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History and description of the Everglades Nutrient Removal Project, a subtropical constructed wetland in south Florida (USA)

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ABSTRACT

The biotic integrity of the Florida Everglades is threatened due to degradation of water quality and hydrologic changes associated with agricultural and urban development in the region. Restoration strategies being implemented by State and Federal governments include building approximately 18,000 ha of treatment wetlands to reduce nutrient loads in runoff before this water enters the Everglades. The South Florida Water Management District (District) built and operated a 1544 ha prototype wetland, the Everglades Nutrient Removal Project (ENRP), to gain the operational experience and design data needed to maximize long-term nutrient removal performance in the larger wetlands. The District conducted extensive research and monitoring in the ENRP from 1994 to 1999. This paper presents a brief history and description of the project and serves as an introduction to this special issue of *Ecological Engineering* devoted to the ENRP.

1. Everglades environmental issues

The Everglades is a vast wetland comprised of a variety of habitat types, including sawgrass marshes, wet prairies, sloughs, ponds, tree islands and mangrove estuaries that dominate the landscape of south Florida (USA) (Davis, 1943a,b; Loveless, 1959). The Everglades is situated in a shallow limestone depression that has gradually p filled in with organic material and sediments over the last 4500–5000 yr. The hydrology of the region was largely rainfall–driven (>90% of water inputs) with periodic inflow from Lake Okeechobee (Parker and Hoy, 1943; Parker, 1984). Before 1900, the Everglades extended from the south shore of Lake Okeechobee to Florida Bay in a sweeping arc (Fig. 1) that was approximately 160 km long, 65–80 km wide and encompassed more than 10,000 km^2 (Gunderson and Loftus, 1993; Light and Dineen, 1994). Agricultural and urban development has since reduced the present-day size of the Everglades to only 50% of its original extent (Fig. 1); 3500 km^2 of the remaining marsh is impounded within shallow, diked reservoirs known as Water Conservation Areas (WCAs) (Light and Dineen, 1994; Chimney and Goforth, 2001). The Everglades that remains (i.e., the WCAs, the Holey Land and Rotenberger Wildlife Management Areas, and Everglades National Park [ENP]) still supports unique biotic communities containing over 40 threatened or endangered plant and animal species (USACE and SFWMD, 1999) and is widely regarded as an ecosystem of immense regional, national and international importance (Lodge, 1994; Maltby and Dugan, 1994). The ENP has been designated as an International Biosphere Reserve, a United Nations World Heritage site and a Wetland

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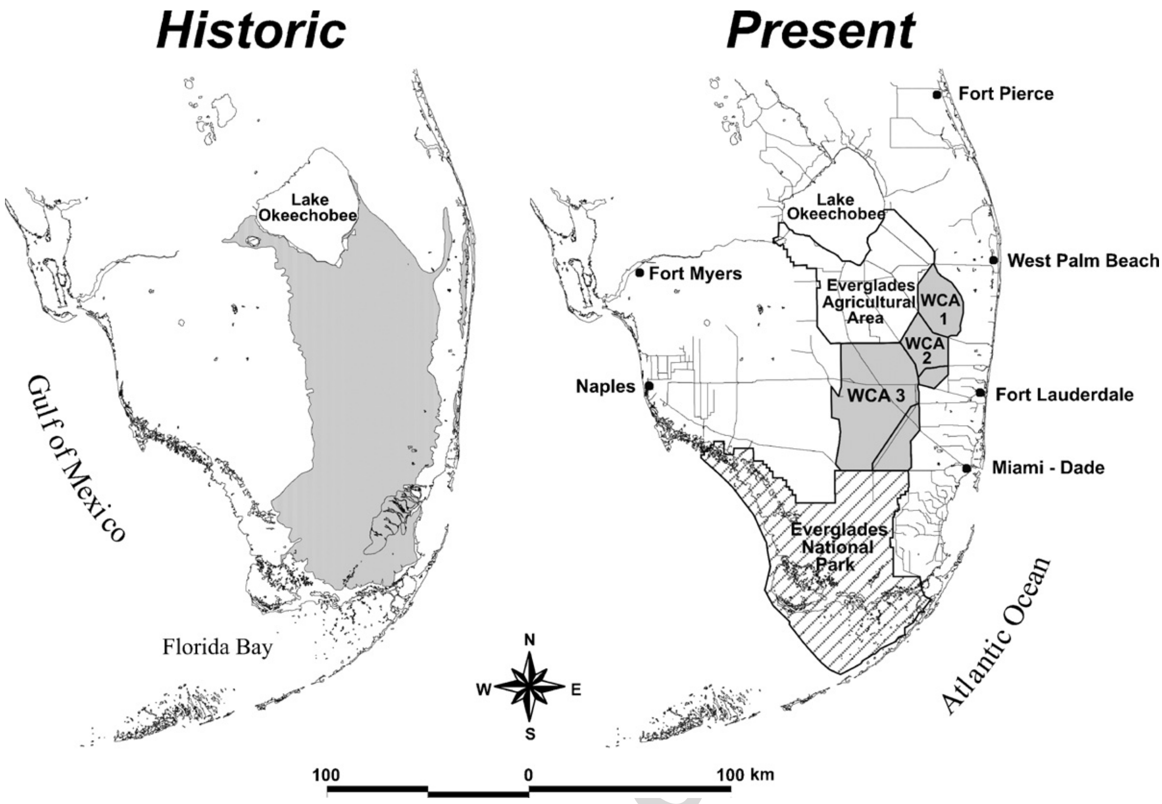

Fig. 1 – Comparison of the areal extent of the historic Everglades (~1900) with the present-day ecosystem.

of International Importance under the 1987 Ramsar Convention, one of only three wetlands in the world to receive all of these recognitions (Maltby and Dugan, 1994). ENP has been granted status as an Outstanding Florida Water and an Outstanding National Resources Waters by the state of Florida and is a Federal Wilderness Area. Water Conservation Area 1 is part of the Arthur R. Marshall Loxahatchee National Wildlife Refuge (LNWR) and has been designated an Outstanding Florida Water. Both ENP and LNWR are federally protected wetlands.

Efforts to manage surface water in south Florida began in the late-1800s. The primary goal was to drain the land and exploit its rich organic soils and subtropical climate for agricultural purposes (Light and Dineen, 1994; Anderson and Rosendahl, 1998; Snyder and Davidson, 1994). Today, the hydrology of the region is managed by the South Florida Water Management District (District), which operates one of the world's largest and most technically advanced drainage systems (i.e., 2400 km of canals and levees, 125 major water control structures, 18 major pump stations and hundreds of smaller structures). Much of this infrastructure was upgraded from the existing drainage system or designed and built by the U.S. Army Corps of Engineers (USACE) from 1953 to 1967 as part of the federally authorized Central and Southern Florida Project for Flood Control and Other Purposes (C&SF Project) (see Table 1 for chronology of important events). Management objectives for the C&SF Project have changed over the years. Throughout much of its history, the project was operated by the District (and its predecessor agency, the Central and Southern Florida Flood Control District [FCD]) primarily to provide regional flood protection during the wet season (May–October) and alternatively, supply water for farm irrigation and domestic use during the dry season (November–April). Within the last 20 yr, preservation and restoration of the remaining Everglades ecosystem has become a priority for the District.

Although relatively few water quality data were collected from the Everglades prior to 1940, the wetland is thought to have been oligotrophic historically, characterized by low surface-water concentrations of phosphorus (P) and other nutrients. This inference is based on three lines of evidence. First, rainfall and dry deposition were the main nutrient sources to the system. Because nutrient concentrations in contemporaneous wet/dry deposition are low (e.g., Brezonik et al., 1983; Pollman and Landing, 1997), historic atmospheric sources are presumed to have delivered relatively small nutrient loads (Waller and Earle, 1975; Parker, 1984; McPherson et al., 1976; Davis et al., 1987). Second, oligotrophic conditions still exist at remote, undisturbed sites in ENP and the WCAs (minimum values for total P [TP] $\leq 10\,\mu g\,L^{-1}$ and soluble reactive $P < 4\,\mu g\,L^{-1}$) (Swift and Nicholas, 1987; Scheidt et al., 1989; McCormick et al., 2002). Third, undisturbed Everglades sediments are nutrient-poor and the native vegetation has low nutrient requirements (Steward and Ornes, 1975; Swift, 1981, 1984; Swift and Nicholas, 1987; Davis, 1994; McCormick et al., 2002). The characteristics of both sediments and the vegetation community change quickly in response to nutrient enrichment and their persistence in the present-day ecosystem suggests a history of low nutrient conditions. Undisturbed

Table 1 – Annotated chronology of important events in the Everglades that resulted in the eventual construction and operation of the Everglades Nutrient Removal Project (ENRP)

Year	Event
1907	Florida legislature creates the Everglades Drainage District (EDD) to fund and manage reclamation projects in the Everglades
1917	By this date, the EDD had completed four major drainage canals (Miami, North New River, Hillsboro and West Palm) totaling 380 km that dissected the Everglades from Lake Okeechobee to the Atlantic Ocean
1931	By this date, the EDD had completed a protective levee around the south rim of Lake Okeechobee and expanded the drainage system within the Everglades to 708 km of major canals
1948	U.S. Army Corps of Engineers (USACE) received Congressional authorization to initiate the Central and Southern Florida Project for Flood Control and Other Purposes (C&SF Project)
1949	Florida legislature created the Central and Southern Florida Flood Control District (FCD) to operate and administer the C&SF Project
1953	USACE started construction of Water Conservation Area (WCA) 1
1967	USACE completed construction of WCA-3, the last major element of the C&SF Project
1972	South Florida Water Management District created by the Florida legislature from the FCD; mission expanded to include water quality, water supply and environmental protection
1976	District began studies to evaluate treatment performance of six different regional wetlands
1979	District implemented the Interim Action Plan (IAP) which reduced backpumping of EAA runoff into Lake Okeechobee, diverting this water instead into the WCAs and increased P loading by ~15% over pre-IAP levels
1988	*February*: Lake Okeechobee Technical Advisory Council (LOTAC) II recommended that the District conduct a long-term, large-scale demonstration of a vegetated flow-way system to remove P from EAA runoff *September*: Governor Martinez proposed using a 1515 ha tract of state-owned land located adjacent to the Loxahatchee National Wildlife Refuge (LNWR) as a constructed wetland to cleanse water discharged into the Everglades. This project became known as the ENRP *September*: first District workshop held to develop a conceptual design for the ENRP *November*: the State did not renew its agricultural lease on the tract of state-owned land proposed for the ENRP
1989	*March*: the State signed a management agreement with the District to convert the Knight tract into a "biological nutrient removal system" *June*: ENRP Phase I completed—first 486 ha of land flooded *October*: completed conceptual design for ENRP perimeter levees, canals and pump stations *November*: second District workshop held to develop a conceptual design for the interior configuration of the ENRP *December*: District proposed alternative interior configuration for the ENRP based on the results of the conceptual design workshops
1991	*April*: Everglades Protection Act passed by the Florida legislature authorizing the District to implement stormwater management systems to restore and protect Everglades water quality *June*: ENRP Phase II construction started on the containment levees, pump stations and other major structural elements associated with the project *December*: interior ENRP cell configuration redesigned to minimize flow disruption caused by earthen pads for power transmission line that crosses the property
1992	*August*: ENRP Phase III construction started on interior levees, canals and water control structures; 810,000 individual wetland plants installed in Polishing Cell 3
1993	*November*: all phases of ENRP construction completed and project fully flooded
1994	*February*: Florida Department of Environmental Protection (FDEP) issued its ENRP operating permit; required a 75% total P load reduction and long-term outflow concentration $\leq 50\,\mu g\,L^{-1}$ *April*: U.S. Environmental Protection Agency (USEPA) issued a National Pollutant Discharge Elimination System (NPDES) permit for the ENRP *May*: NPDES permit was challenged in federal court, which prevented the District from starting flow-through operation in the ENRP *July*: Federal Administrative Law Judge authorized interim discharge from the ENRP *August*: ENRP flow-through operations initiated

portions of the Everglades today are highly P limited (Craft et al., 1995; McCormick and O'Dell, 1996; Richardson et al., 1999).

Everglades plants and animals are adapted to the low nutrient concentrations, hydrology and other physico-chemical conditions (e.g., low dissolved oxygen levels) that are characteristic of the system, (Kolipinski and Higer, 1969; Gunderson and Loftus, 1993; Davis and Ogden, 1994). The timing, distribution, quantity and quality of water entering the Everglades are the most important factors influencing the marsh (Beard, 1938; Davis, 1943a; Schomer and Drew, 1982). Changes in water quality and other environmental disturbances associated with development were first identified in ENP as early as 1938 (Beard, 1938). Operation of the C&SF Project exacerbated these problems. Improved drainage in the region per-

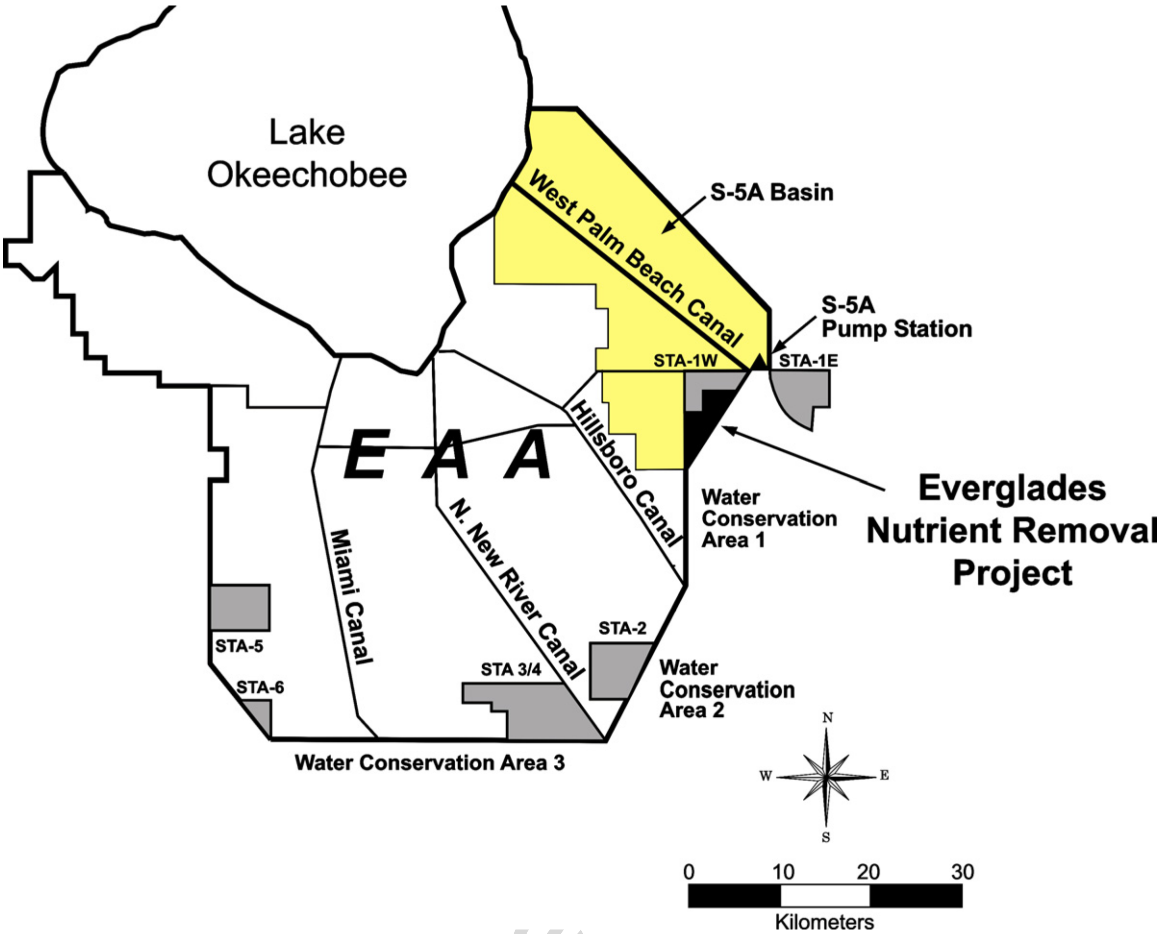

Fig. 2 – Location of the Everglades Nutrient Removal Project in relation to the Everglades Agricultural Area, the S-5A drainage basin and the District's Stormwater Treatment Areas.

mitted a large tract of wetland (2830 km^2) immediately south of Lake Okeechobee, now referred to as the Everglades Agricultural Area (EAA; Fig. 2), to be developed for agriculture. Further degradation of water quality was documented in the 1960s and 1970s (e.g., Klein et al., 1975; Waller and Earle, 1975; McPherson et al., 1976). Most EAA runoff today flows directly into the WCAs and carries elevated levels of nutrients and other constituents (e.g., total suspended solids, BOD, pesticides and bacteria) and decreased levels of dissolved oxygen (Hand et al., 1986; Nearhoof, 1992). Pollutant loads associated with stormwater runoff can be exceptionally high. Heavy P loading has caused eutrophication in parts of the WCAs. Also, enclosing the WCAs within levees and adoption of regulation schedules based on flood control and water supply needs disrupted the region's natural hydropattern (direction and spatial extent of flow) and hydroperiod (water depth, timing and duration). This, in turn, led to excessive flooding in some areas, overdrainage of other areas and periodic reversals in the seasonal delivery of water throughout the system (Kushlan, 1989, 1991). These disturbances resulted in widespread changes to the ecology of the Everglades, such as dramatic declines in the size of wading bird populations (Ogden, 1994) and the invasion of cattail (*Typha* sp.) into >10,000 ha of native sawgrass and slough habitat (Rutchey and Vilchek, 1994; Wu et al., 1997), that are reviewed in Rader and Richardson (1992), Davis and Ogden (1994), McCormick et al. (2002) and Sklar et al. (2002).

It is generally accepted that environmental impacts resulting from the C&SF Project have damaged the Everglades to the extent that the biotic integrity of the remaining ecosystem is threatened (Harwell, 1998; Chimney and Goforth, 2001). These effects were unwanted consequences of what otherwise was widely regarded as a beneficial public works project. Clearly, any actions to remedy this situation need to reduce P loads in EAA runoff and improve the region's hydroperiod and hydropattern (USACE and SFWMD, 1999). The District's long-term strategy for preserving and restoring the Everglades is intended to meet these needs. As part of this effort, the District and USCAE have built approximately 18,000 ha of wetlands, referred to as stormwater treatment areas (STA) to treat runoff from the EAA and adjacent drainage basins (see Fig. 2) (Goforth, 2001).

2. Project design and construction

The District has been involved with environmental issues in the Everglades since the 1970s, and District scientists began evaluating the treatment efficacy of regional wetlands in 1976 (Davis et al., 1985). By the early 1980s, there was a growing consensus that large constructed wetlands could effectively reduce nutrient levels in stormwater runoff before it entered the Everglades. This was based on (1) the success the District's Boney Marsh (Moustafa et al., 1996), the Iron Bridge and Orlando Eastern Service Area marshes (Kadlec and Newman, 1992) and other wetland demonstration projects in Florida (e.g., Reddy et al., 1982a,b) and (2) the fact that WCA-2A continued to remove P even after decades of continuous nutrient loading (Walker, 1995). A recommendation for action from a state–commissioned advisory panel prompted the District in 1988 to begin designing a project that addressed questions on how to best utilize treatment wetlands in the EAA (see Table 1). The advisory panel suggested that these investigations be long-term, conducted at a "large" scale (wetlands ≥160 ha in size) and that publicly owned land be used to help defray costs. In September 1988, Florida's then Governor Martinez proposed that a 1515 ha tract of state-owned land that was leased for agriculture be converted to a biological treatment system for the purpose of reducing P levels in stormwater. The demonstration and research project that evolved from these early initiatives became known as the Everglades Nutrient Removal Project (ENRP).

The District realized the need for the ENRP to have practical P removal benefits in addition to its experiential role and the overall size and scope of the project as initially conceived increased substantially. The ENRP had three primary objectives: (1) it was to function as an operational treatment wetland and remove nutrients from EAA runoff before this water entered LNWR; (2) it was a prototype wetland that would provide the District with the operational experience and design data needed to maximize long-term nutrient removal performance in the STAs and (3) it would allow the District to develop and implement optimal nutrient removal technologies.

The ENRP was designed by a combination of District staff and engineering consultants. Burns and McDonnell were the primary design engineers and were responsible for the earthwork and structural design of perimeter facilities (levees, canals and pump stations). Critical design issues included the optimal delivery of water to the project, sizing of the inflow and outflow pump stations, and construction materials and methods used for the levees. A separate design process addressed the interior features of the ENRP, due to the many scientific uncertainties regarding optimal sizing and configuration of the interior cells. Post, Buckley, Schuh, and

Table 2 – Summary of design criteria, assumptions and performance goals for the Everglades Nutrient Removal Project (ENRP) with and without the use of on-farm Best Management Practices in the Everglades Agricultural Area

S5A drainage basin area	595.7 km^2 (∼147000 acres)
ENRP treatment area[a]	1500 ha (∼3700 acres)
ENRP maximum pumping capacity	
Inflow pumps (G-250)	17.0 $m^3\,s^{-1}$ (=600 cfs)
Seepage return pumps (G-250s)	5.7 $m^3\,s^{-1}$ (=200 cfs)
Outflow pumps (G-251)	12.7 $m^3\,s^{-1}$ (=450 cfs)
Expected Total Phosphorus Removal[a]	1.67 g P $m^{-2}\,yr^{-1}$
Inflow total phosphorus concentration[a]	
No BMPs	190 $\mu g\,L^{-1}$ (=190 ppb)
With BMPs	134 $\mu g\,L^{-1}$ (=134 ppb)
Inflow pumping rate (at 25 mt P yr^{-1} removal target)[a]	
Design maximum	16.99 $m^3\,s^{-1}$ (=600 cfs; =434,678 ac-ft yr^{-1})
No BMPs (at 190 μg TP L^{-1} and 85% efficiency)	4.81 $m^3\,s^{-1}$ (=170 cfs; =123,159 ac-ft yr^{-1})
With BMPs (at 134 μg TP L^{-1} and 78% efficiency)	7.36 $m^3\,s^{-1}$ (=260 cfs; =188,360 ac-ft yr^{-1})
Hydraulic loading rate[a]	
No BMPs (at 170 cfs and 1500 ha)	2.8 cm d^{-1} (=1.1 in d^{-1})
With BMPs (at 260 cfs and 1500 ha)	4.2 cm d^{-1} (=1.7 in d^{-1})
Total phosphorus removal rate (at 50 $\mu g\,L^{-1}$ outflow target)[a]	
No BMPs (at 190 to 50 μg TP L^{-1}; 170 cfs)	1.42 g P $m^2\,yr^{-1}$ (=21.3 t P yr^{-1}; =46,901 lbs P yr^{-1})
With BMPs (at 134 to 50 μg TP L^{-1}; 260 cfs)	1.30 g P $m^2\,yr^{-1}$ (=19.5 t P yr^{-1}; =43,039 lbs P yr^{-1})
Total phosphorus removal efficiency (at 50 $\mu g\,L^{-1}$ outflow target)[a]	
No BMPs (at 190 to 50 μg TP L^{-1}; 170 cfs)	74%
With BMPs (at 134 to 50 μg TP L^{-1}; 260 cfs)	63%
Water depth	
Normal operating range[b]	39.6–91.4 cm (=1.3–3.0 ft)
Normal operating range[a]	30.5–91.4 cm (=1.0–3.0 ft)
Design minimum[b]	15.0 cm (=0.5 ft)
Design maximum[a,b]	137.2 cm (=4.5 ft)
Hydraulic retention time	≥13 d[b] 10–20 d[a]

[a] CH2M Hill (1991) derived from various design documents and memoranda.
[b] SFWMD (1991).

Table 3 – Capital costs associated with the design and construction of the Everglades Nutrient Removal Project

Engineering services	
Plant nursery (Phase I)	$ 43,860
Conceptual and final design (Phase II)	$ 648,034
Conceptual and final design (Phase III)	$ 215,082
Misc. review and support services	$ 209,293
	$ 1,116,269
Land easement acquisition	$ 81,955
Construction costs	
Perimeter levee	$ 1,956,000
Supply canal	$ 1,108,780
Pump stations	$ 4,140,788
Interior works	$ 3,215,324
Research test cells	$ 1,574,102
Access road + misc. items	$ 510,955
	$ 12,505,949
Post-construction costs	$ 622,000
Total project capital costs	$ 14,326,173

Jernigan Inc. completed the initial interior design; however, District staff redesigned several features based on guidance from external scientific panels and the need to accommodate a power transmission line that crossed the project. Performance expectations for the ENRP were based on the amount of available state-owned land and the observation that cattail in nutrient enriched areas of WCA-2A had a P retention capacity of approximately 1.67 $g\,P\,m^{-2}\,yr^{-1}$ (Davis, 1994). Assuming that the ENRP operated at the same efficiency, it was expected to remove approximately 25 metric tonnes (t) $P\,yr^{-1}$ from EAA runoff. Other design details and performance goals inferred from conceptual designs are summarized in Table 2. Note that consideration was given to the effect on design parameters attributable to the presence or absence of on-farm Best Management Practices (BMP) in the EAA and the influence this would have on EAA runoff water quality.

A number of management options associated with start-up and operation of the ENRP were evaluated with the intent of identifying conditions that maximized long-term nutrient removal. Key issues included (1) how to establish the vegetation community, i.e., through natural recruitment versus planting selected species; (2) whether to actively manage the vegetation once established, i.e., harvesting, burning or disking versus an unmanaged vegetation community; (3) whether to maintain a prolonged hydroperiod versus alternate flooding and drying. Initially, it was felt that mimicking the region's natural wet/dry cycle with periodic marsh dryout, coupled with biomass harvesting, were essential to achieving P removal goals. However, this approach was abandoned given that (1) cattail is very aggressive and was likely to colonize the ENRP without intensive management efforts; (2) removal of aboveground plant biomass in other wetlands did not significantly improve their overall treatment performance; (3) substantial physical disruption of the soil that would occur due to harvesting equipment; (4) periodic dryout and reflooding would promote the release of sediment-bound P. Water and vegetation management in the ENRP is discussed below.

The ENRP was built in three phases. Phase I was completed in June 1989 when the first 486 ha of old farmland were flooded. Construction of phase II, which included the perimeter levees, pump stations and other major structural elements associated with the project, began in June 1991 and was completed by September 1993. Phase III, which consisted of building interior levees, canals and water control structures, and establishing wetland vegetation (810,000 seedlings and shoots) in one of the polishing cells, began in August 1992 and was completed by November 1993. The most challenging aspects of construction included dealing with the thick muck topsoil, the hardness of the underlying caprock, managing surface runoff during construction and the sheer magnitude of the planting effort. Capital costs for the ENRP totaled \$14.3M (Table 3) and were paid for largely by mitigation fees from, and cost sharing with, Florida Power and Light, a grant from the EAA Environmental Protection District and agricultural lease revenue from the former tenant (S.N. Knight & Sons Inc.). Numerous construction and operation permits were required for the ENRP, including county, state and federal dredge and fill permits, as well as state and federal discharge permits. Resolving wetland jurisdiction issues was problematic for both state and federal regulatory agencies. A federal discharge permit was issued in April 1994 and legally challenged shortly thereafter by parties who questioned the decision to build constructed wetlands for Everglades restoration. While the challenge was proceeding through the federal administrative process, interim authority to operate the project was sought and received in late July 1994 and flow-through operations began the following August.

Table 4 – Physical characteristics of individual cells within the Everglades Nutrient Removal Project

	Buffer cell	Cell 1	Cell 2	Cell 3	Cell 4
Surface area (ha)	54	526	413	404	147
Mean ground elevation (m NGVD)[a]	3.14[b]	3.08	2.88	3.16	2.94
Minimum ground elevation (m NGVD)	na	2.39	1.37	1.92	2.69
Maximum ground elevation (m NVGD)	na	4.52	4.03	4.85	3.23
Length of perimeter levee (km)	3.9	10.8	10.2	9.1	6.1
Estimated length of flow path (km)	na	3.9	3.6	3.6	2.2
Length:width aspect ratio[c]	na	2.89	3.14	3.19	3.17

[a] NGVD: national geodetic vertical datum of 1929.
[b] Estimated value, the Buffer Cell was not surveyed.
[c] Length: estimated length of flow path; width: cell surface area/estimated length of flow path.

3. Project performance goals

As noted above, the original performance expectation for the ENRP (removal of 25 t P yr^{-1}) was based on the amount of land available and a constant TP removal rate. Design calculations for the inflow water volumes and hydraulic loading rates (HLR) needed to achieve this target considered both the presence and absence of BMPs in the EAA (see Table 2). Subsequent performance expectations for the project focused more on achieving an effluent TP concentration of 50 $\mu g L^{-1}$ rather than removing a specified TP mass. Assuming the same inflow TP concentrations and hydraulic loading rates, slightly lower TP removal rates than the original estimate were required to

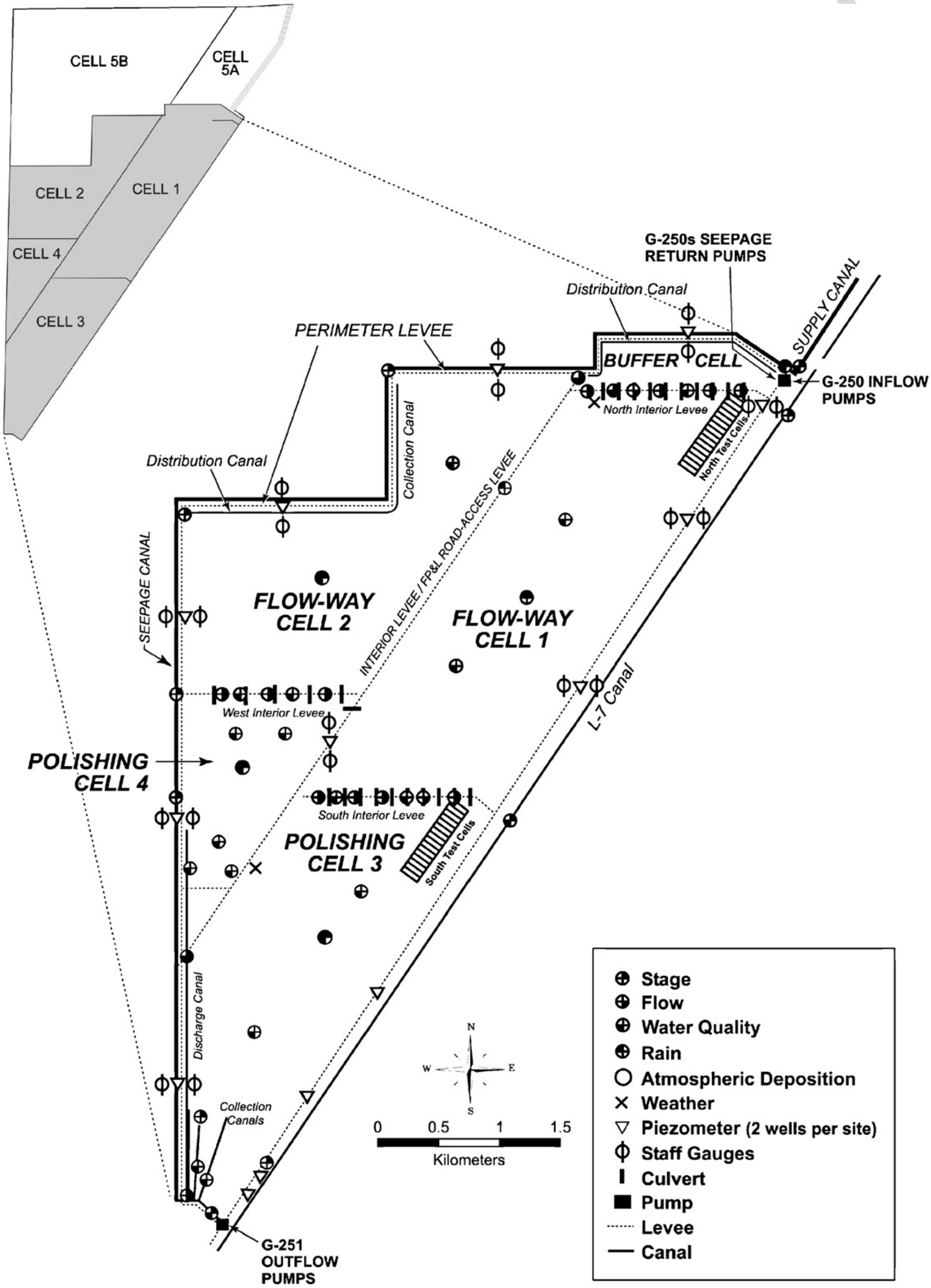

Fig. 3 – Map of the Everglades Nutrient Removal Project showing locations of instrument and sampling sites. Insert indicates the ENRP boundaries in relation to STA-1West. See text for details.

meet the outflow concentration target (1.30–1.42 $g\,P\,m^2\,yr^{-1}$). The ENRP discharge permits required that the wetland meet two performance objectives: (1) achieve a 75% TP load reduction when inflow TP mass was compared to TP mass at the outflow and (2) produce effluent with a long-term average TP concentration no greater the 50 $\mu g\,L^{-1}$. [A long-term outflow TP concentration of 50 $\mu g\,L^{-1}$ was established as an interim goal for STA treatment performance. The State of Florida has adopted a 10 $\mu g\,L^{-1}$ limit to protect the ecological integrity of the Everglades (Sklar et al., 2005).]

4. Site description and operations

The ENRP site is located 25 km west of the city of West Palm Beach on a site that borders the northwest corner of LNWR (26° 38′N and 80° 25′W) (Fig. 2). The land was previously farmed for sugar cane, corn and rice. The soils consisted of poorly drained histosols (0.8–1.8 m thick) belonging to the Pahokee and Terra Celia complexes (predominantly Okeechobee muck) with a near-surface water table that overlaid a hard carbonate rock shelf (caprock). Beneath the caprock was a deep deposit of silty, clay-like sands with interbedded layers of limestone (Jammal & Associates Inc., 1991). Using the U.S. Fish and Wildlife Service's wetland classification scheme (Cowardin et al., 1979), the ENRP would be best described as follows—SYSTEM: palustrine; CLASS/SUBCLASS: combination of emergent wetland/persistent and aquatic bed/rooted vascular; WATER REGIME: nontidal, artificially flooded; WATER CHEMISTRY: fresh-circumneutral; SOIL: organic; SPECIAL MODIFIER: diked.

The ENRP encompassed 1544 ha of wetted surface area. The size of interior cells, ground elevations and other descriptive data are provided in Table 4. The primary sources of inflow water to the ENRP were the S-5A basin, which drains the northeastern portion of the EAA (Fig. 2; Table 2), and releases from Lake Okeechobee. The ENRP was operated as a once-through treatment system with the capacity to process approximately 39–60% of the basin's annual runoff that otherwise would be pumped directly into LNWR. It was assumed during design that the ENRP would operate in a pulsed-flow mode at shallow water depths resulting in hydraulic residence times (HRTs) that would not exceed 20 d (Table 2). Water was conveyed to the ENRP Inflow Pump Station via a supply canal, pumped into the Buffer Cell and then distributed via gravity flow to two parallel flow-ways separated by an interior, longitudinal levee (Fig. 3). The Buffer Cell provided hydraulic dampening of inflow water velocities, allowed for independent water delivery to each flow-way and provided some treatment benefit. A distribution canal was built along the north side of the Buffer Cell to

Table 5 – Annotated list of research and monitoring activities conducted in the Everglades Nutrient Removal Project from 1994 through 1999

Vegetation coverage	Semi-annual aerial photographs were taken using high-contract infrared film; images (~40) were digitized and vegetation mapped using 20 different coverage categories; data were then complied into a master GIS database
Meteorological data	Two automated weather stations provided continuous measurement of air temperature, humidity, wind speed and direction, barometric pressure and light (both photosynthetically active radiation and pyranometer sensors)
Rainfall quantity	A network of seven automated tipping-bucket gauges located throughout the site measured total daily precipitation
Rainfall quality	One automated wet/dry deposition collector provided weekly composite samples that were analyzed for nutrients, carbon, major cations and anions, suspended and dissolved solids and selected metals
Evapotranspiration	Experimental lysimeters (open-water/periphyton, mixed marsh vegetation and cattail) were operated in 1994 and 1995 to establish empirical relationship between daily ET rates, vegetation coverage type and meteorological conditions; ET subsequently was generated using these equations and weather data
Groundwater	A network of 14 shallow wells (10–20 m deep) located along the perimeter and interior levees were sampled quarterly for groundwater; samples are analyzed for nutrients and major cations/anions
Stage	A network of 28 automated stage recorders located throughout the site monitored water levels on a continuous basis
Flow	Flow at the inflow, outflow and seepage return pumps was monitored continuously using pump RMP-discharge rating curves developed for each structure Flow through all 35 interior culverts was monitored continuously using ultrasonic velocity meters Inflow seepage through 21 culverts along the L-7 levee was monitored biweekly in 1994 and 1995 years; regression equation were developed to predict flow based on stage differences between LNWR and the ENRP
Surface contour map	A topographic survey was conducted and used to produce a detailed surface contour map (0.5-ft contour intervals); a stage-volume equation was developed for each treatment cell using these data
Hydrolab® Network	A network of 15 recording Hydrolab® sondes located throughout the site monitored temperature, pH, conductivity, and dissolved oxygen concentration in surface water at continuous 15-min intervals
Cells 1 and 4 monitoring	Sampling programs were conducted in 1994 and 1995 to monitor a number of physical and chemical parameters in sediments, porewater and macrophytes along the nutrient gradient in Cells 1 and 4
Fauna and flora surveys	Informal lists were compiled for the fish, bird and plant species found within the ENRP
Water quality	Water quality samples were collected on a weekly/biweekly basis from 23 locations; samples were analyzed for nutrients, major cations/anions, carbon, suspended and dissolved solids, select metals and other constituents

convey water from the Inflow Pump Station to the west flow-way. Each flow-way was subdivided into an upper flow-way cell and a lower polishing cell by a transverse levee that had multiple culverts (1.8 m diameter) to convey water between cells. The direction of flow was from Cells 1 to 3 and from Cells 2 to 4. Cells 1 and 3 comprised the east flow-way and Cells 2 and 4 comprised the west flow-way. The west flow-way was 40% smaller than the east flow-way. Flow-way Cells 1 and 2 were intended to remove the bulk of the nutrients entering the ENRP (the Buffer Cell also acted in this capacity), while Polishing Cells 3 and 4 would accomplish the final polishing of the water to lower nutrient concentrations. Water was discharged from the two flow-ways at the Outflow Pump Station into LNWR. A perimeter canal collected groundwater seepage from along the western and northern boundaries of the ENRP and returned it to a set of Seepage Return Pumps located at the Inflow Pump Station where it was pumped back to the headwaters of the project. The ENRP is described in more detail in Guardo et al. (1995).

In an attempt to reduce P levels in the ENRP below those observed in other cattail marshes, the District used several different approaches to vegetation management in the project. Flow-way Cells 1, 2, and the Buffer Cell were allowed to revegetate naturally; the dominant emergent macrophyte was cattail (*T. domingensis* Pers. and *T. latifolia* L.). The plant community in Polishing Cell 3 was a mixture of naturally recruited cattail and 164 ha that were planted with 810,000 seedling and shoots of wetland species common to south Florida, i.e., arrowhead (*Sagittaria latifolia* Willd. and *S. lancifolia* L.), spikerush (*Eleocharis interstincta* [Vahl] Roemer & Schultes), maidencane (*Panicum hemitomon* Schultes), pickerelweed (*Pontederia cordata* L.) and sawgrass (*Cladium jamaicense* Crantz), and was referred to as a "mixed-marsh" plant community. Flow-way Cell 4 was actively maintained as a periphyton/submersed macrophyte community dominated by coontail (*Ceratophyllum demersum* L.) and southern naiad (*Najas guadalupensis* [Spreng.] Magnus) through the selective use of herbicides to remove emergent and floating macrophytes. Areas in Cells 1–3 that were not initially colonized by emergent species during construction also supported dense stands of submersed macrophytes (principally *C. demersum*, *N. guadalupensis* and *Chara* sp.). Water hyacinth (*Eichhornia crassipes* [Mart.] Solms.) and water lettuce (*Pistia stratiotes* L.) and other floating species (*Azolla caroliniana* Willd., *Lemna* sp. L., *Salvinia rotundifolia* Willd., *Spirodela polyrhiza* [L.] Schleiden, *Woliffa* sp. and *Wolffiella floridana* [Sm.] Thompson) first appeared in northern areas of the project during construction (S. Newman, SFWMD, personal communication) and became an important component of the ENRP plant community.

The ENRP operated as a stand-alone treatment wetland from August 1994 to July 1999, after which it was incorporated into the boundaries of STA-1 West (STA-1W) (see Fig. 3). During this period, outflow TP concentrations averaged 22 $\mu g\,L^{-1}$, well below the 50 μg TP L^{-1} target (Chimney et al., 2000). With the issuance of new operating permits for STA-1W and the completion of key water control structures in 1999, the ENRP ceased to exist as a separate entity both from a regulatory and operations perspective.

The various research and monitoring studies conducted in the ENRP are listed in Table 5 and have been summarized in Chimney et al. (2000). The companion papers in this volume focus on aspects of wetland limnology, hydrology, plant decomposition and P removal by macrophytes and periphyton; Gu et al. (2006) has a discussion on reduction of nutrient concentrations. Development of the plant community, sediments, dissolved oxygen dynamics and a more rigorous analysis of wetland treatment performance will be the subject of future publications.

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