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Everglades restoration and water quality challenges in south Florida

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Abstract This paper provides background information and a brief overview of water quality issues for the rest of the papers in this volume that are concerned with Everglades restoration. The Everglades of Florida have been diminished over 50% of their former extent. The Everglades are no longer a free-flowing wetland ecosystem, but are now subject to a complicated system of water management that is regulated primarily for flood control and consumptive use. Attempts to restore a more natural hydropattern to the remaining undeveloped Everglades are made more difficult by the natural extremes in rainfall, flat landscape, highly porous geology, and inaccessibility of the remaining natural areas. The Comprehensive Everglades Restoration Plan (CERP) seeks ecosystem restoration by adding water storage capacity, reducing groundwater seepage, improving regulatory delivery and timing of water to avoid environmental damage, and where feasible, improving the quality of water to be used for Everglades restoration. Water quality issues that currently exist for south Florida include eutrophication (especially phosphorus), mercury, and contaminants from agricultural production and the urban environment. Lands once in agricultural production that will be converted back to wetlands or will become reservoirs may contribute to the water quality concerns. Stormwater runoff from managed lands that will be used for restoration purposes will also present water quality challenges. The state continues to seek water quality improvement with a number of pollution reduction programs, and CERP attempts to improve water quality without sacrificing even more natural areas; however providing water quality sufficient for use in recovery of remaining Everglades wetlands and estuaries will remain a daunting challenge.

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Introduction

The Comprehensive Everglades Restoration Plan (WRDA 2000), or CERP, is the conceptual plan for the largest environmental restoration project in history. It is the latest of a number of plans undertaken by the federal government to address the shortcomings of the Central and South Florida (C&SF) Project, a Federal water management project authorized in 1948. The C&SF Project was initiated after several years of disastrous floods to control surface water movement in the region that was known as the Everglades (Perry 2004). The destruction of the Everglades has been well documented (e.g., Grunwald 2006) and began initially as an attempt to alter hydrologic patterns at local scales in south Florida in the early 19th century. These efforts were followed by the regional confinement and management of surface water with the C&SF Project (USACE and SFWMD 1999). Although much of the attention of restoration efforts has been focused on hydropattern restoration in the undeveloped Everglades, water quality issues also exist that are critical factors in determining the degree to which the Everglades may be restored. Water that will be used to restore the vast Everglades wetlands will come from water that has first passed through some degree of atmospheric pollution and has then come into contact with agriculture activities and urban development. The following provides a general overview of contemporary issues in water quality in south Florida that bear on Everglades restoration activities that are planned to occur over the next 40 years.

Historical perspectives

Management of water distribution in south Florida has always been a challenge because of a wet-dry season climate and flat topography. While the average rainfall is over 60 in. per year, wide variations occur because of tropical weather systems (i.e., hurricanes) and regional shifts in weather (i.e., related to the southern oscillation (that includes both el Nino and la Nina), result in extreme high and low rainfall years. The historic Everglades of south Florida once occupied over 11,000 sq m, from its Kissimmee river headwaters in central Florida to the estuaries of Biscayne Bay, the 10,000 Islands, and Florida Bay (Fig. 1). Lake Okeechobee briefly interrupted the north-to-south flows during the dry season (usually November through May), but wet season flows (June–October) spilled over the southern rim of the lake basin to form a continuous, slow-moving sheet of water through a forested wetland and a broad expanse of sawgrass, dotted by tree islands in southern areas (Steinman et al. 2001). The flow path was defined by the central Shark River Slough, flood plains created by the annual wet season-dry season water cycle, discharging into estuaries through streams and rivers

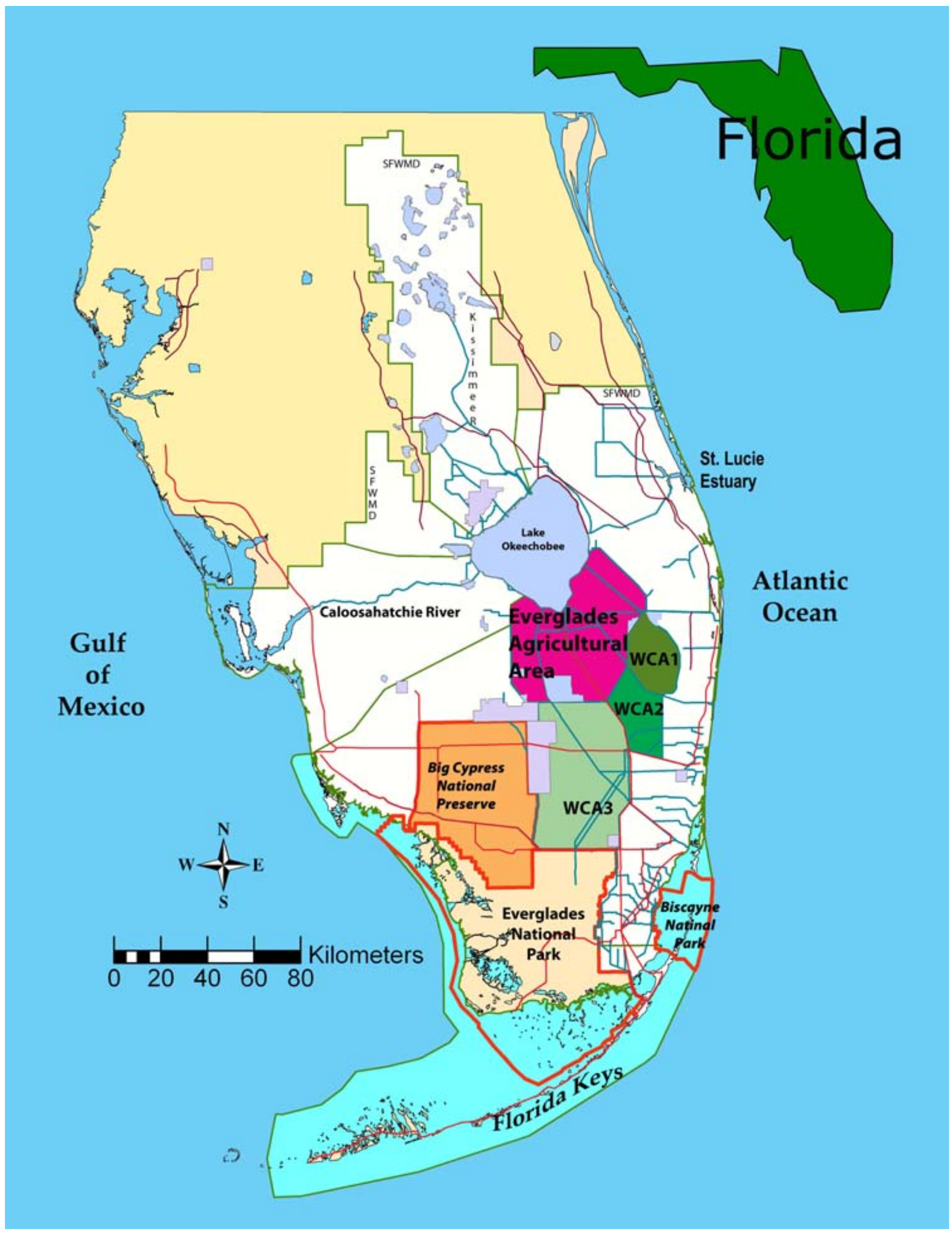

Fig. 1 Water quality challenges

along the southeast Florida coast. This large-scale sheet-flow provided the basis for a complex mosaic of ponds, sloughs, sawgrass marshes, hardwood hammocks, and forested uplands. Fed by high rainfall and periodic drought in an annual cycle that is punctuated by wet season hurricanes and dry season fires, the Everglades evolved into a complex ecosystem that formed much of the ecological infrastructure for the southern half of Florida (e.g., McCally 2000; Davis and Ogden 1994).

An expanding population in Florida in the late 1800s and the promise of cheap land if the Everglades could be drained led to the first serious attempts to convert parts of what is know today as the Everglades of south Florida into arable farming. However, the extremes in rainfall, the flat landscape, and the highly porous geology (key factors in sustaining the Everglades ecosystem) proved costly and hindered the drainage effort. It was not until 1948 that federal funding allowed for building the C&SF Project to manage water in the region (USACE and SFWMD 1999). It eventually included over 1,000 miles of canals, 750 miles of levees, pump stations to move the water off the landscape, and some 200 control structures, with water storage in lake Okeechobee and the water conservation areas (WCA). All were needed to smooth out the regional extremes of rainfall and drought, and to drain most of the rainfall to either the Gulf of Mexico or the Atlantic Ocean. By doing so, large parts of Everglades wetlands were turned into relatively dry ground and permitted the expansion of agriculture and urban development beyond that on the eastern coastal ridge. The south Florida water management district (SFWMD) has the primary responsibility for operating and maintaining this complicated water collection and distribution system.

By the 1970s, approximately 50% of the historic Everglades had been eliminated, and the regional hydropattern was regulated to meet flood control and water supply needs. The remaining undeveloped Everglades exist primarily as WCA 1 (Loxahatchee National Wildlife Refuge), WCA 2, WCA 3, and Everglades national park (ENP; Fig. 1). The park was established in 1947 on 1.4 million acres in the southwestern end of the region. The historic flow path is now compartmentalized, with overland flow interrupted by canals, levees, and the Everglades agricultural area (EAA; see Fig. 1). To remove water from the landscape, an estimated 1.9 million acre-feet annually is now intercepted and routed through lake Okeechobee with canals that drain to the Gulf of Mexico and the Atlantic Ocean. The remaining Everglades are among those compartments, and the natural resources within became significantly degraded because of the altered hydropatterns (USACE and SFWMD 1999). Lowered water tables resulted in oxidation of drained peat soils and damaging peat fires, which have lowered the land surface 3–10 feet in some agricultural areas. Regulating the water levels among compartments has resulted in conditions that are often either too dry or too wet to maintain native plant and animal communities. Water management also results in northern estuaries that are chronically less saline and southern estuaries, particularly Florida Bay, which are more saline than they were historically (NRC 2002b). Eastern portions of ENP are often too dry and more prone to fire, whereas western portions of the park experience extended periods of high water. Water flow is regulated, impounded in lake Okeechobee or the WCAs north of the park (Fig. 1). The altered hydrologic system contributed to significant losses of populations of wading birds (Ogden 1994), a 67% decline in the area of tree islands in the WCAs (Heisler et al. 2002; Sklar and Van der Valk 2002; Wetzel et al. 2005), and profound changes in the ecosystem of Florida Bay (McIvor et al. 1994). Sawgrass (*Cladium jamaicense*), a plant characteristic of the undisturbed Everglades (a low nutrient environment), is being replaced by cattails (*Typhus domingensis*) in the northern Everglades, particularly in WCA 2 where nutrient loading has been excessive (Rutchey and Vilchek 1999; Sklar et al. 2004). Approximately 1 million acres are contaminated with mercury (McPherson and Halley 1996). Phosphorus from agricultural runoff has impaired water quality in parts of the Everglades and has resulted in hyper-eutrophic conditions in lake Okeechobee (SFWMD and FDEP 2006). Halting the decline of the Everglades and restoring more natural hydropatterns and high quality water is challenged by the current regulatory priorities for providing flood control and drinking water for the rapidly developing urban landscape and the intensive agricultural production at its boundaries, within the historic Everglades (i.e., the EAA), and in its headwaters, the Kissimmee river (NRC 2006).

Everglades restoration

Prompted by concerns about deteriorating conditions in the south Florida ecosystem, the public, as well as the federal and state governments, directed increasing attention to the adverse ecological effects of the flood control and irrigation projects, beginning in the 1970s (Kiker et al. 2001; Perry 2004; Grunwald 2006). A number of civil works projects were initiated to accomplish this, including the framework for modifying the C&SF Project, the CERP, which proposes more than 40 major civil works projects and 68 project components (USACE and SFWMD 1999); for details on CERP see: http://www.evergladesplan.org.

The goal of the CERP, as stated in the Water Resources Development Act (WRDA) of 2000, is "restoration, preservation, and protection of the south Florida ecosystem while providing for other water-related needs of the region, including water supply and flood protection." The plan is conceptual, and focuses on restoring natural hydropatterns in the undeveloped wetlands remaining in the south Florida ecosystem, with the assumption that improvements in ecological conditions will eventually follow. Major CERP objectives that will provide additional dimensions to the existing water quality issues in south Florida include:

- Conventional surface water storage reservoirs, built to provide some 1.5 million acre-feet of storage to improve dry season flows in the system.
- Aquifer storage and recovery, to use a large number of wells around lake Okeechobee that will store water approximately 1,000 feet below ground until needed; residence time will be from 1 to 4 years. The technique has not yet been tested at the scale proposed.
- In-ground reservoirs based on quarries created by rock mining.
- Seepage management to prevent unwanted loss of water from the natural system through groundwater flow. This will require below-ground barriers to groundwater flow and/or use of pumps to return seepage water.
- Wetland-based treatment areas (stormwater treatment areas, or STAs) to improve water quality.
- Water re-use (reclaimed wastewater) for additional water supply; two advanced wastewater treatment plants are proposed for Miami-Dade County in order to clean domestic wastewater to a standard that would allow it to be discharged to wetlands along Biscayne Bay or to recharge the Biscayne aquifer. This approach has not yet been tested at the scale proposed.

Current water quality issues

Wetland eutrophication

Eutrophication of the Everglades, including lake Okeechobee (Fig. 1), is a key regional issue that has profound consequences for ecosystem restoration. Drainage and development of the Everglades watershed has had long-term adverse effects on water quality in the region, including the lake. The high nutrient concentrations and loads entering lake Okeechobee and the Everglades from farms, dairies, and cattle lands that surround the lake have degraded water quality. The issue of excess nutrients in surface water in south Florida gained national stature in 1988, when the federal government filed a lawsuit against the SFWMD and the Florida Department of Environmental Protection (FDEP). The federal government alleged that water discharged into ENP and the Loxahatchee National Wildlife Refuge (Fig. 1) violated state water quality standards. In particular the lawsuit alleged that the farm runoff from the Everglades agricultural area (EAA; Fig. 1) contained excessive levels of nutrients, such as phosphorus, that were causing imbalances in natural populations of flora or fauna, a violation of state class III water quality standards (United States vs. South Florida Water Management District and Florida Department of Environmental Regulation, Case no. 88-1886-CIV-HOEVELER). The lawsuit was settled in 1991, and the following consent decree in 1992 prompted the state to begin a significant effort to reduce nutrient loads to the Everglades. The Everglades Construction Project, initiated by the state of Florida to improve water quality, is composed of 12 inter-related construction projects located between lake Okeechobee and the Everglades (for details see: http://www.sfwmd.gov/org/erd/ecp/3_ecp.html). Water quality improvement via nutrient removal is to be accomplished with six large constructed wetlands, which total over 42,000 acres. These stormwater treatment areas (STAs) use naturally-occurring biological processes to reduce the levels of phosphorus in water that will enter the Everglades, to an interim goal of 50 parts per billion (ppb). The treatment objective is to achieve 10 ppb, the established criterion for protection of Everglades biota. Research currently under way is focusing on establishing the long-term phosphorus levels that will prevent adverse impacts to the Everglades ecosystem. This long-term level will no doubt be <50 ppb, and may be in the range of 10 ppb. Thus far, however, no STA has produced effluent water with as little as 10 ppb, and the long-term effectiveness of STAs (over many decades) in providing an adequate degree of phosphorus removal that will prevent eutrophication impacts remains to be tested.

Lake Okeechobee, a key hydrologic element in south Florida and the headwaters of the Everglades, has become hypereutrophic over the last few decades by agricultural and dairy runoff from the surrounding drainage basins and from the downstream EAA, by back-pumping agricultural runoff and excess water to the lake (SFWMD 1989; Hand et al. 1996). In response to the decline in water quality in the lake, state and federal agencies have instituted programs for control and reduction of loading of phosphorus to the lake. Details for these programs are available at: http://www.sfwmd.gov/site/index.php?id=16 and http://www.saj.usace.army.mil/projects/crproj10.htm.

The understanding of water quality problems in south Florida's natural areas has improved since the concerted effort of water quality improvement that began with the 1992 Consent Decree, but areas of uncertainty remain regarding water quality impacts. Phosphorus continues to be a high priority issue, since one of the defining characteristics of the Everglades was its oligotrophic nutrient regime (DOI and USACE 2005), and lake Okeechobee is now surrounded by land use that loads phosphorus and nitrogen to the Everglades. The quality of water that flows into the lake will eventually make its way into the freshwater Everglades or its coastal estuaries; thus control of nutrient loading to lake Okeechobee is a pivotal issue. Other water contaminants, such as mercury, sulfur, and pesticides, have also been demonstrated to have undesirable effects on species and communities found in the Everglades (SFWMD and FDEP 2006).

Mercury

Mercury contamination is also linked to agricultural practices, particularly to the use of sulfate as a soil amendment. The source of mercury appears to be atmospheric mercury emissions and local deposition, but despite a general decline in emission rates relative to the highs of the early 1990s, mercury continues to be a major concern in the south Florida ecosystem (SFWMD and FDEP 2006). Sulfur is a dominant control of mercury methylation rates, with its effect depending on its concentration and chemical species (Atkeson and Axelrad 2004); thus, high rates of sulfate discharge from the EAA pose an existing water quality problem for the health of the Everglades ecosystem. Increasing the flow of water to the Everglades, a major goal of restoration, may increase sulfate loading of the Everglades, even if it is passed through an STA (SFWMD and FDEP 2006). An increase in the amount of sulfate entering the ecosystem could exacerbate the problem of methyl mercury and other effects of sulfate on biota in the ecosystem. At present, the Everglades constitute the largest continuous area in Florida from which consumption of fish is banned or limited because of mercury contamination. Concentrations in fish in all parts of the Everglades remain above the US Environmental Protection Agency's recommended body burden criterion (0.3 mg/kg) and pose risks to fish-eating birds, reptiles, and mammals, including humans (Axelrad et al. 2005).

The relationships among sulfate concentrations, microbially-mediated sulfate reduction, soil/sediment character, and geographic location within the Everglades affect the rate of methylation of mercury, including the concentration rate of methyl mercury itself. These relationships remain complex and not yet well understood (Benoit et al. 1999; Krabbenhoft et al. 2000). A better understanding of the interactions among mercury, sulfur, and phosphorus in the Everglades environment will be extremely important to decisions about land use policy and its potential role in mercury mobilization in south Florida. In particular, the issue of sulfate in water to be used for restoration of the Everglades ecosystem will bear directly on the issue of mercury toxicity and its potential to constrain the recovery of Everglades fish and wildlife populations.

Coastal water quality

Much of the flood control in south Florida is achieved with the C&SF Project, by conveying regional runoff to the Gulf of Mexico (through the Caloosahatchee river system) or the Atlantic Ocean (through the St. Lucie canal and Indian river lagoon). These unseasonal water discharges adversely affect the coastal estuaries with salinity alterations, contaminants, and nutrient loading (USACE and SFWMD 2002; USACE and SFWMD 2004). Harmful algal blooms (HABs) occur in aquatic environments when conditions trigger an increase in the abundance of plankton that produce toxins detrimental to aquatic life and to humans (Boesch et al. 1997). HABs have been estimated to cost the US economy as much as $50 million per year Anderson et al. 2000a, b; Hoagland et al. 2002) owing to closure of fisheries and beaches, and to human health costs associated with exposure to toxins. Hypoxia, caused by the decomposition of algal blooms (although not necessarily by a harmful algal bloom), is a condition where dissolved oxygen concentrations have been depleted to levels unable to support marine life. Both conditions alter local food webs that support fish and shellfish growth and cause economic and ecological damage of their own. Increasing eutrophication of coastal waters from land-based sources appears to be an important factor in the global increase in HABs (Glibert et al. 2005). Red tide (*Karenia brevis*) has been problematic in southwest Florida (Gulf of Mexico); blooms have intensified an average of 15-fold since the 1950s, and the duration of the blooms has increased (Brand and Compton 2006). Studies of Florida's southeast coastal waters have indicated that the red drift macroalgal blooms that degraded beaches in 2003 and 2004 are a recent phenomenon, and may be associated with increasing land-based nutrient pollution (Lapointe and Bedford 2007). The linkage between flood control releases through the Caloosahatchee river and HAB formation on the west coast of Florida will continue to be an important water quality issue, particularly to coastal communities downstream of inland land and water management activities.

Pesticides

The remaining undeveloped Everglades ecosystem is surrounded by agriculture and the intensive landscaping activities of urban south Florida. A large proportion of lands that were drained enough for a crop cycle are currently, or were at one time, under row crop cultivation or in fruit orchard production (e.g., citrus), both of which are managed with fertilizers and persistent pesticides. In the past, frequent applications of DDT, chlordane, and toxaphene were common; although no longer used, they have left residues, and their degradation by-products are bound to and sequestered in the top soil. The SFWMD has conducted a pesticide-monitoring program since 1984, with sampling at multiple locations and at various frequencies over its 1,400 mile system of canals (Miles and Pfeuffer 1997; Pfeuffer and Rand 2004). Atrazine and ametryn were the most commonly detected herbicides in surface water samples; residuals of DDT, dichlorodiphenyldichloroethylene (DDE) and dichlorodiphenyldichloroethane (DDD) were the most frequently detected insecticides in the sediment samples (Pfeuffer and Rand 2004). Current regional pesticide usage has been estimated to be about 14,000 metric tons per year, with 38% as insecticides, 20% as herbicides, 24% as fumigants, and 19% as fungicides and nematicides (Miles and Pfeuffer 1997). The ecotoxicological significance of the presence of these pesticides and other organic contaminants [e.g., polychlorinated biphenyls (PCBs), polycyclic aromatic hydrocarbons (PAHs)] in surface water and sediment remains unclear. What is clear is that water drained from agricultural areas and flooded urban areas that enter the Everglades represents a significant water quality issue to both the freshwater Everglades and the coastal environments that receive canal water discharges.

Water quality and Everglades restoration

The spatial extent of the historic Everglades has been greatly reduced, and as a consequence, they have lost much of their former water storage capacity, which is critically needed in the dry season. Thus, a key objective of CERP is to regain storage capacity. Land acquisition and other forms of land protection within the south Florida ecosystem are crucial to the restoration's success, because a sufficient land base is required for additional storage to increase dry season water quantity, improve water quality (e.g., STAs), and enhance ecological functioning (rehydration of former wetlands) (NRC 2006). By 2005, the land acquisition program had obtained 207,000 acres of land for CERP projects, accounting for 51% of approximately 406,000 acres that planners anticipated for the CERP (DOI and USACE 2005). A large portion of these lands are currently in agricultural production or were at one time. Rehydration of former agricultural lands means a change from a dry and frequently disturbed aerobic environment to one that is perennially or intermittently inundated. Short hydroperiod wetlands undergo a cycle of inundation and dry-out; those that are permanently wetted may be characterized by relatively undisturbed anaerobic sediments.

Rehydration or restoration of wetlands

Wetlands are reconstituted to regain lost native submergent and emergent vegetation, periphyton, invertebrates, and fish and their ecological function. Lands that were once managed for agriculture may have high nutrient levels in the soil, which will not foster recolonization and recovery to plant and animal communities characteristic of oligotrophic Everglades conditions. Restoration of more natural hydropatterns may not be sufficient for achieving restoration, unless plans for addressing the issue of nutrient management and removal in rehydrated wetlands are also included.

Rehydration of former agricultural lands also poses contaminant issues. Remobilization of residual pesticides through sediment leaching, an intermittent wet-dry cycle, or changes in redox potential, and trophic interactions often result in an exposure risk to wetland biota. The significance of the issue gained importance in late 1998 and early 1999, when a large-scale bird kill occurred in areas north of lake Apopka, Florida in November, 1998. As part of an interagency wetland restoration project, some 6,000 acres of farmlands were allowed to remain flooded following the final crop harvest in the summer of 1998. The area to be converted back to wetlands had been previously surveyed for contaminants, and some 20,000 tons of soil removed as part of the remediation process. Observed on-site bird mortality included 441 American white pelicans, 58 great blue herons, 43 wood storks, 34 great egrets and smaller numbers of 20 other bird species. The US Fish and Wildlife Service (USFWS) attributed the deaths to organochlorine pesticide poisoning as a result of restoring wetlands from lands formerly used for farming (USFWS and SJWMD 2004). While this was a dramatic example of acute toxicity following wetland restoration, long-term chronic exposure effects may prove more problematic, because they may be masked by the variation usually encountered in wildlife population dynamics. Identifying ecological risks and developing adequate remediation measures associated with pesticide residuals, including metals, will remain an important water quality issue for Everglades restoration.

Use of land for water storage

Use of former agricultural lands for reservoir storage, particularly those in the EAA, may pose similar water quality issues (NRC 2006). Elevated nutrient levels in the soil could add to eutrophication of the new storage reservoirs; stored water destined for restoration of wetlands will also subject them to increased nutrients. Lands within the EAA and vicinity for surface water storage have a legacy of many decades of intensive agriculture. Water quality concerns with use of those lands for water storage include the local effects of excess phosphorus and exacerbation of the mercury pollution problem in the Everglades from dissolved sulfates. EAA soils have elevated levels of sulfur from past agricultural management practices; elemental sulfur is added to sugarcane grown on organic soils (300–500 lb S/acre) as an acidifying agent to mobilize micronutrients. While nitrogen loading is not an inland issue, its export as part of the water management system may have downstream effects on coastal waters, particularly on Florida Bay (NRC 2002b), in terms of causing algal blooms and conditions that stress seagrass resources in south Florida.

Use of surface mine pits for water storage

Two in-ground reservoirs are proposed to be constructed by converting former rock quarries in the lake Belt region of Miami-Dade County, and a third, smaller reservoir is also planned for western Palm Beach County. To convert the quarries for water storage, seepage barriers must be created to limit the infiltration of groundwater from the surrounding aquifer and to hold the stored water within the reservoirs. About 9,700 acres will be used to store about 280,000 acre-feet. In addition to questions concerning the feasibility of seepage control at the required scale, quality of the water recovered from this type of storage also has its uncertainties. Local basins supplying water to the reservoirs are or will be in suburban/urban land use, with some under intensive agriculture. Constituents associated with this land use include: elevated nutrients; oxygen-demanding biodegradable materials; potentially pathogenic microorganisms of animal, and possibly human origin; a variety of heavy metals, including zinc, cadmium, and lead; and low levels of a wide variety of synthetic organic contaminants (e.g., herbicides, pesticides, and polycyclic aromatic hydrocarbons) used for urban landscaping, or hydrocarbon compounds associated with runoff from areas with high vehicular traffic. Morphometry of the rock pits (i.e., step sides, large mean and maximum depth) may also contribute to changes in water quality, particularly if thermal stratification leads to a persistent anoxic hypolimnion (NRC 2005). Anoxic conditions could lead to an accumulation of undesirable constituents, including sulfide, ammonia, methane, dissolved iron, and manganese. This will cause some fraction of the stored water to be unsuitable for municipal water supply or Everglades restoration, or at least require some degree of treatment before release. Because of these uncertainties, pilot projects are under way to gain a better understanding of how this type of storage may be accomplished (for details, see: http://www.evergladesplan.org/pm/projects/docs_35_lake_belt_pilot.aspx).

In addition to water quality issues regarding water stored in the lake Belt reservoirs, there are concerns about the potential for contamination of the shallow, highly permeable Biscayne aquifer, in which the quarries are sited and which is used for drinking water supply (NRC 2005). The results of groundwater tracer tests in 2003 confirmed high groundwater transmissivity rates in the lake Belt vicinity and the potential for subsurface connectivity (Renken et al. 2005). The degree to which use of the proposed storage will present a water quality problem will likely depend on the source water and on the level of pre-storage treatment applied to water that will be added to the reservoirs, as well as on the hydraulic connection that remains between the reservoirs and the aquifer once seepage barriers have been constructed.

ASR technology and water quality

To achieve additional water storage, the use of aquifer storage and recovery (ASR) is proposed for CERP (USACE and SFWMD 2006). ASR is the storage of water in an underground aquifer by pumping through a well and recovery from that well when needed. The CERP proposed to use porous and permeable units in the Upper Floridan Aquifer to store excess surface water at rates of up to 1.7 billion gallons per day when water is available and then recover it during the dry season or when needed (NRC 2002a). Besides the uncertainty about the potential physical effects, such as pressure-induced changes in surrounding aquifers, changes in regional groundwater flow patterns, and potential leakage of injected water into aquifers and surface waters used for drinking water supply, a number of basic water quality issues remain. These tend to center around leaching of materials from geological formations and reactions with compounds that are in the injected water. Hydrogeochemical changes could be mediated by microbial activity, so multiple factors will bear on ASR well geochemistry, including source water quality, aquifer geology, subsurface redox conditions, and storage time; thus redox condition and rock-water-microbial interactions will be important (NRC 2002a). Source water is to be treated with chlorination, which may pose additional consideration of the fate of chlorinated by-products during storage. Treatment to state drinking water standards, however, may not remove contaminants or nutrients; this is a concern if poor quality water (i.e., from agricultural or urbanized lands) is used for ASR storage. Some of the water quality issues under consideration include:

- Leaching of undesirable solutes, including metals (such as arsenic) and radionuclides, and the biogeochemistry that will alter quality of water recovered.
- Fate of injected contaminants (chemistry and transport).
- Survival of pathogens.

A number of pilot studies are under way to address uncertainties associated with large-scale application of

ASR in south Florida (for details see: http://www.evergladesplan.org/pm/projects/project_list.aspx). Results from completed studies show site-specific conditions are important; concentrations of arsenic and gross alpha in recovered water sometimes exceeded regulatory criteria at ASR sites in southwest Florida (Mirecki 2004; Arthur et al. 2002).

Water re-use for Everglades restoration

The CERP currently proposes to develop and construct two advanced wastewater treatment facilities in Miami-Dade County to provide some 250,000 acre-feet per year of reclaimed water. Wastewater from the Miami-Dade South Wastewater Treatment Plant is currently pumped over 2,000 ft deep into the "boulder zone" of the Floridan aquifer, the standard treatment for disposal in south Florida. It is assumed that advanced techniques in wastewater reclamation will result in water that meets state water quality standards and in doing, increase the quantity of water available for ecological restoration. Currently, pilot projects are planned to evaluate water quality improvement techniques (for details, see: http://www.evergladesplan.org/pm/projects/proj_97_west_miami.aspx). Critical issues that remain to be addressed include level of nutrients (phosphorus and nitrogen) in the reclaimed water and the fate and potential effects of low concentrations of contaminants that may be of concern, especially those that are known to have endocrine activity in wildlife. The wastewater reclamation scheme is proposed as a contingency plan, to be implemented only in the event that more economical sources of water are not discovered during the courses of the pilot projects. Given the high costs anticipated for advanced treatment that will be sufficient to meet required water quality standards, this may not be likely, although there is currently a mandate from the state for the county to recycle at least some part of its waste water for water supply needs.

Summary and outlook

The population of south Florida's lower east coast is projected to swell from 4.8 million in 1998 to 6.6 million in 2020 (Kranzer 2003). In addition to consuming land for development, there will be additional demands for drinking water and waste water disposal. While much of the land will convert from agriculture, water quality associated with urban runoff will not be an improvement. Key existing water quality issues for the region include eutrophication of wetlands from agriculture, dairy, and cattle production that surround the Everglades, coastal eutrophication and HABs, mercury and the production and mobilization of methyl mercury, and a diverse assortment of contaminants derived from agricultural production and urban activity. The factors controlling Hg deposition, transformation to biologically available states, accumulation up the food chain (magnification), and implications to individual species are complex. Sulfate contamination from drainage of the EAA presents a difficult challenge, since the EAA is proposed as a site for significant water storage that will become part of dry season restoration flows.

While much of the water is currently diverted from the inland Everglades through hypereutrophic lake Okeechobee, redistributing it to achieve a more natural hydropattern will require substantial treatment for at least nutrient removal. Lands to be restored as wetlands or used for water storage often contain the legacy of agriculture, high nutrient levels and persistent pesticides; these will add further challenges to meet for their use in restoring a pristine, oligotrophic ecosystem.

There are a number of ongoing water quality improvement programs in south Florida: the National Pollutant Discharge Elimination System (NPDES), point and non-point source regulatory programs, total maximum daily load (TMDL) development and remediation programs, and the Surface Water Improvement and Management (SWIM) planning efforts. While CERP contains a number of projects that include water quality improvement as part of the goal of Everglades restoration, restoration success will depend heavily on the success of these state regulatory and pollution reduction programs, which are outside the scope of the CERP. Successful implementation of basin water quality improvement plans (usually developed under the state's TMDL program) will be essential to achieve ecological restoration in downstream basins.

At present, there is no comprehensive plan for achieving water quality restoration in south Florida that links water quality restoration programs to comprehensive planning for ecosystem restoration. To address the need for a regional perspective, the Comprehensive Integrated Water Quality Feasibility Study was authorized in 2003. It is intended to provide recommendations on development of a comprehensive plan that will coordinate the efforts of the state, Indian tribes, water management districts, and Everglades restoration projects to improve water quality (for details see: http://www.evergladesplan.org/pm/studies/ciwq.aspx).

And finally, the relationship between water quality and the ecological needs of Everglades biota is not well understood. The best information comes from the extensive studies of nutrients and the role of phosphorus, which helped establish the (long-term) criterion of 10 ppb for phosphorus in water that would avoid imbalances in vegetation and habitat and alter the native ecosystem. For this water constituent, the threshold of adverse effects is somewhat clearer, and has provided for establishing the criterion of 10 ppb of phosphorous for maintenance of biota characteristic of the Everglades. However, it remains to be seen if achieving water that meets state water quality standards for other constituents will allow recovery of biotic communities in the remaining Everglades.

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