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Environmental impacts to the Everglades ecosystem: a historical perspective and restoration strategies

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Abstract The Everglades is a vast subtropical wetland that dominates the landscape of south Florida and is widely recognized as an ecosystem of great ecological importance. As a result of anthropogenic disturbances over the past 100 years (i.e., agricultural and urban development, eutrophication resulting from stormwater runoff, changes in hydrology and invasion of exotic species), the biotic integrity of the entire Everglades is now threatened. To protect this valuable resource, the state of Florida and the Federal Government, in cooperation with other interested parties, have developed a comprehensive restoration strategy that addresses controlling excess nutrient loading and reestablishment of a more natural hydrology. These efforts include building approximately 17,000 ha of treatment wetlands, referred to as Stormwater Treatment Areas, to treat surface runoff before it is discharged into the Everglades. We briefly discuss the history of the Everglades in the context of environmental disturbance and outline the steps being taken to ensure its survival for future generations.

Keywords Constructed wetland; Everglades; phosphorus; restoration; stormwater runoff

Introduction

The Everglades is a vast freshwater wetland that dominates the landscape of south Florida. Before the 1900s, the Everglades extended unbroken from the south shore of Lake Okeechobee to Florida Bay (Figure 1) and encompassed more than 10,000 km^2 (Gunderson and Loftus, 1993; Light and Dineen, 1994). Agricultural and urban development have since reduced the present-day Everglades to only 50% of its original extent, of which approximately 3,500 km^2 is impounded within shallow, diked reservoirs known as Water Conservation Areas (WCAs) (SFWMD, 1992a). The wetland that remains (i.e., the WCAs, the Holeyland and Rotenberger Wildlife Management Areas and Everglades National Park [ENP]) still supports unique biotic communities containing many threatened or endangered plant and animal species (USCOE and SFWMD, 1996) and is widely regarded as an ecosystem of immense regional, national and international importance. Everglades National Park has been designated as an International Biosphere Reserve, a United Nations World Heritage site and a Wetland of International Importance under the 1987 Ramsar Convention, one of only three wetlands in the world to receive such recognition (Maltby and Dugan, 1994). Water Conservation Area 1 is part of the Arthur R. Marshall Loxahatchee National Wildlife Refuge (LNWR). Both ENP and LNWR are federally protected wetlands.

History of Everglades impacts

Efforts to manage surface water in south Florida began in the late-1800s. The primary goal was to drain the land and take advantage of its rich organic soils and subtropical climate for agricultural purposes (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 complex drainage systems. Much of this infrastructure was built (or upgraded) by the U.S. Army Corps of

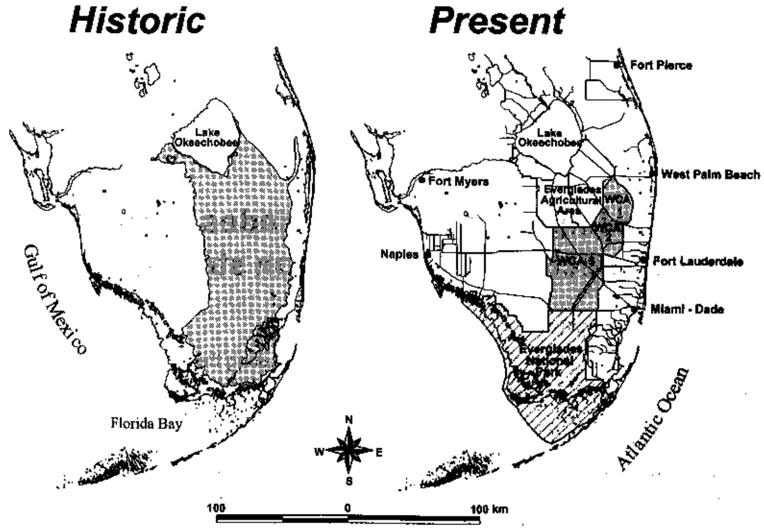

Figure 1 Comparison of areal extent of the historic Everglades with the present-day ecosystem. See text for details

Engineers (USCOE) from 1953 to 1967 as part of the Central and Southern Florida Project (C&SF Project). Management objectives for the C&SF Project have changed over time. Throughout most of its history, the project was operated primarily for regional flood protection during the wet season (May–October) and alternatively, to supply water for farm irrigation and domestic use during the dry season (November–April). Within the last 15 years, preservation and restoration of the remaining Everglades ecosystem has become a top priority for the District.

Although relatively few water quality data exist for the Everglades before 1940, the wetland is thought to have been oligotrophic throughout its history. This inference is based on: (1) rainfall and dry deposition were the main nutrient sources to the system; because nutrient concentrations in contemporaneous deposition are low (Brezonik *et al.*, 1983), historic atmospheric sources are presumed to have delivered relatively low levels of nutrients (McPherson *et al.*, 1976); (2) oligotrophic conditions still exist at interior sites in ENP and the WCAs (minimum values for total phosphorus [TP] ≤ 10 g L^{-1}) (Bechtel *et al.*, 1999); and (3) undisturbed Everglades sediments are nutrient-poor and the native vegetation has low nutrient requirements (Steward and Ornes, 1975; Swift and Nicholas, 1987); the characteristics of 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. Much of the Everglades today is considered to be P limited (Craft *et al.*, 1995).

Everglades plants and animals are adapted to the hydrologic and physico-chemical conditions (e.g., low dissolved oxygen and nutrients) that are characteristic of the region (Gunderson and Loftus, 1993). The timing, distribution, quantity and quality of water entering the Everglades are the most important factors influencing marsh ecology. Changes in water quality and other environmental disturbances were detected in ENP as early as 1938 (Beard, 1938). Operation of the C&SF Project exacerbated these problems. The improved drainage system permitted a 2,830-km^2 area immediately south of Lake Okeechobee, known as the Everglades Agricultural Area (EAA; Figure 1), to be developed for agriculture. Further degradation of water quality in the region was documented in the 1960s and 1970s (McPherson *et al.*, 1976). Most EAA runoff today flows directly into the WCAs through a system of canals (Figure 2) and carries elevated levels of nutrients and other constituents (e.g., total suspended solids and pesticides; Nearhoof, 1992). Runoff from urbanized basins also enters the Everglades at a number of locations along the eastern boundary of the system. Pollutant loads in stormwater runoff can be exceptionally high. Excessive P loading has caused eutrophication in parts of the WCAs (Belanger *et al.*, 1989). In addition, enclosing the WCAs within levees and operating them as impoundments to meet flood control and water supply needs has altered flow paths (Figure 2) and the timing of water delivery throughout the system. This has caused excessive flooding in some areas, overdrainage of other areas and periodic reversals in the seasonal fluctuation in water depth. Eutrophication and changes in hydrology, in turn, have been linked to widespread changes to the ecology of the Everglades as evidenced by dramatic declines in the size of wading bird populations, intrusion of cattail into more than 10,000 ha of native sawgrass and slough habitat, and the widespread invasion of exotic plant species (Rader and Richardson, 1992; Davis and Ogden, 1994; Thayer *et al.*, 2000).

Everglades restoration legislation

The environmental and scientific communities were alarmed over deteriorating conditions in the Everglades. It was clear that the impacts described above had damaged the Everglades to the extent that the biotic integrity of the remaining ecosystem was threatened. These effects were unwanted consequences of what otherwise was widely regarded as a beneficial public works project. Any actions to remedy this situation needed to substantially reduce nutrient loads in EAA and urban runoff and restore the natural hydrology of the region. The District became involved with Everglades environmental issues in the early 1970s and began evaluating the treatment efficacy of both natural and constructed wetlands in 1976 (Davis *et al.*, 1985). By the 1980s, there was a growing consensus that treatment wetlands could effectively reduce nutrient levels in stormwater runoff and therefore might play an important role in any strategy to restore the Everglades.

Concern over the Everglades prompted the Florida Legislature to enact the Everglades Protection Act (EPA) in 1991 (§ 373.4592, F.S.). This bill was intended to help resolve long-standing litigation between the Federal government and the District and State of Florida related to environmental degradation in WCA-1 and ENP. The EPA, together with the legal agreement resulting from settlement of the Federal lawsuit in 1992, required the

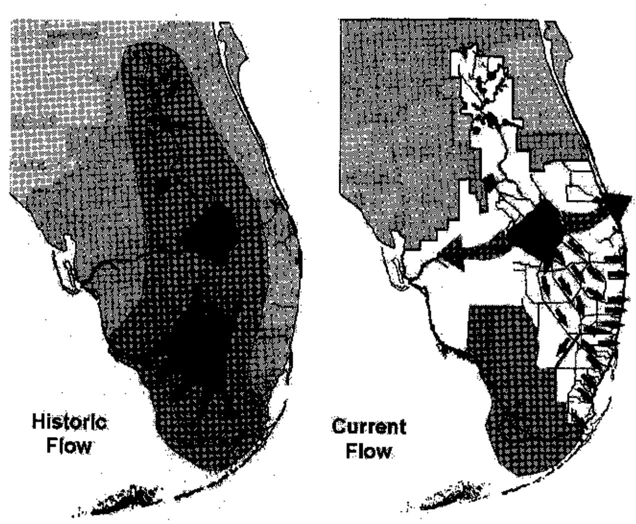

Figure 2 Comparison of major historic and current flow paths in the Everglades (USCOE and SFWMD, 1999)

District to adopt a Surface Water Improvement and Management (SWIM) Plan for the Everglades (SFWMD, 1992b) and initiate design of stormwater management systems that would bring all District facilities into compliance with water quality standards. The resulting conceptual design (Burns and McDonnell, 1992) proposed that three large treatment wetlands covering approximately 13,200 ha be built and operated to reduce P loads in runoff entering the Everglades. These treatment wetlands became known as the Stormwater Treatment Areas (STA) (Figure 3). The basis of design for the STAs was predicated on the success of other treatment wetlands in Florida and the fact that WCA-2A continued to reduce P in surface water even after decades of continuous nutrient loading (Burns and McDonnell, 1992; Kadlec and Newman, 1992; Walker, 1995). While the STAs are sometimes called "filter marshes," this is a misnomer since filtration is only a minor part of the treatment process. The STAs operate primarily by promoting biological uptake, chemical absorption/adsorption and gradual settling and accumulation of nutrients in the sediments.

The 1992 Everglades restoration plan and associated permits were challenged with several legal actions. Between December 1992 and December 1993, the District and other stakeholders engaged in mediation that produced an improved plan, which was incorporated into the 1994 Everglades Forever Act (EFA) (§ 373.4592, F.S.). The EFA was a revision of the 1991 legislation and required restoration of a significant portion of the remaining Everglades through a program of construction projects, research and regulatory controls. The goals and legislated requirements of the EFA call on many state and federal agencies to address water quality, water quantity (including hydroperiod restoration), and exotic species issues. Most of this work will be the primary responsibility of the District,

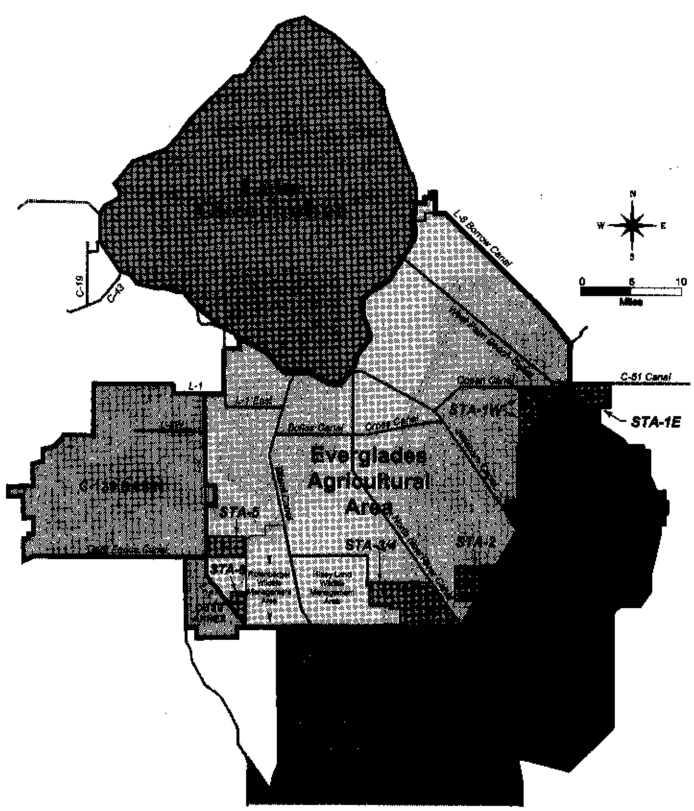

Figure 3 Location of the Stormwater Treatment Areas within the Everglades Agricultural Area

with substantial involvement by the Florida Department of Environmental Protection (FDEP) in more than half of the projects.

Everglades construction project

The EFA established the funding mechanisms and construction timetable for a more comprehensive program of six STAs that now encompass almost 17,000 ha of wetted surface area (see Figure 3). The STAs are designed to treat the annual runoff (~ 1.23×10^9 m^3) from seven of the 16 basins that discharge into the Everglades and regulatory releases from Lake Okeechobee. The District is building five of the STAs and associated infrastructure as part of its Everglades Construction Project (ECP), which has a capital budget of approximately $695 million. The USCOE is responsible for funding, design and construction of the remaining STA (STA-1 East). To date, over 4,720 ha of treatment wetlands have become operational (STA-1 West, STA-5 and STA-6), another 2,600 ha are under construction or in start-up (STA-2) and the remaining areas are in design (STA-1 East and STA-3/4). Even before full completion, the STAs comprise the largest system of treatment wetlands in the world.

The EFA requires the District to conduct water quality research and monitoring programs that, among other things, will seek to optimize nutrient removal (primarily P) by the STAs. In addition to mandating construction of the STAs, the EFA directs the District to (1) conduct research into improving Best Management Practices (BMPs) within the EAA to further reduce nutrient loads coming off farm fields, (2) investigate "alternative" treatment technologies that might be used in conjunction with, or in place of, the STAs to improve their performance, (3) initiate efforts to restore the region's natural hydrology and (4) deal with the invasion of exotic plant species. The water quality research and monitoring, ecosystem-wide planning and regulatory programs that make up the ECP are intended to ensure that the District has a sound foundation for science-based decision-making in its restoration efforts.

The EFA set both interim and long-term water quality goals for the Everglades and recognized that additional measures may be required to achieve compliance with long-term standards. The STAs, in conjunction with BMPs in the EAA, constitute the District's Phase I restoration efforts and are designed to produce effluent that meets an interim standard of 50 $\mu g\ P\ L^{-1}$ on an average basis. The ultimate objective is to combine point-source, basin-level and regional solutions to ensure that by December 31, 2006 all runoff discharged into the Everglades has nutrient levels that do not cause an imbalance in populations of Everglades flora or fauna. A concentration TP limit, i.e., the "threshold" concentration, that achieves this goal, and the methodology to be used in determining compliance with this limit, will be set by December 2003 based on research being conducted by the District (McCormick *et al.*, 1999, 2000) and other parties. The EFA stipulates that the TP standard will be 10 $\mu g\ P\ L^{-1}$ by default if this multi-party research effort is inconclusive or consensus cannot be reached on a single TP concentration. To date, the STAs have produced effluent ranging from 18 to 25 $\mu g\ P\ L^{-1}$ on a long-term basis. STA design considerations and initial treatment performance will be discussed further in companion papers presented during this conference.

Other restoration activities

Despite the massive scale and cost of Phase I restoration, the environmental benefits that will be achieved by these efforts alone cannot meet *all* the water quality and hydrologic needs of the Everglades. The following sections outline other activities that are critically important to the future health of the Everglades.

Advanced treatment technologies

The EFA mandated the District to investigate "alternative" P reduction technologies that could be used in combination with, or in place of, the STAs to treat stormwater runoff. All currently known drinking and wastewater treatment technologies, ranging from low-intensity management of constructed wetlands to full-scale chemical treatment plants were screened for possible use (PEER Consultants, P.C./Brown and Caldwell, 1996). Various combinations of the highest ranked technologies were evaluated based on nutrient removal performance, implementation costs and environmental criteria. These comparisons confirmed that the STAs are indeed the best interim step towards achieving long-term restoration goals. The most promising alternative technologies were identified, and any remaining performance and/or operational uncertainties were documented to guide future research. The USCOE dredge and fill permit to build the STAs required that the District investigate eight technologies in what is now referred to as the Advanced Treatment Technologies (ATT) Research Program. This program is designed to obtain critical design information about nutrient removal performance, hydrologic operating characteristics, land requirements, initial and annual costs and potential environmental impacts. Additional details on the ATT research projects will be provided in companion papers presented at this conference. The ATTs constitute the District's Phase II restoration efforts and, in combination with the STAs and BMPs, are intended to produce effluent that will achieve the P threshold concentration. There is not enough information at this time to estimate costs for full implementation of Phase II restoration.

Everglades stormwater program

The District has initiated a separate effort, the Everglades Stormwater Program (ESP) to address water quality problems in basins that discharge into the Everglades and are not covered by the ECP (Bearzotti *et al.*; 2000). As with the ECP, the ESP has established basin-specific schedules and strategies for regulation, water quality monitoring, construction and other measures and has a target date of December 31, 2006 for full compliance with state water quality standards. Other components of the ESP include inter-governmental cooperative projects, an education campaign and development of a mechanism for reimbursement of restoration expenditures. Cost estimates to fully implement the ESP are not available at this time.

Comprehensive Everglades restoration plan

The District is a partner in a Federal initiative, known as the Comprehensive Everglades Restoration Plan (CERP), which is evaluating modifications to the infrastructure and operation of the C&SF Project to restore, to the greatest extent practicable, the natural hydrology of south Florida while continuing to fulfill flood protection, water supply and all other project objectives. A draft report detailing restoration alternatives was written by an inter-governmental agency team and submitted to Congress in July 1999 (USCOE and SFWMD, 1999). Additional work is needed to (1) determine the total water storage capacity required to achieve hydrologic restoration and (2) define requirements for temporal and spatial distribution of flows. The projected cost for implementing CERP is approximately $7.8 billion, which is an order of magnitude greater than the anticipated cost for the ECP.

Lower east coast regional water supply plan

In May 2000, the District finalized a water supply plan for Florida's lower east coast (the LEC Plan), the region that has the highest concentration of urban development in the District. The LEC Plan defined the hydrologic requirements (e.g., quantity, discharge locations, timing of delivery, etc.) necessary for sustainable future water use and defines how the District will manage the regional water supply over the next 20 years. Because the LEC Plan balances the water needs of urban, agricultural and environmental interests, it is directly linked to implementation of Everglades restoration activities.

Current status of design and implementation

As sufficient information from the various ongoing research programs and other restoration activities discussed above becomes available, basin-specific feasibility studies and conceptual designs will be started to determine the optimal combination of treatment technologies required to achieve long-term water quality goals. For planning purposes, the District is assuming an end-of-pipe discharge limit of 10 μg P L^{-1}. If the final TP discharge limit is significantly different from this value, the optimal long-term solutions may be altered, with possible adverse impacts on final costs and the time required for implementation.

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