MODEL SELECTION REPORT

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1. INTRODUCTION

1.1. Background

The Arthur R. Marshall Loxahatchee National Wildlife Refuge (hereafter referred to as the Loxahatchee Refuge or simply as the Refuge) is the only remnant of the northern Everglades in Palm Beach County, Florida (USFWS, 2000). It includes 143,238 acres (58,000 ha) and is located seven miles west of the city of Boynton Beach. Being part of the Everglades, it is part of a much larger watershed, i.e., the Kissimmee-Okeechobee-Everglades system. Historically, the Kissimmee River discharged into Lake Okeechobee, and during wet cycles the lake would overflow its south bank, providing additional flow to the Everglades (Light and Dineen, 1994). According to Raghunathan et al. (2001) this water would sheet flow across the Everglades, but now, water flows through canals and structures, and through a series of water storage areas (Water Conservation Areas, WCA), to the Everglades National Park (ENP). In the nineteen forties, the U.S. Army Corps of Engineer (USACOE) constructed three impoundment areas (WCA1, 2 and 3), bounded by levees and connected by a series of canals. In 1951, the Loxahatchee Refuge was established at Water Conservation Area 1 (USFWS, 2000). Figure 1 shows the historic and the current flow condition for the Kissimmee-Okeechobee-Everglades system.

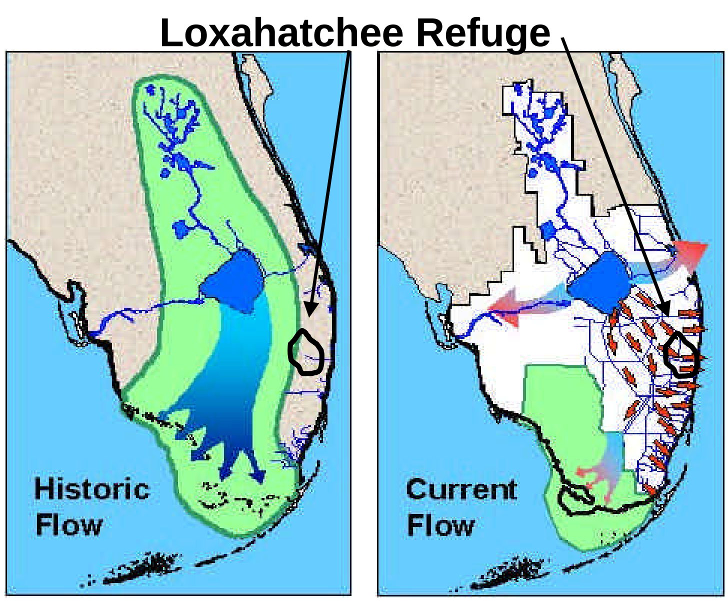

Figure 1. Historic and Current Flow Patterns for the Everglades System.
[Adapted from the Comprehensive Everglades Restoration Plan website, http://www.evergladesplan.org/index.cfm]

As indicated by Richardson et al. (1990), the Refuge is now isolated from the historic Kissimmee-Okeechobee-Everglades watershed as it is completely enclosed within a levee system and a borrow canal along the interior of the levee. As shown in Figure 2, the Refuge is bordered on the northwest by drained agricultural land, the Everglades Agricultural Area (EAA), and by mainly an urban development at the east. Water Conservation Area 2A is located at the southwest of the Refuge.

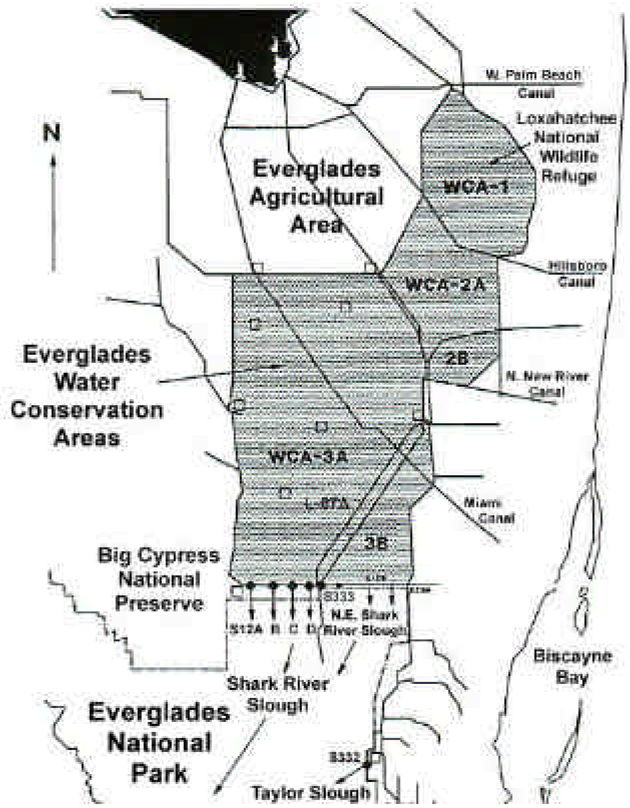

Figure 2. Map of Water Conservation Areas (WCAs)
[Adapted from the Reef Relief Website, http://www.reefrelief.org/Floridabay/report_page4.html]

From a historic perspective regarding water control in the Everglades, Light and Dineen (1994) indicated that the WCAs were designed to accomplish eight objectives: 1) receive and store agricultural runoff from the EAA, 2) prevent water accumulated in the system from overflowing into urban and agricultural areas, 3) recharge regional aquifers, 4) prevent salt water intrusion, 5) store and convey water supply for agricultural, municipal and industrial use, and for the ENP requirements, 6) receive controlled releases from Lake Okeechobee, 7) protect wildlife and promote recreation, and 8) dampen the effect of hurricane-induced wind tides by maintaining marsh vegetation in the system. The Comprehensive Conservation Plan developed by the U.S. Fish and Wildlife Service (USFWS, 2000) emphasizes the role of the Refuge in the South Florida Ecosystem and its use for the national migratory bird management program. The USFWS indicated that in consistency with the South Florida Ecosystem Plan, the Refuge should be used to accomplish the following: 1) reduce exotic species, 2) manage water quality and quantity through partnerships, 3) monitor and inventory wildlife and habitats, 4) promote public awareness about the ecosystem, and 5) provide wildlife-compatible recreation.

1.2. Landscape: Refuge Vegetation, Soils and Physiography

The Refuge landscape consist of a complex mosaic of wetland communities that grade from wetter areas such as sloughs and wet prairies, to sawgrass, brush, and finally tree islands occurring at the dryer end of the scale. Sloughs are the deepest natural marsh communities in the Everglades with water depth that may exceed 3 feet in the wet season; the annually average depth is about 1 foot (USFWS, 2000). Sloughs are typically found in the south part of the Refuge. In contrast to sloughs, wet prairies have shallow water levels. They are prevalent vegetative community in the Refuge with approximately 50 % land coverage. Wet prairies are the primary community type on the central portion of the Refuge (Richardson et al., 1990). Sawgrass accounts for about 25% of land coverage. It is present on all part of the Refuge including a vast area on the west side. The tree islands cover approximately 20% of the Refuge interior. They are basically located at the northern portion of the Refuge ranging in size from less than 1 acre to more than 300 acres (USFWS, 2000). In addition to the aforementioned species, Cattails also grows on the Refuge. The cattail has developed in the Refuge as a response to the anthropogenic load of nutrients in the incoming water. According to Richardson et al. (1990) almost all of the cattail is found within the first 1000 meters of the canal and literally the remaining cattail is found within the next 1000 meters. Cattail is more abundant in the west side of the Refuge.

The Refuge wetland communities occur on top of a bed of peat (Richardson et al., 1990) from seven to nine feet deep (Scheidt et al. 2000; Stober et al. 1996). The peat is lightly colored, fibrous and spongy, reflective of high organic content (USFWS, 2000; Stober et al. 1996). It is important to notice that the Refuge is located in a depression in the underlying-limestonebedrock Fort Thompson Formation, which results in greater water depth than the surrounding Everglades. However, in contrast to other areas of the Everglades where there are only shallow layers of soils, soil depth in the Refuge range from 3.6 to 14.0 feet (Silveira, 1996).

Regional topographic surveys by the United State Geological Survey (USGS) provide elevation data to parameterize hydrologic and ecologic numerical simulation models that are being developed for ecosystem restoration activities. It should be noted that modeling of sheet flow and water surface levels in the wetlands of South Florida is very sensitive to changes in elevation due to the expansive and extremely low relief terrain. Therefore, vertical accuracy on the order of +/- 15 centimeters is required for the elevation data for use as input to hydrologic models (Desmond, 2003).

1.3. Hydrologic and Hydrodynamic Description

This section describes the major characteristics of the Refuge's hydrology and hydrodynamics. These descriptions are based on published information and information processed by the authors for the Period of Record (POR) that goes from January 1, 1995 to December 31, 2004. This period was selected for calibration and validation of the model to be developed (Meselhe et al., 2005) and will be referred in this report as the POR.

1.3.1. Precipitation

According to Abtew et al. (2005) South Florida is a high-rainfall region, with frontal, convective and tropical system-driven rainfall events. They indicated that the annual average rainfall on the entire region managed by the SFWMD is 52.8 inches (this value was obtained from varying lengths or record for each station and from a varying number of stations, in general the periods of record went from 1900 to 2000), being the annual average for WCA-1 slightly lower than this value. Rainfall is the only important type of precipitation in the Refuge.

Using precipitation data from stations S-5A, S-6, S-39, STA1W, WCA1ME, LOXWS, PS-1 (Gage 8), PS-2 (Gage 10), and South Shore South End Gage (Gage 6); and using multiple Thiessen polygons it was found that the annual average rainfall for the Loxahatchee Refuge is about 52.1 inches, for the POR from 1995 to 2004. Multiple Thiessen polygons were used to account for the missing data, i.e, for each day in which data was missing for one or more stations, the areas of the polygons were altered so that the stations with missing data were not included. Similarly, it was found that the maximum daily and monthly values for the POR are about 6.5 and 18.1 inches, respectively. Figure 3 shows the location of the rain gages. The reader is referred to Meselhe et al. (2005) for information about the data acquisition and processing.

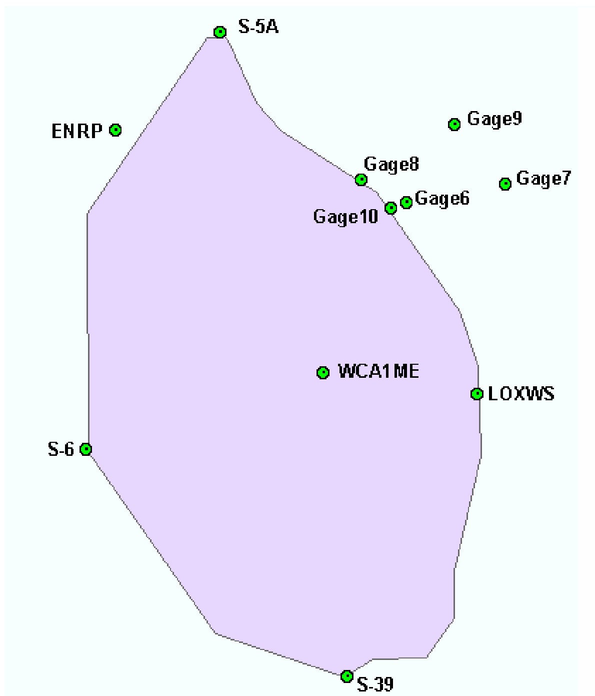

Figure 3. Location of Rain Gages and Weather Stations

In terms of the seasonal variability, Meselhe et al. (2005) reported that more rainfall occurs during the months of June to October, compared to the rest of the year. In fact, the “wet season” for South Florida runs from June through October and accounts for 66% of the annual rainfall (Sklar et al., 2002). A monthly rainfall analysis for the studied POR (1995 – 2004) indicates that June is the wettest months with about 7.7 inches, followed by September with 7.5 inches. On the other hand, the driest month are January and December with 1.8 and 1.9 inches, respectively. The seasonal rainfall variation for the studied POR is shown in Figure 4.

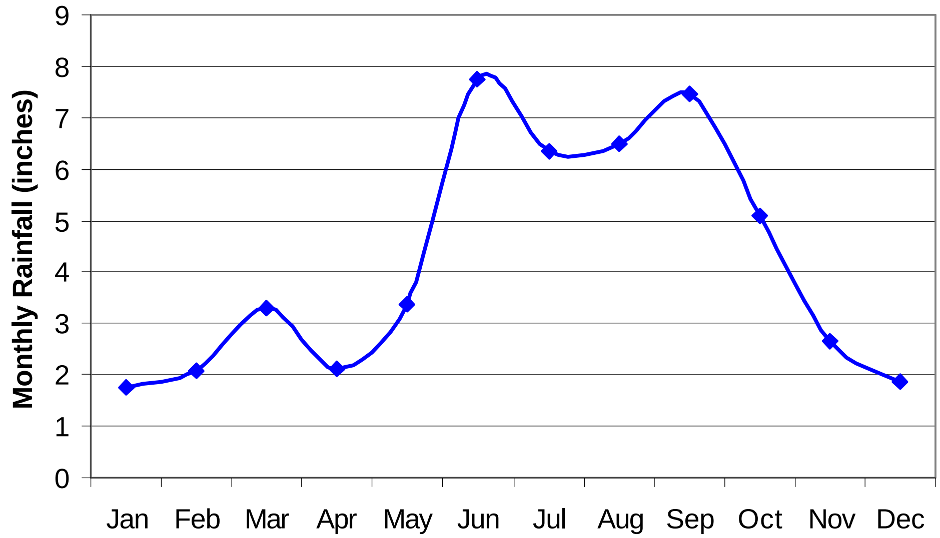

Figure 4. Seasonal Variation of Rainfall in the Loxahatchee Refuge

An annual (calendar year) analysis of rainfall data for the POR, shows a steady distribution for the first five year (1994 to 1999) with an annual value of about 58 inches per year, a sever drought in 2000 (annual average equal to 38.9 inches) and 1999 as the wettest year with 59.1 inches per year. From 2002 to 2004 the annual rainfall dropped below 50 inches with an average value of about 46 inches per year. Figure 5 shows the annual variation of rainfall for Refuge.

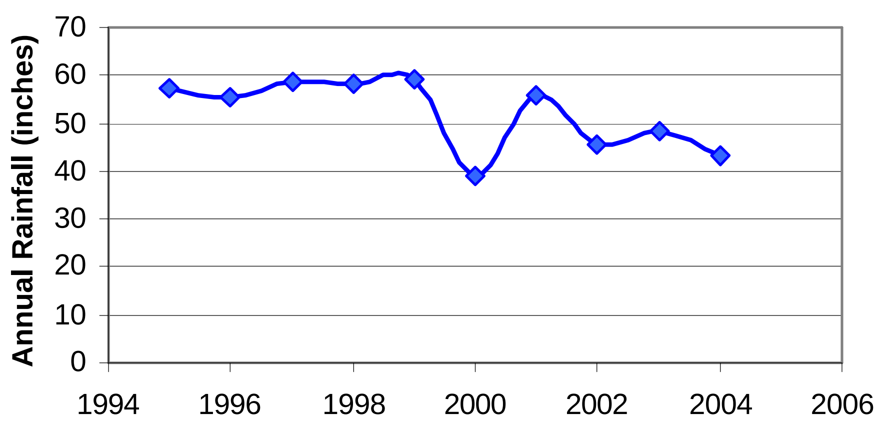

Figure 5. Annual Variation of Rainfall

1.3.1.1. Spatial Distribution of Rainfall in the Loxahatchee Refuge.

Figure 6 shows the spatial distribution of annual average rainfall in the Loxahatchee Refuge, estimated for the period of time between January 1, 1997 and December 31, 2004. This figure is based on the information of 8 active rain gages during the aforementioned period. This period was selected because gages 8 and 10 started operating in January 1, 1997. As can be observed in this figure, the northeastern part of the Refuge received more rainfall compared to the other areas. Conversely, the west and southwest received the least amount of rain. The difference between the zones with the highest and the least amount of rainfall is notorious. This difference is about 19 inches of rain per year. Is important to notice that the research team conducted a thorough evaluation of the rain gages' data, and did not find reasons to avoid the use of any particular gage.

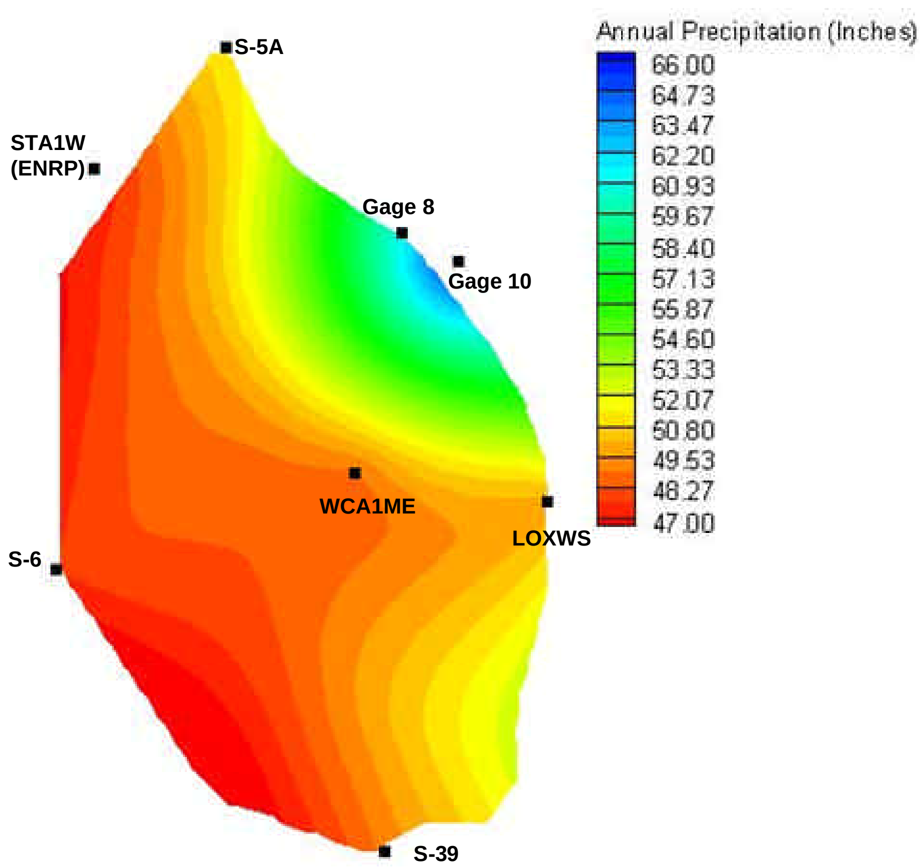

Figure 6. Spatial Distribution of Annual Average Rainfall in the Loxahatchee Refuge

1.3.2. Evapotranspiration

According to Abtew et al. (2005) rainfall and evapotranspiration (ET) are the main parameters in the hydrologic balance of the Everglades. They indicate that the balance between rainfall and ET maintains the hydrology system in either a wet or dry condition. They also indicate that, in South Florida, most of the variation in ET is explained by solar radiation. Sklar et al. (2003) and Abtew et al. (2004) reported that the estimated ET for WCA-1 for water years 2003 and 2004 is about 51.1 inches.

Evapotranspiration data for the Loxahatchee Refuge are available from one station located at the Everglades Nutrients Removal Project (ENRP) (See Figure 3) currently the Stormwater Treatment Area 1-W (STA-1W). For the POR, the annual average measured ET from STA-1W station is equal to 52.1 inches. This station is always wet so the measured ET might be higher than the actual ET in the Refuge. Griborio et al. (2006) estimated the actual ET for the Refuge using the observed ET from STA-1W (ETobs) using the following equation:

$$ET = f_{ET}\, ET_{obs} \qquad (1)$$

where $f_{ET} = Maximum(f_{ET\min}, Minimum(1, \frac{H}{H_{ET}}))$

f_{ETmin} is the minimum reduction of ET because of shallow depth = 20%.
H is the marsh water depth so that $H = Maximum(0, E_M - E_0)$.
E_0 is the marsh ground elevation
H_{ET} is the depth below which ET is reduced = 0.25 m.

Using Eq. 1 and the data from station STA-1W, Griborio et al. (2006) found the annual average ET for the Refuge is about 47.2 inches per year. Figure 7 shows the ET’s seasonal variation estimated from STA-1W for the POR. As can be observed in this figure, ET is higher during the months of March to August (with values higher than 4.5 inches), reaching a peak of about 6 inches in May. A regional evaluation of ET in the everglades conducted by German (2000) presented similar results to those shown in Figure 7.

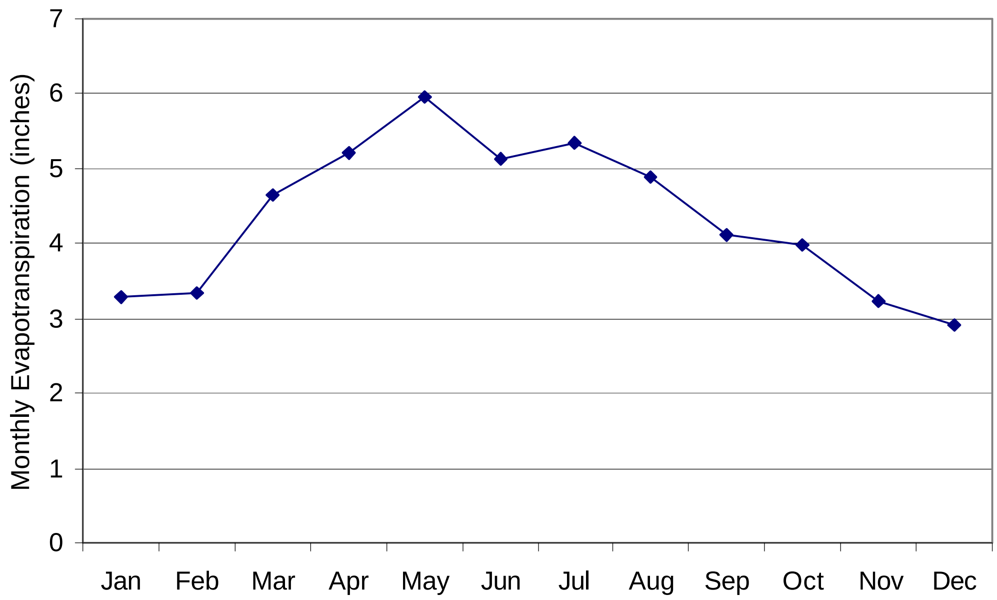

Figure 7. Seasonal Variation of ET Estimated at STA-1W (adapted from Meselhe et al., 2005)

1.3.3. Water Levels

The water levels in the Refuge change due to Precipitation, ET, seepage, and surface water management. According to Abtew et al. (2005) the historic daily average stage (for the period 1960 to 2004) for the Refuge is 15.56 ft NGVD. They indicated that water level was compiled from four sites: 1-8C, 1-7, 1-8T, and 1-9. The location of these gages is shown in Figure 8. For the POR, Meselhe et al. (2005) found that the arithmetic mean of daily average marsh water levels for the Refuge is 16.45 ft NGVD29. For this period, a maximum daily average marsh water level of 18.19 ft NGVD29 occurred on October 16, 1999 (during Hurricane Irene); and a minimum marsh water level of 14.94 ft NGVD29 was attained on May 21, 2001. Meselhe et al. (2005) compiled and evaluated data from five gages located in the marsh, i.e., North, 1-7, 1-8T, 1-9 and South, and one gage locate in the rim canal, i.e, gage 1-8C (See Figure 8). For gage 1-8C, the arithmetic mean of daily average water levels is 16.31 ft NGVD29 (for the POR), and the maximum and minimum daily average stages are 18.19 and 12.06 ft NGVD29, respectively. The minimum daily water level for the canal was reached on May 23, 2002. Figure 9 shows the average marsh water level in the Refuge for the studied POR. More information about the water level data for the Refuge is presented in the Report by Meselhe et al. (2005).

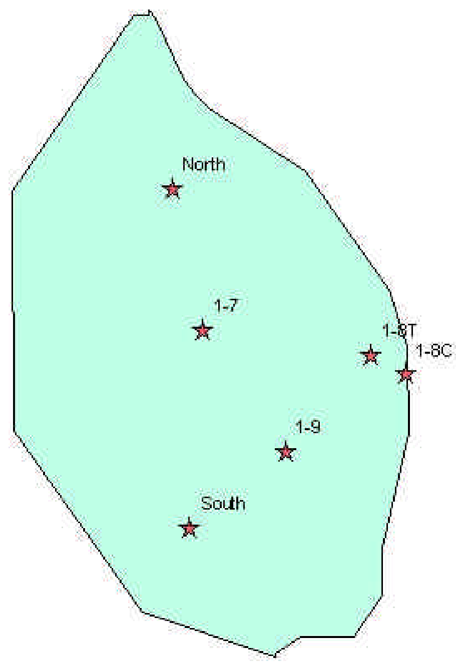

Figure 8. Water Level Monitoring Stations in the Loxahatchee Refuge (adapted from Meselhe et al., 2005)

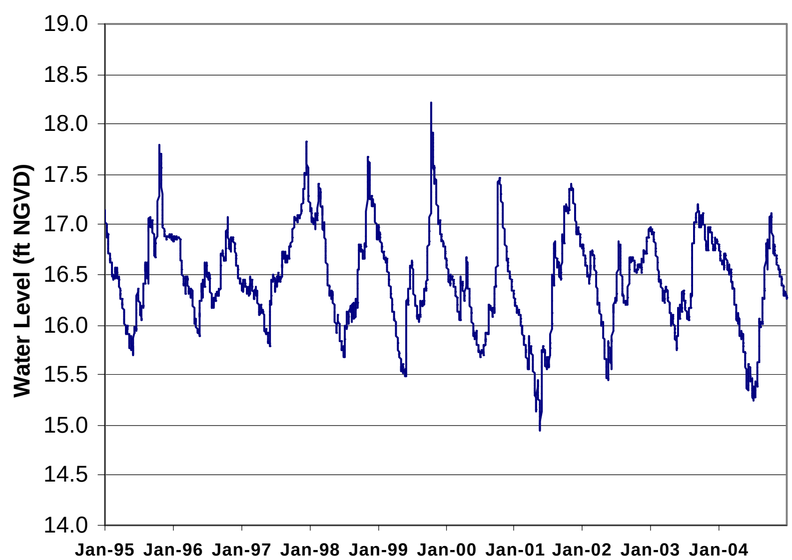

Figure 9. Average Marsh Water Level in the Loxahatchee Refuge.

1.3.4. Hydroperiod and Water Depths

Elevation data for the Refuge are available from the USGS on a 400 by 400 meter grid with horizontal and vertical accuracy of +/- 15 cm. (Desmond, 2003). Based on these data, the bathymetric contours for the Refuge (excluding the rim channel) range from 18.50 to 10.61 ft NGVD29, with a mean elevation of about 15.00 ft NGVD29. Figure 10 shows the bathymetric contours for the Loxahatchee Refuge based on the USGS's data. Based on the average water level (16.45 ft NGVD29) and the mean elevation for the Refuge, we obtain an average depth of about 1.45 ft (for the POR). Assuming a flat pool at the average water level and taking into account the refuge bathymetry, the maximum and minimum depths would be equal to 5.84 ft and 0 ft, respectively. Figure 11 shows the distribution of water depths in the Refuge for different stages (assuming a flat pool). In this figure it can be observed that the spatial distribution of water depth roughly corresponds to the inverse of topography with the northern part of the Refuge being shallower than the southern.

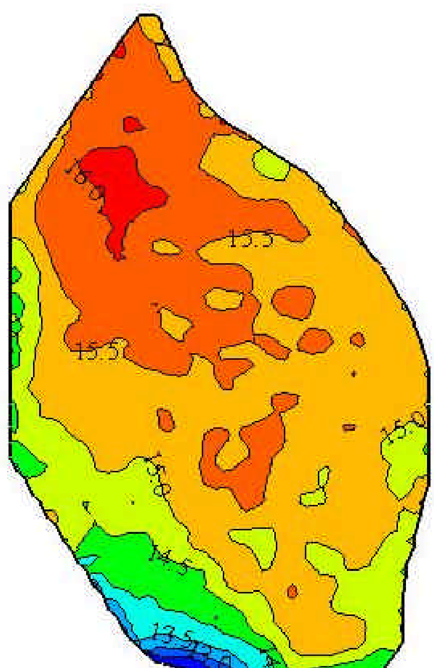

Figure 10. Bathymetric Contours for the Loxahatchee Refuge (ft NGVD29

In terms of hydroperiod the north and south regions of the Refuge are very distinct (as can be observed in Figure 11). The north end has a much greater variance in hydroperiod than the south end. During low water levels, the north part of the Refuge is much more susceptible to staying dry for long periods; while in the south, the dry season is not as likely to completely dewater the marsh for months at a time (Richardson et al., 1990).

Richardson et al. (1990) presented a hydrologic evaluation of the Refuge over a 16 year period (1970 – 1986). They found that the 16-year hydroperiod over the entire Refuge ranges from 70% to 98% exhibiting an obvious north-south trend of increasing hydroperiod with localized anomalies corresponding to topographic features. Richardson et al. (1990) found that mean water depths for the entire 16 year period range from 0.2 ft in the north end to 3.2 ft in the south. The estimated average water level for this 16 year period is about 15.8 ft NGVD.

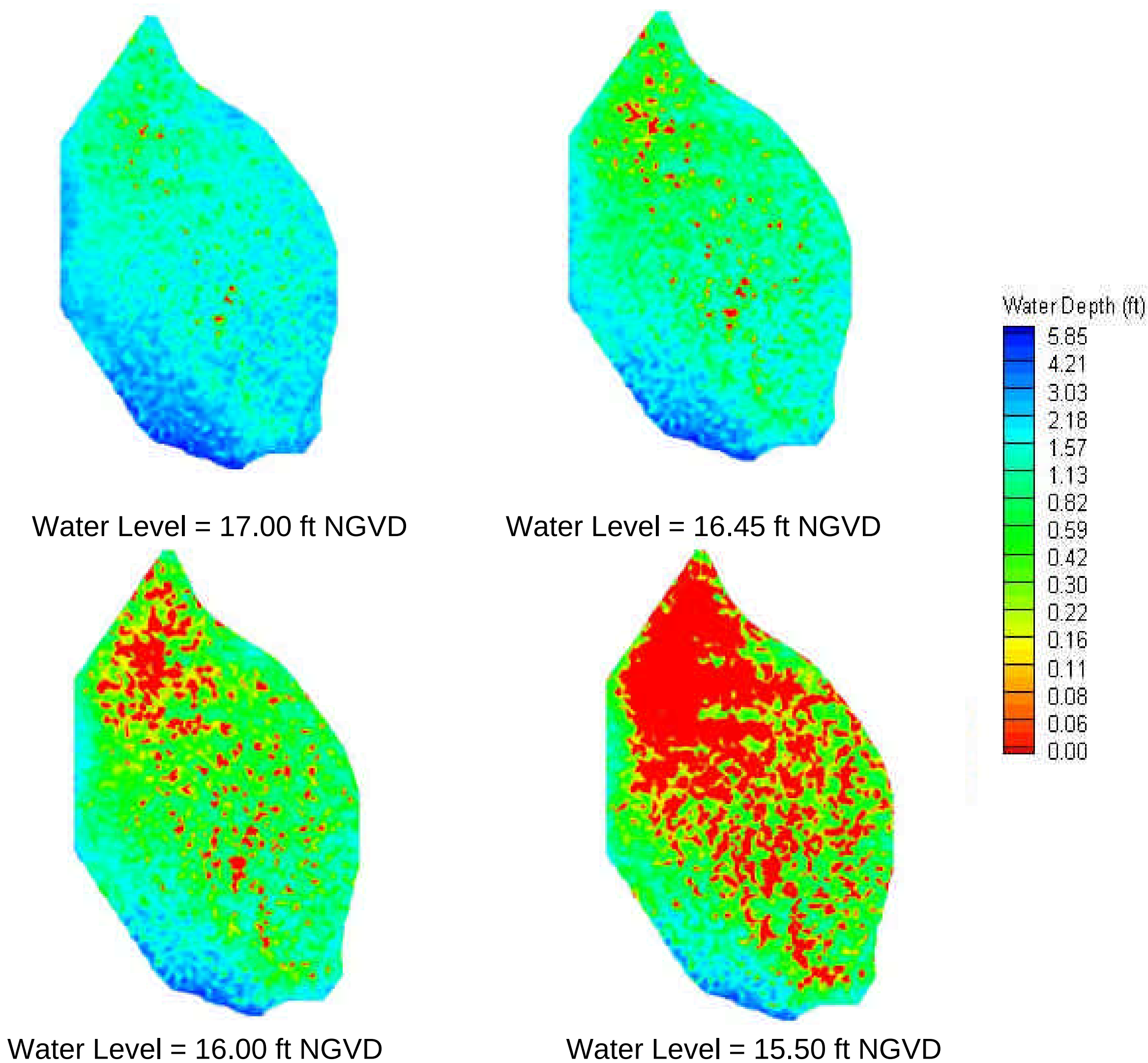

Figure 11. Water Depths in the Loxahatchee Refuge for Different Water Levels

1.3.5. Discharge

Inflows and outflows are important components of the Refuge's water budget. Runoff enters the refuge through the pump stations G-251, and G-310 (STA-1W), the Acme 1 and Acme 2 (via gate G-94D) pump stations, and historically received discharge from the now-diverted S-6 pump station (diverted to STA-2, May 10, 2001) and the S-5A (diverted to STA-1W in August 26, 1999). At times, significant flows continue to be discharged from the S-5A through bypass gates G-300 and G-301 directly into the Refuge. Bypass of the S-6 discharge directly to the refuge is possible through bypass gate G-338, but such bypasses have not occurred since diversion. Pump station S-362 will soon also be discharging to the refuge from STA-1E. Figure 12 shows the location of these pumping stations. The S-5A station pumps water from the West Palm Beach Canal, the G-251 and G-310 pump water from the Stormwater Treatment Area 1-W, and the S-6 station pumps water to the Hillsboro (L-39 canal, see Figure 12). According to USFWS (2000) the amount of water pumped from S-6 was about 155,000 acre-feet per year, representing nearly 30% of the runoff that came in through structures. This water loss needs to be compensated by increasing flows through the G-310 station and Stormwater Treatment Area 1-E and/or by reduction in outflows from the Refuge. These changes in water management may have water quality impacts that need to be evaluated.

The water outlet structures on the Refuge are G-94A, B, and C that provide water supply to the Lake Worth Drainage District (LWDD) on the east side, and the S-10 and S-39 spillways on the south and west side (USFWS, 2000). The S-10 consists of three spillways, i.e, S-10A, S-10C and S-10D (S-10B was proposed but never constructed), and functions as a flood control gate operated by the Corps of Engineers. The S-10E consists of three 6-foot diameter gated culverts, and it is operated as an additional outlet from WCA-1 (see Figure 12) by the SFWMD. The S-39 is operated to make water supply releases from the Refuge during the dry season, and to discharge excess water to the ocean when capacity is available in the Hillsboro Canal and water is not needed in WCA-2 or -3. Water may also be released at the north end of the Refuge through the G-300 and G-301 to the C-51 Canal via the S-5AS for water supply.

Meselhe et al. (2005) presented an evaluation of the Refuge hydraulic structures' flow data for the period of record between January 1, 1994 and December 31, 2004. For this period, they found that the yearly average inflow and outflow to the Refuge (through hydraulic structures) are 579,038 and 576,141 acre-ft, respectively. Table 1 shows the total cumulative inflows and outflows from hydraulic structures into and out of the Loxahatchee Refuge.

Table 1. Cumulative Inflows and Outflows to the Loxahatchee Refuge - Flow Through Water Control Structures for the Period Between January 1995 and December 2004. (After Meselhe et al., 2005)

Structure	Type of Flow	Type of Flow	Operational Dates		Total Operative Days during the POR	Daily Average Flow (cfs)	Net Inflow Volume (Ac-ft)	Net outflow Volume (Ac-ft)
			Start	End				
S-5A	Pump Station	Inflow	1/1/1995	8/26/1999	1698	391.8	1,319,556	0
S-5AS	Spillway	Bidirectional	1/1/1995	6/7/1999	1618	112.8	0	362,004
G-300	Spillway	Bidirectional	8/26/1999	12/31/2004	1954	2.4	9,302	0
G-301	Spillway	Bidirectional	8/26/1999	12/27/2004	1950	28.4	109,845	0
G-310	Pump Station	Inflow	7/7/2000	12/31/2004	1638	411.0	1,335,308	0
G-251	Pump Station	Inflow	1/1/1995	12/31/2004	3652	118.6	859,095	0
S-6	Pump Station	Inflow	1/1/1995	5/15/2001	2326	398.6	1,838,963	0
S-10E	Culvert	Outflow	1/1/1995	12/31/2004	3652	33.4	0	241,937
G-338	Culvert	Inflow	1/1/1995	5/15/2001	2326	0.0	0	0
S-10D	Spillway	Outflow	1/1/1995	12/31/2004	3652	175.9	0	1,274,156
S-10C	Spillway	Outflow	1/1/1995	12/31/2004	3652	146.3	0	1,059,744
S-10A	Spillway	Outflow	1/1/1995	12/31/2004	3652	141.4	0	1,024,250
S-39	Spillway	Outflow	1/1/1995	12/31/2004	3652	184.7	0	1,337,900
S-362	Pump Station	Inflow	9/21/2004	12/31/2004	101	99.2	19,873	0
ACME # 1	Pump Station	Inflow	1/1/1995	12/31/2004	3652	21.4	155,014	0
ACME # 2	Pump Station	Inflow	1/1/1995	12/31/2004	3652	19.8	143,424	0
G-94C	Culvert	Bidirectional	1/1/1995	12/31/2004	3652	38.7	0	280,329
G-94B	Culvert	Outflow	1/1/1995	12/31/2004	3652	4.7	0	34,045
G-94A	Culvert	Outflow	1/1/1995	12/31/2004	3652	20.3	0	147,046
					Total		5,790,380	5,761,411

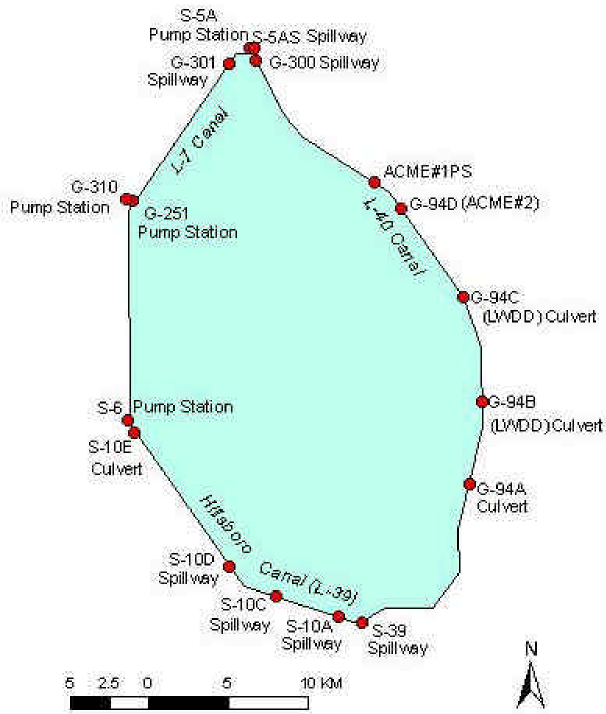

Figure 12. Location of Hydraulic Structures in the Loxahatchee Refuge (adapted from Meselhe et al., 2005)

1.3.6. Groundwater

Renken et al. (2005) indicated that Southeastern Florida is underlain by Holocene- to Tertiary-age karstic limestone deposits that form (in descending order): a highly prolific surficial aquifer system, a poorly permeable intermediate confining system, and a permeable Floridian aquifer. The surficial aquifer system contains water under unconfined conditions with discharging occurring to canals, the Atlantic Ocean and ET. The surficial aquifer system serves as the principal source of water supply for the Palm Beach County (Renken et al., 2005). According to Miller (1988) the average thickness of the surficial aquifer in the Palm Beach County is about 200 feet. Miller (1988) further divided the surficial aquifer in Palm Beach County into three zones: (1) Zone I, is the most permeable part of the surficial aquifer system with transmissivities in the range of 1,000 ft^2/s to 100,000 ft^2/s; (2) Zone II, is a zone in general less permeable than Zone I with an average transmissivity of about 5,360 ft^2/s; and (3) Zone III, is the least permeable part of the aquifer system. For Zone III, Miller stated this zone presents "nearly impermeable marls which almost totally prevent infiltration of surface water in most of the area." According to Miller, most of the Loxahatchee Refuge is in Zone III with just a thin band of the Refuge east in Zone I and a small portion of the south-east in Zone II. As indicated by Welter (2002), Miller findings suggest that, in the Loxahatchee Refuge, surface water processes are much more important than ground water processes.

Ground-water levels are highest near the impounded WCAs and lowest near the coast; consequently, the hydraulic gradient in southeastern Florida is seaward and the movement of groundwater is east and southeast toward the coast (Renken et al., 2005). Water levels are highest in September to October (end of wet season) and lowest during April or May (end of dry season). Renken et al. (2005) showed that for the east boundary of the Refuge, the average water level in the surficial aquifer varied from 16 to 14 ft NGVD29, for the period 1990-1994. Miller (1988) showed that the elevation of the water table around the Refuge varied between 12 ft NGVD29 and 14 ft NGVD29, for the year 1984.

The groundwater information inside the Refuge is very scarce. In fact, there are no groundwater stations in the interior of the Refuge. The general consent is that since water levels in the Refuge are consistently higher than surrounding levels, seepage is usually out of the Refuge (Trimble, 1986; Lin and Gregg, 1998; Welter, 2002; Griborio et al., 2006). Several water budget and hydrodynamic model for the Refuge has neglected the effect of groundwater in the basis that groundwater processes are much less important than surface processes (Richardson et al., 1990; Miller, 1998; Walker, 1995; Munson et al., 2002). However, the estimations presented by Lin and Gregg (1998) and Griborio et al. (2006) indicate that seepage may account for about 5% to 9% of the water outflow from the Refuge. Griborio et al. (2006) used the following equation to estimate the rate of loss of groundwater recharge in the canal or marsh:

$$G_i = r_{seep-i}(E_i - E_B) \qquad (2)$$

where $i = l \ or \ m$ for levee (canal) or marsh, respectively.

r_{seep-l} is the levee seepage rate constant = $6.x10^{-2}$ d^{-1} (Lin and Gregg, 1988).

r_{seep-m} is the marsh seepage rate constant = $4.x10^{-6}$ d^{-1}.

E_B is the boundary water surface elevation = 11.5 ft NGVD (3.5 m).

1.3.7. Hydrologic Budget of the Refuge

The water entering the Loxahatchee Refuge comes from two main sources rainfall and agricultural and urban runoff. Rainfall constitutes approximately 56 to 60 percent of the total input as reported by USFWS (2000) and Richardson et al. (1990). For the selected 10-year POR (1995-2004), the average annual inflow from hydraulic structures is about 579,038 Ac-ft and the average annual inflow from precipitation is about 621,836 Ac-ft. These amounts total an annual total inflow of 1,200,874 Ac-ft with precipitation representing the 51.8% and inflow from structures the 48.2%.

Water leaves the Refuge by ET, infiltration, levee leakage, or through a series of control structures. For the POR, the average annual outflow from hydraulic structures is equal to 576,141 Ac-ft. For the same period, the estimated ET and seepage are 563,160 Ac-ft and 61,570 Ac-ft, respectively. Based on these values, outflow through structures represents the 48.0 % of the total outflow and ET and seepage represent 46.9% and 5.1%, respectively.

1.3.8. Refuge Water Management - Regulation Schedule

Following approximately five years of analysis and negotiation, the current Refuge Water Regulation Schedule was established in May, 1995, and it is administered by the U.S. Army Corps of Engineers (US Army Corps of Engineers Jacksonville District 1994). The Refuge Water Regulation Schedule is described in detail in the Comprehensive Conservation Plan for the Refuge (USFWS, 2000), and is summarized below:

Purpose and Management: regulate the water level in WCA-1 to produce maximum benefits for flood control, water supply, fish and wildlife, and prevention of salt water intrusion. To meet these objectives, water level in the Refuge is adjusted during the year either by release or pump water into the refuge or by a combination of both. A schematic diagram of the water regulation schedule is shown in Figure 13.

Schedule: the water regulation time schedule is grouped into four zones (Neidrauer 2004):

- Zone A1: is the flood control zone from January through June. When water levels reach this zone, active water releases will be made through the S-10 spillway (and S-39 when agreed between USACE and SFWMD). Water supply releases as needed.

- Zone A2: from July through December, attempts are made to maintain water levels within this zone. In this zone, water levels in the Refuge, which are linked with rainfall amounts and the water level at Lake Okeechobee, are permitted to reach a maximum of 17.5 feet NGVD29. Excess water is released from the S-10 and S-39 spillways. When additional water is needed for WCA-2A or other areas, it is released from the Refuge depending on relative water level at Lake Okeechobee. If Lake Okeechobee stage is above WCA-1 stage or no more than one foot below, then water supply releases from WCA-1 must be preceded by an equivalent volume of inflow (Neidrauer, 2004).
- Zone B: is the water supply zone, and ranges from a minimum of 14.0 to 17.5 feet NGVD 29 during the year. When water levels in the Refuge are within this zone, water releases are allowed, as needed depending on the water level at Lake Okeechobee. If Lake Okeechobee stage is above WCA-1 stage or no more than one foot below, then water supply releases from WCA-1 must be preceded by an equivalent volume of inflow (Neidrauer, 2004). This is the zone considered to be most beneficial to fish and wildlife of the Refuge (USFWS, 2000).
- Zone C: when water levels drop to 14.0 feet NGVD or less, there would be no net release of water from the Refuge. Any water supply releases must be preceded by an equivalent volume of inflow.

Benefits of Water Regulation Schedule (USFWS, 2000):

- Increased hydroperiod of interior marshes to avoid annual dryout.
- Increased water depth during the wet years in the northern portion of the Refuge.
- Increased area of interior marsh which serves as nursery areas for aquatic organisms.
- Improvement in timing of winter stage drawdown to benefit wading birds
- Restoration of deep water habitats suitable for nesting Everglades snail kites.
- Greater water storage within the central and southern Florida project system during wet and normal rainfall years

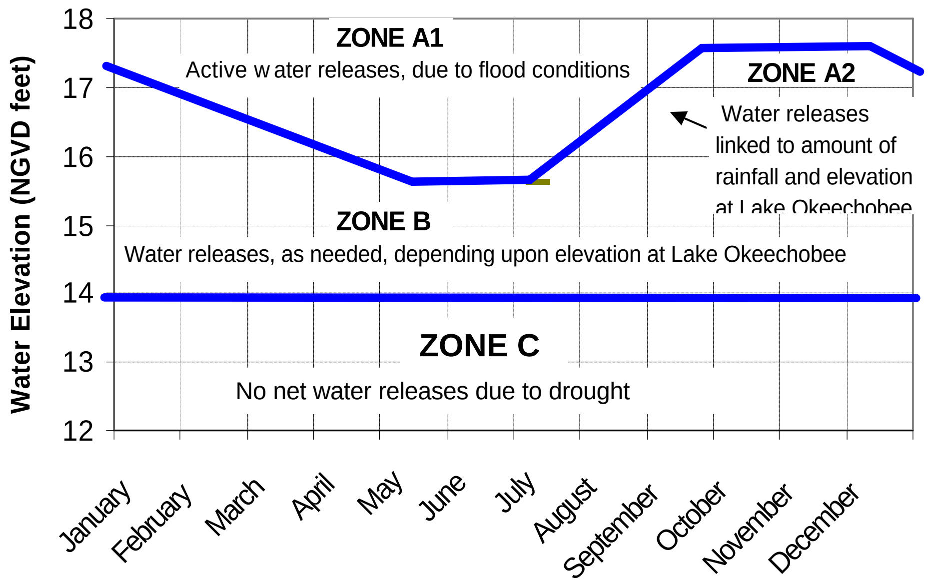

Figure 13. Water Regulation Schedule for Water Conservation Area 1 (Adapted from Comprehensive Conservation Plan for the Loxahatchee National Wildlife Refuge, USFWS, 2000)

There are current discussions of revising the Refuge regulation schedule to take into account newer data and understanding of hydrological, ecological, and water quality relationships. Analyses supporting management decisions concerning alternative schedule revisions should utilize the model being discussed in this report.

1.3.9. Hydrodynamic

Two major features define the hydrodynamic of the Loxahatchee Refuge: a rim canal and the marsh interior. Figure 12 shows the location of the canals around the Refuge. Naturally these two features interact among them, but in a limited manner. All of the water that is pumped into the Refuge goes into the canals and much of this water move through the canals around the perimeter and leaves the Refuge directly through the southwestern and eastern structures. Richardson et al. (1990) indicated that much of the water in the interior part of the Refuge comes from rainfall, and that the interior is basically a rainfall driven system. This conclusion is strongly supported by patterns of mineral constituent concentrations in the interior (Richardson et al. 1990; Weaver and Payne 2004).

The Refuge rim canal can be divided in two major systems, i.e., the western system that is formed by the L-7 and L-39 canals and the eastern system that is formed by the L-40 canal (see Figure 12). For the western canals, the sediment surface elevations range between 7.0 and -1.5 ft NGVD29 with a mean elevation equal to 2.4 ft. For the L-40 canal, the sediment surface elevations range between 6.7 and -5.7 ft NGVD29 with a mean elevation equal to 3.2 ft. The top width ranges between 205 and 120 ft for the western canal, and between 173 and 88 ft for the L-40 canal, the mean top widths are 169.7 and 121.5 ft for the western and for the L-40 canals, respectively. The thalweg profiles for the sediment surface elevations and for the channel bottom elevations are presented in Figures 14 and 15, for the L-7/L39 canals and for the L-40 canal, respectively. The profiles for the L-7/L-39 canals are quite irregular with almost a horizontal average slope. On the other hand, the profile for the L-40 canal is better defined with a north to south mild slope of about 3.2 inches per mile. For the POR, the average depths in the L-7/L-39 canal systems vary between 17.9 ft and 9.4 ft, with a mean depth of about 14.1 ft. For the L-40 canal the water depths vary between 22.0 ft and 9.8 ft with a mean depth of about 13.2 ft.

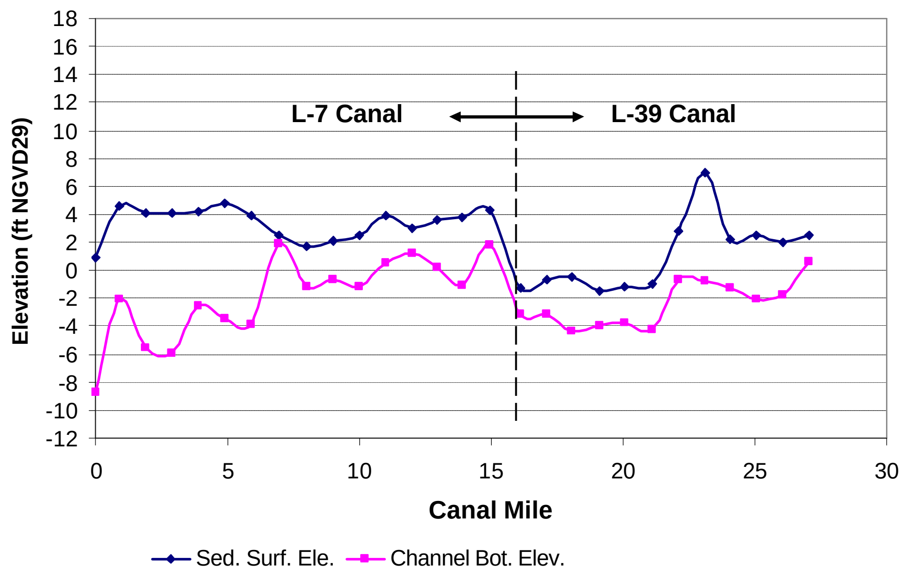

Figure 14. Thalweg Profiles for the Sediment Surface Elevation and Channel Bottom Elevation for the Western Canals (L-7 and L-39) (adapted from Meselhe et al., 2005)

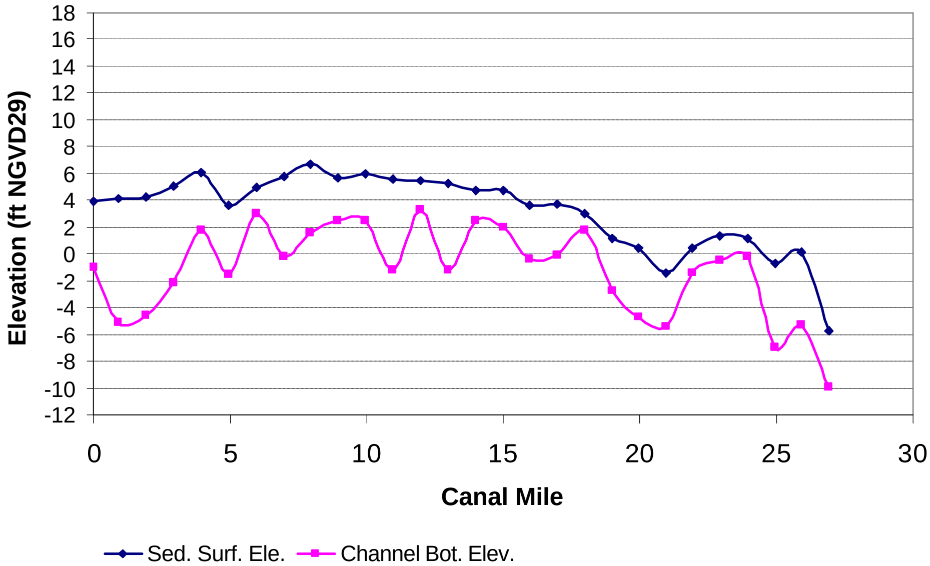

Figure 15. Thalweg Profiles for the Sediment Surface Elevation and Channel Bottom Elevation for the Eastern Canal (L-40) (adapted from Meselhe et al., 2005)

The marsh area of the Refuge has a very mild north to south slope, which results in a slow southward flow movement (Meselhe et al., 2005). The north to south slope is about 1 inch per mile. As indicated in a previous section, for the POR, the average water depth in the marsh area of the Refuge is about 1.45 ft ranging between 0 ft and 5.84 ft.

There are not water velocity measurements in the Loxahatchee Refuge, neither in the canal nor in the marsh. However, the estimated velocity in the marsh is about 100 m/d (Waldon, 2005). This value agrees with the results of tracer experiment conducted by Saiers et al. (2003) at a wetland in the Florida Everglades. They found the mean surface-water velocity to be equal to 5.3 m/h (about 127 m/d). Saiers et al. (2003) results indicated that longitudinal, lateral and vertical diffusion were small, and nearly equal to 0.16, 0.15 and 0.001 m^2/h, respectively. The U.S. Army Corp of Engineers (Ferguson, 2002) presented estimation of canal water velocities at the junction of the L-40 canal and the S-362 discharge canal using a 2-Dimensional (2-D) hydrodynamic model. The predicted velocities in the junction were 0.1, 0.2 and 0.8 feet per second for discharges of 550, 960 and 4200 cfs, respectively.

The flow resistance in the marsh area is affected by vegetation and water depth. Naturally, there is significant increase in flow resistance due to vegetation. Similarly, the flow resistance increases as the water depth decreases. Shih and Rahi (1982) presented the field evaluation of Manning's roughness coefficient in a Floridian slough marsh. They found that Manning's n ranged from 0.16 to 0.55 as the water depth varied from 0.40 to 0.65 m. Rosendahl (1980) also presented a field investigation of Manning's Roughness Coefficient and longitudinal dispersion coefficients in the Everglades marsh. Rosendahl found that Manning's n varied between 0.43 and 2.76 for water depths between 0.2 and 2.0 ft. He also found that the longitudinal dispersion coefficient varied between 0.37 and 22 m^2/hr. In the application of the South Florida Water Management Model (SFWMM), MacVicar et al. (1984) calibrated the friction losses for overland flow. They found good results using the following relationship for Manning's n:

$$n = a H^{b} \qquad (3)$$

Where H is the water depth in ft, and a and b are usually equal to 0.5 and -0.77. Using Eq. 3 and the average depth of 1.45, the average Manning's n for the Refuge is about 0.38.

Barnes and Tarboton (2002) provided a list of *a* and *b* coefficients for different land uses and vegetative communities. These values were provided as starting values for the South Florida Water Management Model (SFWMM) 2000 calibration effort. Table 2 shows an overview of these coefficients.

Table 2. Overland Flow Coefficients for Eq. 1 (after Barnes and Tarboton, 2002)

Land Use Type	Manning's n Coefficients		Land Use Type	Manning's n Coefficients	
	a	*b*		*a*	*b*
Urban	.080 - 0.200	0.00	Cattail	1.110	-0.77
Citrus	0.2250	0.00	Mix Cattail/Sawgrass	1.110	-0.77
Row Crops	0.2250	0.00	Wet Prairie	1.200	-0.77
Sugar Cane	0.2250	0.00	STA	1.350	-0.77
Irrigated Pasture	0.2250	0.00	Forested Wetland	0.155	-0.77
Shrubland	1.5500	-0.77	Forested Uplands	0.850	0.00
Marl Prairie	0.6000	-0.77	Mangroves	0.950	-0.77
Ridge & Slough	0.700 - 1.000	-0.77	Melaleuca	0.350	-0.77
Sawgrass Plains	1.1100	-0.77	Water	0.010	0.00

Barnes and Tarboton (2002) specified that Ridge and Slough are the predominant vegetation cover for WCA-1 with an "*a*" coefficient equal to 0.9 and a "b" coefficient equal to -0.77.

There is not concrete information about the effect of wind in the Refuge's hydrodynamic. However, since the density of emergent vegetation in the Refuge is very high, is it not expected that wind will be a major forcing component. Even though, the effect of wind will be included in the modeling effort.

1.4. Water Quality

Along with the changes in water quantity and timing, changes in water quality are introducing negative impacts to the Everglades ecosystem (Richardson et al., 1990; Walker, 1991 and 1995; Davis et al., 1994; Light and Dineen, 1994; McCormick et al., 1996; USFWS, 2000; Brandtl et al., 2000; Raghunathan et al., 2001; Childers et al., 2003). The Everglades ecosystem is characteristically oligotrophic (Childers et al., 2003) and phosphorus limited (McCormick et al., 1996, Raghunathan et al., 2001) and is comprised of species that have evolved to develop under low nutrient conditions (USFWS, 2000). According to Childers et al. (2003) water column total phosphorus concentrations in the Everglades are typically less than 10 μg/L. It is well documented that water flowing into the Everglades has an important load of nutrients and other contaminants (e.g., Richardson et al., 1990, Stober et al., 1996; USFWS, 2000). Nutrient loading from urban areas and the EAA has significantly increased nutrient concentrations, particularly phosphorus, in the water conservation areas (USFWS, 2000). Childers et al. (2003) reported that in northern Everglades regions, near the EAA, total phosphorus concentrations often exceed 100 μg/L. Atmospheric deposition is another important source of nutrients. Richardson et al. (1990) reported that, from 1979 through 1988, atmospheric deposition accounted for 25% of the P and 15% of the N entering the Refuge compared to 75% of the P and 84% of the N entering via S5 and S6 combined.

Despite the specific values reported by Richardson et al. (1990), the estimate of average rainfall phosphorus concentration is uncertain, and analysis of aerial deposition data is statistically challenging (Ahn 1999a; Ahn 1999b; Ahn and James 1999a; Ahn and James 1999b; Grimshaw and Dolske 2002; Pollman et al. 2002; Redfield 2002; Walker and Jewell 1997). Measurements of atmospheric deposition rates are complicated by numerous sources of contamination which can cause positive bias. Estimates of atmospheric phosphorus deposition have ranged from 17 to 96 mg/m^2 per year for different locations in South Florida (Walker, 1995). Most modeling approaches for the Everglades have used a constant value for the atmospheric phosphorus deposition. Walker (1995) assumed a constant value of 43 mg/m^2-yr for an area adjacent to the Refuge. Raghunathan et al. (2001) used a temporally and spatially constant value of 43 mg/m^2-yr. Munson et al. (2002) used an equivalent rainfall concentration of 30 ppb (about 35 mg/m^2-yr). It will be particularly challenging to correctly address atmospheric deposition in this modeling effort.

The Refuge is unique in that most of the high nutrient water received from the control structures remains in the rim canals without actually flowing through the interior of the Refuge. Some high nutrient water does move into the Refuge, but evidence indicates that it moves slowly and affects only a limited distance of habitat near the canals (USFWS, 2000). Richardson et al. (1990) indicated that there is a large central core area of water in the interior of the Refuge whose nutrient composition is typical of rain water atmospheric deposition, surrounded by an area with a higher nutrient composition affected by the pumped inflows to the perimeter canal. USFWS (2000) reported that areas in the western, southwestern, southern, and southeastern portions of the Refuge are currently being eutrophied by nutrients inputs.

Wetlands respond to nutrient enrichment with characteristic increases in soil nutrients and shifts in plant community compositions (Childers et al. 2003). Among the negative effects from increased nutrients are: loss of native sawgrass communities, conversion of wet prairie plant communities to cattails, invasion of exotic plants, and loss of important habitats for wading birds (USFWS, 2000). Important efforts are being made to reduce the nutrient load entering the Everglades ecosystem, e.g., construction of Stormwater Treatment Areas. However, Childers et al. (2003) found that, even though water quality improved throughout much of the Everglades in the 1990s, water quality impacts worsened during such time in areas of the northern Everglades. For the Loxahatchee Refuge, Childers et al. (2003) found that zones of high phosphorus (exceeding 700 mg P/Kg dry wt. soil) increased to more that 1 Km from the western margin canal, between the period from 1989 and 1999. For the same period they found that cattail-dominated marsh increased from 0.5 to 1.0 Km, measured east from the S-6 pump station. It is important to notice that there is some level of uncertainty in Childers et al. (2003) results for the Loxahatchee Refuge, since he reported a transect length of 30 Km (west to east across the

Refuge from the S-6 pump structure to the L-40 boundary canal), while such a transect is only 22 Km.

2. LITERATURE REVIEW

2.1. Historical Review of Previous Modeling Effort for the Refuge

Significant efforts have been devoted to model the hydrology and water quality of the Loxahatchee Refuge, alone or as a part of the greater Everglades. This section provides a chronological review of documented-past modeling efforts related to the Refuge:

- Lin (1979) adapted and modified the Receiving Water Quantity Model (EPA, 1971) to model the Water Conservation Areas in order to investigate the hydraulic impact of additional inflow under different pumping scenarios. Lin (1979) modeled Water Conservation Areas 1, 2A and 3A with 20 link-nodes each. The network system for WCA1 contained 20 nodes and 57 channels. The calibration of the model was based on comparison of predicted and observed stages at selected gages. The model was calibrated for the 1974 year data, and then was applied to the period from 1962 to 1973. For WCA1, predicted and recorded values at gages S-6, 1-8, 1-7 and 1-9 were compared. It should be noted that gages S-6 and 1-8 are located in the existing canal system, while 1-7 and 1-9 are located in the central marshland of the Refuge. For the validation period, important deviations were observed between the model results and the measurements. The deviation for interior gages was far less than the one in the canal system. Lin (1979) recommended that the number of nodes in the network system should be increased in order to provide a better representation of the real water body, and also that some existing relationship in the model should be improved (see Lin, 1979, for details). The investigator did not model groundwater or water quality in the study.

- MacVicar et al. (1984) presented the application of the South Florida Water Management Model (SFWMM) to two planning areas, the Lower East Coast (LEC) and the Upper East Coast (UEC). The WCA1 was included in the LEC model that also included the other Water Conservation Areas, the Everglades Agricultural Area, most of Big Cypress National Preserve, Everglades National Park, and the urban areas of the LEC that covered Dade, Broward, Palm Beach, and parts of Monroe and Collier Counties. A two by two mile node spacing was used to cover the 6,880 square miles area modeled. A time step of one day was used. The model was able to simulate overland, channel and groundwater flow. McVicar et al. (1984) indicated that simplified mathematical formulations were implemented in order to make the model computationally efficient. For example, the canal routine developed for this model was a mass balance procedure that sums all the inflows and outflows of a canal to determine the water surface position at the end of each day. The canals were defined as continuous channel reaches with flow control structures at the upstream and downstream ends. On the other hand, the overland flow was simplified using a diffusion flow approximation based on Manning's equation. Naturally, this model cannot be expected to provide detailed flood routing results for single events, or to define in detail the depression cone around municipal wells; but, according to MacVicar et al. (1984) the model did simulate regional flooding in undeveloped areas, and also indicated excessive groundwater drawdowns when they occurred.

MacVicar et al. (1984) indicated that the period 1969-1971 was chosen as the calibration period because it contained the extremes of severe drought and heavy rainfall within the three-year span. The period of 1973-1975 was selected as validation period. The investigators reported a good agreement between simulated and recorded water levels at two gages in WCA1 (gages 1-8 and 1-7). They reported that evapotranspiration and overland friction losses were the two major calibration parameters. Water quality and mass transport were not simulated during this study.

The SFWMM continues to be developed and its period-of-record for simulation extended in support water resources management in the South Florida area (SFWMD 2003). A companion model, the Natural Systems Model (NSM), also continues in development. The NSM is essentially the SFWMM with manmade alterations of the system (e.g. canals, levees, water control structures) removed, and topography restored to an estimate of pre-development conditions. The NSM has provided a basis for some restoration targets but its application remains a source of controversy .

- Richardson et al. (1990) studied the distribution of water over space and time, and how vegetation was being structured on the Refuge by hydroperiod pattern. A hydrologic model was developed to better understand the hydrologic characteristic of the Refuge. For this task, topographic data was gathered at a resolution of approximately 1 minute of latitude and longitude. Data recorded at each site included water depths, and percent cover by each vegetation class. Elevations were determined by measuring the water depths at all of the grid locations and then subtracting from an assumed horizontal water level. A flat pool condition of water in the Refuge was obtained by holding water at the 17 foot level during the time that the grid survey was being conducted.

  A hydrologic simulation model was constructed utilizing the Adaptive Environmental Assessment Everglades Simulation Model (AEA Everglades Model) developed by Carl Walters (Walters, 1990; Tait, 1990). Among the modifications to the AEA Everglades model to make it applicable to the Refuge, are: 1) the cell size was reduced from 4000 meters to about 915 meters (3,000 ft.), 2) the roughness coefficient used in the Manning equation to calculate fluxes between cells were adjusted to the new grid size, 3) rainfall data for the Refuge (from SFWMD) were substituted for South Florida rainfall, and 4) the cells along the edge that were influenced by the rim canal were tagged in the model as canal cells. The stage of the rim canal was not modeled but used as a boundary. The input and output to the canal were controlled using the historic monthly canal levels (data form SFWMD) by adjusting the water depths in canal cells.

  A 16 years period, 1970 through 1985, represented the standard base run of the model. The simulations were compared to two stage stations, one approximately in the center of the Refuge (gage 1-7) and the other in the south-east portion of the Refuge (gage 1-9). Recorded data indicated that, during the 192 month time period, there were 33 and 11 months of drawdown at the 1-7 and 1-9 gages respectively. With water depths smaller than 0.075 feet set as dry, it was predicted there were 30 months of drawdown at the 1-7 gage and 14 months of drawdown at the 1-9 gage. The model slightly underestimated the 16-year hydroperiod for the central gage and slightly overestimated the hydroperiod at the southeast gage. The R^2 values were 0.75 and 0.83 for water levels at gages 1-7 and 1-9, respectively. The model was later used for approximating spatial hydroperiods for the Loxahatchee Refuge. Estimates of water depth, variance in water depth, hydroperiod, variance of hydroperiod, and water surface elevations for each monthly time period over the 16 year simulation were obtained for each of the 750 grid cells. The 16 year hydroperiod over the entire Refuge ranged from 70% to 98% (wet period over total period) exhibiting an obvious north-south trend of increasing hydroperiod with localized anomalies corresponding to topographic features. Mean water depth for the study period ranged from 0.2 ft. in the north end to 3.2 ft. in the south. It was found that the north end of the Refuge had much greater variance in hydroperiod than the south end. Richardson et al. (1990) stated that during dry years, the north end of the Refuge is much more susceptible to staying dry for long periods, while in the south the dry season is not as likely to completely dewater the marsh for months at a time.

- Raghunathan et al. (2001) developed the Everglades Water Quality Model (EWQM) to predict phosphorus (P) fate and transport in the Everglades. The Water Conservation Areas and the Everglades National Park (ENP) were included in the model. The output from the SFWMM was used to transport phosphorus between model cells and canals. As in the SFWMM, the model used 2 x 2 mile grid-cells. A simplified relationship based on a single apparent net settling rate coefficient was used to represent the combined effect of all biogeochemical processes that control the dynamics of phosphorus in the water column. This simplified relationship indicated a net deposition of phosphorus in the sediments. An apparent net settling rate equal to 6.30 m/year was found for WCA-1 during the calibration period. The model simulation period extended from 1979 to 1989. Model results indicated that the interior of WCA-1 exhibits much lower concentration than the areas near the rim canal. However, the rim canal was simulated with a single water quality segment without nutrient concentration gradients (the EWQM assumed a constant canal water depth of 3m). Model results also suggested that reduction of P concentrations leaving the EAA will result in lower concentrations entering the Everglades National Park (Raghunathan et al. 2001). Even though a good tool for screening the effects of nutrient reduction options in the regional scenario of the EAA-WCAs-ENP system, this model lacks the level of details necessary to accurately model the phosphorus dynamic, and the temporal and spatial distribution of water within the Loxahatchee Refuge.

- Welter (2002) used the Regional Simulation Model (RSM) to simulate the hydrology of the Loxahatchee Refuge. The model used a grid with 16,292 triangular cells with average element size of 650 ft. Overland, canal, and groundwater flows were modeled. Welter (2002) expressed that the groundwater portion of the model was simplified as much as possible, since the overland processes seems to be more important. Welter (2002) indicated three reasons for this approach: 1) the RSM was currently a single layer model and could not simulate vertical head gradients; 2) there were no ground water stations in the interior of the Refuge (i.e. there were no sufficient information for calibrating a model, and even if the model simulated vertical exchange, it could not be calibrated); 3) previous work by Miller (1988) and the SFWMD suggested that groundwater processes are much less important than the surface water processes.

  The RSM was calibrated over the period of record of 1988 and 1990, and verified for the four-year period, 1991 to 1994. The model results showed the same trends observed in the field measurements. However, some deviations were observed. Welter indicated that "the most disappointing aspect of these results is that measured data shows a larger slope in the canal's water level than the model calculates", he attributed this discrepancy to inaccurate cross section data which, according to him, overestimated depths. He also expressed that "the limiting factor in this modeling effort is the sparse network of stage monitoring stations in the Refuge". Welter (2002) indicated that most of the stations are in the perimeter canal, and that the only stations in the marsh areas are the 1-7, 1-8 and 1-9 water recorders. Water quality and mass transport were not simulated during this study. To the best of our knowledge, and at the time of writing this report, the water quality module of the RSM is in development and is not currently available.

- Munson et al. (2002) developed the Everglades Phosphorus and Hydrology (EPH) model to simulate water movement and phosphorus dynamics in the water that flows from the EAA through WCAs and into the Everglades National Park. The EAA-WCAs-ENP system was modeled as a series of cells with water flowing from one cell to the next, using a monthly time step. In this application the Loxahatchee Refuge was modeled with only three cells, cell

1 had a surface area of 250 ha. representing the rim canal, cell 2 had a surface area of 46,952 ha. representing the north-central portion, and cell 3 with 11,734 ha. represented the southern part of the Refuge. The hydrologic processes simulated by the EPH model included precipitation, evapotranspiration, inflow and outflow. Total phosphorus in the water column was the only nutrient modeled in this application.

Evapotranspiration parameters and stage-discharge relationship were adjusted during the calibration process to obtain the best results for flows and water surface elevations. The period of record of 1980-1988 was used for this purpose. The phosphorus removal rate in each cell was adjusted in order to match simulated and observed concentrations. During the calibration, the average deviations between simulated and observed values for water depths and phosphorus concentrations were 7 and 6%, respectively. The model was later applied to simulate the impacts on annual average total P concentrations in each cell as a result of the implementation of the management plan mandated by the Everglades Forever Act. Model results indicate that reductions in input P concentrations will have little impact on P concentrations for 85% of the area of the WCAs and on the water entering the ENP.

- Fitz et al. (2002a) presented the calibration of the Everglades Landscape Model (ELM) to match the observed data on water stages and total phosphorus concentration in the water column at about 60 point locations distributed throughout the greater Everglades using a 1 Km x 1 Km square grid. ELM simulates surface, canal and groundwater flow, but it only considers advective flow (dispersion is not modeled). Cell surface and groundwater flows are solved using a finite difference, Alternating Direction Explicit (ADE) technique, providing for propagation of water and water-borne constituents across space. The simulation of phosphorus cycles includes uptake, remineralization, sorption, diffusion, and organic soil loss/gain. Sixty gages were used for the calibration of water stages (during the period from 1979 to 1995), but only three gages were located inside the Loxahatchee Refuge (gages 1-7, 1-9 and 1-8T). The water quality data used in the calibration was total phosphorus (TP) concentration sampled in the surface water column during the period from 1979 to 1995. Of 57 monitoring sites, 21 were located inside the Loxahatchee Refuge. A goodness of fit statistic indicated that for water levels, the ELM simulated values explained 68% of variability in observed values. While for surface phosphorus concentrations, the results were poorer, with an overall R^2 of 0.10 for the individual simulated versus observed pairs. When weighted seasonal means were used, the average R^2 improved to 0.20. When each simulated and observed weighted-seasonal mean surface water TP concentration (at all stations) were compared, simulated values explained more than 50% of variability in observed values (Fitz et al., 2002a). However, differences close to ten orders of magnitude could be found at specific locations. It should be noted that the model was not validated. The authors claimed, "in our opinion, we do not have to validate the ELM. To build confidence in the models' utility we only need to demonstrate that it performs in a manner consistent with objective" (Fitz et al., 2002b). The authors (Fitz et al., 2002b) also stated "ELM is not currently intended for application by any individual other than the developers". At the time of writing this report, and to the best of our knowledge, the ELM model has not been validated for the Refuge nor has been used by any research group other than the developers.

- The U.S. Army Corp of Engineers utilized the RMA-2 finite element model to evaluate the discharge impacts of S-362 pump station outflow into the Refuge (SFWMD, 2004; Ferguson, 2002). The model only considered the area of the Refuge immediately adjacent to the S-362 pump station. It predicted, under various discharge scenarios, velocities at the junction of the L-40 canal and the S-362 discharge canal and velocity contours entering the Refuge. According to the SFWMD (2004), 1953 as-built cross sections of the L-40 borrow canal were used in the RMA-2 model simulations. The predicted velocities at the junction of the L40 and S-362 discharge canal were 0.1, 0.2 and 0.8 feet per second for a discharge of 550, 960 and 4200 cfs, respectively.

2.2. Previous Modeling Effort in other Wetland Systems

Several researchers have developed simulation models of the processes associated with wetland systems. A wide variety of hydrologic/hydrodynamic models have been used in conjunction with water quality models to evaluate the transport, removal and fate of nutrients in these shallow water environments. The hydrologic/hydrodynamic models used for simulating wetland systems range from simple empirical relationship (Kadlec and Hammer,1982) and simple hydrologic models (Mitsch and Reeder, 1991; Walker, 1995; Wang and Mitsch, 2000) to more sophisticated hydrodynamic models (Guardo and Tomasello, 1995; Martin and Reddy, 1997; Tsanis et al., 1998; Moustafa and Hamrick, 2000; Raghunathan et al., 2001; Munson, 2002; Fitz et al. 2002a; Meselhe and Douet, 2002). Similarly, the level of complexity on the water quality modules is also variable among the different models and applications. This section provides an overview of previous modeling effort on wetland systems that were not described in the previous section.

Kadlec and Hammer (1982) presented a theoretical paper discussing the transport of pollutant in wetland systems. They indicated that water flow in wetlands ecosystems, usually occurs in thin-sheet flows at slow rates, which are controlled by the ground slope, water depths, type of vegetation and by the degree and type of channelization. Kadlec and Hammer (1982) indicated that removal rates in wetland systems are fast in comparison to typical biological processes, and can be represented by a first-order reaction. They conclude that the velocity of the reaction suggest a rapid capture mechanism such as adsorption. Kadlec and Knight (1996) also suggested nitrogen and phosphorus removal in wetland systems can be approximated by first-order models. They indicated that corrections need to be made to account for non-ideal flow, infiltration, and atmospheric inputs and outputs. Mitsch (1988) and Mitsch and Reeder (1991) stressed the importance of developing a proper hydrologic model as the first step in producing a productivity and/or nutrient mass balance simulation. Mitsch and Reeder (1991) developed a hydrologic-nutrient removal model to estimate the fate of phosphorus in a wetland area adjacent to Lake Erie (one of the North American Laurentian Great Lakes). The only state variable in the hydrologic model was the volume of water in the marsh, which was affected by rainfall, inflow, evapotranspiration and outflow. The TP model included incoming phosphorus, macrophyte and plankton uptake, and sedimentation and resuspension of phosphorus. The calibration of the TP model was done by varying a resuspension coefficient until the model predicted phosphorus concentrations similar to field data. They also modeled plankton and macrophyte biomass productivity. Wang and Mitsch (2000) used a similar model to the one presented by Mitsch and Reeder (1991) for the evaluation of phosphorus dynamics in created riparian wetlands. The hydrology module was updated to include seepage, and bank storage in the water volume balance calculation, and periphyton community was included in the productivity model. The authors indicated that simulated TP concentrations did not follow observed data well especially during no outflow or low flow periods. They expressed that it was due to the fact that the model itself is a steady-state lumped model, unable to capture influences of disturbance and random effects such as carp or wind stirring of sediments. The lack of an atmospheric deposition term may have also introduced errors in the phosphorus budget calculations.

Walker (1995) presented the development of a mass-balance model for predictions of long-term-average phosphorus removal in Water Conservation Area 2. The model was driven by inflow volumes, precipitation, evapotranspiration, phosphorus loads in the influent and by atmospheric deposition, and a calibrated first-order settling rate. Walker (1995) concluded that a settling rate of 8.9 to 11.6 m/yr was supported by peat-accretion and water column data. He stated that, over a long time period, accumulation of P in plant biomass approaches zero as the ecosystem matures and approaches dynamic equilibrium.

Martin and Reddy (1997) used a simple two-dimensional hydrodynamic model to evaluate the fate and transport of nitrogen (N) in wetlands. Horizontal distribution of N was modeled by advective transport, and the vertical distribution was simulated as diffusive flux. The effects of precipitation and evapotranspiration were neglected in the model. Nitrogen transformation simulated in the model included enzymatic hydrolysis of organic N, mineralization, nitrification, NH_4-N adsorption/desorption, NH_3-N volatilization, denitrification, and vegetative assimilation and decay. The N processes, with the exception of vegetative uptake, were modeled using first-order kinetics. In this study, the diffusive flux was varied over three orders of magnitudes, ranging from rates indicative of molecular to turbulent diffusion. They concluded that other transport processes of magnitudes greater than molecular diffusion account for the transport of soluble N in wetland systems. Martin and Reddy (1997) proposed that the turbulent diffusion was augmented by vegetation induced water movement, i.e., drawing of water towards the roots; however, such explanation does not seem satisfactory to explain an increase of three orders of magnitude in the molecular diffusion. A fully dynamic 2-D depth average hydrodynamic model was used by Tsanis et al. (1998) to predict phosphorus and suspended solids concentrations in a marsh area (Cootes Paradise). They modeled the eddy diffusivity as a constant-isotropic value equal to 0.1 m^2/s. They used a simplified phosphorus model based on a sedimentation loss term that yielded partially good results. Even though the predicted and measured average values, for the total study area, were very similar; important differences were observed in discrete concentration for specific sites.

Guardo and Tomasello (1995) also used a fully dynamic 2-D depth average hydrodynamic model. They applied the SHEET2D model to the Florida's Everglades Nutrient Removal (ENR) Project. The ENR project contained 3815 acres limited at the east by WCA1, simulated in the application by a constant grid size of 600 by 906 feet. Guardo and Tomasello (1995) stressed the importance of wetland vegetation in hydrodynamic modeling. They stated that vegetation influence hydrologic conditions by consolidating the soil to protect against erosion, trapping sediments, building peat deposits, interrupting water flows, and changing flow paths. They also indicated that the capability of a model to simulate and predict water quality depends on its ability to simulate the relevant hydrodynamic processes. Guardo and Tomasello (1995) indicated that a limitation in the modeling effort was the fact that SHEET2D was constraint for a constant grid size, they observed that a variable-sized grid network is required for a better representation of channels, and in areas where steep topographic gradient exist, such as between the marsh and canal bottoms. The hydrodynamic of The Everglades Nutrient Removal (ENR) Project was also modeled by Moustafa and Hamric (2000). They applied the Everglades Wetland Hydrodynamic Model (EWHM), a version of the 3-D environmental fluid dynamic code (EFDC), to the ENR project in two dimensions (i.e., depth-averaged mode). Wind forcing, rainfall and ET were applied uniformly to the surface layer over the entire domain, and seepage from WCA 1 was estimated following Prymas (1997), and distributed evenly along the L-7 boundary levee. An interesting feature of the model is that the effect of submerged and emergent vegetation was incorporated into the turbulence closure model and flow resistance formulation, which is dependent of plant density. In fact, Moustafa and Hamrick (2000) indicated that, based on the vegetation resistance features, the model had no parameters to adjust and it was readily calibrated. The EWHM calibration to the ENR Project included comparison between predicted and observed water surface elevations, and between modeled and observed chloride (Cl) concentrations (no velocity measurements were available at interior sites). According to Moustafa and Hamrick (2000) the Cl comparison provided an additional assurance that modeled transport of a conservative tracer was accurate. R^2 values between 0.79 and 0.84 were reported for predicted and observed water levels at different locations, and the authors also claimed that modeled and observed Cl data showed a good agreement. In a comment to the Moustafa and Hamrick (2000) modeling effort, Kadlec (2002) stated, "Moustafa and Hamrick (200) were quite satisfied that their model was successfully calibrated to depth data. But their tracer transport predictions are now known to be badly in error”.

Recent works in modeling wetland areas have been presented by Welter (2002), Ferguson (2002), Munson (2002), Fitz et al. (2002a), Meselhe and Douet (2002, 2003 and 2004), and Saiers et al. (2003). The work of Welter, Ferguson, Munson, and Fitz et al. is directly related to the Loxahatchee Refuge and was detailed in the previous section. Meselhe and Douet (2002) presented the application of the 3-D hydrodynamic model, H3D (Stronach et al., 1993) to predict water levels variations, and salinity fluctuations in the Brown Lake of the Calcasieu-Sabine Basin. The modeling area contained approximately 2,800 acres of wetlands, consisting of vegetated marsh and open water. The local model was coupled with a 3-D model of the entire Calcasieu-Sabine Basin (Meselhe and Noshi, 2001) which provided boundary conditions for the project area. The model was calibrated and validated against observed water level and salinity data. The comparison between field measurements and predicted values showed good agreement. The calibrated/validated model was then used to evaluate the feasibility of a wetland restoration project designed to reduce tidal fluctuations, flooding durations and salinity level within the project area. Meselhe and Douet (2003) studied the freshwater introduction into the eastern central portion of the Rockefeller State Wildlife Refuge in South Louisiana. They realized that water movement through the brackish marsh area was dominated by channel flow rather than through sheet flow across the area. Meselhe and Douet (2003) set up a channel network within the numerical domain and used the 1-D hydrodynamic model Mike 11 to perform the hydraulic calculations, accounting for storage capacity of adjacent marsh, hydraulic structures and salinity transport. They calibrated and validated the model for water level and salinity concentrations, and reported acceptable agreement between predicted and observed values. They applied the calibrated model to evaluate the salinity distribution in the project area under different management scenarios.

Saiers et al. (2003) conducted a tracer experiment at a wetland in the Florida Everglades, and compared the measured surface-water transport of inorganic particles with a 3-D transport model. Their results indicated that longitudinal, lateral and vertical diffusion were small, and nearly equal to 0.16, 0.15 and 0.001 m^2/h, respectively. The mean surface-water velocity was estimated to be equal to 5.3 m/h.

Meselhe and Douet (2004) evaluated the effectiveness of the “West Pointe a la Hache Outfall Management Project” in the reduction of the Barataria Basin wetland loss rate. The proposed project is intended to diminish wetland loss by enhancing the distribution of sediment and nutrients, and by reducing saltwater intrusion into the area. Meselhe and Douet (2004) used the H3D three-dimensional hydrodynamic model for this task. Actual wind data was used to calculate the shear stresses of wind onto the surface water. During the calibration, the authors reported that despite “isolated instance of questionable data or unexplained deviations between model results and field measurements”, the model presented a good agreement between model results and field data for water levels and salinity. After validation, with two additional data sets, the model was applied for different simulation scenarios in order to provide an assessment of the project features.

3. OBJECTIVES AND NEED FOR RESEARCH

According to the Comprehensive Conservation Plan for the Refuge (USFWS, 2000): "Water quality, quantity and delivery timing affect the welfare of fish, wildlife and plants…Because the Everglades is no longer a free-flowing system that relies on temporal weather patterns to sustain it, humans must now attempt to provide water when and where the system can most benefit". The Refuge is impacted by elevated concentrations of nutrients, particularly phosphorus, in pumped stormwater. Such nutrients enhance the growth of non-indigenous and invasive species to the detriment of native species (USFWS, 2000). Therefore, it is a priority for the Refuge to better understand and minimize the impacts of this excessive nutrients loading. Hence, the goal of this modeling effort is to provide a quantitative framework 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, Stormwater Treatment Area (STA) performance, and structural changes within the Refuge.

When fully calibrated and validated, the selected model(s) should assist in answering questions as:

- What is the impact of different management scenarios on the water distribution inside the Refuge?
- Which management scenario will cause portions of the Refuge to dry out and for how long? In other words what is the impact of the management scenarios on the hydro-period?
- Does the water depth (duration and frequency) satisfy the needs of plants and wildlife?
- What are the spatial and temporal distributions of phosphorus levels within the Refuge?
- What are the impacts of management decisions and strategies on the water quality?
- What are the impacts of alternative regulation schedules on the water quantity and quality in the Refuge?
- What are the effects of the surface-groundwater interactions on the Refuge?
- How does the surface and ground water interact in the Refuge?

3.1. Project Description

The project is divided into two phases and nine tasks. The effort in Phase 1 will be focused primarily on collecting and organizing the information needed to support model implementation, including field measurements, topographic data, aerial maps, etc. Phase 2 of the project is the model implementation and application.

Description of each of the project tasks and a summary table of the project deliverables are provided below.

3.1.1. Phase I: Preparation of Data

Task 1: Data acquisition and processing

Task 1 is already completed and is documented in the report by Meselhe et al. (2005). The topics included in such report include:

1.1: Select candidate constituents for modeling

1.2: Select period-of-record

1.3: Types of data

1.4: Geographic data – elevation, base map –

1.5: Hydraulic data – stages and structure flows –

1.6: Meteorological data – rainfall, temperature, ET, wind –

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

1.8: Procure and QA all data

1.9: Format data as required

Task 2: Develop boundary condition time series

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.

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

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 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.

3.1.2. Phase II: Model Implementation

Task 4: Selection of model(s)

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, available models will be screened to reduce the list of candidate models. A report will be developed and provided to an independent committee tasked with recommending model or models selected for implementation. This independent committee will be made up of three or more experts selected by DOI. In order to maintain their complete independence, DOI funding of costs for committee members' participation will be contracted separately from modeling support contract(s). This report addresses the model selection.

Task 5: Model implementation

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.

Task 6: Model calibration and verification

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. At a minimum, calibration statistics reported by the SFWMD for the SFWMM and ELM will be reported (bias, RMS error, r^2, and efficiency). Reporting will discuss the adequacy of calibration and verification, implications on model uncertainty, and possible mechanisms causing degraded calibration statistics. Effectiveness of calibration will be quantitatively measured and reported. At the completion of this task, the working model will be installed on a USFWS computer, and training provided to USFWS staff sufficient to allow independent model runs to be performed by the USFWS staff.

<u>Task 7: Scenario analysis</u>

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.

<u>Task 8: Documentation</u>

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.

At the completion of task 6, a report will be delivered fully documenting task 4-6. Model training and training materials will also be provided to interested federal employees following completion of task 6.

Task 9: Archive of program and all other files

All programs, input and output datasets, and reports will be centrally archived in electronic form. At project completion, a copy of this archive will be provided to the Refuge.

Table 3. Summary of Project Deliverables

	Due Date
General	
Monthly activity and progress reports – short (1-page or less)	5th business day of following month
Annual report – year 1 report of progress	End of 14th project month
Final completion report	In the last month of project
Presentation abstracts and draft publications derived from this project	When submitted
Task related deliverables	
PHASE I: PREPARATION OF DATA	
Task 1: Data acquisition and processing	
Task 2: Develop boundary condition time series	
Task 3: Develop daily water/material budgets for all structures and simple models - a report on load methods and estimates over POR and simple mass balance modeling for the POR	Completion of task 3
A data report fully describing data sources and transformations will be submitted, all data will be archived and documented	Completion of phase-1
PHASE II: MODEL IMPLEMENTATION	
Task 4: Selection of model(s) – report supporting model selection including listing and describing candidate models	Completion of task 4
Task 5: Model implementation	
Task 6: Model calibration and verification – model documentation report	Completion of task 6
Task 7: Scenario analysis – management decision support report	Completion of task 7
Task 8: Documentation – revision of previous reports (if needed), training materials and of model users	Project completion
Task 9: Archive of program and all other files – final copies of all computer files including data, input and output files, and programs will be transferred to a Refuge computer or server	Project completion

4. MODEL SELECTION

4.1. Candidate Models

Eighteen models were considered as candidates for this modeling effort. To be included in this list, available models had to meet one or more of the following criteria:

- The model has capabilities for simulating hydrodynamics and transport processes.
- The model has capabilities for simulating water quality processes.
- The model is available and documented through manuals, publications and/or user guides.

The Eighteen models or combination of models included in the evaluation are:

1. MIKE 3
2. Wetlands/WASP 6 - EFDC
3. H3D
4. TELEMAC
5. MIKE Flood + MIKE SHE
6. ECOMSED-RCA
7. SSIIM
8. ELM
9. CCHE-2D, -3D, -WQ
10. SFRSM
11. MODHMS
12. FTLOADDS
13. TABS-MD(RMA2-RMA4)
14. WQMAP
15. GSSHA
16. GEMSS
17. FVCOM
18. WASH 123

4.2. Model Evaluation Sheet

A model evaluation sheet was designed in order to simplify and standardize the evaluation. Each of the identified models was reviewed, and the key information was summarized in the respective model sheet (see Appendix A for the model evaluation sheets).

The model evaluation sheet divides the model information in three major components:

A) Hydrodynamics

Spatial Dimension: identifies the spatial dimension of the model, e.g., one dimensional (1D), two-dimensional (2D), or three-dimensional (3D)

Time Dimension: identifies whether or not the model simulates time-varying (unsteady) conditions, and what are the limitations, e.g., only daily variations, monthly variations, etc.

Model Characteristics: provides an overview of the hydrodynamic features in the models, e.g., what is the numerical method/scheme used in the model.

Wetting and Drying: identifies whether or not the model is able to simulate flooding and drying processes.

Ground Water Flow: identifies the ability of the model for simulating surface-groundwater interactions.

Additional Information: provides additional information about hydrodynamics features in the model.

B) Water Quality

Components: identifies the main components of the water quality module in the model.

Vegetation: identifies the type of vegetation included in the water quality module. It indicates if the model is able to simulate nutrients plant uptake and plant growth.

Soil: identifies the ability of the model for simulating nutrients transformation in the soil, and soil –water column interactions. At a minimum, models must have the capability of simulating a stationary mass compartment that interacts with the surface water column.

Additional Information: provides additional key information about water quality features in the model.

C) General Information

Public Availability: identifies the availability of the model for use and distribution.

Run Time: identifies whether or not it is possible to run long-term simulations with a reasonable execution time. It should be emphasized that our judgment is somewhat subjective since we did not perform a true comparative testing for all the models in a single platform. Therefore, the information listed is based on either on our own experience or gathered from developers or users.

Acceptance: identifies the general acceptance of the model within the professional community based on factors such as: prior peer-reviewed publications, adopted by agencies or successful applications to similar projects.

Documentation: indicates the availability of model documentation through user manuals, publications and/or other technical documents.

Pre/Post Processor: indicates the availability of pre/post-processing modules.

Contact Information: identifies contact person and location information for model information, procurement, and technical support.

Platform: indicates the model platform, e.g., Windows, Linux, etc.

Technical Support: indicates the availability of technical support for the model.

Source Code: identifies whether or not the source code is available, and what programming language it is based on.

Other Model Features: provides any key information that was not included in the previous sections.

Other Capabilities: lists additional capabilities that may be important for the Refuge application.

Limitations: summarizes the technical or practical limitations that were not explicitly indicated in the previous sections.

It should be emphasized that it was challenging to collect all the aforementioned information for each of the models. For certain models, if the information was not readily available in published reports or papers, effort was devoted to personally contact the developers to complete the forms as much as possible. We were unable to completely fill the forms for all models. However, we believe the information gathered is sufficient and adequate to select a model (or two) for the proposed modeling effort. It is important to realize that model development is a continuous process, and new models will become readily available. Similarly, some of the models that were included might evolve and become more suitable for this application. Although the "perfect" model may be an elusive target, migrating to new models with superior capabilities as they emerge is recommended.

4.3. Model Selection Criteria

It is crucial to ensure that the model selection is guided by the project objectives. A summary of the project objectives is provided below:

- Provide the best available technical support for management decisions related to Refuge inflow and outflow quantity and quality.
- Provide projections of water movement and water quality resulting under alternative scenarios of structure operation, treatment performance, and structural changes within the Refuge.
- Provide a quantitative platform for analysis of causes of elevated phosphorus events.

Based on these objectives, the research team designed the following system to evaluate the candidate models. It should be noted that a computer model that fully satisfy all the requirements might not be readily available. Therefore, some compromise among the selection criteria will almost certainly be required. It is anticipated that some customization and formulation improvements will be needed. However, due to time and budget constraints, it is highly desirable to minimize code development effort. Based on the project objectives, we established essential and desirable features. A summary of the essential and desirable features are listed below:

Essential Features

- The model must have at least a 2-D (depth averaged) fully dynamic surface flow module. A 1-D model is not suitable for this application. A 3-D model may not be needed but is not detrimental, unless it severely impacts the execution speed.
- The model must be able to simulate wetting and drying phenomena. This is a crucial component. Since it is challenging to develop and fully test a robust module for wetting and drying, any model that does not have such feature available should not be selected.
- The model must have either a water quality module, or at least user-defined reactive transport module.
- The model must include vertical exchange with the groundwater. Although the significance of the surface-groundwater interaction is a subject of debate, per the Refuge personnel the ability to model such interaction is important. Even though,

a complete groundwater subroutine is preferred, there are not sufficient data to calibrate a horizontal groundwater model.

- The model must have a surface water module with variable spatial resolution or other mechanism to link channel to marsh.

- The investigators should have at least partial access to the source code to implement improvements to the formulation especially to the water quality module.

Desirable Features

- The model should have good pre/post processing modules.

- The model should have documentation that includes theoretical background, input and output formats, and any pre and post processors.

- The model should have availability of technical support from developers, experienced staff, or other users.

In summary, the most appropriate model(s) for this project should have as many of essential and desirable features as possible in order to minimize the development effort.

4.4. Preliminary Evaluation Results

Table 4 shows a comparison for the models relative to the essential and desirable features listed above. The table also indicates the number of essential and total criteria met by each model. As seen in the table, two points were assigned for each essential feature, while one point was assigned for each desirable feature. Models that scored at least 10 points for the essential features and 12 points overall were selected for further consideration. These models are:

- Wetlands/WASP 6 - EFDC
- H3D
- TELEMAC
- MIKE FLOOD
- SSIIM
- ELM
- GSSHA

- GEMSS
- FVCOM
- WASH-123

Table 4. Model Selection Matrix

	Criteria / Model	Essential Features 1: 2D or 3D Hydrodynamics	Essential Features 2: Wetting and Drying	Essential Features 3: Water Quality/Transport Module	Essential Features 4: Ground Water Flow	Essential Features 5: Channel flow link to overland flow or variable spatial resolution	Essential Features 6: Open Source Code	Desirable Features 7: Pre/Post Processing	Desirable Features 8: Documentation	Desirable Features 9: Technical Support	Summary: Number of Criteria Met – Essential	Summary: Number of Criteria Met – Total	Summary: Consider Further?
1	MIKE 3	●	●	●	X	X	X	●	●	●	6	9	No
2	Wetlands/WASP 6 - EFDC	●	●	●	⊖	●	●	⊖	●	⊖	11	13	Yes
3	H3D	●	●	●	⊖	⊖	●	⊖	⊖	●	10	12	Yes
4	TELEMAC	●	●	●	⊖	●	⊖	●	●	⊖	10	12.5	Yes
5	MIKE-FLOOD	●	●	●	⊖	●	X	●	●	●	9	12	Yes
6	ECOMSED - RCA	●	X	●	⊖	X	●	⊖	●	●	7	9.5	No
7	SSIIM	●	●	●	?	●	●	●	●	X	10	12	Yes
8	ELM	⊖	●	●	●	●	●	●	⊖	⊖	11	13	Yes
9	CCHE-2D,- 3D, -WQ	●	●	●	?	●	?	●	●	?	8	10	No
10	SFRSM	⊖	?	●	●	●	⊖	X	⊖	?	8	8.5	No
11	MODHMS	⊖	●	?	●	⊖	X	●	●	●	6	9	Yes
12	FTLOADDS	●	●	⊖	●	X	●	⊖	●	⊖	9	11	No
13	RMA2 - RMA4	●	●	●	?	●	⊖	●	●	●	9	12	No
14	WQMAP	●	●	●	⊖	⊖	⊖	●	●	●	9	12	No
15	GSSHA	⊖	●	⊖	●	●	●	●	●	●	10	13	Yes
16	GEMSS	●	●	●	⊖	⊖	●	●	●	●	10	13	Yes
17	FVCOM	●	●	●	⊖	●	●	⊖	●	⊖	11	13	Yes
18	WASH123	●	●	●	●	●	X	●	⊖	⊖	10	12	Yes

● Criterion fully met (two points for essential feature, one point for desirable)

⊖ Criterion partially met (one point for essential featurs, half point for desirables)

X Criterion is not met (no point)

? No information

Additional Information about the selected models:

- Regarding the SSIIM, it has several components that have not been fully tested, and it does not have any technical support available.
- The hydrodynamic module of ELM does not include the longitudinal dispersion process. Additionally, the overall evaluation indicates that the complexity of the formulation in the ELM model is beyond the scope of the Refuge's modeling project. Accordingly we do not recommend considering this model further. However, this model is a valuable resource of information regarding modeling of Phosphorus in a wetland system. Therefore, we may use some of the formulations in ELM to improve the water quality module of the selected model(s).
- The ELM calibration to Everglades TP data was reported by Fitz et al. (2002a). Other comments that reflect negatively on the selection of ELM for this Refuge modeling project were expressed during a RECOVER inter-agency review of ELM for application in CERP project evaluation (Fitz et al. 2002b). These include:
  - Use of Manning's equation to characterize wetland flow
  - Unsatisfactory calibration statistics and patterns of model bias
  - Large number of parameters and model complexity
  - Concerns regarding the ET formulation in ELM and coupling transpiration with TP movement
  - Lack of users manual or other similar documents describing file formats for input and output
- The overland flow module of the GSSHA modeling system is based purely on the diffusion approximation. The impact of ignoring advection is unknown at this time.
- To the best of authors' knowledge, the run time of the WASH-123 modeling system is of concern. The Refuge personnel prefer to run models on their local computers and avoid the need to use super computer centers. The run time of WASH 123 might be prohibitive especially for decadal simulations. Moreover, the developer indicated that for this current application we would be only given the hydrodynamic source code. Therefore we will not be able to implement additional capabilities to the water quality module if needed.

Accordingly, the following five models are the most suitable models for the Refuge.

- FVCOM
- MIKE FLOOD
- Wetlands/WASP 6 - EFDC
- TELEMAC
- H3D
- GEMSS

In order to select the one or two most suitable models for the Refuge from the top five models listed above, the following pros/cons table may be considered (See Table 5).

Table 5. Additional Pros and Cons of Selected Models

Model	Pros	Cons
FVCOM (11 - 13)	1) Unstructured grid 2) Excellent mass conservation 3) Fully open code 4) Fully parallel	1) New improvement to an existing model (ECOM-SED) 2) Requires separate software for Post processing. 3) Might require a minimum number of elements to adequately represent the channel 4) Not very fast
Wetlands EFDC (11 – 13)	1) 1D channel to couple with 2D overland 2) Fully open code	1) Coarse Cartesian grid will not capture tree islands well. Fine grid is a high cost. 2) Kadlec negatively commented on the transport module of EFDC
MIKE FLOOD (10 – 13)	1) 1D channel coupled with 2D overland 2) Good Pre and Pos processing code	1) The source code is not open.
TELEMAC (10 – 12.5)	1) Unstructured grid 2) Fully parallel 3) Good post processing	1) Not very fast 2) Source code partially open. 3) Might require a minimum number of elements to adequately represent the channel

H3D (10 – 12)	1) Extremely computationally efficient 2) Fully open	1) Coarse Cartesian grid will not capture tree islands well. Fine grid is a high cost. 2) Requires separate software for Post processing 3) Stair-casing in the channel
GEMSS (10 - 13)	1) Good pre and post processing 2) Fully open	1) To capture the rim canal and interior tree islands will cause curvilinear grid to be quite large

It will be difficult to adequately capture the canal and the canal-marsh interaction using the model H3D or GEMSS. Therefore, these models will not be further considered. Also the model Wetlands-EFDC will not be further considered, since it was already applied to a similar case and the results were not satisfactory. Both FVCOM and TELEMAC present the limitation that a minimum number of elements might be needed to adequately capture the channel. Therefore, computational time is a concern when using FVCOM or TELEMAC. FVCOM has two important advantages over TELEMAC: (1) it is a public domain-fully open source code model and TELEMAC is a proprietary model, and (2) the mass conservation properties of the Finite Element method used in TELEMAC is a concern, while FVCOM use the Finite Volume method which is mass conservative. TELEMAC will not be further considered.

This selection leaves us with two final candidates: FVCOM and MIKE FLOOD.

MIKE FLOOD is a model with a proved record of successful applications and is widely accepted. MIKE FLOOD can capture the channel and the channel-marsh interaction; however is a proprietary-closed source code model. FVCOM is public domain –fully open source code, but is a new model with a short record of applications. The research team decided to continue with the modeling effort using these two candidate models, i.e., FVCOM and MIKE FLOOD. The two models will be set up and further evaluated. Based on model performance, it will be later decided whether to continue using the two models or to direct all the efforts in one of them.

4.5. Resource Models

The model evaluation team also reviewed a series of models that did not match the selection criteria because of their hydrodynamic features. These models include information, especially water quality formulation, that can be transferred and used for the Refuge application. Eleven models were considered for future utilization as resource models:

19. DMSTA
20. CE-QUAL-R1
21. CE-QUAL-W2
22. LOWQM
23. WQRRS
24. WASP 6 – DYNHYD5
25. HSPF
26. RCA
27. GLEAMS
28. BLTM
29. SWAT

Even though these models are not considered as candidate model for this Refuge application, their information was also summarized using the same model evaluation sheet utilized for the candidate models. Appendix B shows the Model Evaluation Sheet for the resource models.

5. SUMMARY

The effects of different management scenarios on the spatial and temporal distribution of water quantity and quality in the Refuge have not been fully quantified and assessed. Therefore, a predictive tool that can support management decisions, and provides answer to the questions related to water quality, quantity and timing is needed.

Based on the review of previous modeling efforts in the Refuge, it is clear that the current needs have not been adequately addressed. To be specific, these efforts lacked adequate spatial resolution, and thorough calibration and validation of water quality parameters. It is also important to note that thus far, validation of velocities and transport subroutines have not been done primarily due to lack of field measurements.

None of the models previously implemented for the Refuge address the dynamic interaction between the rim canal and the interior. Moreover, interaction between surface and ground water was either not simulated or not calibrated. Again, currently there are no field data to calibrate such interaction. Therefore, it will be recommended to Refuge personnel to collect surface flow velocities in the rim canal as well as in the Refuge interior, and collect data to estimate the interaction between surface and groundwater. Overall, previous models have captured the general trends, and the monthly-seasonal dynamics (e.g., ELM, SFWMM). However, no model has described in detail the internal dynamics in the Refuge. Accordingly, these models are unable to provide detailed spatial and temporal information of water quantity and quality within the Refuge.

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8. APPENDIX A: CANDIDATE MODELS- EVALUATION SHEETS

Model Evaluation Sheet

Model No. 1: Mike 3

Component A: Hydrodynamics

Dimension	Spatial:	3D	Time:	Unsteady
Model Characteristics	Complete hydrodynamic model, implicit ADI finite difference scheme of 2nd order accuracy			
Wetting and Drying	Flooding and drying is included		Ground Water Flow	It is not included
Additional Information	Includes different turbulence models			

Component B: Water Quality

Components	Nutrients and DO/BOD. Basic and extended eutrophication module
Vegetation	Algae, macro algae and benthic vegetation
Soil	Sediment nutrient flux model and sediment diagenesis
Additional Information	Complete N, P and phytoplankton cycles

Component C: General

Public Availability	Available	Contact Information	DHI; www.dhigroup.com
Run Time	No information	Platform	Windows
Acceptance	Wide	Technical Support	Available
Documentation	Available	Source Code	Not public
Pre Processor	Available - Included	Post Processor	Included – animated presentation
Other Model Features	Complete sediment transport module. Transport of suspended substance, including erosion, transport and deposition		
Other Capabilities	Modeling the transport of trace and dissolved substance, might include decay		
	Simulates heat exchange with the atmosphere, including evaporation and precipitation		
	Accepted by the US Federal Emergency Management Agency (FEMA)		
Limitations	Proprietary model		

Model Evaluation Sheet

Model No. 2: Wetlands/WASP 6-EFDC (Environmental Fluid Dynamic Code)

Component A: Hydrodynamics

Dimension	Spatial:	EFDC? 3D	Time:	Unsteady
Model Characteristics	Complete hydrodynamic model, finite difference Cartesian or curvilinear-orthogonal grid			
Wetting and Drying	EFDC can simulate wetting and drying		Ground Water Flow	Vertical Exchange
Additional Information	Computes changes in surface water elevation and horizontal movement that result from inflows and outflows to and from the wetland			
The hydrodynamics is affected by evaporation and precipitation, The model can include source/sink representing groundwater exchange or can include a soil moisture layer				

Component B: Water Quality

Components	Floating periphyton mat, water column, benthic periphyton mat, detrital litter layer, and a sediment layers. Eutrophication submodel
Vegetation	Uptake by periphyton and emergent vegetation
Soil	Sediment nutrient flux submodel and back flux
Additional Information	Complete N, P and DO cycles.
Dissolved and particulate nutrients. Includes temperature for WQ control	

Component C: General

Public Availability	Available	Contact Information	http://www.epa.gov/athens/wwqtsc/html/efdc.html John Hamrick, Tetra Tech
Run Time	No information	Platform	Windows
Acceptance	Wide	Technical Support	Partial
Documentation	Available	Source Code	EFDC is available
Pre Processor	EPA BASINS (in development)	Post Processor	EPA BASINS (in development)
Other Model Features	The Everglades Wetland Hydrodynamic Model (EWHM), a version of EFDC, dynamically coupled 1D channel with 2D overland flow		
Other Capabilities	Includes chemical and atmospheric precipitation for P and others (chemical sub-model)		
	The vegetation model considers above- and below-ground biomass. Models the interactions between sediment nutrients, plant growth and plant nutrient composition		
Limitations	Floating and benthic periphyton mats, the litter layer and the sediment layers are fixed in space, and are not influenced by horizontal transport, only by vertical diffusion		

Model Evaluation Sheet

Model No. 3: H3D

Component A: Hydrodynamics

Dimension	Spatial: 3D		Time:	Unsteady
Model Characteristics	Complete hydrodynamic-free surface model. Finite difference model, second order accurate in time			
Wetting and Drying	Wetting and drying is included		Ground Water Flow	Vertical exchange
Additional Information	The model is semi-implicit, so that relatively large time steps can be used. H3D economizes in storage by storing only active cells			
The model can use Cartesian or curvilinear-orthogonal grids. The model conserves scalar quantities in flooding and drying process.				

Component B: Water Quality

Components	Dissolved/suspended substances with a source term for reaction.
Vegetation	Algae
Soil	
Additional Information	Eutrophication module

Component C: General

Public Availability	Available	Contact Information	J.A. Stronach; stronach@hayco.com. E. Meselhe, meselhe@louisiana.edu
Run Time	Computationally Efficient - Fast	Platform	Windows/DOS/ Linux/Unix
Acceptance	Wide	Technical Support	Available
Documentation	Partial	Source Code	FORTRAN - Available
Pre Processor	Partial	Post Processor	Tecplot output
Other Model Features	Complete sediment transport module and sediment settling module		
Other Capabilities	Simulates heat exchange with the atmosphere		
	Includes wind and density effects		
	Can include dry cells in the computational domain, and passes through the cells to simulate channel flow		
Note	Investigators are familiar with the model		
Limitations	Tecplot is a proprietary software, but it is not expensive		

Model Evaluation Sheet

Model No. 4: TELEMAC

Component A: Hydrodynamics

Dimension	Spatial:	2D, 3D	Time:	Unsteady
Model Characteristics	Complete hydrodynamic – free surface model. Finite element model			
Wetting and Drying	Flooding and drying is included		Ground Water Flow	Vertical exchange
Additional Information	Different turbulence models are available. The model has the flexibility of an unstructured grid of triangular elements, which			
means that it can be easily refined particularly in areas of special interest				

Component B: Water Quality

Components	Dissolved/suspended substances with a source term for reaction. Includes a eutrophication module
Vegetation	phytoplankton
Soil	Fluxes can be included: flux of erosion, and flux of deposition on benthic conditions
Additional Information	The model has been extended to include reactive processes

Component C: General

Public Availability	Available	Contact Information	CHC; www.telemacsystem.com
Run Time	Relatively slow/ Fully Parallelized	Platform	Windows
Acceptance	Wide	Technical Support	Available. The response time is slow
Documentation	Available	Source Code	Partial
Pre Processor	Available - Included	Post Processor	Included – animated presentation
Other Model Features	Complete sediment transport module and sediment settling module. Includes sediment consolidation		
Other Capabilities	Includes wind and density effects		
	Simulates heat exchange with the atmosphere		
	Can include dry cells in the computational domain		
Note	Investigators are familiar with the model		
Limitations	Proprietary model		

Model Evaluation Sheet

Model No. 5: HEM-3D - EFDC

Component A: Hydrodynamics

Dimension	Spatial:	EFDC? 2D, 3D	Time:	Unsteady
Model Characteristics	Complete hydrodynamic – free surface model. Finite difference model.			
Wetting and Drying	Flooding and drying is included		Ground Water Flow	Vertical exchange
Additional Information	It's very computationally efficient, it economizes in storage by storing only active cells			
Sigma vertical coordinate system, and Cartesian or curvilinear-orthogonal grid				

Component B: Water Quality

Components	Complete eutrophication model
Vegetation	Algae
Soil	Sediment nutrient flux model and sediment diagenesis
Additional Information	Complete N, P, DO and phytoplankton cycles
Includes refractory particulate, labile particulate, and dissolved organic P and TPO4	

Component C: General

Public Availability	Available	Contact Information	Virginia Institute of Marine Sciences; boon@vims.edu
Run Time	No information	Platform	UNIX or DOS
Acceptance	Wide	Technical Support	Partial
Documentation	Available	Source Code	EFDC is Available
Pre Processor	EPA BASINS (in development)	Post Processor	EPA BASINS (in development)
Other Model Features	Complete sediment transport module. Transport of suspended substance, including erosion, transport and deposition		
Other Capabilities	Includes wind stresses and density effects. Includes transport equation for temperature		
	The HEM-3D model can be coupled with others hydrodynamic and sediment transport models		
	The Everglades Wetland Hydrodynamic Model (EWHM), a version of EFDC, dynamically coupled 1D channel with 2D overland flow		
Limitations	The WQ model has not been fully tested		

Model Evaluation Sheet

Model No. 6: Mike Flood

Component A: Hydrodynamics

Dimension	Spatial:	Dinamically couples Mike 11 (1D) with Mike 21 (2D)	Time:	Unsteady
Model Characteristics	Complete hydrodynamic model, implicit ADI finite difference scheme of 2nd order accuracy			
Wetting and Drying	Flooding and drying is included	Ground Water Flow	It is not included	
Additional Information	Mike Flood uses Mike 11 for river hydraulics and Mike 21 for surface water modeling			

Component B: Water Quality

Components	Nutrients and DO/BOD. Basic and extended eutrophication module
Vegetation	Algae, macro algae and benthic vegetation
Soil	Sediment nutrient flux model and sediment diagenesis
Additional Information	Complete N, P and phytoplankton cycles

Component C: General

Public Availability	Available	Contact Information	DHI; www.dhigroup.com
Run Time		Platform	Windows
Acceptance	Wide	Technical Support	Available
Documentation	Available	Source Code	Not public
Pre Processor	Available - Included	Post Processor	Included – animated presentation
Other Model Features	GIS integration for spatial and temporal analysis		
Other Capabilities	Same as Mike 21		
	Accepted by the US Federal Emergency Management Agency (FEMA)		
Limitations	Proprietary model		

Model Evaluation Sheet

Model No. 7: ECOMSED-RCA

Component A: Hydrodynamics

Dimension	Spatial:	3D	Time:	Unsteady
Model Characteristics	Complete hydrodynamic – free surface model. Finite volume method second order accuracy			
Wetting and Drying	It is not included		Ground Water Flow	Vertical exchange
Additional Information	Good mass conservation properties associated with the discretization scheme.			
Sigma vertical coordinate system, and Cartesian or curvilinear-orthogonal grid				

Component B: Water Quality

Components	Simple and advanced eutrophication, wetland systems (based on coupling with RCA)
Vegetation	Algae (multiple algal groups)
Soil	Includes a sediment nutrient flux subroutine (deposition and resuspension)
Additional Information	Fully closed P and N cycles, complete DO/BOD dynamics

Component C: General

Public Availability	Available	Contact Information	HydroQual, Inc.; Hydroqual.com
Run Time	Relatively slow	Platform	UNIX, LINUX and DOS
Acceptance	Wide	Technical Support	Available
Documentation	Available	Source Code	Available, FORTRAN
Pre Processor	Partial	Post Processor	Tecplot output
Other Model Features	Complete sediment transport module (cohesive and non-cohesive sediment transport)		
Other Capabilities	Includes wind stresses and density effects. Includes transport equation for temperature		
	Includes heat flux module (including precipitation and evaporation)		
Limitations	Tecplot is a proprietary software		

Model Evaluation Sheet

Model No. 8: SSIIM

Component A: Hydrodynamics

Dimension	Spatial:	3D	Time:	Unsteady	
Model Characteristics	Complete hydrodynamic free surface model. Finite volume method				
Wetting and Drying	Wetting and drying is included			Ground Water Flow	No information
Additional Information	A control volume method is used for discretization with power law or 2nd order upwind schemes				
SIMPLE method is used for pressure coupling. Can use non-orthogonal grids. Complete turbulence model					

Component B: Water Quality

Components	Transport of up to 20 constituents with source terms for each one
Vegetation	Algae
Soil	Resuspension is included
Additional Information	The model has some prescribed functions for nutrient cycles, and allows flexible modifications

Component C: General

Public Availability	Available	Contact Information	Nils R. Olsen; Nils.R.Olsen@nhl.sintef.no
Run Time	No information	Platform	Windows
Acceptance	Wide	Technical Support	No
Documentation	Available	Source Code	Available
Pre Processor	Available - Included	Post Processor	Available - Included
Other Model Features	Includes a complete sediment transport module with movable bed		
Other Capabilities	Includes heat flux module and transport equation for temperature		
	Includes gas reaeration at the water surface		
Other Limitations	There are relevant-new implemented algorithms that are not fully tested		

Model Evaluation Sheet

Model No. 9: ELM (Everglades Landscape Model)

Component A: Hydrodynamics

Dimension	Spatial:	2D	Time:	Varying
Model Characteristics	The model captured the spatio- temporal dynamics of hydrology. Cell surface and groundwater flows are solved using a finite difference, Alternating Direction Explicit (ADE) technique, providing for propagation of water and water-borne constituents across space			
Wetting and Drying	It is included	Ground Water Flow	It is included	
Additional Information	ELM divides the landscape into a uniform grid of square cells. The ELM supports user specified grid cell resolution			
The hydrology may be driven by daily flow data, using either historical observations, or output from the SFWMM for management scenarios				

Component B: Water Quality

Components	Phosphorus cycles included uptake, remineralization, sorption, diffusion, and organic soil loss/gain
Vegetation	Periphyton biomass and community type, macrophyte biomass and habitat type
Soil	Phosphorus accumulation in the soils
Additional Information	Growth of macrophyte and periphyton communities responds to available nutrients, water, sunlight and temperature

Component C: General

Public Availability	Available	Contact Information	SFWMD; www.sfwmd.gov/org/wrp/elm/
Run Time	Computationally Efficient - Fast	Platform	Unix, LINUX
Acceptance	Wide	Technical Support	Limited
Documentation	Partial	Source Code	ANSI C
Pre Processor	Available	Post Processor	Available
Other Model Features	Canal/levee can be superimposed on the grid to define the hydrologic basins and provide for rapid flow of water through the system		
Other Capabilities	ELM has been applied with a finer grid to adjacent areas to the Loxahatchee Refuge		
	Rainfall and saturated hydraulic conductivity can be included for water budget purposes		
Limitations	The finite difference is first order accuracy, and dispersion is not simulated		

Model Evaluation Sheet

Model No. 10: CCHE2D, CCHE3D, CCHE-WQ

Component A: Hydrodynamics

Dimension	Spatial:	2D depth-averaged, 3D	Time:	Unsteady
Model Characteristics	Complete hydrodynamic – free surface model. It is based on Efficient Element Method, a collocation approach of the FEM			
Wetting and Drying	Flooding and drying is included		Ground Water Flow	No information
Additional Information	The model strictly enforces the mass conservation within the computational domain through the user of control volume approach			
The model includes different turbulence closure schemes. CCHE3D uses a structured quadrilateral mesh in the horizontal plane				

Component B: Water Quality

Components	Phosphorous and nitrogen cycles, dissolved oxygen balance.
Vegetation	Phytoplankton kinetics
Soil	
Additional Information	CCHE-WQ is a physical and bio-chemical process based module which simulates WQ variables and pollutant transport dynamically. CCHE-WQ considers the impacts of environmental factors such as temperature, pH, and salinity on the WQ processes.
Different sources can be simulated, e.g, multiple point and non-point, and time-varying flow conditions.	

Component C: General

Public Availability	Available	Contact Information	CCHE University of Mississippi http://hydra.cche.olemiss.edu/
Run Time	No information	Platform	Windows 95, 98, 2000 and XP
Acceptance	Wide	Technical Support	No information
Documentation	Available	Source Code	No information
Pre Processor	Mesh Generator – GUI	Post Processor	Graphical User Interface (GUI)
Other Model Features	Includes a complete sediment transport module with erodible and non-erodible sub-regions.		
Other Capabilities	The roughness of the moveable bed changes due to change in sediment size and change in bed form		
	The sediment module includes the curvature effects for sediment transport in bends		
Limitations	The CCHE-WQ module is currently being tested using field data		
	The GUI for CCHE3D is under development		
	CCHE-WQ and CCH3D are proprietary		

Model Evaluation Sheet

Model No. 11: SFRSM (South Florida Regional Simulation Model)

Component A: Hydrodynamics

Dimension	Spatial:	2D	Time:	Dynamic	
Model Characteristics	The Hydrologic Simulation Engine (HSE) simulates the hydrology in south Florida, including the canals, structures and levees. A weighted implicit finite volume method is used in the HSE to simulate diffusion flow in both overland and groundwater flow				
Wetting and Drying	No information		Ground Water Flow	Included	
Additional Information	The model domain is discretized using triangular cells whose walls control the flow rates into the cells based on Manning's equation				
for overland flow and the Darcy's equation for ground water flow.					

Component B: Water Quality

Components	Under development, full mass transport not yet available
Vegetation	
Soil	
Additional Information	

Component C: General

Public Availability	Available	Contact Information	Randy Van Zee, Hydrologic Systems Modeling Department, SFWMD http://www.sfwmd.gov/org/pld/hsm/models/sfrsm/index.html
Run Time		Platform	UNIX
Acceptance	New Model	Technical Support	No information
Documentation	Partial	Source Code	C++
Pre Processor	Under development	Post Processor	Under development
Other Model Features	The processes modeled include overland and groundwater Flow, precipitation, evapotranspiration, infiltration, levee Seepage, canal and structure flow		
Other Capabilities			
Limitations	This model is currently 'under development'. Individual components are being developed independently and are in various stages of completion		
	This model is designed for regional, long-term applications. Although scalable, performance constraints may impose practical limits on the time and space scales. This model is not intended for local-scale decision-making support.		

Model Evaluation Sheet

Model No. 12: MODHMS

Component A: Hydrodynamics

Dimension	Spatial:	3D subsurface, 2D surface	Time:	Dynamic	
Model Characteristics	A MODFLOW variant that fully integrates ground water with surface water modeling				
Wetting and Drying	Included			Ground Water Flow	Included
Additional Information	MODFLOW simulates three-dimensional ground-water flow through a porous medium by using a finite-difference method				
MODHMS includes interactions between overland flow, channel flow, and groundwater flow. Overland flow/runoff is characterized by the two dimensional diffusion wave approximation to the St.Venant equations governing shallow-water flow.					

Component B: Water Quality

Components	No information
Vegetation	
Soil	
Additional Information	

Component C: General

Public Availability	Available, proprietary, free to federal government	Contact Information	Sorab M.Panday, HydroGeoLogic, Inc. http://modhms.com/software/modhms.html
Run Time	No information	Platform	Windows
Acceptance	Wide	Technical Support	Available
Documentation	Complete	Source Code	Not public
Pre Processor	Available	Post Processor	Available
Other Model Features	The hydrologic cycle is viewed as a fully integrated system with dynamic interactions between all regimes of flow		
Other Capabilities	A curvilinear grid option is available to allow for flexible gridding		
Limitations	No information		

Model Evaluation Sheet

Model No. 13: MIKE SHE

Component A: Hydrodynamics

Dimension	Spatial:	3D subsurface, 2D surface	Time:	Dynamic	
Model Characteristics	2D, diffusive wave, finite-difference overland flow and 3D, finite-difference groundwater flow				
Wetting and Drying	Included			Ground Water Flow	Included
Additional Information	Surface water simulation using flow-routing methods and water levels calculated by Manning's equation or specified relationships				
Includes drainage routing to surface water bodies. Can be coupled with Mike 11 for modeling open channel flow					

Component B: Water Quality

Components	Can be coupled with DAISY that is a single column model, which describes all the major processes related to water, carbon and nitrogen in an agricultural ecosystem.
Vegetation	Complete crop model
Soil	Plant uptake of nitrogen
Additional Information	DAISY calculates nitrate and pesticide leaching from agricultural areas
MIKE SHE can be used to simulate solute transport across the various hydrologic process boundaries	

Component C: General

Public Availability	Available	Contact Information	DHI; www.dhigroup.com
Run Time	No information	Platform	Windows
Acceptance	Wide	Technical Support	Available
Documentation	Complete	Source Code	DAISY is open source code
Pre Processor	Available	Post Processor	Included – animated presentation
Other Model Features	Precipitation, evapotranspiration, overland sheet and channel flow, unsaturated and saturated ground water flow are included		
Other Capabilities	GIS integration for spatial and temporal analysis		
	Weirs, culverts and spillways can be easily modeled using Mike 11		
Limitations	Proprietary model		
	DAISY does not include phosphorous process		
	MIS SHE/DAISY does not model crop and nitrogen processes under flooded conditions		

Model Evaluation Sheet

Model 14: FTLOADDS (Flow and Transport in a Linked Overland Aquifer Density Dependent System)

Component A: Hydrodynamics

Dimension	Spatial:	2D (surface flow), 3D (groundwater flow)	Time:	Unsteady
Model Characteristics	Fully dynamic 2D finite difference for surface water flow, and 3D finite difference for variable-density groundwater flow			
Wetting and Drying	Included		Ground Water Flow	Included
Additional Information	The main linkage between surface and groundwater flow is through a leakage quantity passed between the two models			
Leakage is calculated using a variable-density form of Darcy's law, the surface water stage, the groundwater head, and a leakage coefficient				

Component B: Water Quality

Components	Tracer mass transport model
Vegetation	
Soil	
Additional Information	

Component C: General

Public Availability	Available	Contact Information	langevin@usgs.gov
Run Time	Computationally Efficient - Fast	Platform	DOS
Acceptance	Wide	Technical Support	Available
Documentation	Available	Source Code	Available
Pre Processor	Partial	Post Processor	Partial
Other Model Features	The model combines SWIFT2D (for overland surface water flow) and SEAWAT (for groundwater flow)		
Other Capabilities	SWIFT2D was modified to include rainfall, ET and flow resistance of marsh vegetation		
	Recharge and ET are applied to the cells in the uppermost layer in the groundwater model		
	The model includes the capability for upward leakage to rewet a surface water cell		
Limitations	FTLOADDS has not be linked to a water quality model		

Model Evaluation Sheet

Model 15: TABS-MD (RMA2 – RMA4)

Component A: Hydrodynamics

Dimension	Spatial:	2-D depth-average	Time:	Unsteady	
Model Characteristics	RMA2 is a two dimensional, free-surface, depth averaged finite element model for subcritical flow problems				
Wetting and Drying	Included (adjust for wetting and drying by element)		Ground Water Flow	No information	
Additional Information	RMA2 computes a FE solution of the Reynolds form of the Navier-Stokes equations for turbulent flows using the Galerkin Method of				
weighted residuals. Friction is calculated with the Manning's or Chezy Equation, and eddy viscosity coefficients are used to define turbulence characteristics.					

Component B: Water Quality

Components	RMA4 simulates the depth-average advection-diffusion process in an aquatic environment.
Vegetation	Algae (RMA11)
Soil	
Additional Information	It computes concentrations for up to 6 constituents, either conservative or non-conservative using a first order deacy
The RMA11 (from BOSS Intl.) model may be use to simulate temperature with a full heat exchange with the atmosphere, nitrogen and phosphorous nutrient cycles, BOD-DO, algae, cohesive or non-cohesive suspended sediments and other non conservative constituents	

Component C: General

Public Availability	Available	Contact Information	CHL WES USACE; tabs@hl.wes.army.mil BOSS International; www.bossintl.com
Run Time	No information	Platform	Windows
Acceptance	Wide	Technical Support	Available
Documentation	Available	Source Code	FORTRAN 77 - Partial
Pre Processor	Available	Post Processor	Available
Other Model Features	It can use one-dimensional networking for channels in conjunction with the two-dimensional finite element formulation		
Other Capabilities	The model has the flexibility of an unstructured grid of triangular elements		
	Models up to 5 different types of 1D flow control structures (2D structures are also permitted)		
	Can be linked with the sediment transport model SED2D		
Limitations	The model does not allow for baroclinic calculations		
	Simple turbulence models: direct value, by Peclet number, and by Smagorisky coefficient.		

Model Evaluation Sheet

Model 16: WQMAP

Component A: Hydrodynamics

Dimension	Spatial:	3D	Time:	Unsteady
Model Characteristics	Finite Difference model that solves the water mass and momentum equations on curvilinear grid to predict a dynamic field of surface elevations and velocities. The exterior mode is solved using a semi-implicit solution technique. The interior mode is solved explicitly			
Wetting and Drying	It is included		Ground Water Flow	Vertical exchange
Additional Information	Environmental forcing includes tides, winds, river flows and density distributions			
The basic model is configured to run in a vertically averaged fully dynamic mode. As an option, a full three-dimensional, coupled prognostic, baroclinic version of the model can be incorporated. A sigma coordinate transformation on the vertical are applied to the governing equations				

Component B: Water Quality

Components	Pollutant transport model and WASP eutrophication model
Vegetation	Phytoplankton
Soil	The vertically averaged version is configured with one water column layer and a sediment layer
Additional Information	Complete N and P cycles, DO balance

Component C: General

Public Availability	Available	Contact Information	Applied Science Associates, Inc. (ASA); www.appsci.com
Run Time	Computationally efficient	Platform	Windows
Acceptance	Wide	Technical Support	Available
Documentation	Available	Source Code	Partially available
Pre Processor	Available - Included	Post Processor	Available - Included
Other Model Features	Integrated Geographic Information System (GIS)		
Other Capabilities	The transport equation may included a first order decay coefficient and settling		
	Surface heat exchange is included		
Limitations	It is a proprietary model		

Model Evaluation Sheet

Model 17: GSSHA

Component A: Hydrodynamics

Dimension	Spatial:	2D (surface flow), 2D (groundwater flow)	Time:	Unsteady
Model Characteristics	The overland flow is based on a 2-D lateral diffusive wave. The model uses a Cartesian grid			
Wetting and Drying	It is included		Ground Water Flow	It is included
Additional Information	Channel routing is also simulated using an explicit solution of the 1-D diffusive wave equation			
The Manning formula is used to relate flow depth to discharge				

Component B: Water Quality

Components	Transport by advection-dispersion and first order reactions in both the overland and the channel modules
Vegetation	
Soil	
Additional Information	

Component C: General

Public Availability	Available	Contact Information	Barbara Parsons, http://chl.wes.army.mil/software
Run Time	Fast, except when simulating unsaturated zone with Richard's equation	Platform	Windows, Unix, Linux
Acceptance	Wide	Technical Support	Available
Documentation	Available - Complete	Source Code	Available
Pre Processor	Available	Post Processor	Available
Other Model Features	Precipitation, infiltration, evapotranspiration, unsaturated and saturated ground water flow are included		
Other Capabilities	Can simulate sediment transport on both the overland flow plane and within the stream channels		
	Soil moisture in the unsaturated zone can be simulated using the Bucket method or the Richard's equation		
Limitations	Simplified representation of cross section geometry		

Model Evaluation Sheet

Model 18: GEMSS

Component A: Hydrodynamics

Dimension	Spatial:	3D	Time:	Unsteady
Model Characteristics	Fully dynamic 3D finite difference semi-implicit hydrodynamic model			
Wetting and Drying	It is included		Ground Water Flow	Vertical exchange
Additional Information	Different turbulence models are available. The grid generator module allows the user to create both rectilinear and boundary fitted			
grids				

Component B: Water Quality

Components	I can be coupled with EPA supported EUTRO5 that simulates the interaction of eight water quality state variables, i.e., the dissolved forms of ammonia nitrogen, nitrate nitrogen, inorganic phosphorus, carbonaceous BOD, organic nitrogen, organic phosphorus, phytoplankton and dissolved oxygen
Vegetation	Phytoplankton kinetics
Soil	It allows sources and sinks of NH3 and DO from and to the sediments
Additional Information	Complete P and N cycles

Component C: General

Public Availability	Available	Contact Information	J.E. Edinger Associates, Inc.; www.jeeai.com
Run Time	Computationally efficient	Platform	Windows
Acceptance	Wide	Technical Support	Available
Documentation	Available	Source Code	Available
Pre Processor	Available - Included	Post Processor	Available - Included
Other Model Features	The modules are embedded in a geographic information and environmental data system (GIS)		
Other Capabilities	It includes a sediment transport module		
	Surface heat exchange, wind shear and surface precipitation/exchange are included		
Limitations	The GEMSS is proprietary, however a free version is available for academic and research purpose		

Model Evaluation Sheet

Model No. 19: FVCOM

Component A: Hydrodynamics

Dimension	Spatial: 3D		Time:	Unsteady
Model Characteristics	3D, unstructured grid, finite volume, free surface coastal ocean model			
Wetting and Drying	It is included		Ground Water Flow	Vertical exchange
Additional Information	Uses a triangular-unstructured grid. The model has good mass conservation properties associated with the discretization scheme.			
Sigma vertical coordinate system. Mellor and Yamada level-2.5 turbulent closure submodel				

Component B: Water Quality

Components	Phosphorus-Controlled Lower Trophic Level Food Web Model, and WASP-EPA adapted water quality module
Vegetation	Small phytoplankton and large phytoplankton
Soil	The benthic flux from sediment resuspension
Additional Information	Nitrogen, phosphorous and oxygen cycles are included

Component C: General

Public Availability	Available	Contact Information	Dr. Changsheng Chen1; c1chen@umassd.edu
Run Time	No information/ Parallelization is available	Platform	Linux/Windows
Acceptance	New Model	Technical Support	Available
Documentation	Available	Source Code	Available, Fortran 90
Pre Processor	Partial	Post Processor	Tecplot output
Other Model Features	Includes heat flux and precipitation/evaporation modules		
Other Capabilities	Includes wind stresses and density effects. Includes transport equation for temperature and salinity		
	Includes Sediment Suspension and Tracer-Tracking Models		
Limitations	Tecplot is a proprietary software		
	It requires a grid generation software		

Model Evaluation Sheet

Model No. 20: WASH123

Component A: Hydrodynamics

Dimension	Spatial:	2D (surface flow), 2D (groundwater flow)	Time:	Unsteady
Model Characteristics	Fully dynamic 3D groundwater flow, and fully dynamic (full Saint Venant Equations) for 1D channel flow and 2D overland flow			
Wetting and Drying	No information		Ground Water Flow	It is included
Additional Information	Galerkin Finite Element Method for solving the 3D Richard's Equation for variably saturated flow and Lagrangian-Eulerian Finite			
Element Method for solving the 2D full Saint Venant Equations for overland flow. The model utilizes an unstructured mesh				

Component B: Water Quality

Components	It includes a generic water quality module. Transport of dissolved substance in surface and ground water is included
Vegetation	
Soil	Deposition and resuspension is simulated as well as interaction of chemical with bed and suspended sediments
Additional Information	The model contains a comprehensive and generic component for chemical transformation on the groundwater flow, capable of
simulating multispecies reaction and interactions	

Component C: General

Public Availability	Available	Contact Information	Dr. Gour-Tsyh Yeh;'gyeh@mail.ucf.edu
Run Time	Slow Model/ Parallelization is available	Platform	Windows
Acceptance	Wide	Technical Support	Partial
Documentation	Partial	Source Code	Available
Pre Processor	Available	Post Processor	Available
Other Model Features	The model chooses between the kinematic, the diffusive, or the dynamic wave approximation depending on the elements' conditions		
Other Capabilities	Interactions between groundwater, channel and overland flows are accomplished through a mass conservative iterative procedure		
	Includes Sediment Transport capabilities		
	Includes heat flux and precipitation/evaporation modules		
Limitations	Long execution times reduce the practicality of the model for multiple year simulations using single processor machines		

9. APPENDIX B: RESOURCE MODELS - EVALUATION SHEETS

Model Evaluation Sheet

Model No. 21: DMSTA (Dynamics Model for Stormwater Treatment Areas)

Component A: Hydrodynamics

Dimension	Spatial:	1D longitudinal	Time:	Daily variations
Model Characteristics	Simple Hydrodynamic Model; uses wetland treatment cells divided in CFSTRs for reaction. Includes simple reservoir model			
Wetting and Drying	Dry out frequency and supplemental water needs		Ground Water Flow	Seepage in - out
Additional Information	Can Simulate up to 6 cells			
Water Balance: In flow, bypass, rainfall, ET, outflow, seepage in-out				

Component B: Water Quality

Components	Phosphorus (P), P load reaction of wetlands
Vegetation	It is included. Parameter estimation for various types
Soil	
Additional Information	The phosphorus removal performance of stormwater treatment areas (STAs) have been evaluated using DMSTA
Can not model P removal by particle settling, biological uptake and net refractory biomass storage, or chemical precipitation. Can not model release of P from sediments.	

Component C: General

Public Availability	Available	Contact Information	William Walker; wwwalker.net/dmsta
Run Time	Computationally Efficient - Fast	Platform	Excel
Acceptance	Wide	Technical Support	No information
Documentation	Available - Complete	Source Code	Available
Pre Processor	Excel Spreadsheet/macros	Post Processor	Spreadsheet
Other Model Features	Currently used in the evaluation of STAs.		
Other Capabilities	Easy to use, simple dynamics with limited number of parameters		
	Calibrated to a very large number of wetland systems similar to the refuge		
Limitations	20% standard error for predicted outflow TP		

Model Evaluation Sheet

Model No. 22: CE-QUAL-R1

Component A: Hydrodynamics

Dimension	Spatial:	1D vertical	Time:	Varying
Model Characteristics	Simple hydrodynamic model. Flux model with vertical sequence of horizontal layer			
Wetting and Drying	It is not included		Ground Water Flow	Possible
Additional Information	Simulation of surface flows, interflows and underflow are possible			

Component B: Water Quality

Components	Can model up to 27 variables and 11 materials in sediments, including P, nitrogen (N) and dissolved oxygen (DO)
Vegetation	Phytoplankton and macrophytes
Soil	
Additional Information	Can simulate water quality (WQ) problems associated with reservoir eutrophication
Complete N & P Cycling models	

Component C: General

Public Availability	Available	Contact Information	Dorothy Tillman, http://smig.usgs.gov
Run Time	No information	Platform	Windows
Acceptance	Wide	Technical Support	Limited
Documentation	Available - Complete	Source Code	Available
Pre Processor	Available	Post Processor	Available – Graphics tool
Other Model Features	Good surface heat exchange and DO sub-models		
Other Capabilities	Includes anoxic-anaerobic conditions. Uptake-excretion kinetics and regeneration of P and N under both aerobic and anaerobic		
Limitations	It is strictly a reservoir model		

Model Evaluation Sheet

Model No. 23: CE-QUAL-W2

Component A: Hydrodynamics

Dimension	Spatial:	2D longitudinal - vertical	Time:	Varying
Model Characteristics	Implicit finite difference (FD) scheme, laterally averaged equations of momentum, continuity and transport			
Wetting and Drying	No information		Ground Water Flow	No information
Additional Information	The model predicts water surface elevations. Used in lakes, reservoirs, and estuaries			

Component B: Water Quality

Components	Can model up to 22 parameters, including P, nitrogen (N) and dissolved oxygen (DO)
Vegetation	Phytoplankton
Soil	
Additional Information	Can simulate water quality (WQ) problems associated with reservoir eutrophication
Complete N & P Cycling models	

Component C: General

Public Availability	Available	Contact Information	Thomas Cole; www.wes.army.mil/el/elmodels
Run Time	No information	Platform	Windows
Acceptance	Wide	Technical Support	Limited
Documentation	Available - Complete	Source Code	Available
Pre Processor	Beta Development	Post Processor	Needs to be developed for graphics
Other Model Features	Multi-branches is possible, variable grid spacing		
Other Capabilities	Surface wind stress, long-term simulations		
	Hotstart, autostepping		
Limitations	Does not include macrophytes		
	Requires knowledge of hydrodynamics, chemisty, aquatic biology		

Model Evaluation Sheet

Model No. 24: LOWQM (Lake Okeechobee Water Quality Model)

Component A: Hydrodynamics

Dimension	Spatial:	One stirred tank plus benthos	Time:	Dynamic
Model Characteristics	In-lake water movement can be simulated by a separate hydrodynamic model			
Wetting and Drying	No information		Ground Water Flow	No information
Additional Information				

Component B: Water Quality

Components	Uses WASP to simulate eutrophication in both water and sediments
Vegetation	Algae
Soil	Include sediment resuspension based on hydrodynamic model
Additional Information	Lake water model
Modified WASP by including three algae groups instead of one	

Component C: General

Public Availability	Under Development	Contact Information	Thomas James; tjames@sfwmd.gov http://www.sfwmd.gov/org/wrp/wrp_okee/projects/lowqm.html
Run Time	No information	Platform	Windows
Acceptance	No information	Technical Support	No information
Documentation	Partial	Source Code	No information
Pre Processor	WASP interface	Post Processor	Post-processing graphics routines
Other Model Features			
Other Capabilities	Same WASP capabilities		
	Models sediment resuspension		
Limitations	Model is currently under development		

Model Evaluation Sheet

Model No. 25: WQRRS (Water Quality for River-Reservoir Systems)

Component A: Hydrodynamics

Dimension	Spatial:	1D longitudinal	Time:	Steady and unsteady
Model Characteristics	One-dimensional representation of reservoirs and the stream hydraulic module routes flow using different methods			
Wetting and Drying	It is not included		Ground Water Flow	No information
Additional Information	1D representation of well-mixed reservoir and longitudinal conditions in river networks			

Component B: Water Quality

Components	Reservoir and stream WQ modules; can simulate 18 different parameters, including P, N and O
Vegetation	Phytoplankton and benthic algae
Soil	
Additional Information	Can simulate water quality (WQ) problems associated with reservoir eutrophication
In the stream quality module the rate of transport of quality parameters can be represented for aerobic streams, and peak pollutant loads into the steady or unsteady hydraulic environment can be simulated.	

Component C: General

Public Availability	Available	Contact Information	HEC USACE
Run Time	No information	Platform	DOS
Acceptance	Wide	Technical Support	No information
Documentation	Available	Source Code	No information
Pre Processor	Available	Post Processor	No information
Other Model Features	Flow and WQ can be simulated for stream network, including branching channels and islands		
Other Capabilities	Includes weather data		
Limitations	Assumption of completely mixed for reservoirs, requires the assumption of instantaneous dispersion of all inflow quantities		
	Present minor errors in mass conservation		
	Limited to aerobic systems		

Model Evaluation Sheet

Model No. 26: WASP 6 – DYNHYD5

Component A: Hydrodynamics

Dimension	Spatial:	DYNHYD5? 1D	Time:	Unsteady
Model Characteristics	Simple hydrodynamic model, predicts water height and volumes			
Wetting and Drying	It is not included		Ground Water Flow	It is not included
Additional Information	The flow that defines advective transport can be supplied directly or calculated by a hydrodynamic model			
WASP6 might be linked to other 1D, 2D or 3D hydrodynamic models				

Component B: Water Quality

Components	WQ for aquatic systems including both the water column and the underlying benthos. Complete eutrophication module (WASP EUTRO module)
Vegetation	Benthos or benthic vegetation, algae
Soil	Benthic fluxes, accumulation in sediments. Sediment diagenesis
Additional Information	Complete N and P cycles, DO balance. Complete phytoplankton model
Used for WQ problems in ponds, streams, lakes, reservoirs, rivers, estuaries and coastal waters. Used for the development of TMDL	

Component C: General

Public Availability	Available	Contact Information	EPA; Wool.Tim@epamail.epa.gov
Run Time	Computationally Efficient - Fast	Platform	Windows
Acceptance	Wide	Technical Support	Available
Documentation	Available	Source Code	FORTRAN - Available
Pre Processor	Available - Included	Post Processor	Included – graphical presentation
Other Model Features	Used for the development of TMDL		
Other Capabilities	The eutrophication module can simulate some or all of the parameters		
	Includes flux for resuspension of heavy metals		
	Can be modified to include other reactions		
Limitations	Needs to be linked to a hydrodynamics model		
	The sediment diagenesis module is in development		

Model Evaluation Sheet

Model No. 27: HSPF (Hydrological Simulation Program – FORTRAN)

Component A: Hydrodynamics

Dimension	Spatial:	lumped spatial 2 D	Time:	Varying
Model Characteristics	Can simulate hydrologic and WQ processes on pervious and impervious surface and in streams and well-mixed impoundments			
Wetting and Drying	Partial		Ground Water Flow	Included
Additional Information	The model produces a time history of the runoff flow rate, sediment load, nutrients and pesticide concentrations			
Overland flow is treated as a turbulent flow process. It is simulated using the Chezy-Manning equation and an empirical expression which relates outflow depth to detention storage. The outflow from active groundwater storage is based on a simplified model, it assumes that the discharge of an aquifer is proportional to the product of the cross-sectional area and the energy gradient of the flow				

Component B: Water Quality

Components	Nutrients cycling in watershed
Vegetation	Allows and optional yield-based method for simulating nutrient uptake by plant
Soil	Land and soil contaminant runoff processes with in-stream hydraulics and sediment-chemical interactions
Additional Information	Includes atmospheric deposition as a mass flux or as concentration in rainfall
The reaction processes included are hydrolysis, oxidation, photolysis, biodegradation, volatilization and sorption	

Component C: General

Public Availability	Available	Contact Information	h2osoft@usgs.gov; EPA; epa.gov
Run Time	Computationally Efficient - Fast	Platform	Windows
Acceptance	Wide	Technical Support	Limited
Documentation	Available	Source Code	FORTRAN - Available
Pre Processor	Available	Post Processor	Available
Other Model Features	Includes resuspension of silts and clay		
Other Capabilities	Includes heat exchange and evapotranspiration modules		
	The stream channel simulation includes flow routing and oxygen and nutrients biochemical modeling (through phytoplankton)		
	Is able to simulate point and non-point sources, is integrated into the EPA BASINS GIS based modeling support system		
Limitations	Assumes that the receiving water body is well-mixed		

Model Evaluation Sheet

Model No. 28: RCA

Component A: Hydrodynamics

Dimension	Spatial:	Coupled with ECOMSED or EFDC	Time:	Unsteady
Model Characteristics	WQ model that has been applied to rivers, lakes, estuaries and coastal systems			
Wetting and Drying	Depends on the hydrodynamic model used		Ground Water Flow	Depends on the hydrodynamic model used
Additional Information	Uses finite difference			

Component B: Water Quality

Components	Simple and advanced eutrophication, wetland systems
Vegetation	Algae (multiple algal groups)
Soil	Includes a sediment nutrient flux subroutine (deposition and resuspension)
Additional Information	Fully closed P and N cycles, complete DO/BOD dynamics
The model is based on USEPA WASP	

Component C: General

Public Availability	Available	Contact Information	HydroQual, Inc.; Hydroqual.com
Run Time	No information	Platform	UNIX, LINUX and Windows
Acceptance	New Model	Technical Support	No information
Documentation	Partial	Source Code	Available, FORTRAN
Pre Processor	No information	Post Processor	No information
Other Model Features	Flexible input structure (different points and diffuse sources)		
Other Capabilities	Transport of dissolved and particulate substances		
	Includes volatilization in the water-air interface		
Limitations	The model was recently release for public use; it has not been fully tested		

Model Evaluation Sheet

Model No. 29: GLEAMS (Groundwater Loading Effects of Agricultural Management Systems)

Component A: Hydrodynamics

Dimension	Spatial:	Field Scale	Time:	Daily variations
Model Characteristics	The models simulates runoff and percolation			
Wetting and Drying	Partial		Ground Water Flow	Percolation-vertical movement
Additional Information	It consists of four major components: hydrology, erosion/sediment yield, pesticide transport, and nutrients			
The model tracks movement of pesticides with percolated water, runoff, and sediment				

Component B: Water Quality

Components	Conservative, erosion and sediments, pesticides, nutrients
Vegetation	Plant uptake of pesticide
Soil	Soil profile description and crop data are used to estimate effective rooting depth
Additional Information	Soils data are input by soil horizon, and the model distributes values of porosity, water retention characteristics, and organic matter
into the appropriate computational layers	

Component C: General

Public Availability	Available	Contact Information	Daren Harmel, USDA-ARS, Temple, TX http://www.cpes.peachnet.edu/sewrl/Gleams/gleams_y2k_update.htm
Run Time	Computationally Efficient -FAST	Platform	Windows
Acceptance	Wide	Technical Support	No longer supported by ARS
Documentation	Available - Complete	Source Code	FORTRAN
Pre Processor	Available in C code	Post Processor	Included
Other Model Features	Upward movement of pesticides and plant uptake are simulated with evaporation and transpiration		
Other Capabilities	Widely used to simulate nutrient nonpoint source impacts on water quality, nutrient dynamics may be incorporated into RSM		
	Nutrient dynamic formulation may provide ideas for implementation in other models		
Limitations	Assumes that a field has homogeneous land use, soils and precipitation		
	Field scale model		

Model Evaluation Sheet

Model No. 30: BLTM (Branched Lagrangian Transport Model)

Component A: Hydrodynamics

Dimension	Spatial:	1D with branches	Time:	Dynamic
Model Characteristics	Must be integrated with flow model (BRANCH and DAFLOW frequently used)			
Wetting and Drying	It is not included		Ground Water Flow	It is not included
Additional Information	The model solves the one-dimensional convective-diffusion equation with reaction kinetics			

Component B: Water Quality

Components	Two subroutines are available, one to route any number of independent constituents with first order decay, and one which duplicates the reactions kinetics in the EPA QUAL2E
Vegetation	Phytoplankton
Soil	
Additional Information	The model includes a subroutine to predict stream temperature

Component C: General

Public Availability	Available	Contact Information	Harvey E. Jobson, USGS http://water.usgs.gov/software/bltm.html
Run Time	No information	Platform	Windows, UNIX
Acceptance	Wide	Technical Support	No information
Documentation	Available - Complete	Source Code	FORTRAN 77
Pre Processor	Included	Post Processor	Included
Other Model Features	Specalized reaction kinetics can be easily developed by modifications to one of the existing kinetic subroutines		
Other Capabilities	Water quality model, easily modified by user. Lagrangian technique eliminates numerical dispersion		
Limitations			

Model Evaluation Sheet

Model 31: SWAT (Soil and Water Assessment Tool)

Component A: Hydrodynamics

Dimension	Spatial:	Lumped 2D, Field Scale	Time:	Daily variations
Model Characteristics	The model includes surface runoff, base flow, transmission losses, pond and reservoir storage, reach routing and groundwater flow			
Wetting and Drying	Partial		Ground Water Flow	Included
Additional Information	Surface runoff volume is computed using a modification of the SCS curve number method or the Green @ Ampt infiltration method			
SWAT partitions groundwater into a shallow, unconfined aquifer and a deep-confined aquifer. Open channel flow is calculated using Manning's equation				

Component B: Water Quality

Components	Nitrogen and phosphorus cycling. Nutrients routing. Algae, DO and BOD models
Vegetation	Plant growth model. Nutrients plant uptake is simulated
Soil	Includes transformation of N and P in the soil. In addition to plant use, the nutrients may be removed via mass flow of water
Additional Information	SWAT tracks the movement and transformation of several forms of N and P in the watershed, and nutrient transformations in the
stream are controlled by the in-stream WQ model which is adapted from QUAL2E	

Component C: General

Public Availability	Available	Contact Information	www.brc.tamus.edu/swat/ Jeff Arnold; jgarnold@spa.ars.usda.gov
Run Time	Computationally efficient	Platform	DOS/Windows, UNIX
Acceptance	Wide	Technical Support	No information
Documentation	Available	Source Code	Available
Pre Processor	Included	Post Processor	Included
Other Model Features	Incorporates features of SWRRB, CREAMS, GLEAMS and EPIC. The model includes a SWAT/ArcView interface		
Other Capabilities	Enable users to study long-term impacts, e.g., several decades.		
	In addition to return flow, water stored in the shallow aquifer may replenish moisture in the soil profile in dry conditions		
	Model components also include weather, percolation, ET, crop growth, irrigation and water transfer from channels and reservoirs		
Limitations	SWAT is a continuous time model, i.e. a long-term yield model. It is not designed to simulate detailed, single-event flood routing.		