Large-Scale Constructed Wetlands for Nutrient Removal from Stormwater Runoff: An Everglades Restoration Project

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ABSTRACT / The South Florida Water Management District (SFWMD) constructed a wetland south of Lake Okeechobee to begin the process of removing nutrients (especially phosphorus) from agricultural stormwater runoff entering the Everglades. The project, called the Everglades Nutrient Removal (ENR) project, is a prototype for larger, similarly constructed wetlands that the SFWMD will build as part of the Everglades restoration program. This innovative project is believed to be one of the largest agricultural stormwater cleanup projects in the United States, if not in the world. This publication describes the ENR project's design, construction, and proposed operation, as well as the proposed research program to be implemented over the next few years.

The Everglades is an internationally recognized ecosystem, supporting a variety of rare, threatened, and endangered species whose survival depends on the natural cycles of water and nutrients under which the system evolved. These natural cycles historically included very low nutrient levels, with particularly low levels of phosphorus (P). In the past, rainfall was the primary source of all nutrients to the Everglades; this still is true for areas away from stormwater discharges (Parker 1974).

In recent times, phosphorus enrichment of the Everglades has had far-reaching consequences, including changes in water quality, vegetation, algae community structure, oxygen levels, sediment chemistry, and food web dynamics. One origin of the excess P is stormwater runoff from 284,900 ha (704,000 acres) of adjacent highly productive farmlands. These farmlands are planted primarily in sugarcane in an area south of Lake Okeechobee (Figure 1) referred to as the Everglades agricultural area (EAA). The movement of water from the EAA down through the Everglades is controlled by an extensive canal system managed by the South Florida Water Management District (SFWMD).

The Marjory Stoneman Douglas Everglades Protection Act of 1991 gives the District the authority by Florida law to develop stormwater treatment areas (STAs) and to implement a regulatory program for EAA land users that will reduce stormwater P loading to the Everglades. The Everglades Forever Act of 1994 mandates, among other things, completion of STAs, and research to optimize their phosphorus retention capacity and to define the threshold phosphorus concentrations that do not lead to an imbalance of flora or fauna. One element of the Everglades restoration effort entails the construction and operation of six man-made wetlands encompassing a total area of approximately 16,400 ha (40,500 acres) to remove P from water entering the Everglades. Construction of the STAs is scheduled to begin in mid-1996, with completion by late 2003. Completion of the STAs is based on a number of significant assumptions concerning sources of funding, implementation responsibilities, and prioritization of the various components of the Everglades Protection Project (Burns and McDonnell 1994).

Unfortunately, no water pollution control or water management agency, including SFWMD, has experience in constructing and operating wetlands for nutrient removal on the scale proposed. To gain experience, the District has constructed a demonstration-scale wetland, the 1544-ha (3815-acre) Everglades Nutrient Removal (ENR) project (Figure 2), located on state-owned land formerly leased mainly for sugar cane and vegetable farming (Figure 3). The primary goal of the ENR project is to reduce P loads in agricultural runoff that presently enters the Arthur R. Marshall Loxahatchee National Wildlife Refuge. The Refuge, also known as

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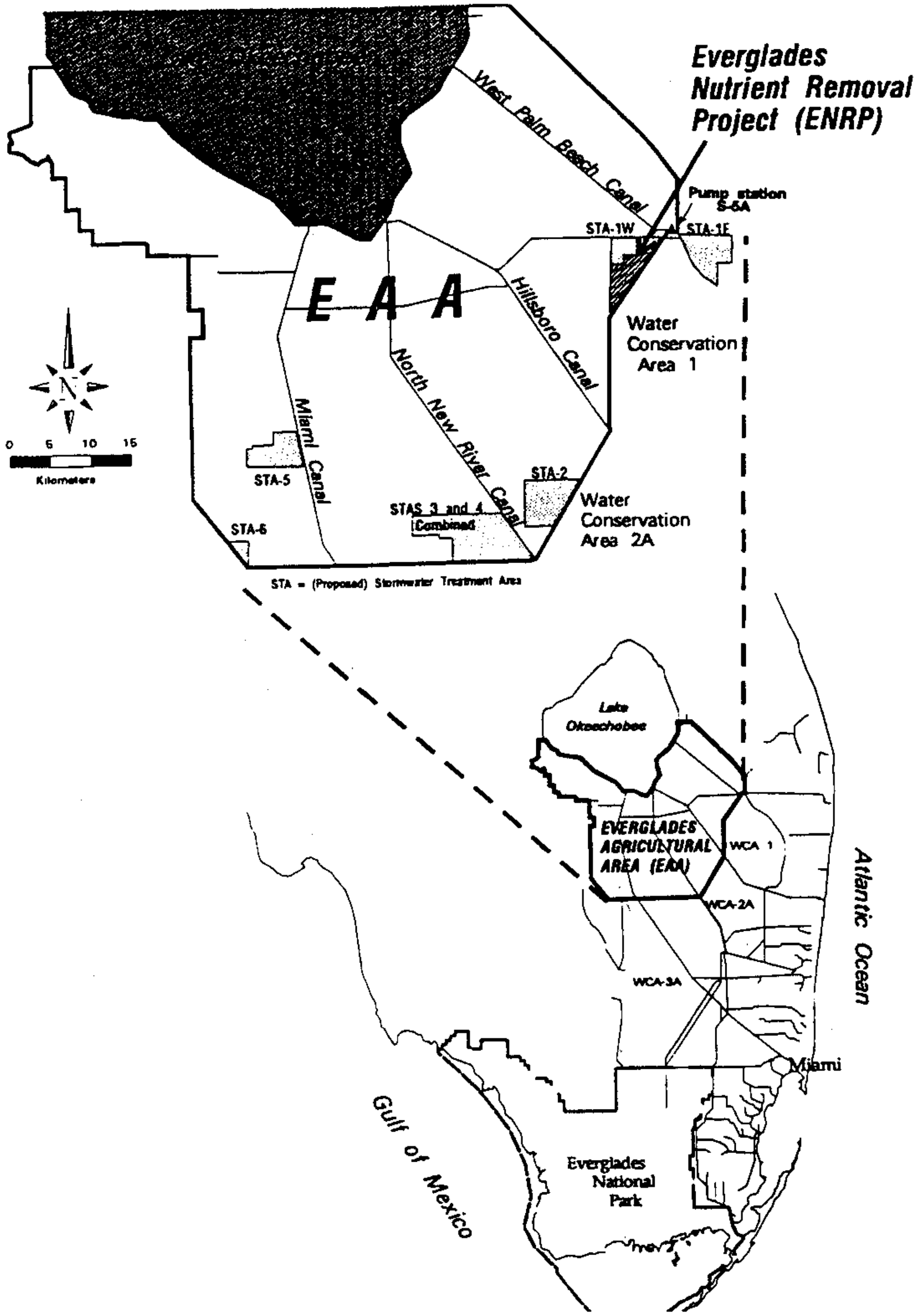

Figure 1. Location of the Everglades Nutrient Removal (ENR) project.

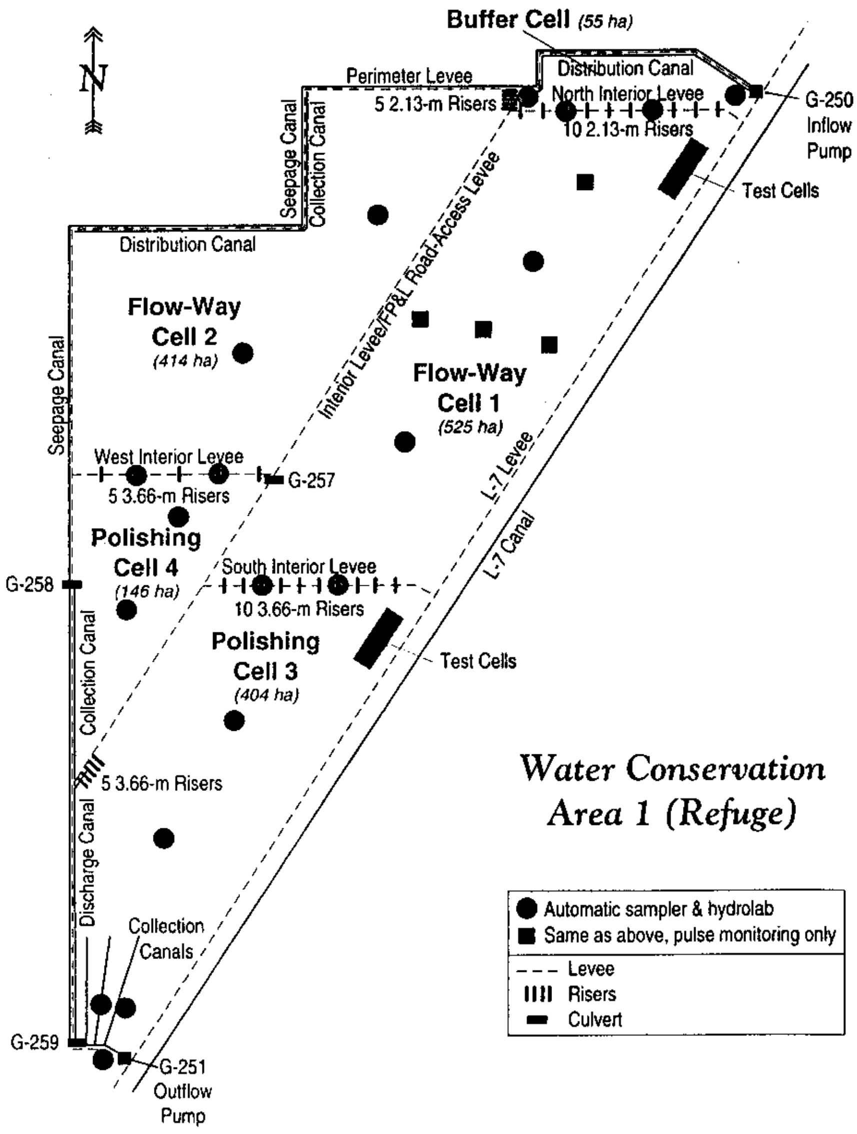

Figure 2. The ENR project and its water quality monitoring network.

Water Conservation Area 1(WCA-1), is one of the remaining sections of the original northern Everglades ecotype and has been designated as an Outstanding Florida Waterbody. Construction of the ENR project was completed at the end of 1993, at a cost of about 13.9 million dollars. The ENR project began operation in August 1994. After a period of at least three years of operation, the SFWMD plans to incorporate the ENR project into one of the STAs (Figure 1).

Conceptual and Engineering Basis of Design

There are four generally accepted mechanisms for P removal within a wetland system: (1) soil sorption, (2) coprecipitation of inorganic phosphate salts with calcium carbonate at elevated pH, (3) uptake by and subsequent permanent sedimentation of algae and bacteria, or (4) uptake and subsequent peat formation by rooted and floating plants. In areas with mineral soils, formation of stable associations of P with the aluminum or iron components of the soil can be the most important mechanism of P retention (Richardson 1985). The primary P removal mechanism within the ENR project and STAs, however, is expected to be through peat accumulation. This is based on data from Water Conservation Area 2A (WCA-2A), a 51,800-ha (128,000-acre) impoundment for water storage and wildlife habitat (Figure 1), that has shown significant accretion of macrophyte-derived peat sediments and associated P in this nutrient-impacted wetland (Koch and Reddy 1992).

Figure 3. Native wetland vegetation quickly colonized sugarcane fields that were burned and/or disced under and flooded two years prior to construction of the ENR project.

It has been hypothesized that hydraulic retention time (HRT) in wetland systems ceases to be a primary determinant of P removal efficiency when it exceeds five days (R. H. Kadlec, personal communication, Wetland Management Services, Chelsea, Michigan). Current operational plans call for a mean of 4.25 m^3/sec (150 cfs) to be diverted into the ENR project, which will result in a HRT of approximately 14 days (Burns and McDonnell 1992). Based on hydrodynamic simulations (at steady state), a HRT of about 18 days is expected in the ENR project for the mean flow (Guardo and Tomasello 1995) at mean water depths slightly lower than 0.60 m (2.0 ft).

It is anticipated that hydraulic loading rate (HLR), which represents the volumetric flow per surficial area, and mean water depth, rather than HRT, will be the primary determinants of P removal efficiency in the ENR project, as well as in the STA design. The project design HLR is a mean value over time. However, as observed in WCA-2A stormwater, pulses may account for a significant portion of the P load to the ENR project. Agricultural runoff is primarily driven by storm events; therefore, the ENR project will receive pulsed hydraulic loads, which means that hydraulic steady state will not be achieved often.

Hydrodynamic Model Simulation

To generate estimates of mean flow velocities, water depths, and flow distribution expected within the ENR project, hydrodynamic simulations were performed using SHEET-2D (Guardo and Tomasello 1995), a two-dimensional model. These results were useful for forecasting hydrologic conditions to which the levees, pumps, and wetland vegetation will be subjected. In addition, simulation results were used as input to a lumped parameter-box water-quality model to analyze the long-term performance of the ENR project with respect to hydrology and P uptake (Burns and McDonnell 1992). SHEET-2D solves the continuity and momentum differential equations by finite difference using an implicit scheme and simulates sheetflow generated by runoff or inflow pump hydrographs on an array of over 300 computational grids, each 182.9 m × 276.1 m (600 ft × 906 ft). The model estimates water depths and flow vectors in each treatment cell, flow distribution between treatment cells after leaving the buffer cell, and HRT of the ENR project. The computational grids are connected by sheetflow unless separated by an inactive (dry grid) or by barriers. If a barrier separates two grids within the system, flow may exist between those grids by means of a structure or conveyance flows. The hydraulic structure options include pumps or any combination of weirs, pipes, and bleeders. The area/slope/conveyance and irregular weir option are also available for flow-through grid barriers.

Individual grid inputs include topography, roughness (i.e., Manning's *n*), initial water surface elevation, and hydrologic inputs including soil storage and depression storage. Input stage or flow hydrographs may be applied to any active grid within the grid system. Stage/discharge relationships can be applied in grids as a boundary condition.

Constant inflow hydrographs were input into the model. The simulation time was 30 days in order to reach steady state conditions for a constant inflows ranging from 2.12 to 17 m^3/sec (75–600 cfs). To simulate waterbodies (e.g., canals) within or adjacent to the grid network, the multibasin routing (MBR) model features that are built into SHEET-2D were employed (Guardo and Tomasello 1995). The MBR basins can be connected to the SHEET-2D grid network by sheetflow or by structural or channel conveyances. The MBR model assumes a "level pool" routing condition, which, in this case, is a reasonable assumption for simulation of the distribution and collection canals within the project wetlands.

Vegetation Effects on Hydrology and Modeling

Wetland vegetation affects hydrologic conditions through its ability to consolidate soil against erosion, trap sediments, build peat deposit, interrupt water flows, and change flow paths. Use of color infrared aereal photographs can be an important tool to determine these effects (Figure 4). The influence of vegetation on infiltration and soil water storage comes from trapping of decaying leaves and subsequent build-up of peat. In addition, plant roots affect water storage by stabilizing

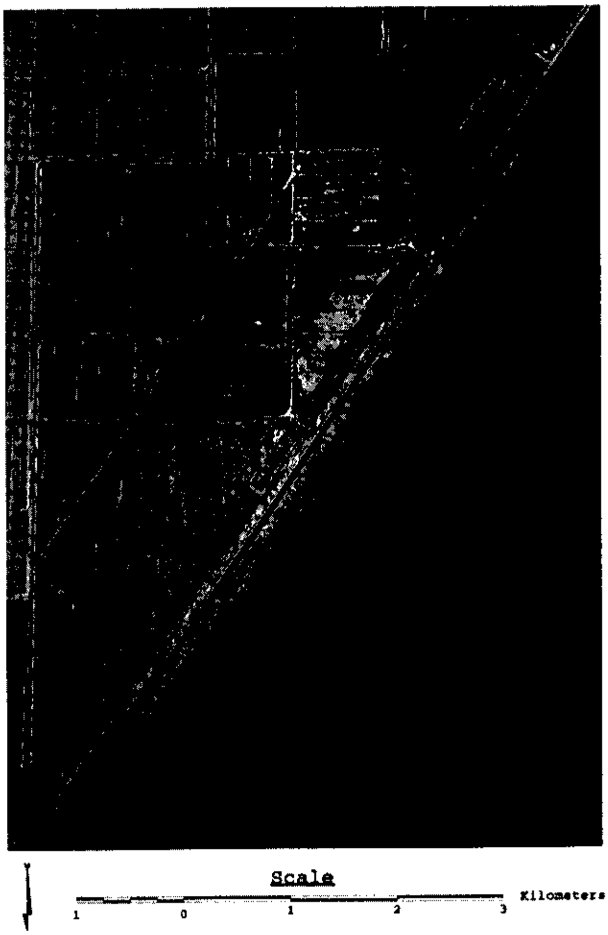

Figure 4. Digitally scanned color infrared aerial photography of the ENR project site in October 1993.

the soil and through transpiration. Experiments (Mitsch and Gosselink 1986) have shown a positive correlation between the quantity of organic matter present in the soil and its water-holding capacity.

Currently, little information is available on flow resistance values in heavily vegetated wetlands. While Manning's equation has been extensively used to estimate overland flow resistance as a function of velocity, depth, and slope, resistance values in marshes also are a function of lateral and vertical vegetation density, species composition, and seasonal variations. Manning's *n* values could be predicted, under there circumstances, as a function of flow depth and vegetation characteristics. Therefore, one aspect of ENR site research will be to determine vegetation-specific seasonal variations of hydraulic resistances that will be useful for calculation of water budgets and calibration of hydrodynamic simulations. Some monitoring of hydraulic resistance will be conducted during extreme events (storms).

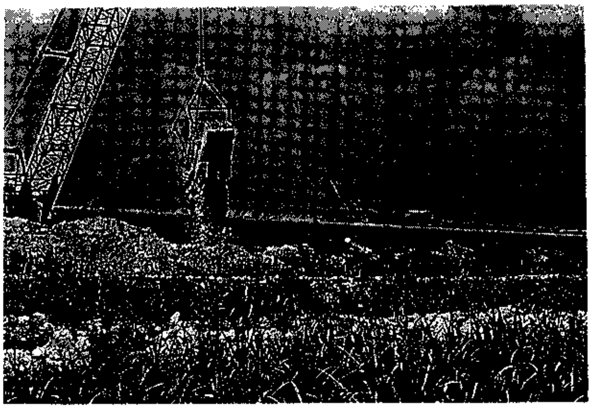

Figure 5. Dragline excavates fill material for construction of perimeter levee. Over 12 km of perimeter levee have been constructed in this fashion.

ENR Project Construction

Construction of the ENR project involving building structural elements (levees, pump stations, etc.) and establishing the wetland vegetation required for nutrient uptake and retention. All structural elements were completed by fall 1993. These include a 12.1-km (7.5-mile) perimeter levee (Figure 5) with a top elevation ranging from 5.03 to 4.57 m National Geodetic Vertical Datum of 1929 (NGVD) (16.5–15.0 ft NGVD), interior levees to separate the treatment cells, a seepage collection canal to minimize impacts to adjacent farmland; a 3.4–km (2.1-mile) supply canal to divert water to the project, and inflow and outlfow pumping stations (Figure 6). The perimeter levee together with the L-7 levee surround the project site (Figure 2).

The aspect of a constructed wetland is defined as the ratio of its length to its width. The ENR project has an aspect ratio of approximately 2.5:1. Treatment cells 1 and 3 have a 3:1 aspect and treatment cells 2 and 4 have an aspect of about 2:1.

Flow-way cells 1 and 2 will be vegetated through natural regrowth of emergent aquatic plants (primarily cattails). This process is now well underway. Polishing cell 3 has been partially planted as a mixed-species emergent macrophyte marsh, and polishing cell 4 will be managed as a submerged macrophyte/algal-based system.

ENR Project Operation

A portion of the stormwater runoff from the EAA will be diverted from the West Palm Beach Canal just upstream of the S-5A pump station (Figure 1) to the ENR project using six elecric pump units (Figure 6)

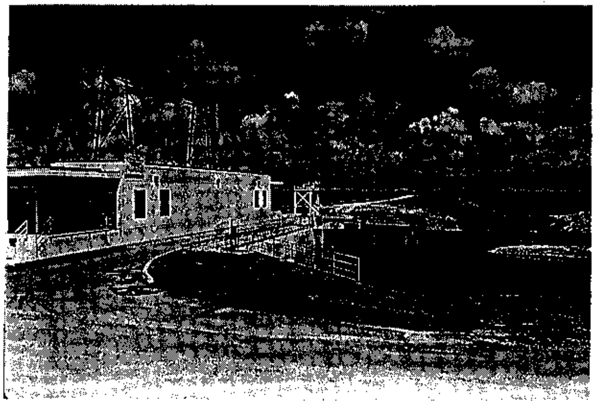

Figure 6. Agricultural runoff water is pumped into the ENR project through this inflow pump station. Water from the seepage canal, pictured behind the sheet pile which separates inflow from seepage supply, can be recirculated into the project.

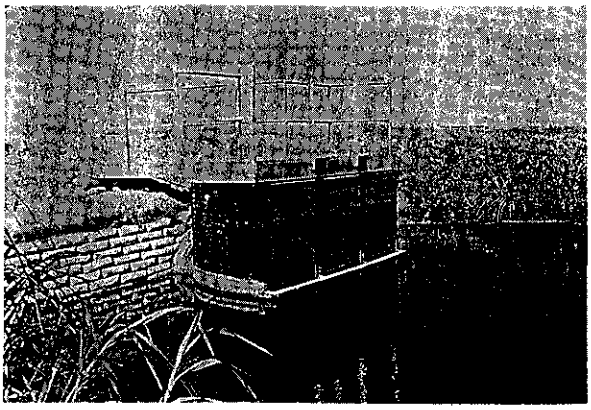

Figure 7. Risers, 3.66 m in diameter, form the inlet to 1.83-m culverts that transfer water from the flow-way cells to the polishing cells. Flashboards are manipulated to control stages and flows.

with a total capacity of 17 m^3/sec (600 cfs). A 55-ha (136-acre) buffer cell receives the diverted flow from the inflow pump station. Water is then routed from the buffer cell to the two treatment trains formed by the 525-ha (1297-acre) flow-way cell 1 with the 414-ha (1023-acre) polishing cell 3, and the 404-ha (998-acre) flow-way cell 2 with the 146-ha (361-acre) polishing cell 4. The two treatment trains are separated by a transverse levee that crosses the ENR project in a northeast–southwest direction. Flow-way cells 1 and 2 are intended for initial bulk P removal processes, while polishing cells 3 and 4 are for refined P removal in a lower concentration range. Corrugated metal pipe culverts 1.83 m (6 ft) in diameter divide the flow from the buffer cell to flow-way cell 1 (10 culverts) and to flow-way cell 2 (five culverts). Their inlets are risers 2.13 m (7 ft) in diameter with flashboards, which can be used to control water depths (stages). Flow is conveyed from flow-way cell 1 to polishing cell 3 by ten similar structures with risers 3.66 m (12 ft) in diameter (Figure 7). Three collection canals facilitate conveyance from polishing cell 3 to the outflow pump station. Flow from flow-way cell 2 to polishing cell 4 is through five structures, and at the outlet of cell 4, five additional structures pass the water through the transverse levee, prior to entering a collection canal separated from polishing cell 3 by a berm (Figure 8). This canal conveys the treated water from both treatment trains to six electric pump units with a total capacity of 12.74 m^3/sec (450 cfs) for discharge into L-7 borrow canal, which forms the western boundary of the Refuge (WCA-1). ENR project components are depicted in Figure 2.

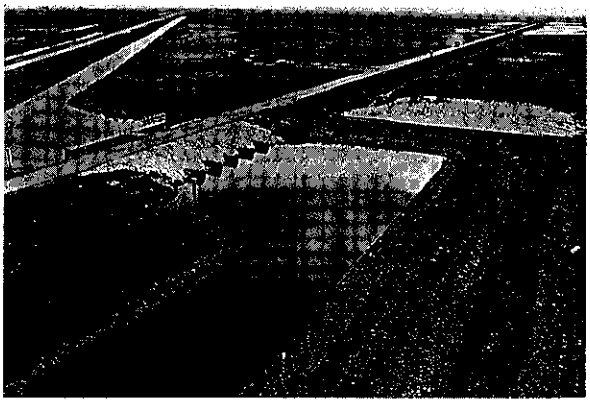

Figure 8. The berm in the right side of the picture separates the discharge canal of polishing cell 4 from polishing cell 3. Five culverts 1.83 m in diameter with risers 3.66 m wide cross the transverse levee at the downstream end of polishing cell 4.

Either flow-way cell can be bypassed for drydown. Polishing cell 4 can be dried out independently of flow-way cell 2, but polishing cell 3 cannot be dried out independently of flow-way cell 1. Seepage through the western and northern perimeter levee is returned to the upstream end of the distribution canal in the buffer cell via a seepage canal using three electric pumps (Figure 6) with a total capacity of 5.66 m^3/sec (200 cfs). If necessary, the discharge to the refuge can be stopped and the effluent can be recirculated to the inflow pump station via the seepage collection canal by diverting water through two gated culverts (G-258 and G-259; Figure 2).

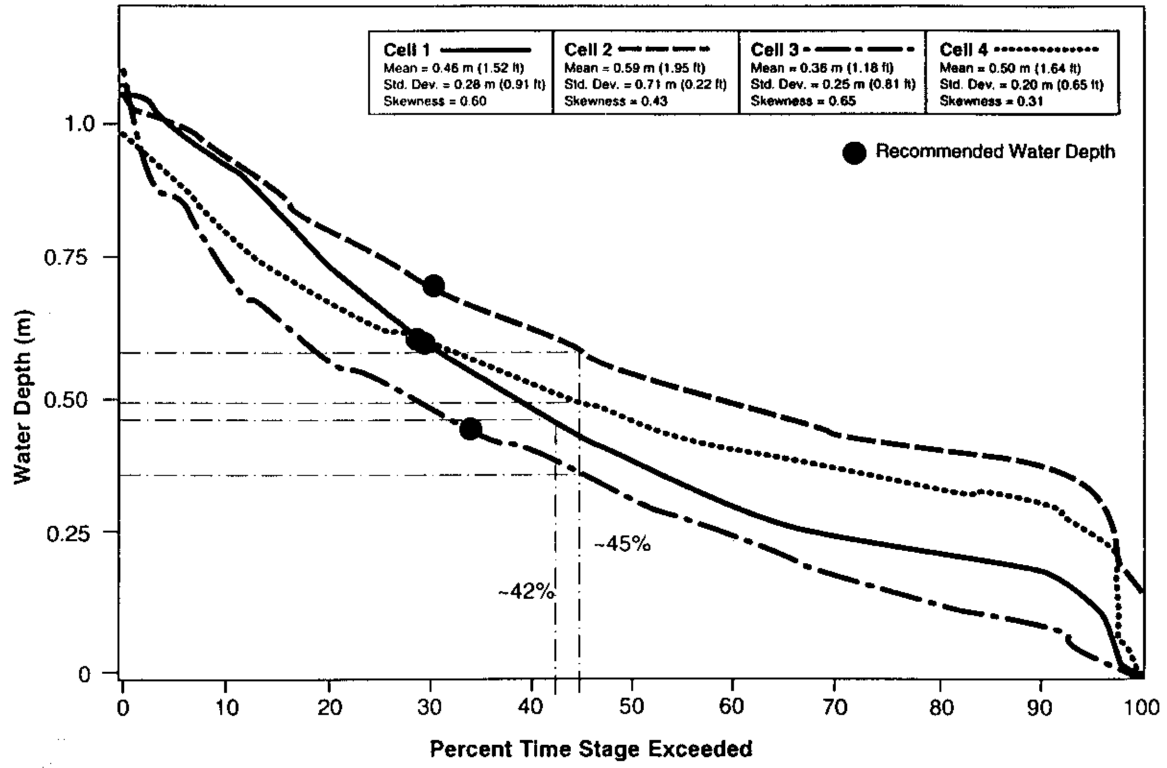

Figure 9. Stage-duration curves for the treatment cells.

The operational mean water depth of the flow-way and polishing cells will affect the types of plants that colonize the wetland, their rates of colonization, and the rate of associated peat deposition. Selection of mean water depths is particularly critical in the polishing cells, where lower stages may favor rooted macrophyte establishment, while higher stages may favor algal colonization.

There will be two ENR operation phases, each with distinct water level criteria: the startup phase (stage I) and the normal operational phase (stage II). Stage I will last one or two years, and it is divided into an early and late startup period. During stage I, it will be necessary to ensure adequate development and growth of the vegetation within the treatment cells. Therefore, long periods of flooding with high water depths will be avoided since the lack of oxygen and light would damage the developing plants. During stage II, higher water depths will be allowed in the treatment cells (Guardo and Kosier 1993). Stage-duration curves for the ENR project derived from ten-year historic flow data for the EAA show that the recommended water depths may be exceeded approximately 28%–33% of the time on an annual basis (Figure 9). The mean water depths for the four treatment cells coincide with exceedence probabilities of 42%–45% (Guardo and Kosier 1993).

Assessing ENR Project Performance

To evaluate the nutrient removal performance of the ENR Project, nutrient mass and hydrologic water balances for each treatment cell will be calculated.

Hydrologic Water Balance

Water budgets will be calculated by monitoring rainfall, evapotranspiration, surface inflows, surface outflows, and seepage into and out of the project. The balance of these components yields a change in storage, which represents the seasonal pattern, i.e., hydroperiods of water stages within a wetland. The hydroperiod will be affected by external forces as well as topography, soil and groundwater conditions, and vegetation type. Weather stations play an important role to obtain estimates of required meteorological parameters (Figure 10).

An extensive stage monitoring program will be implemented for the ENR project. Water levels or stages will be recorded either continuously using stage gauges or

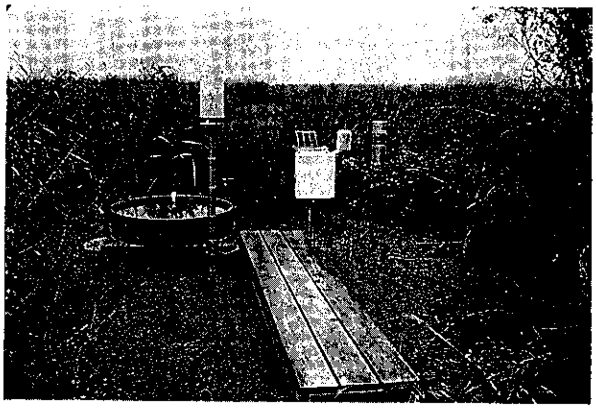

Figure 10. An extensive hydrologic monitoring program was implemented for the ENR project. Pictured is one of the weather stations on the project site.

by occasional site inspections of staff gauges. Monitored stages provide water depths, the hydroperiod, and the frequency and duration of flooding events. In some instances the stages can be used to estimate changes in storage in a water budget if one of its hydrologic components needs to be estimated.

Initially, ten continuously recording, tipping-bucket type rain gauges will be installed to analyze the spatial and temporal variability of rainfall over the project site (Guardo and others 1994). Areal rainfall in the entire project and for each treatment cell will be determined by the Thiessen polygon method. After determining the temporal (hourly and daily) and spatial rainfall variations, the number of rain gauges will be appropriately adjusted.

Evapotranspiration will be estimated using the Penman-Monteith equation (Smith 1991) with data obtained from a complete weather station at the project site. These estimations will be verified experimentally using 3.51-m (11.5-ft) -diameter lysimeters. At least three lysimeters will be installed with different vegetation to measure evapotranspiration losses from the major plant communities. A lysimeter is already in operation in flow-way cell 1. This lysimeter was planted with cattail and provides daily estimates of evapotranspiration as a residual of its water balance (Abtew and others 1993).

Fifteen piezometers, located along the exterior and interior levees, and 11 pairs of staff gauges will be utilized to measure hydraulic gradients across the perimeter levee. This will allow an estimate of seepage into and out of the ENR project. During a recent test of short duration, seepage from the refuge across the L-7 levee was estimated to be about 88 liters/sec/km (5 cfs/mile) for a 2.44-m (8.0-ft) head difference.

Flow measurement methods. The ability to quantify flow and nutrient mass balances is critical to the fine tuning of project operation and documentation of nutrient removal efficiency. Accurate discharge measurements into and out of the project will be obtained from pump records. Accurate discharge measurement for flows between treatment cells is more problematic due to the low velocity expected and will be measured with automated ultrasonic velocity meters (UVMs). It is known that the drop in hydraulic gradient across the 1.83-m (6.0-ft) -diameter culverts between treatment cells well be extremely small, creating a high degree of submergence. Because of their size, the culvert invert elevation is at 1.52 m NGVD (5.0 ft NGVD) and the adjacent ground surface area for the project site is at 3.05 m NGVD (10 ft NGVD). These structures will work totally submerged, and the possibility of developing rating curves based on the difference between headwater and tailwater of the hydraulic structures is practically impossible.

A pair of UVM transducers (single path) will be installed inside the barrels of 30 of the 35 culverts. The five culverts at the downstream end of polishing cell 4 across the transverse levee will not have UVM transducers since their outflow computations can be obtained from the UVM transducers (double path) in the collection canal (Figure 8). The 14 UVM sites for the barrels of the culverts are capable of recording data from two paths (four transducers). Five UVM sites will be used for inflow to flow-way cell 1, one for inflow to flow-way cell 2, five for inflow to polishing cell 3 (or outflow-way cell 1), and three for inflow to polishing cell 4 (or outflow from flow-way cell 2). Two double-path UVMs (four transducers each) will be installed in the collection canal at the southern end of the ENR project to monitor the outflow from polishing cell 3. One double-path UVM installed downstream of the five structures in the collection canal will monitor the outflow from polishing cell 4 (Figure 8). These three UVM canal sites will consist of cross-path systems that have two acoustic paths (four transducers) that cross each other (Abtew and others 1993). The total outflow from the ENR project to the Refuge will be obtained from the UVM site at the downstream end of the discharge canal and ouflow pumps station's operational records. The operational records from the inflow pump station will be used to determine discharges into the buffer cell.

Nutrient Mass Balance

The 25 inter- and intracell water-quality monitoring stations involved in nutrient mass balance are shown in Figure 2. Each station consists of an autosampler/multiparameter meter (Hydrolab) pair with attendant electronics (i.e., CR-10 dataloggers, radio, antenna, and battery) installed on a wooden platform. Data generated by the Hydrolabs will be sent via radio to the receiving station at the District's West Palm Beach headquarters. Autosamplers will collect time-composite weekly samples for analysis of total nutrients. Grab samples will be taken bi-weekly and analyzed for nutrient type, common ions, standard water-quality parameters, iron, aluminum, TOC, and chlorophyll *a*. Together with the flow data, the water-quality data will be used to calculate nutrient and cofactor loads into and out of the buffer cell, each treatment cell, and across the project.

In addition to the routine mass balance monitoring studies, six autosamplers will be configured to switch to storm pulse monitoring mode to characterize the transport and dissipation of nutrient loads as the storm pulse moves through flow-way cell 1. Four pulse monitoring stations are within flow-way cell 1, plus one by the inflow pump station, and one by the outflow pump station (Figure 2). Samples will be collected hourly for the first 12 h of the storm event, every other hour for the next 12 h, and every 8 h thereafter for the next two days. Two wet-season and two dry-season storm events will be tracked in this way. With this information, it will be possible to evaluate the unsteady state performance of the system when pollutant and hydraulic loading rates are high but HRT is low. These data and other mass balance data will be used to calibrate a water quantity/quality model that is under development for predicting nutrient removal performance over the expected range of its hydraulic and pollutant loading conditions.

Project Research Program

Objectives and Goals

Although the construction of wetlands for wastewater treatment is becoming a common practice, many factors need to be considered during the design, construction, and subsequent operation of these systems. It is important that a fully functioning wetland is established for cleansing efficiency to be realized. The ultimate quality of water discharged from wetlands can be influenced by a number of factors, including hydrologic characteristics, vegetation community establishment, characteristics of the wastewater to be treated, and initial site preparation.

The research objective of the ENR project (ESRD 1993) are to:

1. Determine and quantify the hydrologic regime necessary to maximize long-term P retention;

2. Determine the optimum wetlands design (vegetation species, soil preparation technique, exclusion of undesirable species) to maximize P retention;

Table 1. Process level research to be conducted on ENR project

Vegetation
Hydrological conditions required for long-term maintenance of desirable vegetation communities
Time required for establishment of the wetland under different hydrologic conditions
Effect of water depths and hydraulic loading rates (HLR) on the species composition, productivity, and P removal capacity of emergent, submersed, and algal vegetation
Effect of alternate and continuous flooding and drying on plant decomposition and nutrient release
Effect of wetland vegetation on hydraulic resistance
Soil and Water
Extent and duration of nutrient release following initial flooding of the project site
Peat accretion and carbon, nitrogen and P accumulation rates in soil
Short- and long-term changes in interstitial water chemistry as a function of hydrologic conditions
Diel changes in water column nutrients

3. Determine and quantify the predominant physical, chemical and biological mechanisms for P removal in the treatment cells; and

4. Develop, calibrate, and verify a mechanistic model of P dynamics in a constructed wetland for purposes of optimizing future system design, operation and maintenance.

To meet these research goals, the previously described hydrology and water-quality mass-balance monitoring network was established. In addition, research on dynamics of vegetation, soils, and water chemistry will be conducted to furnish information for development of the mechanistic model of P dynamics in constructed wetlands (Table 1).

ENR Project Test Cells

A major objective of the ENR project is to optimize nutrient removal based on applied research into the effects of hydrologic manipulations on mechanisms of nutrient cycling and storage. However, it will not be possible to manipulate HLR, water depth, wetlands design, and drydown cycles in the full-scale treatment cells without compromising P removal efficiency. Instead, these manipulations can be conducted within two banks of 15 parallel test cells located in flow-way cell 1 and polishing cell 3 (Figure 2). Fifteen simultaneous, independent nutrient-removal studies can be conducted using water of similar quality to that entering the flow-way and polishing cells (Figure 11). The effects of hydraulic loading rate and other variables on P retention can be examined with statistical rigor in these test cells.

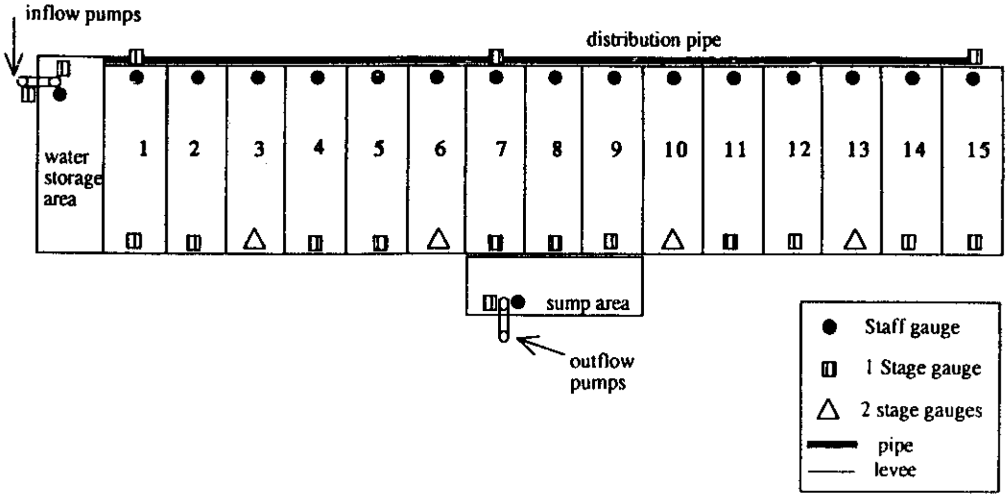

Figure 11. Illustration of the Test Cells of the ENR project.

Each test cell is 27 × 80 m (88 × 262 ft) with an aspect of 3:1, which corresponds to the aspect of flow-way cell 1 and many common constructed wetland designs. Water is pumped into a storage basin and flows by gravity through a common 0.76-m (2.5-ft) -diameter supply pipe (Figure 11). This pipe has 15 outlet pipes 0.46 m (1.5 ft) in diameter that convey the flow to each test cell. The inflow to each test cell is regulated by a 5.08-cm (2-in.) gate valve located at the downstream end of each inlet pipe. Inflows into the test cells obtained from the considered hydraulic loading rates of 0.7, 2.1, and 6.3 cm/day are 0.16, 0.53, and 1.58 liters/sec (2.8, 8.3, and 25.0 gal/min), respectively. Outflow from each test cell is through a culvert with an inlet riser that can be utilized to control water stage within the test cell. The combined outflow from the individual test cells is collected by a pipe system that discharges into the sump area (Figure 11). Water from this sump area is pumped back to the originating treatment cell (Figure 2).

The test cells are designed to provide a flexible research facility, small enough to be readily manipulated but large enough to minimize edge effects and be representative of larger systems. Because the operational and wetlands design parameters of the test cells can be controlled, replicated, and changed systematically over a specified range, true differences in nutrient removal performance under a particular range of experimental conditions is more likely to be detected in the test cell research program than in the full-scale treatment cell mass balance studies.

Project Startup

As the approximately 1550 ha of former farmland revegetates, the flooded agricultural soil will slowly convert over to a marsh ecosystem (Figure 3). This transformation will be carefully documented and implications for nutrient removal will be carefully quantified. The ENR project is expected to require at least several years until vegetation is fully established and soil conditions are stabilized. As a result, while the ENR project will receive water after physical construction is completed, it will not begin discharging until interior marsh P concentrations are consistently less than inflow P concentrations.

Summary

Much has been learned in each phase of the ENR project, from conceptual design to construction, to planning of the research and monitoring program. By the time the ENR project begins operation in 1994, it will have already begun to provide critical data in the design and construction of a large-scale constructed wetland for nutrient removal from agricultural stormwater runoff.

During the first three years of the project sufficient physical, chemical, and biological data will be collected with which to calibrate and validate a multidimensional mathematical water quantity/quality model. The model will be used to evaluate the effect of various combinations of HLR, mean water depth, and vegetation types and densities on nutrient removal. The operating schedule for the project will be developed to optimize long-term nutrient removal via peat accretion under the operating conditions to be experienced in the South Florida environment. The monitoring data, research results, and water-quality model obtained from this demonstration-scale STA will be used to optimize wetlands design and hydrologic management of the full-size STAs.

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