.8: Procure and QA all data

There are a number of potential data sources. All procured data must undergo quality assurance checks. Datasets must also be accompanied with metadata descriptions that document sources and all modifications made following procurement. Documentation must be adequate to allow efficient and consistent future extension of dataset POR. Data from the other sections of this work plan will be incorporated into this task.

1.9: Format data as required

Data will need to be organized and placed in proper database or format for use in model input and calibration.

<u>Task 2: Develop boundary condition time series</u>

Flows and concentrations of all modeled constituents at every inflow structure (boundary conditions or BCs) must be estimated and compiled into time-series datasets. Time series will also be developed for all outflow structures. This is not necessarily a trivial task. Improvement of estimation of complete time-series from measurements taken at single times (grab samples) or from composite samples has been identified as a significant source of model uncertainty in the ELM calibration (Fitz 2003, Water Quality Team presentation). This task should include investigation of alternative approaches and selection of the optimal technique. The task also includes using this technique to provide BC estimates for model implementation.

<u>Task 3: Develop daily water/material budgets for all structures and simple models</u>

Using time series of flow and concentration, historic daily loads for every structure will be calculated over the selected POR. This calculation will be performed for all candidate constituents identified in Task 1, including budgets (daily totals) for net inflow and net outflow flow and load of each constituent. These daily budgets will be combined into seasonal and annual budgets over the POR for each constituent. Trends in load and retained load (inflow minus outflow load) will be examined. Simple net refuge mass balance models will be developed.

PHASE II: MODEL IMPLEMENTATION

<u>Task 4: Selection of model(s)</u>

Model objectives, needs, and required specifications will be developed. Available models will be reviewed. Based on an objective evaluation of how well existing models meet project needs, a model (or models) will be selected for hydrodynamic and water quality simulation.

<u>Task 5: Model implementation</u>

The selected model(s) computer programming will likely require alteration to adequately model selected constituents and meet model objectives. This task will therefore involve computer code modification and testing. The model will then be implemented using datasets developed in preceding Tasks 1 and 2.

<u>Task 6: Model calibration and verification</u>

A preliminary calibration of the hydrodynamic model will be performed using observed stage from refuge interior and canal sites. Calibration of mass transport using a relatively conservative constituent (*e.g.*, chloride) may then require additional adjustment of hydrodynamic model parameters. Within the refuge, chloride concentration may be accurately estimated from conductivity. Initial conductivity mapping data will be used in model calibration. Calibration of other reactive water quality constituents should not make further adjustment of the hydrodynamic calibration. Preliminary water quality observations acquired in the monitoring phase of this project will be directly or indirectly used for calibration. Effectiveness of calibration will be quantitatively measured and reported.

Task 7: Scenario analysis

Alternative management strategies will be defined and simulated. Performance measures and simple statistics, as well as spatial mapping, will be used in comparison of alternatives. Examples of scenarios that may be simulated include:

- Given a projected inflow condition project the temporal and spatial pattern of water depths. Determine the area of the refuge that will have suitable conditions for wading bird foraging and estimate duration.
- Analyze benefits and impacts of revisions to the refuge regulation schedule. This may include changing zone boundary stages or the sequence in which water supply make-up water is delivered.
- Analyze the effect of changing relative flow through the S-10 structures for water delivery to WCA-2. It is conjectured that water quality benefits are maximized by gate openings that minimize the east-west canal stage difference across the refuge.
- Analyze the benefit of balancing inflows between STA-1E and STA-1W. Is it important to, as far as practical, synchronize discharge to minimize canal intrusion?
- Estimate the long-term impact on interior chloride concentration resulting from discharge by the STAs.
- Test changes in hydroperiod and water quality resulting from possible alternative designs for CERP project KK, the “Loxahatchee National Wildlife Refuge Internal Canal Structures.”
- Estimate water quality improvement at interior stations that would result from meeting 10 ppb P concentration at all inflows.
- Explore other operational changes that reduce the impact of external loads on interior stations.

Task 8: Documentation

Full documentation of all tasks of this project is required. Publications in peer-reviewed journals will be encouraged and supported. However, peer reviewed publications do not substitute for detailed project reporting and exhaustive review by DOI staff and management, SFWMD/COE staff, and consultants familiar with the system and project. The standard for project reporting is that a professional without specific knowledge of this site or project could implement every task of the project using only project reports and without need to consult the modeling staff. Although a final report and final documentation will be deliverables, documentation will be required throughout the project as an essential part of every task and deliverable.

Task 9: Archive of program and all other files
All programs, input and output datasets, and reports will be centrally archived in electronic form. This task will proceed at the same time as preceding tasks. Resources necessary for completion of this task are included in these preceding tasks.

Task 10: Model maintenance for use
This task extends beyond the funded end of the project. It involves program maintenance to support future changes in programming environments, and extension of datasets to include newly acquired monitoring data.

Results and implications:

Resources needed:
It is estimated that total project cost will not exceed $300,000 and will require 4.2 FTEs (an FTE is defined here to be a full time equivalent effort for one year) of additional effort by staff dedicated to this modeling project over a planned 25-month period.

The task resource chart presented below provides estimates of additional personnel requirements and personnel costs required to complete this project. Cost estimates are crude and can be considerably refined following decisions on methods for personnel procurement. Resources estimated here do not include the cost and effort of current federal employees for project management, oversight, and review.

Prior to initiation of the project, a more detailed timeline and milestone chart will be developed, and a detailed project deliverable list will be formulated. These milestones and deliverable requirements will be used in project management.

Task resource chart

Task	Months	FTEs	Cost* $1000
1	3	0.50	30
2	6	1.00	60
3	3	0.50	30
4	1	0.17	10
5	3	0.50	30
6	4	0.68	40
7	2	0.33	20
8	3	0.50	30
Total	25	4.18	$250

*Assumes $60,000 per FTE.

Assuming $50,000 for supplies, equipment, travel, and contingency, total project cost is estimated to be $300,000. Project is anticipated to require 2.5 years for completion.

Project schedule:
Scheduling of all tasks will depend in part on availability of personnel.

January 2004- February 2004	Investigate contracting alternatives.
February 2004- February 2005	Phase I: Preparation of data.
June 2004- February 2006	Phase II: Model implementation.

Implementation:
It is anticipated that some personnel resources (including contract administration, oversight, and/or direct project participation) will be required from existing federal staff. Resource estimates presented above do not include this cost or effort.

References

Adaptive Assessment Team. (2003). "RECOVER: Monitoring and Assessment (MAP) Plan (Revised) Draft - March 2003." *report available at http://www.evergladesplan.org/pm/recover/recover_docs/aat/040703_cerp_map_1.pdf*, RECOVER.

Ash Engineering, and Engineering and Applied Science. (2003). "Technical Memorandum: Water Quality Model Selection for Southwest Florida Feasibility Study (DRAFT)." South Florida Water Management District, Fort Meyers, FL.

Browder, J. A., Gleason, P. J., and Swift, D. R. "Periphyton in the Everglades: Spatial Variation, Environmental Correlates, and Ecological Implications." *Proceedings of Everglades Symposium, Key Largo, FL 1989*, 76 pp. +.

Browder, J. A., Gleason, P. J., and Swift, D. R. (1994). "Periphyton in the Everglades: Spatial variation, environmental correlates, and ecological implications." Everglades: The Ecosystem and its Restoration, J. C. Ogden, ed., St. Lucie Press, Boca Raton, FL, Ch. 16, 379-418.

Childers, D. L., Doren, R. F., Jones, R., Noe, G. B., Rugge, M., and Scinto, L. J. (2003). "Decadal change in vegetation and soil phosphorus pattern across the Everglades landscape." *Journal of Environmental Quality*, 32(1), 344-362.

Daroub, S., Stuck, J. D., Rice, R. W., Lang, T. A., and Diaz, O. A. (2002). "Implementation and Verification of BMPs for Reducing Loading in the EAA and Everglades Agricultural Area BMPs for Reducing Particulate Phosphorus Transport." *Phase 10 Annual Report, WM 754*, Everglades Research and Education Center, Institute of Food and Agricultural Sciences, University of Florida, Belle Glade.

Fitz, H. C., and Sklar, F. H. (1999). "Ecosystem Analysis of Phosphorus Impacts and Altered Hydrology in the Everglades: A Landscape Modeling Approach." Phosphorus Biogeochemistry in Subtropical Ecosystems, C. L. Schelske, ed., Lewis Publishers, Boca Raton, FL, 585-620.

Flora, M. D., and Rosendahl, P. C. (1982). "Historical changes in the conductivity and ionic characteristics of the source water for the Shark River Slough, Everglades National Park, Florida, USA." *Hydrobiologia*, 97(3), 249-254.

Gleason, P. J. (1974). "Environments of south Florida: past and present." Miami Geological Society Memoir 2, Miami Geological Society, Miami, 553 pp.

Lin, S. (1979). "The application of the Receiving Water Quantity Model to the Conservation Areas of South Florida." *DRE-91*, South Florida Water Management District, West Palm Beach, FL.

Lin, S., and Gregg, R. (1988). "Water Budget Analysis: Water Conservation Area 1." *DRE 245*, South Florida Water Management District, West Palm Beach, FL.

MacVicar, T. K., and Lindahl, L. J. (2000). "The "Natural System Model" and its application in support of Everglades restoration." Florida Department of Agriculture and Consumer Affairs, and Everglades Agricultural Area Environmental Protection District.

MacVicar, T. K., Van Lent, T., and Castro, A. (1984). "South Florida Water Management Model Documentation Report." *Technical Publication 84-3*, South Florida Water Management District, West Palm Beach, FL.

Munson, R., Roy, S., Gherini, S., McNeill, A., Hudson, R., and Blette, V. (2002). "Model Predication of the Effects of Changing Phosphorus Loads on the Everglades Protection Area." *Water, Air, and Soil Pollution*, 134(1/4), 255-273.

Payne, G., and Weaver, K. (2004). "Status of Phosphorus and Nitrogen in the Everglades Protection Area." 2004 Everglades Consolidated Report, G. Redfield, ed., South Florida Water Management District, West Palm Beach, Florida, Chapter 2C.

Raghunathan, R., Slawecki, T., Fontaine, T. D., Chen, Z., Dilks, D. W., Bierman, V. J., Jr, and Wade, S. (2001). "Exploring the dynamics and fate of total phosphorus in the Florida Everglades using a calibrated mass balance model." *Ecological Modelling*, 142(3), 247-259.

Richardson, J. R., Bryant, W. L., Kitchens, W. M., Mattson, J. E., and Pope, K. R. (1990). "An evaluation of refuge habitats and relationships to water quality, quantity, and hydroperiod: A synthesis report." Florida Cooperative Fish and Wildlife Research Unit, Univ. of Florida, Gainesville.

Scheidt, D., Stober, J., Jones, R., and Thornton, K. (2000). "South Florida Ecosystem Assessment: Everglades Water Management, Soil Loss, Eutrophication and Habitat." *EPA 904-R-00-003*, EPA.

SFWMD. (2002). "Field Sampling Quality Manual." Water Quality Monitoring Division and Water Quality Analysis Division, South Florida Water Management District, West Palm Beach, FL.

SFWMD. (2004). "2004 Everglades Consolidated Report." *Available at http://www.sfwmd.gov/org/ema/everglades/howto.html*, South Florida Water Management District, West Palm Beach, FL.

Swift, D. R., and Nicholas, R. B. (1987). "Periphyton and water quality relationships in the Everglades Water Conservation Areas: 1978-1982." *DRE 233*, South Florida Water Management District, West Palm Beach, FL.

US Army Corps of Engineers, and South Florida Water Management District. (1999). "Central and South Florida Project Comprehensive Review Study Final Integrated Feasibility Report and Programmatic Environmental Impact Statement." USACOE, Jacksonville, FL.

USFWS. (2000). "Arthur R. Marshall Loxahatchee National Wildlife Refuge Comprehensive Conservation Plan." *available at http://loxahatchee.fws.gov*, US Fish and Wildlife Service, Boynton Beach, Florida.

USFWS. (2003). "Arthur R. Marshall Loxahatchee National Wildlife Refuge Water Quality Monitoring Plan. A.R.M. Loxahatchee National Wildlife Refuge." Boynton Beach, Fl.

Walker, W. W., and Kadlec, R. H. (2002). "Development of a Dynamic Model for Everglades Stormwater Treatment Areas." *Available through web site www.wwwalker.net*, Prepared for U.S. Department of the Interior, Concord, Massachusetts.

Walker, W. W., and Kadlec, R. H. (2003). "Compliance of Marsh Phosphorus Concentrations in A.R.M. Loxahatchee National Wildlife Refuge with Interim Levels Required under the Consent Decree." *report available at* *http://www.sfwmd.gov/org/ema/toc/archives/docs/refuge_compliance.pdf*, US Department of Interior, Boynton Beach, FL.

Water Quality Team. (2002a). "Internet Survey of Water Quality Model Codes." *report available at* *http://www.evergladesplan.org/pm/recover/recover_docs/wqt/091702_wqt_wq_internet_summary.pdf*, RECOVER.

Water Quality Team. (2002b). "WQ Model Survey Results." *report available at* *http://www.evergladesplan.org/pm/recover/recover_docs/wqt/091702_wqt_existing_wq_models.pdf*, RECOVER.

Weaver, K., and Payne, G. (2004). "Status of Water Quality in the Everglades Protection Area." 2004 Everglades Consolidated Report, G. Redfield, ed., South Florida Water Management District, West Palm Beach, Florida, Chapter 2A.