Florida Lake Management Society

"New Perspectives and Tools for Lake and Watershed Management"

The mission of the Florida Lake Management Society is to: promote protection, enhancement, conservation, restoration, and management of Florida's aquatic resources; provide a forum for education and information exchange; and advocate environmentally sound and economically feasible lake and aquatic resources management for the citizens of Florida.

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Conference Chairman: Charles Hanlon, SFWMD
Technical Sessions Chairman: Garth Redfield, SFWMD

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The 1997 annual Meeting was organized by:

Florida Lake Management Society, FLMS
South Florida Water Management District, SFWMD
Florida Center for Environmental Studies, CES

The 1997 FLMS annual meeting consisted of eight sessions covering the following topics:

Session 1. Management of Lake Kissimmee and the Upper Chain of Lakes. This session will provide case histories on the challenges of water level regulation, fisheries management, control of eutrophication and aquatic plant management for the Upper Chain of Lakes, Lake Kissimmee and other Florida lakes.

Session 2. Restoring Florida Lakes through Watershed Management. Speakers will address the science and policies underlying the use of phosphorus control as the primary foundation of the restoration of Lake Okeechobee, Lake Apopka and other eutrophic lakes in Florida. Innovative approaches to groundwater, stormwater and septic tank inputs will be emphasized.

Session 3. Getting the Most from Data on Water Quality and Lake Status. Presentations for this technical session will provide state-of-the-science approaches for analyzing and interpreting water quality data.

Session 4. Establishing Minimum Flows and Levels for Florida Lakes and Rivers. Representatives from the water management districts will take the lead in presenting the science and policy issues associated with setting minimum flows and levels for lakes and rivers, and making the trade-offs with consumptive uses.

Session 5. Constructed Wetlands for Water Quality Management; Can they be successful for large-scale applications? This session will present information on the Lake Apopka Marsh, Everglades Nutrient Removal Project, and other constructed wetlands. Speakers will address practical issues in the performance of constructed wetlands with emphasis on long-term utility and application to regional ecosystems.

Session 6. Role of Research in Water Management. This session will illustrate ways of conducting and utilizing research conducted by and for governmental agencies to reduce the uncertainty of water management decisions.

Session 7. Aquatic Plant Management; Linkages to Water Quality, Fisheries and Wildlife. This session will provide information on documented linkages between macrophyte community structure and abundance, and the functions of lake ecosystems.

Session 8. The Kissimmee River Restoration and Management of Florida Rivers. A summary of the Kissimmee River Restoration and the lessons learned from the project on the science of ecosystem restoration will one focus of papers in this session. Other papers will address management issues in flowing water systems of the southern U.S.

1. Resource Management in the Kissimmee Chain of Lakes

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The Kissimmee Chain of Lakes is a series of inter connected lakes south of Orlando. These waters feed the Kissimmee River, forming the headwaters of the greater Kissimmee-Okeechobee-Everglades ecosystem. Major lakes in the chain include Kissimmee, Tohopekaliga, East Lake Tohopekaliga, Hatchineha, Cypress, Gentry and Alligator. There are fifteen lakes in the chain connected by canals owned and maintained by the South Florida Water Management District.

The Kissimmee Chain of Lakes, located in the Upper Kissimmee Basin, has seen many changes in the last century. The lakes have been altered for flood control and to encourage development - sometimes at the expense of environmental values. The first major alterations were made by the Disston Construction Project in 1881-1894. The lakes from Kissimmee through Alligator were connected by dredging channels between them. A Federal Navigation project was authorized in 1902 for a one meter deep ten meter wide channel through the Kissimmee River and north through the lakes to the City of Kissimmee.

Historically, the lakes fluctuated one half to three meters seasonally, providing cleansing and drying out periods. Central Florida's biological communities are adapted to periodic extreme fluctuations in depth. Natural fluctuations provided maintenance of prime fishery and wildlife habitat, but made residential and agricultural development nearly impossible because of flooding. These extreme high and low water levels needed to be controlled for both flood protection and water supply. Flood control came to central Florida in the 1960's after the devastating effects of Hurricane Donna, which left standing water in downtown Kissimmee for nearly three months. The Central and Southern Florida Flood Control Project was expanded to improve drainage connections from the Upper Kissimmee Basin lakes to the Kissimmee River. The Kissimmee River was channelized to provide increased flood protection in the river valley. Existing canals connecting the lakes in the Upper Kissimmee Basin were dredged to facilitate the movement of water for flood control and new canals were dug from Alligator Lake south through Lake Gentry to Cypress Lake. Structures were built to control water levels in the lakes. The Central and Southern Florida Flood Control Project greatly benefited people by providing stabilized fluctuations in lake levels and reducing risk of flood damage, enabling residential, commercial and agricultural development to establish a secure foothold around the Kissimmee Chain of Lakes. However, the flood control benefits it provided eliminated extreme high and low water periods that are beneficial to the ecological health of the chain of lakes. Lake fluctuations, based on an operating "regulation schedule", have been reduced to a seasonal range of about one half meter, equal to the historic average minimum. Natural drying out and flushing of lakes has essentially been eliminated, therefore accelerating their life cycle by promoting dense vegetation growth in the lake littoral zone.

Today, a number of programs are under way to correct these environmental problems. Several agencies, including the Florida Game and Freshwater Fish Commission, South Florida Water Management District, US Army Corps of Engineers, Florida Department of Environmental Protection, and local county governments, are involved in several projects in the Upper Kissimmee Basin which address resource management problems associated with flood control impacts, and protection and improvements to natural systems.

A management plan is being developed to address a broad array of resource management issues. The plan is focused on the Kissimmee Chain of Lakes, although activities in tributary lakes and watersheds do interact with and impact the lakes in the chain. As the plan evolves over time, it will make recommendations for other tributary lakes in the basin such as Jackson, Marian, Marion, Pierce, Rosalie, and Tiger. The plan serves as an umbrella for coordinating resource management activities and decision making for the chain of lakes.

2. Resource Planning Process for Kissimmee Chain of Lakes

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The South Florida Water Management District (SFWMD) held a Governing Board Workshop in February 1995 in Kissimmee that focused on a number of water management issues in the Upper Kissimmee Chain of Lakes. Some major topics discussed included aquatic plant control, water level regulation schedules, and extreme drawdowns and habitat restoration projects. An interagency group had been periodically meeting to discuss and coordinate aquatic plant management activities in the Upper Basin. In April 1995 the SFWMD hosted a meeting of several of the management agencies to evaluate the way water levels in the Upper Basin Lakes were regulated. The representatives soon recognized the benefit of improved coordination between agencies. The Upper Kissimmee Chain of Lakes Roundtable Discussion meetings have became a way of routinely meeting to discuss ongoing projects and plan for upcoming projects . The Roundtable Discussion group includes representatives from SFWMD, Department of Environmental Protection (DEP), Florida Game and Freshwater Fish Commission (GFC), U.S. Fish and Wildlife Service (FWS), U.S. Army Corps of Engineers (ACOE), Osceola County, and members of the public. Deyle (1995) notes that recent literature suggests that collaborative and coordinated multi-organizational decision making structures can evolve that are built upon common goals due to the recognition of the interdependence among organizations. He notes that once interdependencies are acknowledged, successful collaboration requires agreement on a shared vision that can only be accomplished through collective action. The move from initial collaboration to more formal modes of coordination appears to depend on the success of the initial efforts, development of a climate of trust, mutual learning among participant organizations, and recognition of interdependencies that extend beyond solving occasional problems. The Roundtable Discussion group appears to have effectively made the transition from initial collaboration to more formal coordination modes in part for the reasons Deyle mentioned above. The agencies' and citizen's groups in the Upper Kissimmee Basin involved in the Roundtable Group are leveraging resources, sharing information and data, reducing institutional impediments, improving communication, improving customer service, and developing a interagency, multi-disciplinary team approach. This effort seems to fit the objective of the National Performance Review of creating a government that works better and costs less.

Public involvement is an important goal of this interagency group. A variety of tools and techniques have been used. Through the cooperative efforts of a number of agencies a day long workshop was held in Kissimmee in November 1995. Presenters from the different agencies prepared visual displays of their projects and were available for informal discussions with workshop participants during the day. The GFC has prepared newsletters on the Lake Kissimmee and Alligator Chain of Lakes extreme drawdown and habitat enhancement projects. The interagency group has used public involvement approaches on the Alligator Chain Habitat Enhancement Project drawn from the ACOE Central and Southern Florida (C&SF) Restudy. Public involvement goals included gathering input critical to defining the problems and opportunities and for developing alternative plans, develop relationships critical to the success of the project and study, and to manage expectations (Sanders and Orth, 1995). The Interagency Group used a variation of the "large group response technique" described by Sanders and Orth. This approach was well received at the December 1996 workshop on the Alligator Chain of Lakes project. The views expressed are those of the author and do not necessarily represent those of the U.S. Army Corps of Engineers.

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3. The 1996 Lake Kissimmee Habitat Enhancement Project

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Degraded littoral habitat, caused by water level stabilization, has resulted in dense aquatic plant growth and organic sediments building up near Lake Kissimmee's low pool stage. Floating tussocks have also formed in these areas and together these problems have caused a reduction in the biological productivity in the shallow water areas. An extreme drawdown and muck removal project was planned to remove the organic material and restore quality habitat. Over 40 kilometers (50%) of shoreline was cleared of over 775,000 cubic meters of organic material. Several state, local and federal agencies combined to spend over $3,500,000 for this habitat enhancement project. Fish, wildlife and recreational users will benefit for years to come.

The Florida Game and Fresh Water Fish Commission, in cooperation with the South Florida Water Management District and other agencies, conducted a major habitat enhancement project for Lake Kissimmee. The program began in November 1995 and included an extreme drawdown, muck removal, extensive burning, and hydrilla management. These intensive lake management activities were necessary because of heavy build-up of organic sediments on the lake bottom, tussock formation and dense growth of littoral vegetation and the rapid expansion of hydrilla.

The drawdown was coordinated with the District, which has the responsibility of regulating water levels in the Kissimmee Chain of Lakes. Lakes Tohopekaliga and East Lake Tohopekaliga were used to store additional water upstream for refill after the habitat enhancement work was completed. A sheet pile weir was placed in Canal C-37 (Hatchineha Canal) just upstream from Lake Kissimmee, which eliminated navigation through Canal C-37 after Labor Day 1995 through July 1996. The structure was used to hold lakes Cypress and Hatchineha approximately 1.4 meters above the level of Lake Kissimmee. In addition, an earthen plug and sheet pile weir were placed in Tiger Creek to maintain higher lake levels in lakes Tiger, Rosalie and Weohyakapka.

Water levels on Lake Kissimmee were held at the summer high pool stage of 15.0m msl going into fall 1995 and not allowed to rise to the normal winter high stage of 15.8 m msl. The planned drawdown target elevation was 13.5 m msl by March 1996. Due to above normal rainfall, the drawdown target elevation was not reached until May 1996. Reflooding started June 1996 and reached the target 14.8m msl by 5 July 1996, over one month early. At that time, the weirs in canal Canal C-37 and Tiger Creek were removed and navigation restored. Approximately 6,400 hectares of lake bottom were exposed and organic bottom sediments compacted and consolidated during the drying period. Coverage of beneficial aquatic vegetation such as Kissimmee grass and bulrush should increase due to germination of seeds exposed during the extreme drawdown. Habitat enhancement activities such as muck removal, burning of dense vegetation and reduction of tussocks were implemented during the low water period. Muck removal occurred along 40 kilometers of shoreline. Approximately 775,000 cubic meters of organic material were removed from prime spawning and feeding areas for sport fish and wading birds. In conjunction with muck removal, an aggressive burning program targeted about 4,000 hectares of dense vegetation, reducing the biomass of dense pickerelweed and cattail. Tussocks stranded on dewatered lake bottom during the drawdown were also reduced in size by burning. Hydrilla treatments for Lake Kissimmee were completed by the District in conjunction with the Florida Department of Environmental Protection in spring 1995 and 1996 to provide environmental, navigational and flood control benefits.

4. Management of Aquatic Plants in the Kissimmee Chain of Lakes

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Since the South American water hyacinth (*Eichhornia crassipes*) was introduced to North American in the late 1880s, aquatic plant control has been needed in many waters of the southeastern United States. By 1894, the water hyacinth had reproduced so rapidly that navigation was shut down in waterways throughout temperate to sub-tropical areas along the coastal plain from Texas to the Carolinas. Since water-borne commerce was essential to the period's economy, Congress quickly funded control efforts through the Rivers and Harbors Act of 1897. This Corps of Engineers-administered program has continued to the present day. Today, it supports aquatic plant management efforts of more than 100 federal, state and local governments nationally.

In Florida, state and federal aquatic plant control funds are combined and administered by the Department of Environmental Protection (DEP), Bureau of Aquatic Plant Management. This grants program makes weed management funds available for more than 1.25 million acres of public waters in the state. Twenty years of unified DEP oversight has successfully controlled water hyacinth across Florida, yet a more recent invader, hydrilla (*Hydrilla verticillata*) has had less consistent funding and continues to seriously threaten natural aquatic functions and human waterbody uses. Hydrilla, the submersed freshwater weed, is perhaps native to tropical Asia, but has been found in much of the world's tropics for centuries. In South Florida, it is adequately managed in canals of the South Florida Water Management District (SFWMD) and most secondary drainage systems, but has recently exceeded the existing management capacity in waters of the state, namely lakes of central Polk, Osceola, and Highlands counties.

Since the early 1980s, when hydrilla first appeared in some lakes of the region, control efforts have aimed to control new infestations whenever possible. Generally, this has been possible only in smaller lakes which present simpler physical situations including fewer boat ramps, in-flowing waterways, and other common sites of hydrilla introduction. Hydrilla can be managed. Minimal hydrilla infestations have been kept under control in many lakes within SFWMD including Lakes Gentry, Alligator, Marian, East Lake Tohopekaliga, Fish, Butler, and Conway in Osceola and Orange counties. The DEP aquatic plant management bureau personnel have found cost benefit ratios of 1:5,000 when new stands of hydrilla are kept under control, and large-scale treatments are prevented.

In the Kissimmee chain of lakes, by 1996 hydrilla covered all 6,000 acres of Lake Hatchineha, along with much of the 34,000 acre Lake Kissimmee, the 18,000 acre Lake Tohopekaliga and 4,000 acre Cypress Lake. Aquatic growth has impaired water flows from these lakes, including emergency releases after 1994's Tropical Storm Gordon and large volume releases to the Kissimmee River. DEP, with interagency guidance, prioritizes lakes to receive funding on the basis of many factors. These include whether a given lake/canal infrastructure provides essential flood protection functions, has public access, harbors endangered species, and/or has a new or small hydrilla infestation which might be completely controlled if funded. Therefore, lakes of the primary Kissimmee

Waterway system have always received high priority rankings when funds have been allocated.

Currently, state and federal funds made available through the DEP’s aquatic plant control grants vary widely with annual fluctuations of state and federal budgets. Planners aims to control as much hydrilla as each year's funding allows within the DEP’s scheme of prioritizing all aquatic plant control needs statewide. By the mid-1990s, hydrilla infested more than 100,000 acres of public waters statewide. Funding was erratic and generally inadequate to effectively attack the problem. However, in 1997 a record amount of money was available. This may prove to be a unique occurrence because of the means by which Florida Department of Transportation mitigation funds were tapped by the 1996 Legislature. But, record amounts of hydrilla will be treated in 1997, probably decreasing hydrilla in the region, at least through 1998. DEP staff predict a record low level of funds to be available to treat hydrilla in 1998. Although latest reports from the 1997 Florida Legislature are that $5-6 million may be available for 1998 from a unique surplus in Recovery and Recycling Trust Fund.

Canals begun in the early 1900s connected all of this system to the Kissimmee River, and, ultimately, Lake Okeechobee. The canals and water control structures allow direct control of water levels, flood protection and water management. Yet the water levels are controlled within a very narrow vertical range when compared to the fluctuations that occurred naturally. This less-than-natural range of fluctuation has encouraged excessive proliferation of native aquatic plants along the shorelines of these lakes. Water level drawdowns have become essential to restore healthy conditions in the lakes. While water levels are down, heavy equipment has scraped organic material and plants from the productive shallows of the lakes. Other restoration methods, including burning and disking, are used in areas inaccessible to heavy equipment used. Burning can reduce the volume of plant matter by up to half, while disking aerates organic accumulations leading to desiccation and volume reduction.

Drawdown costs have ranged from several hundred thousand dollars to clean several miles of a lake, to about $4 million when 30 miles of Lake Kissimmee were scraped in 1996. Florida Game and Freshwater Fish Commission has managed these projects, with cooperation wrung from many entities including DEP, SFWMD, COE, local governments and landowners. Cooperative interagency planning has sought to involve all users of a waterbody and respond to as many needs of users as possible. While coordination is time-consuming, it enables a wide range of aquatic plant control projects on these lakes to proceed in an open atmosphere supporting a broad sweep of involved parties.

5. Results of the 1996 Lake Tarpon Waterfront Residents' Survey.

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A mail survey of Lake Tarpon waterfront residents was undertaken in 1996 to provide comparable data to previous county park boat ramp surveys prior to the adoption of a drainage basin management plan. Questions in the mail survey addressed such subjects as the number and type of boats owned by residents, amount and time of lake use and specific activities. Residents were queried on concerns about enforcement, safety, crowding, need for speed limits and availability of information on the lake. Respondents were encouraged to list problems with other lake users and with the lake in general. Two questions were included asking if residents were willing to plant native aquatic vegetation along their waterfront and, if so, how much.

This survey was conducted according to a method outlined in Pollock, et. al. An initial mailing was sent to waterfront property owners with a stamped return envelope. Out of state owners were sent surveys at both the local and remote addresses. Two repeat mailings were sent at one month intervals to unresponsive residents. The repeat mailings increased the response rate from 53% to 77% (493 of 643). Few responses were received from nonresident owners of vacant waterfront lots (2 of 62).

Watershed residents were first surveyed by the local lake association, S.O.L.I.D. (Save Our Lake Invite Discussion) in 1989. Two mail surveys were sent to association members with limited success. Cursory information on boat type, size and horsepower was collected. All of the respondents of one survey were concerned with boat safety on weekends and holidays. Most indicated that setting and enforcement of a lake speed limit and monitoring reckless behavior was the best way to insure lake safety. Sightseeing (61%), fishing (53%) and skiing (29%) were the activities listed. Several respondents to the second survey felt that public access through county parks should be limited until adequate law enforcement was available. Ramp fees to pay for enforcement and user permits were supported by most respondents.

The 1996 mail survey showed that waterfront residents make extensive use of the lake with 93% of these individuals participating in some activity on the water. The most frequent activities during the day were boating (81%), fishing (63%), skiing (36%) and personal watercraft (12%). Night activity involved one third of the people living on the water with the most common activities being boating (68%) and fishing (53%). The average waterfront resident uses the lake 72 times per year. Each trip lasts about 3 hours, involving 2 to 4 people. About 85% of the users indicated that they felt safe on the lake. When concerns were expressed, safety on weekends was mentioned along with the speed and proximity of other craft. About one third of the residents felt the lake is too crowded, especially on weekends and holidays. About 39% wanted some sort of speed limit. Almost 48% of the residents indicated some sort of user conflict. There was concern about speeding, especially in no wake zones. Fast power boats and personal watercraft drew the most complaints. Most of the complaints about fast boats involved speed and noise. Many of the complaints about personal watercraft relate to unsafe or careless behavior or speeding in no wake zones. Two thirds of the residents complained of other problems, especially too much aquatic vegetation. Canal residents in particular wanted their canals maintained for vegetation.

There was an initial assumption that the average waterfront resident would resist efforts to increase native emergent vegetation along their shoreline. Surprisingly over half of all residents were willing to plant their shoreline. A higher percentage of canal residents (60%) were willing to plant their shoreline but would plant less of it (40%). Fewer lake front residents (46%) would plant natives but they would plant more (49%) of their shoreline.

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6. The Primacy of External P Load Reduction in Restoration of Hypereutrophic Shallow Lakes with Specific Reference to Lake Apopka

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Since the 1970's, there has been growing recognition that internal processes, such as internal P loading, can markedly influence the trophic state of lakes, particularly shallow lakes. Some limnologists have argued that, for many lakes, these internal processes are so potent that reduction of external P loading may not cause a decline in trophic state, or that the decline may require many decades. Although most authors maintain that substantial reduction of the external P load eventually will lower the trophic state in lakes with initially high internal P loading (e.g., Marsden, 1989), this message seems to have been lost. Concern for internal loading in the short term has been misinterpreted to mean that P load reduction will not be effective in the long term.

The theory of alternative stable states in shallow lakes (Scheffer et al., 1993), which emphasizes the importance of internal processes, has bolstered the view that P load reduction will be ineffective for shallow lakes. For example, in the past year it was hypothesized that Lake Apopka's hypereutrophic condition stems from a change in internal processes elicited by a hurricane in 1947 (Bachmann and Canfield, 1996). Consequently, it was proposed that P load reduction will not be effective in reducing algal levels or in restoring macrophytes (Canfield, Hoyer, and Bachmann, 1996).

Although there are many significant internal processes which influence the trophic state of lakes, and although these processes are particularly strong in large, shallow lakes, the weight of evidence indicates that internal processes are secondary to the rate of external nutrient supply in setting the trophic status of shallow lakes. Lake Apopka is an archetypical example. Despite intense internal loading and potent, internal biological processes, Lake Apopka has, twice in this century, shown significant ecological changes following large changes in the rate of nutrient loading.

A detailed analysis of the history of Lake Apopka indicates that a large increase (more than four-fold) in the rate of external P loading, not a hurricane, caused the shift from macrophyte- to algal-dominance. The increase in P loading caused an increase in macrophyte abundance followed by an extensive algae bloom. These changes occurred before the hurricane of 1947. Prior to 1947, many tropical storms and hurricanes passed within 50 miles of the lake. These storms would have exerted much greater disturbance of the bottom than did the 1947 storm (which missed the Lake Apopka region) yet the lake was dominated by macrophytes until 1947. If storms could, on their own, cause the shift from macrophyte- to algal-dominance, then these earlier storms should have elicited the shift. A hurricane in 1947 may have accelerated the loss of submersed macrophytes but cannot be the ultimate cause of the ecological changes which occurred in the 1940s.

In the last four years, Lake Apopka has seen a 30 - 50 % reduction in external P loading. In the last two years, levels of trophic state variables (TP, TN, Chl.a, Secchi) have indicated a shift towards a lower trophic status. The changes in these variables are in keeping with predictions based upon the reduction in P loading. Case studies for many other lakes indicate that P load reduction is effective in reducing the P concentration even in shallow lakes.

The theory of alternative stable states emphasizes the importance of internal processes in shallow lakes but retains the primacy of P availability in determination of the potential for macrophyte- or algal-dominance. For hypereutrophic, algal-dominated lakes, large reductions in the P concentration are required to create the potential for a stable, macrophyte-dominated condition. The reduction in loading must be sufficient to cause a decrease in algal turbidity sufficient to allow re-establishment of submersed macrophytes or to shift the balance between planktivorous and piscivorous fish populations. After P load reduction has reduced the P concentration to moderate levels, fish harvesting, water level fluctuation, or other means of manipulating internal processes, can elicit a stable, clear-water state. Theory and experience indicate that manipulation of internal processes without sufficient P load reduction can cause temporary improvements in trophic state, but these improvements will spontaneously degrade.

The most effective strategies for restoration of hypereutrophic lakes will combine P load reduction with manipulation of internal processes. We have recommended a combined strategy for restoration of Lake Apopka: substantial reduction of the P load, rough fish harvesting, lake-level fluctuation, and planting of shallow areas.

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7. Alum Treatment of Stormwater Runoff: The First Ten Years

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The BMP of treating stormwater runoff with alum originated in 1986 in a lake restoration project at Lake Ella in Tallahassee, Florida. This system provides treatment of stormwater runoff entering the lake by injecting liquid alum into major stormsewer lines on a flow-weighted basis during rain events. When added to runoff, alum forms non-toxic precipitates of Al(OH)3 and AlPO4 which combine with phosphorus, suspended solids and heavy metals, causing them to be deposited into the sediments of the lake in a stable, inactive state. The alum stormwater treatment system for Lake Ella resulted in immediate and substantial improvements in water quality which has led to implementation of additional systems on other urban lakes and receiving waterbodies. There are currently 12 operational alum stormwater treatment systems in existence, with 11 located in the State of Florida and one in Seattle, Washington. An additional 8 alum stormwater treatment systems are under construction in Florida, with 6 treatment systems under design or permitting.

The existing alum stormwater treatment systems have been designed with dosage rates ranging from 5-10 mg Al per liter. Based on hundreds of laboratory tests performed over the last 10 years, alum treatment of stormwater runoff has consistently achieved a 85-95% reduction in total phosphorus, 90-95% reduction in orthophosphorus, 60-70% reduction in total nitrogen, 50-90% reduction in heavy metals, 95-99% reduction in turbidity and TSS, 60% reduction in BOD, and >99% reduction in fecal coliform bacteria compared with raw stormwater characteristics. Ultimate water quality improvements in the receiving waterbodies have been closely related to the proportion of total inputs treated by each alum system. The alum stormwater treatment system for Lake Ella, which treats approximately 90% of the total annual runoff inputs into the lake, has reduced in-lake concentrations of total nitrogen by 78%, orthophosphorus by 91%, total phosphorus by 89%, chlorophyll-a by 97%, and BOD by 93%. In contrast, the alum stormwater treatment system for Lake Osceola, which provides alum treatment for approximately 25% of the annual inputs into the lake, has reduced in-lake concentrations of total phosphorus by 30%, with a 13% reduction in chlorophyll-a. Measured concentrations of dissolved aluminum in lake systems receiving alum treatment of stormwater inputs have been typically low in value, with mean concentrations ranging from 50-100 µg/L.

Sediment core samples collected in receiving waterbodies for alum treatment systems suggest that the alum floc becomes incorporated into the sediment material over time rather than accumulating on the sediment surface as a distinct layer. The primary mechanisms for this mixing process are thought to be a combination of wind action and benthic activity. As alum floc ages in the sediment, it is transformed into a long chain crystalline structure which is extremely stable and inert. Heavy metals such as cadmium, copper, chromium, lead, nickel and zinc, which are bound into the crystalline formation, exhibit virtually no potential for re-release in the sediment pH range of 5.0-7.0 and at redox conditions ranging from highly reduced to highly oxidized. Sediment samples collected in lake systems prior to receiving alum treatment have indicated a large potential for re-release, particularly under reduced environments. Introduction of alum floc into lake sediments has been shown to substantially reduce pore water concentrations of total phosphorus, total aluminum, and heavy metals.

Long-term benthic monitoring data indicates a general trend of improved benthic populations in lake systems following introduction of alum treatment. Prior to introduction of the alum stormwater treatment system, no benthic organisms were found in sediment samples collected from Lake Ella. However, after approximately 2.5 years of system operation, benthic organisms such as Tubifex and leeches began to inhabit the lake sediments. In Lake Lucerne, overall benthic organism density decreased by approximately 47% following introduction of alum treatment, which closely followed the reduction in system productivity and nutrient concentrations within the lake. In Lake Lucerne, there was also a dramatic shift from detritivores to carnivores. No deformities were noted in post-treatment organisms compared with numerous deformities observed in pre-alum treatment samples. In Lake Osceola, no significant differences were observed in benthic populations, taxa richness, sample diversity, or sample evenness in pre- and post-treatment monitoring events.

In general, alum treatment of stormwater runoff is substantially less expensive than traditional treatment methods, and often requires no additional land purchase. Construction costs for existing alum stormwater treatment facilities have ranged from $135,000-$400,000, depending upon the number of outfall locations treated. The capital construction costs of alum stormwater treatment systems is independent of watershed size and depends primarily on the number of outfall locations treated. Estimated annual O&M costs for chemicals and routine inspections range from approximately $6,500-$25,000 per year. In general, alum stormwater treatment systems provide removal efficiencies for common stormwater constituents which are similar to those achieved by dry retention systems and substantially greater than removal efficiencies achieved by wet detention, dry detention, and detention with filtration systems.

Current alum treatment system designs emphasize floc removal prior to reaching the receiving waterbody. Several innovative floc collection systems are currently being evaluated which utilize small settling basins or filter fabric for floc collection and retention. Automatic floc disposal systems are also currently being designed which pump settled floc from sump areas into the sanitary sewer system or adjacent upland drying beds. Recent system improvements include the use of fiber optic cables for lightening-sensitive components, intelligent PC control systems to regulate alum addition as a function of pollutant loading, and system simplifications to further reduce the number of components and capital construction costs.

8. Can Watershed Management Restore Shallow, Florida Lakes?

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The theory behind lake restoration through controlling phosphorus inputs is based largely on research conducted on deep lakes. For example in the case of Lake Washington near Seattle the diversion of treated sewage effluent from the lake resulted in a rapid improvement in water quality. There is a question whether this technique will produce the same results in shallow, lakes like Lake Apopka where internal recycling of phosphorus from the sediments plays a major role (Brezonik 1978; Reddy et al., 1996). In deep lakes, fine particles containing phosphorus will eventually settle out in the deep parts of the lake where they are protected from wind-driven water movements and are eventually buried. Phosphorus will leave the sediments only by a slow process of diffusion and may not reach the euphotic zone if the lake has a thermal stratification. In very shallow lakes, water movements produced by surface waves may resuspend the sediments and cause an enhanced release of phosphorus stored in the sediments. This phosphorus can be rapidly transferred to phytoplankton in the euphotic zone.

We investigated the potential for sediment resuspension in several Florida lakes using techniques reported by Carper and Bachmann (1984). For each lake, a grid was established on a morphometric map, and for each grid intersection we calculated the minimum wind velocity required for wave movements to reach the sediment surface for each of 36 wind directions. These data were used with records of the frequencies of winds of various velocities and directions from nearby recording stations to derive curves showing the frequency with which different percentages of the lake bed were being disturbed. The results for Lake Apopka were at the extreme end of the family of curves for the various lakes. The calculations indicated frequent disturbances of the sediments by wind-driven waves over most of the lake area. This was in contrast to smaller and deeper lakes where there were deep holes where fine particles could accumulate and not be disturbed.

The model findings corroborated other observations that the sediments of Lake Apopka were frequently disturbed. Brezonik et al (1978) described sediment resuspension during wind events, and Carrick et al. (1993) show that wind-driven water movements resuspended benthic algae into the open water. Reddy et al. (1996) used profiles of SRP to conclude that sediment resuspension was the major process involved in releasing phosphorus from the top 8-cm of Lake Apopka sediments. Our own measurements of primary production and respiration in Lake Apopka this past year using diel oxygen measurements indicate that organic matter in resuspended bottom sediments is being oxidized in the water column. The conclusion is that sediment resuspension plays a major role in the metabolism of Lake Apopka. Similar conclusions have been suggested for Lake Okeechobee (Canfield and Hoyer 1988).

The concept of Alternative Stable States (Blindow et al. 1993; Scheffer 1989, 1990) seems to explain what is happening in Lake Apopka and other large shallow lakes in the world. In brief, it has been shown that shallow, eutrophic lakes in the U.S. and in Europe tend to be either clear and dominated by macrophytes or turbid and dominated by plankton algae. We have found the same to be true in Florida. In the macrophyte stage, a large percentage of the surface area is covered by macrophytes and the water within the plant beds is clear. The plants markedly reduce water turbulence and the sediments are protected from resuspension. In the turbid or algal phase there are almost no macrophytes and wind-driven waves stir the bottom sediments. The water is turbid and algae are the dominant plants. The sediments are loose and unstable and provide a poor habitat for benthic organisms.

The macrophyte stage resists change because with reduced turbulence plankton algae tend to settle out, sediments are not resuspended, and macrophytes and their attached algae can outcompete the plankton algae for nutrients. The algal state also resists change, for the unstable bottom sediments provide a poor substrate for macrophyte attachment and the turbid water shades out the bottom sediments. Sediment resuspension enhances nutrient recycling and frequent mixing keeps algae in suspension. Thus the macrophyte state and the algal state represent alternative stable states that tend to resist change.

Under certain circumstances changes do occur. The literature records several shallow lakes that have changed from macrophyte dominated to algal dominated and visa versa without any change in external nutrient loading. Factors that have been documented to bring about changes from macrophytes to algae have included windstorms, water level changes, macrophyte control with fish or herbicides, and ice action. Lowered water levels and poisoning of benthivorous fish have been implicated in switches from the algal state to the macrophyte state in some lakes.

It seems probable that the theory of alternative stable states applies to shallow lakes in Florida as well as those elsewhere in the world. Management activities should take this into account and recognize that reductions in external nutrient loading will not necessarily lead to clear water. Reestablishment of macrophytes through water level changes and/or the construction of protected areas for macrophyte regeneration may be more effective.

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9. Using Spatial, Dynamic Energy, and Emergy Models as a Basis for Watershed Policy

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While numerous hydrology models estimate overall runoff quantity, nutrient loading and timing changes, their lack of spatial specificity hinders their utility in watershed management. Further, most surface water indices are static and minimize the contributions and interactions of macrophytes, consumers and watershed inputs. Simulations of succession within the surface waters using an overall system perspective and the energy driving the watershed are largely absent. Models that provide a better understanding of these spatial and cumulative temporal effects can be used by planners to reduce the negative impacts of watershed development by directing it to less sensitive areas, to assist in prioritizing conservation of more sensitive areas, and to identify critical locations for water quality monitoring.

A phenomenological and three dimensional phosphate runoff model has been developed and simulated for seven Florida lake watersheds, using composite, mapped overlays of land use/cover/imperviousness, soil characteristics, topography, and water table elevations. This spatial model is a graphical representation of complex partial derivations describing fluid flow and transport phenomena, with summation of final composite values equivalent to integration of the equation. This allows the retention, infiltration and subsequent sub-surface seepage, and macro/micro slope. The resulting spatial statistics have been regressed versus measured chlorophyll, calculated trophic state index (TSI), and total phytoplankton diversity, with positive and significant correlations for all three factors.

In addition, dynamic simulation of lake ecosystem models is explored as a means of evaluating trophic status. Continuous calculation of important state variables and their exchanges provides a useful evaluation of which may be both predictive and more indicative of the lake's trophic state. Phytoplankton, macrophytes, zooplankton, fish, watershed runoff, and fluctuating water volume are simulated for the lakes modeled spatially.

Several new indicies are proposed based on simulation results and compared with those developed by Huber, et al. (1982). Emergy analysis is used to quantify watershed contributions to the lake, facilitating direct comparison of disparate inputs by using the common unit of solar emjoules.

Emergy is a useful measure of all energy used to produce the component being evaluated, and has been useful in developing resource management policy in numerous areas (Odum, 1996).

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10. A Success Story for Section 319: Lake Jackson

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Lake Jackson, located in north central Leon County, Florida, became nationally renowned for its bass fishing in the late 1950's. In the early 1970's, rapid urbanization of its watershed resulted in dramatic changes to the lake. In addition to urban development, a major federal highway, Interstate I-10, was built across the Megginnis and Fords arms subbasins in 1972-1973. Above average rainfall during this period, coupled with inadequate sediment controls, caused a large turbidity plume over the southern third of the lake. Studies of the lake between 1974 and 1976 documented increased sediment and nutrient loading, as well as contamination of bottom sediments by heavy metals and other pollutants. The Northwest Florida Water Management District (NWFWMD) determined that stormwater runoff was the primary cause of water quality degradation, and recommended that nutrient and sediment loads to the lake be reduced. Using Section 314 Clean Lakes Program funds, a detention pond, sand filter and marsh system was completed to help stem stormwater pollutant loads discharged to the lake through Megginnis Arm.

Unfortunately, no matter how efficiently the system was operated, it was undersized for the level of development within the watershed, and the lake and Megginnis Arm continued to deteriorate. The states Surface Water Improvement and Management (SWIM) Act in 1987 created new opportunities to take a comprehensive look at this problem. An interagency task force helped prepare the Lake Jackson SWIM plan which prompted stricter land use ordinances for the watershed and several important construction projects. A large stormwater facility devoted to creating runoff from I-10 and nearby neighborhoods was built with SWIM funds adjacent to the District's constructed marsh. The City of Tallahassee also built regional stormwater facilities on Boone Boulevard and John Knox Road, both of which provide treatment for the Megginnis Arm subbasin. Additionally, the new local regulations required a large mall to retrofit its stormwater system as part of a planned expansion of its shops and parking areas.

Research showed that nutrient cycling by sediments already in Megginnis Arm would perpetuate high levels of productivity despite reductions of external loadings. Various methods to reduce this in-lake nutrient source were considered which eventually led to a decision that hydraulic dredging together with alum treatment of the slurry would yield the best results. The Florida Department of Environmental Regulation committed Section 319 national nonpoint source pollution control program funding in 1990 to remove the troublesome sediments from Megginnis Arm.

Work began in October, 1990, and centered around establishing sediment controls and site barricades. Favorable weather, coupled with minimal equipment problems, enabled rapid construction of the disposal area and a sheetpile dam to isolate Megginnis Arm from the main body of Lake Jackson. Low water levels aided progress until they became low to support the dredge. The City of Tallahassee helped out by providing ground water to augment the pool allowing work to continue.

Dredging activities in Megginnis Arm were completed by July 1991, followed by reconditioning of the marsh area, removal of the sheetpile dam and consolidation of the disposal area. Remaining details such as grading and landscaping the containment area were completed by May 1992. All told, more than 100,000 cubic yards of contaminated sediment was removed from Megginnis Arm.

Following the dredging project, Section 319 funds were used to help remove exotic or nuisance vegetation (primarily Chinese tallow & alligator weed) from the littoral area of Megginnis Arm and to reestablish native wetland species. Forty thousand herbaceous wetland plants and 700 trees were ultimately planted in Megginnis Arm to enhance the natural biological communities. *Vallisneria americana* (tape grass) was the predominant species used because of its affinity for deeper water areas. *Scirpus validus* (bulrush), *Sagittaria subulatum* (arrowhead) and *Panicum hemitomon* (maidencane) were also used extensively. *Cyperus spp*. (sedgegrass), *Nuphar luteum* (spatterdock), *Nymphaea spp.* (water lily) and *Cladium jamaciense* (sawgrass) completed the herbaceous component of the plan. Bald and pond cypress, red maple, and sweetgum were planted in higher ground areas.

In Megginnis Arm, nitrate-nitrite, orthophosphorus, total phosphorus, turbidity, conductivity and chlorophyll a are all at the lowest levels they have been in over twenty years. Dissolved oxygen concentrations at the surface are near all time highs for that time frame and even more importantly were above 8 mg/L at mid-depth and the bottom during sampling events in April and July 1996.

The Section 319 nonpoint source pollution control program has helped considerably in correcting past mistakes and providing better management of Lake Jackson. The lake is still ranked as a NWFWMD SWIM priority water body. It is also included in the state’s aquatic preserve program and is designated an Outstanding Florida Water, all of which guarantees that attention will continue to be directed towards protecting and restoring this valuable resource. The partnerships formed on behalf of Lake Jackson have achieved remarkable results, nonetheless, a lot of work remains to be done to assure that Lake Jackson is a sustainable resource.

11. Florida Lake Regions

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The assessment and management of the more than 7,700 lakes in Florida is complicated by the physical, chemical, and biological diversity of these water resources. Cost-effective lake management strategies regarding protective by-lake basis only, but must consider regional differences in limnological capabilities and potentials. Water resources can be managed more effectively if they are organized by regions that reflect differences in their quality, quantity, hydrology, and their resilience to ecological disturbances. Hydrologic unit or watershed frameworks are often used for water quality assessments and ecosystem management activities, but watersheds or basins do not correspond completely to the spatial patterns of characteristics that influence the physical, chemical, or biological nature of Florida lakes.

General patterns of geology and physiography have been used to explain regional differences in Florida lake water chemistry (Canfield and Hoyer 1988; Pollman and Canfield 1991). Ecosystem characteristics of Florida lakes have been summarized by Brenner et al, 1990. Building on this work, as well as on a recent Florida ecoregion project (Griffith et al, 1994), we have defined these forty-seven lake regions as part of the Florida Department of Environmental Protection's Lake Bioassessment/Regionalization Initiative. The spatial framework was developed by mapping and analyzing water quality data sets in conjunction with information on soils, physiography, geology, hydrology, vegetation, climate, and land use/landcover, as well as relying on the expert judgment of local limnologists and resource managers. This framework delineates regions within which there is homogeneity in the types and quality of lakes and their association with landscape characteristics, or where there is a particular mosaic of lake types and quality. More detailed descriptions of methods, materials, and lake region characteristics can be found in Griffith et al, (1996). The identifier for each lake region consists of two numbers: the first number (65, 75, or 76) relates to the U.S. ecoregion number (Omernik 1987; U.S. EPA 1996), and the second number refers to the Florida lake regions and associated maps and graphs of lake chemistry are intended to provide a framework for assessing lake characteristics, calibrating predictive models, guiding lake management, and framing expectations by lake users an lakeshore residents.

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12. Correlation vs. Causation - Case Studies from Florida Lakes

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In the field of limnology (the scientific study of inland waters), and in the related discipline of lake management, correlative statistics is a common approach that is used to evaluate relationships between two or more environmental parameters. The analyses used include parametric and nonparametric correlations, as well as simple linear, non-linear, and multivariate regressions. Regardless of how complex the tests are, however, the scientist or manager must be aware not to infer causation from correlation, until such time that ancillary studies are conducted, including a more careful consideration of the underlying processes, and optimally, controlled experimental studies.

My objective here is to present two case studies from Florida lakes in order to illustrate the potential pitfalls associated with improper use of correlative statistics in lake management. Neither case should be interpreted as a criticism of the published papers that are cited. I simply use the collected data to illustrate a point.

The first case study involves water quality-fisheries relationships in 60 north-central Florida lakes. The data were collected by Canfield and Hoyer (1992) during a study conducted for the Bureau of Aquatic Plant Management, and include information on fish biomass, total phosphorus (TP), total nitrogen (TN), chlorophyll (Chl), and other water quality parameters. In a recent paper, Bachmann et al. (1996) analyzed these data in order to test the hypothesis that fish biomass increases with trophic state (indexed by TP, TN, and Chl). Log-log regression analysis, a form of correlative statistics, gave overwhelming support for this hypothesis, and demonstrated clearly that hypereutrophic Florida lakes support a high biomass of recreationally-important fish (large mouth bass, for example). But were the observed increases in fish biomass along the trophic spectrum caused by increases in nutrients, and presumably food availability? I re-analyzed Canfield and Hoyer's data, this time looking at how fish biomass was related to another variable - lake water pH. This approach also produced statistically significant results. Total fish biomass declined with declining pH (increasing acidity), and several fish taxa disappeared suddenly at approximately pH 6.0, a typical pattern that has been documented in the acid lake literature. Are these patterns caused by acid stress? Here we have a classic case of cross-correlation between several environmental variables, and (at least) two ecologically sound explanations for the observed results. This puzzle cannot be solved unless a different (experimental) approach is subsequently applied.

The second case study involves TP concentrations and two potential environmental forcing functions in Lake Okeechobee. Canfield and Hoyer (1988) documented a highly significant positive correlation between yearly-averaged water levels and lake-wide average TP. They presented a hypothesis that when water levels are high, the littoral marsh region of the lake (~20% of the lake surface area) is flooded, with a net release of P from sediments and dying plant material. Subsequent studies in Lake Okeechobee showed that the marsh is a sink, rather than a source of P under high water conditions (reviewed by Havens 1996). Maceina and Soballe (1990) showed that TP in Lake Okeechobee actually is more strongly correlated with wind velocity than with water levels. The TP-wind relationship also has an ecologically-sound explanation. In this shallow lake, increased wind velocities result in greater shear stress on sediments, and subsequent resuspension of the sediments and their associated P into the water column. Again one is faced with a question -- is high TP caused by high water level or high wind? Wind and stage are strongly correlated with one another on a yearly basis, probably because windy years are also years with more frequent storms and hence more rain. This is yet another puzzle that cannot be solved by correlations alone.

The two cases presented here have important management implications. Fisheries managers certainly may want to predict, with some degree of accuracy, whether reducing nutrient loading to a lake will result in reduced fisheries production. Scientists and managers at the SFWMD need to know whether changes in the Lake Okeechobee regulation schedule will cause substantial changes in lake water TP. In neither case can they reliably depend on the correlative statistical results alone, and it is for this reason that subsequent process-oriented and experimental work is in progress for the large lake.

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13. Calculating the Probability of Algal Blooms in Lake Okeechobee, Florida.

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Lake Okeechobee, a large, shallow, eutrophic lake in south-central Florida is subject to algal blooms throughout the year (Havens et al. 1994). Because these blooms have increased in frequency since the 1980s (Havens et al. 1995), there is increased need for predictions of when, where, and under what conditions they occur.

Our objectives were to quantify the relationships between algal blooms, nutrients, lake water level (stage), temperature, light, and wind, through the construction of empirical models that relate the occurrence of algal blooms to these various factors. From this information we can calculate the probability that a bloom will occur in one of the four dissimilar open water regions of the lake: central, northwest, southwest, and a transition region between the Lake's western marsh and open water regions. For those regions that included total phosphorus and total nitrogen as significant predictors of algal bloom occurrence, an additional objective was to determine the phosphorus and nitrogen concentrations at which a relatively low (< 10 percent) probability of blooms would occur.

Using logistic regression techniques (Hosmer and Lemeshow 1989) and a 40 mg L chlorophyll a standard to define an algal bloom (Havens 1995), we constructed models with samples collected at monthly or biweekly intervals from 1981 to 1994 at nine long-term stations, from 1986 to 1994 at 26 western near-shore stations, and from 1990 to 1994 at two transition stations on Lake Okeechobee (James and Havens 1996). Over 15 percent of all water samples collected on Lake Okeechobee since 1980 have chlorophyll a concentrations of 40 mg l^{-1} or greater, indicative of algal blooms. Parameters that were significantly related to algal bloom occurrence, the type of the relationship (positive or negative), and the number of observed comparisons (in parenthesis) were by region: stage, positive in the northwest (995) and southwest (961); wind, negative in the central (1,320) and positive in the transition (412); solar radiation, positive in the northwest (990) and southwest (974); and temperature, positive in the central (1,279).

Strong positive relationships existed between the occurrence of algal blooms and total nitrogen and phosphorus concentrations in the northwest (998) and southwest (963) regions. The model predicts an algal bloom probability greater than 95 percent in the northwest region when total phosphorus exceeds 0.10 mg L and total nitrogen exceeds 2.5 mg L. However, these concentrations occur in only 6 and 1 percent of the samples respectively. The model predicts a 100 percent algal bloom probability in the southwest region when total phosphorus exceeds 0.10 mg L and total nitrogen exceeds 2.8 mg L. Again, these conditions occur in less than 1 percent of samples.

Based on the relationships between algal bloom occurrence and total phosphorus and total nitrogen concentrations, nutrient concentration goals can be established based on an acceptable probability of algal bloom occurrence. If this probability is 10 percent, the target concentration for total nitrogen would be 1.2 mg l^{-1} in the northwest region and 1.1 mg l^{-1} in the southwest region, given a total phosphorus concentration of 0.06 mg l^{-1}.

Because the probability of an algal bloom varies among the different regions of the lake, in-lake regional goals for nitrogen and phosphorus concentrations should be considered.

This successful application of logistic regression to calculate algal bloom probability demonstrates the usefulness of such a tool for lake managers, especially in defining nutrient concentration goals, and calculating the probability of algal blooms based on nutrient and physical conditions.

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14. Compliance with Biological Criteria in Lake Okeechobee, Florida

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Lake Okeechobee, Florida, is an important water resource for much of south and central Florida. It is managed to support multiple uses, and maintenance of water quality and biological conditions in the lake is a major consideration in its management.

Historical data and the results of a supplementary monitoring program were reviewed to evaluate compliance with applicable state water quality criteria for Lake Okeechobee and the major inflows to the lake. The South Florida Water Management District monitored 22 water quality parameters at 9 in-lake stations and 33 inflow structures during a 19-year period. A supplementary 12-month monitoring program provided data for 53 additional water quality and biological parameters that have numerical criteria. Acute toxicity tests with water flea, and fathead minnows were performed on samples from 6 inflows and 4 in-lake control locations (not near inflows) to assess potential toxicity to invertebrates and fish in the lake. Algal assays were performed on samples from the same inflow and control locations to evaluate the potential inhibition of algal growth by pesticides or other contaminants. Benthic macroinvertebrates were also sampled in the lake at the 6 inflows and at 4 in-lake control locations with similar depth and sediment characteristics that were not near inflows.

There did not appear to be a pattern between the sample location or water quality conditions and the observed survival rates of water flea and fathead minnow in the acute toxicity tests. The laboratory algal assays did not show any inhibition of algal growth for water samples from inflows or in-lake control locations. Sample locations did not show a consistent pattern of initial nutrient concentrations, algal growth using ambient water, or algal growth using ambient water with nutrient additions.

The inflow stations had benthic macroinvertebrate community structures and species diversity index values that were similar to communities at control locations. The state criterion for biological integrity requires species diversity index values for benthic macroinvertebrates to be no less than 75 percent of values at background locations. Of the 18 inflow station samples collected during the supplemental monitoring, 2 had species diversity values that were less than 75 percent of the values from the respective control stations. Based on annual average species diversity index values, the inflow locations complied with the state criterion for biological integrity. At 4 of the 6 inflow stations, annual average species diversity values were higher than at the corresponding control locations. This finding could suggest a positive influence of the inflows on benthic macroinvertebrate community structure. However, additional sampling at more stations over a longer time would be needed to further evaluate the influence of inflows on benthic macroinvertebrates in Lake Okeechobee.

Fecal and total coliform bacteria levels from the supplemental monitoring program exceeded criteria at many in-lake and inflow stations, although there was no spatial or temporal pattern to the high values. No point sources of coliforms discharge to the lake or its inflows; therefore, nonpoint source runoff appeared to be the most likely source.

The evaluation of water quality data (Ogburn et al., 1996) documented that nearly 90 percent of the water quality measurements for Lake Okeechobee and its inflows (53,372 out of a total of 59,781) complied with applicable criteria. Dissolved oxygen (DO) and iron concentrations exceeded criteria most frequently, but they did not appear to affect the designated uses of the lake. Low DO concentrations were observed most often at inflows, and infrequently at in-lake stations. Iron values in the lake frequently exceeded the Class I surface water criterion (secondary drinking water standard - based on the aesthetic quality of potable water), but rarely exceeded concentrations required for protection of aquatic biota. During the supplemental monitoring program, only a few measurements for selected parameters exceeded the criteria for trace metals (including mercury) and organic contaminants. Even though agriculture dominates the basin, pesticide application methods, degradation processes and dilution appear to be responsible for the generally low concentrations of pesticides and herbicides observed in the lake and its inflows.

Other studies have documented long-term changes in benthic macroinvertebrate community structure and phytoplankton biomass in Lake Okeechobee (Warren et al. 1994, Smith et al. 1995, and Havens et al. 1995). However, those changes appear to be related to changes in nutrient concentrations, which do not have numerical criteria. The biological results from this study indicate that inflows to the lake were not acutely toxic to aquatic invertebrates or fish, and no clear relationship between inflow quality and algal growth was demonstrated. The biological changes in the lake do not appear to be related to specific water quality parameters that exceed applicable criteria. Additional biological monitoring in conjunction with the water quality sampling is recommended to further evaluate the relationship between biological conditions in Lake Okeechobee and specific inflow locations or water quality parameters.

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15. Importance of Monitoring Network Design and Mass Balance Analysis for Best Management of Watersheds and Water Bodies

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Best Management Practices of watersheds and water bodies require sufficient hydrologic and water quality monitoring network design and implementation. Historical data collection has to be supplemented with periodic mass balance analysis to serve as a feedback to the evaluation of the sufficiency of the data collection network and understanding of the system. Since the implementation and maintenance of data collection network is costly, the short and long term objectives of data collection have to be defined first to determine the spatial and temporal resolution of the network. The purpose of this paper is to present in particular the importance of hydrologic monitoring network design and periodic mass balance analysis for best management of watersheds and water bodies. Both in the watershed and the receiving water body, a hydrologic and a water quality monitoring network is essential. Mass balance computations of water and constituents is essential to make management decisions based on accurate information about the system. Watershed management methods such as landuse regulations, Best Management Practices and mitigation practices require sufficient data. Hydrologic monitoring, which is essential for hydrologic mass balance computation, requires a representative network of rainfall, evapotranspiration, flow and stage measurements in the watershed and the receiving water body.

Rainfall: In south Florida, daily rainfall varies within short distances. But monthly and annual rainfall spatial variability is lower than daily rainfall. According to a study done at the Everglades Nutrient Removal Project site (Abtew et al., 1995), one rain gauge per 3 km^2 area is required to adequately characterize daily areal rainfall in the area. A study of spatial rainfall variation in south Florida (Abtew et al., 1993) showed that the correlation distance (r=0.60) for monthly rainfall is 32 km. After analysis of annual rainfall from the south Florida rain gauge network , Van Lent and Tracy (1994) stated that removing 15% (25 gauges) of the south Florida network will only reduce the performance of the network by 4%. They indicated that no gauge is redundant in the South Florida Water Management District area if daily rainfall values are required. In short, the rainfall monitoring network has to match the temporal resolution of mass balance analysis.

Evapotranspiration: one of the hydrologic parameters that is least understood is evaporation from open water surfaces and evapotranspiration (ET) from terrestrial and wetland vegetation. Evapotranspiration from open-water surfaces and wetlands can be estimated as the potential evapotranspiration in the area. Estimates of daily evapotranspiration can be made in three ways: a) if good quality standard pan evaporation data is available, potential evapotranspiration (ET_p) can be estimated as 85% (K_p) of the annual pan evaporation (E_{pan}) under South Florida conditions (Abtew and Sculley, 1991). b) in the absence of all the essential meteorologic data to apply complex evapotranspiration estimation models, a simple model (Eq. 1) based on solar radiation can be applied to estimate daily ET from shallow water bodies and wetlands (Abtew, 1996). $ET_p = K_1 R_s$ **Eq. 1** where ET_p is in mm d^{-1}; R_s is solar radiation in mm of water and K_1 is a dimensionless coefficient of 0.54, 0.52, 0.53 for cattails, mixed marsh vegetation and open-water. c) In cases where high resolution data for all required meteorologic and surface parameters (humidity, temperature, wind speed, net radiation, aerodynamic and crop resistance) is available, the Penman-Monteith ET estimation model can be applied to estimate potential ET (Jensen et al., 1990).

Flows: Inflow and outflow monitoring into and out of the water body is essential for water and constituent mass balance computations. Flows through structures such as culverts, spillways and pumps can be computed with standard methods of flow computations. Flow through streams without flow control structures can be estimated through stage-discharge (canal rating), slope-stage-discharge or velocity-area methods. Velocity in streams is measured with flow meters, ultrasonic transducers, floats and tracer solutions. Open-channel formulas are applied to compute discharge through canals, flume, tunnels and partially filled pipes of regular geometry (Linsley and Franzini, 1979). Rainfall-runoff models are also common methods of estimating runoff from watersheds into receiving water bodies.

Mass Balance Computation: Periodic hydrologic and constituent mass balances for a system are essential to understanding of sources and sinks and the respective magnitudes. Mass balance computations are usually required to determine regulatory constituent loads and to evaluate the performance of environmental mitigation projects. Mass balance analysis can also be used to provide feed back on the effectiveness of the hydrologic and water quality monitoring networks. In summary, best management decisions for watersheds and water bodies can only be achieved through sufficient data collection and mass balance analysis which are necessary for understanding the hydrologic system.

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16. Establishing Lake Management Levels at the Southwest Florida Water Management District

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In the course of the last twenty years the Southwest Florida Water Management District (the District) has established management levels for over 400 lakes within its boundaries through its Lake Levels Program. In the late 1970's Lake Levels Program staff developed a methodology to identify water level fluctuation ranges, and potential management levels, based on the connection between hydrologic regimes within a lake and the biological communities found there. Additionally, the locations and elevations of cultural features (e.g. docks, sea walls, septic tanks, etc.), as well as anecdotal evidence presented by lakeside residents, were considered when establishing the management levels. Four management levels were developed and subsequently adopted into Chapter 40D-8 of the District's rules:

Ten year flood warning level - An advisory level for property owners around lakes that indicates the one in ten year flood event or a flood event that has a 10% chance of occurring in any one year. This level is calculated by watershed runoff models.

Minimum flood level - Represents a seasonal high level that historically equaled or exceeded 5-10% of the period of record as determined from a stage duration curve. Biological indicators of this level included the fringes of saw palmetto and the most landward cypress trees.

Minimum low management level - Represents a seasonal low level equaled or exceeded 80-90% of the period of record as determined from a stage duration curve. Cultural features play a larger role in determining this level.

Extreme low management level - Represents a drought year low level equaled or exceeded 90-95% of the period of record as determined from a stage duration curve. It is roughly equal to the lakeward extent of the emergent vegetation.

In 1996 the Florida Legislature directed the five Water Management Districts to set schedules to establish minimum flows and levels for watercourses within their respective districts. Pursuant to Chap. 373.042(2), by October 1, 1997 the Southwest District is required to set these flows and levels for "watercourses, aquifers, and surface waters in the counties of Hillsborough, Pasco, and Pinellas." Additionally, the District is required to set minimum levels below which "significant harm to the water resources or ecology of the state or region" would occur. To develop the methodology to identify the "significant harm" level the District assembled a Technical Advisory Committee (TAC) consisting of District staff, representatives of local governments and interested citizens. The TAC was subsequently divided into subcommittees that, by March 1, 1997, would reach a consensus on methodologies related to lakes, wetlands and aquifers.

The Lake Levels Subcommittee (LLS) began by evaluating the District's current methodology for lakes (above) to determine if these methods could be refined to identify the "significant harm" level or whether a completely new method would be more appropriate. After a thorough evaluation, the LLS decided that satisfactory results could be achieved by slightly modifying the existing methodology. These modifications consisted primarily of a greater reliance on stage duration and biological data and lesser reliance on cultural indicators than the existing methods.

A field trial of the existing and new procedures was performed on 15 lakes in Hillsborough and Pasco counties. These lakes represented a variety of hydrological, biological and developmental conditions; but all had extensive stage records from which accurate stage duration curves could be computed. Also, management levels had already been established for most of the lakes (using existing methods). Additional biological and physical indicators of the Minimum Flood Level (e.g. lichen line, pines, oaks, was myrtles, scarps) and Low Management Level (i.e. low cypress) were also identified as potential modifications.

An extensive review and analysis of the field and hydrologic data indicated that the management levels established using the current methodology, particularly the Minimum Flood and Low Management Levels, were very close to those calculated using the modifications noted above. After this review the LLS also decided to use points on the stage duration curve rather than a range to describe the levels. The Minimum Flood would be the P10 level or the elevation exceeded 10% of the time while the Low Management and Extreme Low Management Levels would be the P90 level (elevation exceeded 90% of the time) and P95 level (elevation exceeded 95% of the time) respectively.

A number of ideas were considered on how to incorporate a Minimum Level-Significant Harm (or Significant Change as it became known) into these management levels. Most ideas centered on some statistical description of changes from the normal pool level, or the P50 level (elevation exceeded 50% of the time). Based on the field trial, as well as a review of other hydrologic data, it was determined that the normal annual fluctuation range for lakes within this specific hydrogeologic setting was approximately two feet. A process was then developed to relate prolonged changes in stage to changes in lake surface area and volume and thence to biological and ecological consequences, as well as potential effects on cultural features in and around the lake. Based on these factors it was then decided that a downward shift of the P50 by one foot (which coincided with the Low Management Level), for a yet to be determined period of time, would represent "Significant Change". This process, or some variant, will be used by our Governing Board to set lake management levels.

Several technical issues remain to be fully resolved including the amount and specific period of stage record necessary to develop accurate historic stage duration curves. An additional challenge is how to develop stage record for lakes with little or no hydrologic data available. The LLS has proposed the use of a Reference Lake Water Regime (RLWR) to act as surrogate stage data from which to develop stage duration curves for these lakes. The RLWR would be developed from stage data on lakes with adequate stage record for a similar hydrogeologic region. The application of the RLWR is currently being evaluated by the LLS.

17. The St. John's River Water Management District Multiple Minimum Flows and Levels (MF&Ls) Approach: What are they; How are they Determined, and Applied

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Chapter 373.042 [F.S.] requires WMDs to set minimum flows and levels (MF&Ls) using best available information and, when appropriate, reflect seasonal variations. MF&Ls are to protect the water resources and ecology from "significant harm." MF&Ls are not optimum or necessarily desirable flows and levels.

Most MF&Ls related literature is from flowing systems. Stalnacker (1990) indicated that a single minimum flow is not protective, and a minimum flow regime is needed to protect the ecology of riverine systems. Hill et al. (1991) identified four types of flows; valley maintenance flows (once every 25 years or more [³1:25 years]), riparian maintenance flows (out-of-bank flows), channel maintenance flows (channel-full flows), and instream flows (baseflows). Our basic concepts are: 1) more than one flow or level is required, 2) MF&Ls should be hydrologic statistics, 3) MF&Ls should be ecologically based, and 4) implementation should consider the cumulative effects of management actions. Although used for lakes and rivers, this talk will focus on minimum levels for lakes.

Our five minimum levels are the Minimum Infrequent High, Minimum Frequent High, Minimum Average, Minimum Frequent Low, and Minimum Infrequent Low. Each minimum level is composed of an elevation in feet NGVD (how high) and a temporal component and are therefore hydrologic statistics. The temporal component may be a return interval (how often) and duration (how long) or a hydroperiod category. Our hydroperiod categories were adapted from the water regime modifiers in the wetland classification of Cowardin et al. 1979. Intermittently Flooded should re-occur infrequently after above average rainfall at about a 1:10 year return interval for about several months. This hydroperiod category would likely be associated with a Min. Infrequent High and maintains full-pool area of sandhill-type lakes or the wetland boundary and species composition of highly fluctuating wetland systems. Temporarily Flooded should re-occur infrequently after above average annual rainfall once in about five years for up to several weeks. This hydroperiod category would likely be associated with the Min. Frequent High of sand-hill type lakes and promotes the benefits of more frequent flooding. Seasonally Flooded should re-occur frequently after normal or above normal annual rainfall about every year or two for several weeks to several months. This hydroperiod category would likely be associated with the Min. Frequent High of wetland-type lakes and promotes the benefits of "pulse" flooding. Typically Saturated can re-occur about yearly in the dry season for about six months during periods of normal rainfall. This hydroperiod category would likely be associated with the Min. Average and maintains the typically saturated condition of wetland soils. Semipermanently Flooded can re-occur about every 5-10 years for three or more months during moderate droughts. This hydroperiod category would likely be associated with the Min. Frequent Low and promotes the benefits of minor drawdowns in all types of wetlands. Intermittently Exposed can re-occur infrequently about once every 20 or more years for several months to several years. This hydroperiod category would likely be associated with the Min. Infrequent Low and promotes the benefits of substantial drawdowns in deep marshes or lake littoral zones and recognizes the cyclic nature of fluctuating regime of sandhill-type lakes. Permanently Flooded defines hydrological conditions where water is never expected to recede lower in forecasted droughts. This level would likely be associated with the Min. Infrequent Low and conserves habitat for aquatic biota.

Each is a "regulatory" level designed to protect the structure and functions of aquatic and wetland systems. Although the actual water level of a lake will fluctuate above, below, and among the minimum levels, management actions, should not cause a violation of the any minimum level over a long time period.

Staff are determining minimum levels for a lake every three weeks and have completed more than 60 lakes. The Minimum Frequent High, Minimum Average, and Minimum Frequent Low are determined for these systems. Additionally, staff have determined five MF&Ls for larger systems. A MF&Ls determination uses literature-based and resource-based data and information. Literature-based information may include: aerial photography, wetland and topographic maps, soil surveys, and the scientific literature. Resource-based information may include: elevation transects from open water and uplands; data collection focuses on plant species and community structure, ecotones, and hydric soil types and depths; measured or simulated stage; bathymetry and outflow elevations; water quality data; and other indicators of water levels.

Conceptually, minimum levels are thresholds that are compared with output from water budget models. New users should be evaluated cumulatively with existing users to determine if a violation of any of the minimum levels occurs. A violation should result in permit denial or modification. No additional withdrawals should be permitted once a system is maximally allocated .

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18. Minimum Flows and Levels: Opportunities and Challenges; A Water Management District Perspective

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The statute requiring establishment of minimum flows and levels (MFLs), Section 373.042 F.S., was adopted by the Florida Legislature in 1972 and at first glance may seem rather simple and straightforward. The statute, in summary, requires that the water management districts establish minimum flows and levels for all watercourses, and minimum levels for aquifers and surface waters, at which further withdrawals would be significantly harmful to the water resources and ecology of the area.

The initial focus was to implement the intent of the statute through the consumptive use permitting program on a case by case basis. In 1992, the SJRWMD adopted MFLs by rule for the Wekiva River Basin (including the Wekiva River, Blackwater Creek, and 8 springs) as directed by the Wekiva River Protection Act. This effort was instrumental in developing a scientific approach for setting multiple levels to protect water resources. Since that time, SJRWMD has used this approach to adopt MFLs by rule for 43 lakes. These MFLs have proven very useful in both the water supply planning and water use permitting programs. There are many interesting policy issues concerning the establishment and implementation of the MFL provisions of the statute. This presentation will summarize the primary challenges and opportunities we have encountered thus far with MFLs at SJRWMD.

Opportunities & Challenges: Priorities for setting MFLs. Within SJRWMD, there approximately 1300 named lakes and probably just as many unnamed lakes, not to mention the major rivers and tributaries in our 11,000 square mile district. Early on, it was recognized that is was not practical nor necessary to set MFLs on every waterbody and water course to comply with the statute. Initial priorities at SJRWMD were determined by legislative directive and an agreement to settle a lawsuit brought from a citizens group concerned about a specific set of lakes. Since that time, SJRWMD has now instituted a priority setting process considering the regional significance of the waterbody, the sensitivity of the waterbody to impacts from water withdrawal, areas projected to experience significant increases in future water withdrawal, and use of indicator lakes to measure impacts from regional groundwater conditions. Scientifically based approach to define significant harm. The SJRWMD has adopted a fairly rigorous scientific approach, defining several MFLs, expressed as a hydrologic statistic, necessary to protect naturally fluctuating hydrologic regime of a system. This methodology requires intensive effort of field data collection, analysis, and ongoing monitoring as the means to define significant harm. Tools to implement MFLs. Given the nature of MFLs (hydrologic statistics), it is necessary to develop the appropriate tools to evaluate the impact of water use allocations on the overall hydrologic regime. As a result, significant effort is also being made to develop water budget models and groundwater-surface water interface models for lakes and rivers with MFLs. Without such models, implementation is difficult. Public perception & expectations. The more rigorous approach that we have taken, while defensible and understandable within the scientific community, is not easily explained or understood by the public. Even when understood, the public may not accept the basic premise that MFLs recognize and allow for lake level fluctuation in response to both short and long term climatic conditions. Many lakefront owners believe that low lake levels during periods of drought are undesirable, are a result of water withdrawals only, and should be prevented at all costs. This situation points out the need to continue to educate citizens groups, local elected officials, and legislators, as to the benefit of water level fluctuation in Florida lakes.

Case Studies in Implementing Minimum Flows and Levels: Water Supply Planning in Central Florida. MFLs that were established by SJRWMD for the Wekiva River and springs along the river in 1992 were immediately used as a threshold for identifying unacceptable impacts from groundwater pumping as part of the SJRWMDs Water Supply Needs and Sources Assessment. This assessment evaluated existing and future water supply demands (year 2010) and determined locations where water sources could not meet these demands without unacceptable impacts. As part of the assessment, a regional groundwater flow model, along with a surface water flow model for the Wekiva Basin, was used to determine if groundwater pumping would result in levels and flows falling below established MFLs. It was determined that springflows did not violate MFLs under existing groundwater withdrawals. However, under the groundwater pumping scenario likely in the year 2010, the potentiometric surface of the Upper Floridan aquifer would be lowered to a point that several springs and the resulting baseflow component of the Wekiva River would not meet established MFLs. As a result, SJRWMD has designated the groundwater basin contributing to these springs as a Water Resource Caution Area and is currently conducting feasibility studies of alternative water supply sources and strategies to meet future water supply demands. Consumptive Use Permitting (CUP) Actions. MFLs have already been used in several CUP actions taken by SJRWMD. For instance, in the Wekiva River basin, new water withdrawals that would contribute to future declines in springflow below adopted MFLs have not been issued, except in one case for a very limited duration while an alternative surface water source was developed. In the Crescent-Deland ridge, an irrigation well proposed near a lake had to be moved some distance from the lake, and withdrawals reduced to protect the MFLs for that lake. Impacts from existing users, when identified, will need to be addressed at the time of permit renewal and in the water supply planning process.

Water Shortage Declarations: MFLs have proven to be a useful benchmark for the Governing Board to consider in declaring water shortage orders requiring all water users to reduce usage during critical periods of drought. The SJRWMD declared a water shortage in the Wekiva Basin during 1993 to 1994, based on Wekiva River flows falling below the water shortage levels set in the Wekiva MFL rule.

19. Development of Minimum Water Level Criteria for the Everglades Protection Area

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Section 373.036 Florida Statutes, requires each water management district to establish minimum flows and water levels for all watercourses in the region. The minimum water level is defined as the level of water in an aquifer, or level of surface water at which further withdrawals would be significantly harmful to the water resources of the area. The statute requires that minimum flows and levels be developed using the "best information available" and that they be established within a reasonable time period. The South Florida Water Management District is scheduled to develop minimum flows and levels for the Everglades Protection Area (Everglades National Park and the Water Conservation Areas) by 1996.

This presentation will review the process, basic assumptions and technical information that were used to develop minimum water level criteria for the Everglades Protection Area (EPA). The proposed minimum criteria are intended to protect the Everglades by preventing the loss of hydric soils (organic peat and marl) and are based on the rationale that groundwater drawdowns and durations greater than those recommended will cause adverse impacts to hydric soils and their associated vegetation and wildlife communities. Hydric soils were selected because; (1) more than 90 percent of the remaining Everglades are comprised of either organic peat or marl soil; (2) these soils sustain all of the major terrestrial and wetland plant and animal communities that characterize the Everglades system; (3) the literature indicates that both soil types are reliable indicators of past hydrologic/biological conditions within the Everglades; and (4) sufficient data exists concerning the historical and present-day hydrological conditions that support the formation and maintenance of hydric soils within the Everglades.

The proposed criteria consist of four components: 1) a minimum water depth- the water level which, if maintained for a defined period of time, is too low to prevent harm from occurring to Everglades soils, plant and animal communities to the degree that the system is no longer sustainable; 2) duration -the estimated period of time that water levels can remain below ground at the specified minimum water depth without harming Everglades soils, plant and animal communities; 3) return frequency -the average periodicity that wetland ground water levels recede below minimum levels over a prescribed period of time (e.g., once in 10 years). If minimum water level conditions recur more often than the stated criteria, the risk of harm to wetland wildlife habitat or predator/prey relationships is increased; 4) potential for harm -This includes adverse impacts such as peat oxidation, soil subsidence, loss of dry season aquatic refugia, and increased frequency of severe fires. These harmful effects impact ecosystem sustainability by causing the loss of tree islands as well as impacts to wildlife populations, to the extent that many years, decades or perhaps centuries may be required to restore the resource to its former condition.

Minimum Depth and Minimum Duration Criteria. The numerical values for the proposed criteria were determined based on: (a) a review of available literature that describes water level and hydroperiod conditions needed to sustain hydric soils within the EPA, (b) comparison with measured or observed historical data, and c) comparison with simulated water levels derived from output of the Natural Systems Model (version 4.4). Information from all these sources were analyzed to determine minimum water depths and durations experienced at selected monitoring sites for the natural, pre-drainage Everglades.

Return Frequencies. The literature provided little information concerning minimum depth/duration return frequencies that would protect Everglades soils, plant communities or wildlife. As a surrogate, output from the Natural Systems Model (NSM) was used to estimate minimum depth and duration return frequencies for the natural, pre-drainage Everglades at selected sites within the EPA.

Criteria for the Protection of Organic Peat Soils. The following minimum criteria are proposed to protect organic peat soils and associated wetlands -- Water levels within wetlands overlying organic peat soils within the Water Conservation Areas(WCAs), Rotenberger/Holey Land Wildlife Management Areas, and Shark River Slough (ENP) should not fall 0.3 m (1.0 ft) or more below ground level during any period when water levels are continuously below ground surface for a period of 30 days or more, at a return frequency ranging from one in three years to one in ten years, depending upon the specific area (water management gage) where the criterion is applied.

Criteria for the Protection of Marl Soils. Marl-forming wetlands soils occur primarily within ENP. These soils appear to experience a much greater natural range of variability. The following criteria have been proposed--(a) Water levels within marl-forming wetlands located east and west of Shark River Slough, should not fall 0.46 m (1.5 ft) or more below ground level during any period when water levels are below ground surface for a period of 90 days or more, at a return frequency ranging from one in five years to one in seven, years depending on location; (b) Water levels within marl-forming wetlands that are located within the Rocky Glades should not fall 0.92 m (3.0 ft) or more below ground level (as measured from the top of the pinnacle rock) during any period when water levels are below ground surface for a period of 150 days or have a return frequency ranging from one in five years to one in seven years, depending on location.

Application of the Criteria. The operational feasibility and effects of the proposed minimum flows and levels criteria were evaluated using the South Florida Water Management Model. Minimum levels were established at eight strategically located interior marsh water management gages within the WCAs. These minimum levels were used in addition to existing canal minimum levels previously established for other purposes as a basis for controlling how and when water is delivered from the WCAs to the Lower East Coast urban areas. When water levels fall below the established minimum level for any of the selected marsh locations for longer than the defined minimum criteria, then water supply releases from the WCAs are discontinued. Using this procedure water can only be released from the WCAs if an equivalent amount of water is brought in from an upstream source. This is similar to the District’s current use of canal gages as "trigger" locations to control the release of water to the lower east coast. The application of minimum levels at key interior marsh sites is intended to help assure that marsh soils and associated plant and animal communities are adequately protected during periods of low rainfall and high water supply demand.

20. Minimum Water Level Criteria for Lake Okeechobee

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Under Chapter 373 of the Florida Statutes, Water Management Districts are directed to implement several provisions for water resource protection. The statutes require that surface waters be managed in such a way as to prevent significant harm to the natural resources, including fish and wildlife, and that they lay out tools that may be used to regulate water use. One of the management tools specifically referred to in the statutes is Minimum Water Level (MWL), defined as the level of ground water in an aquifer and the level of surface water at which further withdrawals would be significantly harmful to the water resources of the area. The statute further specifies that the minimum levels be established using "best available information" and that they be established within a "reasonable" time period.

In this presentation, I will review the process used to develop minimum water level criteria for Lake Okeechobee based on existing data. As it will become apparent, the "best available information" was very limited, and the criteria established must be viewed as tentative, and subject to validation or perhaps modification as additional research/modeling results become available. A major focus of the current ecological research program on the lake addresses the issue of system-wide responses to water level variation.

The Lake Okeechobee MWL criteria include three components: (1) minimum depth - a lake water level that, if sustained for a defined period of time, will result in harm to the resource; (2) duration - the estimated period of time that water levels can remain below the specified minimum depth without causing harm to the resource; and (3) return frequency - the frequency of occurrence for events wherein water levels may recede below the minimum depth without causing harm to the resource. The criteria were established in reference to the littoral marsh zone of the lake, a large (about 20% of the total lake area) region of emergent vegetation along the south and west edges of the lake. This region of the lake is the principal spawning area for commercial and recreational fishes, the feeding and nesting area for wading birds, and critical habitat for other wildlife, including the American alligator and the endangered snail kite.

Minimum depth criteria were established based on GIS data regarding littoral zone inundation and drying under different water regimes, information on vegetation spatial distribution, bird and fish use of different vegetation types, and relationships between depth and recreational use of the water resource. Two criteria were established (11 and 12 ft NGVD), each with a specified duration and return frequency (see below). When the lake recedes to 11 ft NGVD, 94% of the littoral zone has exposed soils, and no longer can function as a habitat for fishes. Large regions of the lake that are dominated by the wetland plant spike rush (the preferred habitat for the apple snail, the primary food item of snail kite) become dry, and susceptible to encroachment by torpedo grass, an exotic grass that has expanded over large high elevation areas of the marsh. At 11 ft NGVD, the lake's bulrush community (which occurs between the 12 and 11 ft depth contours and is a primary habitat for largemouth bass nesting) is dry. At this low water level, access to large portions of the lake by boats also becomes impossible. At 12 ft NGVD, the marsh is dry to a lesser extent, but still over 74% of the littoral zone is exposed.

Although the best available information indicates that harm to the water resource may occur when lake levels fall below 12 and especially below 11 ft NGVD, it must be recognized that such events do occur periodically as part of South Florida's natural flood and drought cycle. This fact was taken into account by also establishing duration and return frequencies, based on historical water level from the lake ecosystem. During the 20-year period from 1953, when the dike was completed, to 1972, prior to the establishment of a higher water regulation schedule by the USACE, there were three exceedences of the MWL criteria -- to 10.1 ft NGVD in 1956, 10.2 ft NGVD in 1962, and 10.3 ft NGVD in 1971. This corresponds to a return frequency of approximately 7 years. During these events, water levels were below 11 ft NGVD for as long as 120 days. Likewise, water levels declined below 12 ft NGVD on 7 occasions, for as long as 180 days per event. From this information the following criteria were established: for duration, not more than one time every 7 years below 11 ft NGVD, and not more than one time every 3 years below 12 ft NGVD; and for return frequency, not to exceed the MWL of 11 ft NGVD for longer than 120 days per event, nor the 12 ft NGVD criterion for longer than 180 days per event.

It is important to recognize that when operational measures are established based on these criteria, natural variability should be taken into account. Droughts may occur, on average, once every 7 years, but this does not mean that in a natural system they would occur exactly at 7-year intervals, nor that they always would last 120 days or less. To fully protect the ecosystem from harm, it also is critical that water levels be established at the other extreme -- i.e., for the maxima that occur during prolonged high water periods. Recent evidence indicates that those events may be just as harmful to the ecosystem as prolonged lows. Finally, it must be reiterated that the criteria established here are subject to change, as new and improved information is provided by the ongoing lake research program.

21. Nutrient Removal and Lessons Learned in the Marsh Flow-Way Demonstration Project at Lake Apopka

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Lake Apopka is a large (125 km^2), shallow (mean depth 1.6 m), hypereutrophic lake in central Florida. Phosphorus (P) loading from floodplain farms has been the primary cause of eutrophication. A critical step in the restoration of Lake Apopka is to increase water transparency to allow regrowth of submersed, rooted plants. Lower lakewater P concentrations are essential for this to happen, and models predict that supplemental removal of P from lakewater will accelerate the decline of in-lake P levels after loading from the watershed is controlled. A wetland filter (marsh flow-way) will be built by SJRWMD on 14 km^2 (3,500 acres) of floodplain farmland immediately adjacent to the lake. The primary goal of this wetland is to remove algae, suspended sediments, and particle-bound nutrients from lakewater.

The Marsh Flow-Way Demonstration Project is a pilot-scale (>2 km^2) wetland filter constructed by SJRWMD to examine the capacity of a wetland treatment system to remove suspended sediments and particulate nutrients from lakewater. This field experiment was designed to evaluate the relationships between nutrient removal, flow, and loading; the hydraulic behavior of a wetland filter; and the development and management of vegetation. Our presentation will focus on removal of nutrients and suspended matter by the demonstration project and will emphasize areas where conclusions from the demonstration project were used in the conceptual design of the full-scale flow-way treatment system.

The demonstration project consists of two cells (0.73 km^2 and 1.4 km^2) arranged in series. Water enters the first cell via gravity and pumped inlets from Lake Apopka, flows into the second cell through a connecting cannel between the two, and is pumped back into the lake from the bottom of the second cell. The wetland was allowed to vegetate naturally. The project started in 1990, and experimental changes designed to improve flow patterns were made to the first cell in 1992. Effects of these hydraulic modifications were immediate and undesirable, increased channelization of flow through remnant agricultural ditches lowed water residence times which reduced nutrient removal rates. The project was drained in 1994 to test drawdown as a technique to consolidate newly deposited sediments.

The demonstration project's first cell was considered the best model of the full-scale flow-way wetland, and we will focus on performance data from this area. Areal hydraulic loading rate (HLR) for the first cell varied from 4 to 18 cm d^{-1}. Mean water depths ranged from 0.6 to 0.9 m, and residence time ranged between 4 and 12 d. Total suspended solids (TSS) ranged from 40 to 180 mg L^{-1} in the inflow from Lake Apopka. Removal efficiencies for TSS generally were >90% before hydraulic modification.

Total nitrogen (TN) in the inflow ranged from 3 to 9 mg N L^{-1}. Particulate organic N (PON) averaged 65% of TN in the inflow, while dissolved organic N (DON) accounted for most of the remaining N. Removal efficiencies of PON in the first cell varied between 75% and 90%. Removal efficiencies calculated for TN (30% to 50%) were lower than those for PON because of the relatively high levels of DON in the inflow. DON concentrations were little changed as water passed through the wetland.

Total phosphorus (TP) in the inflow ranged from 0.08 to 0.38 mg P L^{-1}, and particulate organic phosphorus (POP) accounted for more than 90% of TP. Removal efficiencies for POP varied between 50% and 90% before hydraulic modifications. Removal efficiencies calculated for TP were much lower initially than those for POP because of release of soluble reactive P (SRP) from soils. Approximately 3 g P m^{-2} (SRP) leached from the oxidized, organic soils after initial flooding. As soil leaching declined, removal efficiencies for TP reached 30% to 50%.

A first-order area-based model was used to characterize nutrient removal in the wetland. The rate constant, k, describes the decrease in concentration of a substance from the inlet level to a background level (C*). C* values for the particulate fractions TSS, PON, and POP were curvilinear functions of temperature. Rate constants calculated for removal of TSS and particulate nutrients increased with hydraulic loading up to a HLR of about 8 cm d^{-1}. The increase in k indicated an increase in the fraction of the wetland area active in particle removal at higher flows. The median k value for TSS at higher HLR was about 100 m yr^{-1}. Median values of k for POP were 33 and 50 m yr^{-1}, depending on whether C* was taken as zero or estimated from temperature, respectively. Corresponding median k values for TP were 23 and 36 m yr^{-1}. Values of k calculated for TP removal were less than k for POP removal because of release of dissolved organic P.

After 29 months of operation, net removal of TSS totaled 4750 g dw m^{-2}, net removal of N was 130 g N m^{-2}, and net removal of particulate P was 5.5 g P m^{-2}. About 4.6 g P m^{-2} was in the accumulated sediments, 3.3 g P m^{-2} was in vegetative biomass, and 3.4 g P m^{-2} was released as soluble P. The P budget for the wetland demonstrated that P in pre-existing soil pools was the major source for release of soluble P and for uptake of P by vegetation.

Net removal of P in the first wetland cell was 0.5 g P m^{-2} yr^{-1} during the period before hydraulic modification. This removal rate was sub-optimum because of 1) leaching of SRP from soils after initial inundation, and 2) low gravity flows during periods of low water levels in Lake Apopka. Use of inlet pumping to maintain at least 10 cm d^{-1} HLR would have increased net P removal to 1.0 g P m^{-2} y^{r-1}. With additional measures to prevent initial leaching of SRP from flooded soils, net P removal would have exceeded 3 g P m^{-2} yr^{-1}.

Lessons learned in operation of the demonstration project and applied in design of the full-scale treatment wetland include the following:

* Hydraulic functioning of the wetland is key to effective nutrient removal. Multiple parallel cells are preferable to a single, large treatment area. Large-scale channelization must be avoided to maximize the hydraulic residence time. Solutions include distributed inlet and outlet structures and deep areas perpendicular to flow to intercept channelized flow. Up to 10 cm d^{-1} HLR could be maintained with natural, high vegetation density.

* Leaching of soluble P occurred after soils first were inundated and after inundation of soils dried for consolidation. Solutions include treating soil to bind P, recycling floodwaters, and minimizing the frequency and duration of drawdowns.

* The wetland could meet target efficiencies of 85% and 30% removal of suspended solids and total phosphorus, respectively. Particulate N and P fractions were removed; dissolved fractions were unchanged or augmented.

* Drawdown was a necessary and effective technique to consolidate the newly deposited flocculent sediment (median = 33 cm after 29 months of operation). Bulk density and P content of the sediment after drawdown confirmed earlier projections of sediment storage in the full-scale project. The sediment consolidated over 7-fold, but renewed leaching of soluble P occurred after refill.

22. Design of the Lake Apopka Marsh Flow-Way

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Lake Apopka, the fourth largest lake in Florida, is shallow, turbid, and hypereutrophic. Restoration of the lake was mandated by the Florida Legislature in 1985. A diagnostic and feasibility study resulted in a restoration plan that calls for reduction of external nutrient loading to the lake, constructing a wetland treatment system, harvesting gizzard shad, restoration of littoral zone areas in the lake, and continuing public education and long-term basin-wide planning.

The Lake Apopka Marsh Flow-Way is a multi-cell wetland treatment system designed to accumulate and bury suspended solids and particulate phosphorus (P) in inflow water from Lake Apopka and to replace peat sediments lost through oxidation during past farming operations. The design was based on the performance of the Lake Apopka Marsh Flow-Way Demonstration Project, and the experiments conducted in that system. Four key elements are included in the design:

1. Interior cells with length: width aspect ratios of ~2:1 on a 101-hectare footprint. 2. Multiple independent cells. 3. Internal drainage works sufficient to rapidly draw down cells and expose sediments. 4. Use of soil amendments as a management tool to control release of soluble P upon reflooding.

The size and dimensions of the Marsh Flow-Way cells were designed to maximize active treatment area. Sediment accumulation in the Demonstration Project fell off sharply with increasing distance from the inflow, and significant accumulation occurred in the western half (i.e., downstream) of the cell only after several years. Before that occurred, sediment accumulation in the eastern (i.e., upstream) side of the cell was sufficient to warrant a drawdown for compaction.

The size of the Marsh Flow-Way cells resulted from incorporating the desired length: width aspect ratio within the east-west levee system already present on the site. The distribution of inflow and outflow structures across the west and east levee of each cell encourages relatively even distribution of flow across the width of a cell regardless of the area involved. Each cell will receive a hydraulic load of approximately 9 cm d^{-1} (about 95,000 m^3 d^{-1}).

Cells in the Marsh flow-Way are arranged south to north in sets of two, each approximately one quarter mile wide (south to north) and one half mile long (west to east, the direction of flow). Each cell has an independent water supply and drains into a canal common to several cells leading to a pump station. Control structures allow each cell to be operated independently. This is necessary if we are to maintain a total flow of about 1,250,000 m^3 d^{-1} while doing necessary maintenance on an individual cell. Intensive cell management will be necessary to maintain long-term P removal goals for the system. Each cell will accumulate particulate solids at a rate that exceeds that of natural soil formation. Consequently, after several years of constant operation, a cell will fill up with flocculent sediments. When this occurs, the cell will be rapidly drawn down to expose and compact the sediments. Drawdown of the water table below the soil surface is necessary to achieve compaction. An internal series of north-south ditches about 90 m apart, and connected through small (20-cm wide) culverts to an external drainage ditch, will provide this ability in less than sixty days.

Effective sediment compaction occurs within several weeks after drawdown, but also exposes the sediments to oxygen. In the Demonstration Project, oxidation produced labile P through sediment oxidation, which was subsequently released upon reflooding. Unmanaged release of P could greatly reduce the overall efficiency of the nutrient removal process. Levels of labile P increased with length of exposure. We recommend a maximum exposure period of sixty days. Laboratory and field experiments with a variety of chemicals demonstrated the value of lime application to the sediment before reflooding to sequester labile P.

We estimate that we can complete an effective drawdown within thirty to sixty days, and we expect to draw down and manage three to four cells annually. This is approximately 5% of the annual operation days for all cells combined.

The 1,250,000 m^3 daily design inflow to the Marsh Flow-Way is sufficient to filter the entire lake volume twice annually. It is also sufficient to filter the maximum capacity of the Apopka-Beauclair Canal. Thus, all downstream discharges from the lake will be treated. Annually, about 85% of the filtered water will be returned to the lake, providing a source of clean inflow water. At this operating rate, design treatment efficiency is projected to be 30% for total phosphorus removal, and >85% for suspended solids removal. This will remove about 30 metric tons of P per year at an average lake total P concentration of about 0.2 mg L-1. Based on the performance of the Demonstration Project, the Marsh Flow-Way has the capacity to remove all the available P stored in Lake Apopka sediments.

After the Marsh Flow-Way has done its job as a treatment system, we will reconstruct the original lake system in that area. Habitat restoration of the uplands is an ongoing project. Results from the Demonstration Project suggest that the treatment system will not remain a cattail monoculture, but during restoration of the marsh habitat, we may encourage further vegetative diversity through selective removal and plantings. The levees separating the marsh and lake (and the Apopka Beauclair Canal) will be breached as the final step.

Currently, we are moving toward construction of the first four treatment cells of the system, at a cost of about $4 million. An 18 - 24 month construction contract will be let in the summer of 1997, and these cells will begin operation 18 - 21 months thereafter, while we construct the next phase of the system. We expect to complete construction of the entire system by the year 2002 and plan up to 25 years of project operation.

23. Ecology of Constructed Marshes of Varying Age and Design: Implications for Surface Water Quality Management.

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A study of natural and constructed freshwater marshes of varying age may provide some indication of the ability of newly constructed marshes to assimilate wastewater. Water and sediment quality data and biological data were collected from 11 constructed marshes in central Florida ranging from 3 months to 8 years in age. The marshes varied in size from 2.4 to 24.3 hectares. Dominant vegetation included of *Pontederia cordata*, Typha spp., *Sagittaria lancifolia*, *Panicum hemitomon*, and *Hydrocotyle umbellata*.

Based on measurements taken within the interior of each marsh, annual mean values of various water column physiochemical parameters are related to wetland age. Dissolved oxygen decreased with age from greater than 10 mg/Ll to 5 mg/Ll. Total phosphorus decreased from 2.0 mg/l to 0.15 mg/l. Water column pH, which can be primarily controlled by algal photosynthesis, declined from > 9.0 in the youngest marshes to approximately 7.5 in older marshes.

A single sampling event was conducted to assess sediment quality in the constructed wetlands. Total phosphorus in sediments increased from 1.8 to 18.5 mg/g dry weight with increasing wetland age. Detrital TKN on a percent dry weight basis increased from approximately 1.4 % in the youngest wetlands to approximately 2 % in the oldest wetlands. Litter mass (g dry weight/cm^2) and detrital density (g dry weight /cm^3) increased with wetlands age from 0 to approximately 0.5 and from 0 to 0.035, respectively.

A chlorophyll a index used by Kiefer (1991) corrected for phaeophytin (APHA-AWWA-WPCF 1975) was used as an indicator of general condition of algal communities. Index values, which range from zero to 1, decreased with wetland age from 0.8 to less than 0.1. Snail populations, which depend on algae as a food resource, declined significantly with wetland age ($p=0.008$). The results of this study are consistent with expected changes in environmental conditions as newly constructed wetlands shift from an algal-dominated community to a rooted emergent plant community. These observations mimic the trends observed during other 5- to 10- year studies of constructed wetlands in Florida (Evans and Sullivan 1987; Erwin 1988; Evans 1989; Erwin 1990).

In a comparison of water quality in mulched and unmulched wetlands, pH, iron, total phosphorous and dissolved oxygen tended to be lower in mulched wetlands. Based on percent cover, emergent and floating plants tended to become established more rapidly in marshes designed with gradual slopes (< 1.5 percent). Vegetation cover in constructed marshes attained levels typical of natural marshes within 3 to 4 years.

These data support the notion that constructed emergent marshes can effectively maintain good water quality (low in nutrients, high in clarity). In newly constructed wetlands, efficiency of nutrient removal from the water column likely increases as emergent plants become established (Stewart and Ornes 1973; Dolan et al. 1981). Timing of effluent introduction may be critical in wastewater treatment wetlands. The rate at which maximum efficiency is achieved may be enhanced by mulching and by designing marshes with gentle slopes. Future long-term studies regarding the capacity of newly constructed marshes to serve as chemical sinks are warranted.

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24. Orlando Easterly Wetlands; Management of a Constructed Wetland Treatment System

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During the 1980's, the City of Orlando's Iron Bridge Regional Water Pollution Control Facility needed an alternative discharge point for its wastewater effluent. Due to a stringent waste load allocation, the City could not create a new direct discharge point for this facility. In 1986, construction started on a 1,220 acre created wetland, which was designed to receive and treat up to 20 mgd of wastewater. Since startup in July 1987, the Orlando Easterly Wetlands (OEW) has exceeded performance expectations. From 1988 to 1995, the average total nitrogen (TN) and total phosphorus (TP) concentrations discharged from OEW were 0.81 mg/L and 0.07 mg/L, respectively. The average monthly permitted discharge limits for OEW are 2.31 mg/L for TN and 0.20 mg/L for TP. The annual average flow through the wetland during this eight-year period was 12.8 mgd.

A 1,650-acre site was selected in east Orange County adjacent to the St. Johns River to construct the wetland treatment system. The wetland itself was built on approximately 1,220 acres of improved pasture, which was divided into 17 cells that support three different community types. The first community type, the deep marsh, was designed primarily for bulk nutrient (i.e., nitrogen and phosphorus) removal, and initially had low plant species diversity. The second community type, the mixed marsh, was designed for wastewater polishing and provides a diverse wildlife habitat. The final community was designed as a hardwood swamp to provide additional wildlife habitat. Twenty different plant species were originally planted in the latter two community types, and about 120 additional species have subsequently recruited naturally from the seed bank present in the sediment or from adjacent natural wetlands.

Approximately 18 miles of berm were constructed to create the wetland. To control water depth within each cell, 23 water control structures were incorporated into the system. The existing topography of the site was maintained, except along the eastern boundary, where a 75-acre lake was excavated to provide fill material for berm construction. Ground elevation drops 15 feet across the site, which promotes gravity flow between cells and created the need for the internal water control structures. The water detention time of the system is approximately 30 days. Water exits the wetland through a weir control structure and flows into a receiving ditch. Treated wastewater must cross an adjoining property (the state-owned Seminole Ranch Wildlife Management Area) before reaching its final discharge point, the St. Johns River. Once wastewater enters Seminole Ranch, it can flow directly into backwater areas of the St. Johns River or it may be diverted into floodplain marshes adjacent to the river.

The OEW is regarded as high-quality wildlife habitat as evidenced by wildlife usage patterns. Bird surveys indicate that more than 150 species have used portions of the site at some point since startup in 1987. In addition, 18 threatened or endangered species of birds, reptiles, and mammals have used, or are currently using, this system for some, or all, of their habitat needs. During the summer of 1996, a pair of endangered Everglades snail kites successfully nested and fledged a chick on site. The successful nesting of these kites at OEW is very significant since it constitutes a range expansion for the species. Based on visual observations, it appears that the abundance and species diversity of small mammals, reptiles, amphibians, and benthic macroinvertebrates found in OEW are similar to communities in adjacent natural wetlands.

Because of the uniqueness and educational/recreational potential that the OEW offers, the City of Orlando incorporated the 1,650-acre site into its parks system. Every year, thousands of hikers, joggers, school groups, bird watchers, and naturalists visit the OEW to enjoy and learn about the treatment system.

In order for a created wetland treatment system of this size to maintain outstanding effluent water quality as well as provide valuable wildlife habitat and passive recreational opportunities, several competing goals have to be balanced. These goals include providing final polishing of treated wastewater, maintaining the overall vegetative component of the OEW, and providing wildlife habitat throughout the created treatment system. Wildlife and vegetation methods management methods have included herbicide application, water level manipulation, biological control, mechanical removal (i.e., cutting, harvesting, mowing), and prescribed burns. The methods, trials, and errors of balancing these goals will be discussed in this presentation.

25. Periphyton Filtration: An Economically and Environmentally Sustainable Phosphorus Removal Engine

Jenson, Kyle. Science Applications Incorporated

Periphyton is widely known to remove many elements and compounds from water. Managed periphyton or Periphyton Filtration (TM) is a term describing an artificial culture surface which is harvested on a 7 to 14 day interval or longer under certain conditions. The harvested algal biomass is removed from the water system for true export of pollutants.

Several Periphyton Filtration Systems have been constructed and operated at both small and large scales in various water types. Costing on this construction allows for accurate projections on cost per pound of phosphorus removed. Three of the many systems constructed and operated are described.

Floway Systems are sloped culture surfaces roughly 10-50 times longer than wide. Curbs at the long sides provide for a deployable harvester to service the culture surface. Floways are designed to be constructed on virtually any consistent low moisture soil.

Examples: 1) A 12 m^2 Linear Floway was operated in Belle Glade, Florida, in canal water with phosphorus (P) ranging 12 to 148 ppb. Observations from this operation indicate very rapid periphyton growth. Microinvertabrate grazing pressure was observed. Phosphorus removal correlated to large scale ranged 380-500 Kg/ha/yr. Diel uptake rates varied, however, no significant release during night operations was measured.

2) A 120 m^2 linear Floway operated on treated wastewater in Lake Placid New York demonstrated significant diel pH response. Artificial lighting in this apparatus was used to augment natural light. The system was operated through the winter at very low temperatures. This stream was very low in alkalinity and high in phosphorus. Phosphorus export was observed during the dark period operation.

3) A 11,000 m^2 Floway system was constructed and operated for one year. Phosphorus removal rates were significantly higher likely due to pH gradient and associated co-precipitation of phosphorus. Tissue P measurements ranged from 1.2 to 3.5 % with the higher measurements on the down stream end of the culture surface.

Conical Periphyton Culture systems have been developed for areas where soil bearing capacities allow. This configuration reduces costs for culture surface construction and allows for less costly harvesting equipment. Harvest is executed downslope and outward from center to perimeter.

Periphyton Water Gardens are shore side filters for urban lakes and ponds. Periphyton culture surfaces are artistically deployed in a park like setting amongst sculpture, a sundial, and other art with a philosophical and scientific organization. Educationally descriptive plaques round out a facility which has a lake oriented natural remediation function as well as social and educational benefits. Periphyton Filters are most economically designed to operate with an associated basin to attenuate storm surges. Oversizing to treat storm flows allows large P export from lakes in between rain events. Detailed examples of system sizing and illustrations will provide a general basis for understanding the scaling advantages for storm water P removal.

The diel unloading of Periphyton Filters can be problematic in some systems requiring a constant level of effluent. In these cases sequential basin treatment as demonstrated by Hoffman have shown to be effective in treating higher strength waste streams with consistent effluent requirements.

For many lake / wetland treatment applications there is not a requirement for consistent effluent quality and in this case P removal per unit area is the most effective useful attribute. Chemical augmentation of P removal uses chemicals like alum to bind P in sediments. The Periphyton Filter is superior to the chemical approach in this case as it is removing the P in biomass and is probably more environmentally benign.

The use of biomass generated from Periphyton Filtration has lagged behind the development of the filtration effectiveness. The use of the algal biomass for agronomic and feed uses are reported in the literature. Drying and handling of the biomass is achievable with off the shelf equipment but it has been difficult to access economic viability without large quantities to work with. Inexpensive concentrated chemical fertilizer makes competition tough for this natural amendment.

A new process combines shredded recycled paper products with the harvested algal biomass. The dry fibrous nature of the paper has a synergistic dewatering effect. The resulting pulp is molded into various products which are currently sold at profit. Detailed financial study and prototype products indicate profitability which covers operational cost as well as construction cost recovery over 20 years. Molded packaging and incorporated nutrients can be transported out of basin and can be used to amend soils at the destination saving landfill volume.

26. The Role of Research in the Everglades Nutrient Removal Project.

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The Everglades supports many rare and endangered plant and animal species, and is widely recognized as an ecosystem of international importance. Historically, the Everglades was highly nutrient-limited; open-water total phosphorus (TP) concentrations were typically at, or below, 10 Fg P L^{-1}. Eutrophication (i.e., nutrient enrichment) of the Everglades in recent decades has been associated with excessive phosphorus loading from agricultural runoff. Total phosphorus concentrations entering portions of the Everglades today typically range from 100 to 200 Fg P L^{-1}. Increased TP loading in some of these areas, together with changes in the natural hydroperiod, have dramatically altered the species composition of plant communities, and disrupted food chains. An important component of the South Florida Water Management District's proposed $685M+ Everglades Restoration Plan is construction of six treatment wetlands to serve as Stormwater Treatment Areas (STAs) and reduce nutrient levels (primarily TP) in the incoming agricultural water. These proposed wetlands will eventually encompass approximately 16,000 ha (40,000 acres). The primary treatment mechanism of the STAs is initial uptake of nutrients by vegetation and subsequent burial of this plant material in the bottom sediments (i.e., accretion of peat). The District completed construction of a large-scale treatment wetland, the Ever-glades Nutrient Removal (ENR) Project, in 1993 and is operating this facility as a technology demonstration project to validate the STA concept and to gain the experience that will be needed to construct and operate the STAs. Research conducted in the ENR Project has played a vital role in documenting the wetland's overall nutrient removal performance and in characterizing other important wetland physical and chemical parameters.

The ENR Project covers 1,545 ha (3,818 acres) and is currently the largest constructed wetland in the United States. The wetland was built on cropland farmed mainly for sugarcane and is divided into four treatment cells that are arranged into two parallel flow-through trains. The upper treatment cell in each train was allowed to revegetate naturally with cattail (*Typha spp*.); one of the lower treatment cells was partially planted with a mixture of common marsh species, while the remaining treatment cell has been actively maintained as a periphyton/submersed macrophyte community. The vegetation grow-in phase within each treatment cell, estimated from the time of first flooding, lasted approximately 28 to 44 months. *Typha* initially spread quickly while water levels were low during construction. However, submersed macrophytes (e.g., largely *Najas* and *Ceratophyllum*) rapidly colonized most of the remaining open areas after project start-up. Measurements of one-year sediment accretion in vegetated areas ranged from 1.7 to 5.9 cm of deposition.

The ENR Project began flow-through operations in August 1994. Total phosphorus loading rates were ca. 1.2 and 1.8 g P m^{-2} yr^{-1} for the first two operational years, respectively. On a monthly basis, 78 to 97% of the TP load entered the wetland via the Inflow and Seepage Return pumps with the remainder coming from wet/dry atmospheric deposition and groundwater seepage. To date, the ENR Project has surpassed its design goals (i.e., 75% TP load reduction and a long-term outflow concentration < 50 Fg P L^{-1}). Monthly TP load reduction usually exceeded 80% and the 24-month volume-weighted mean TP concentration at the project outflow was 23 Fg P L^{-1} (corresponding inflow = 118 Fg P L^{-1}). The ENR Project has not been nearly as efficient at retaining nitrogen. Only 35 to 74% of the incoming total nitrogen (TN) load was removed on a monthly basis (estimates uncorrected for atmospheric cycling). Cumulative inflow and outflow volume-weighted mean TN concentrations for the first 24 months of operation were 2.91 and 1.83 mg N L^{-1}, respectively. Preliminary data analysis suggests that under a water load of 2.5 cm day^{-1}, which corresponds to the STA design water load, optimal TP removal occurred at a water depth of ca. 60 cm.

Lessons learned in the construction and initial operation of the ENR Project have already been applied to the design of the STAs. Continued research and monitoring efforts planned for the ENR Project will provide information on long-term performance characteristics of subtropical treatment wetlands which will help refine operational guidelines for the STAs.

27. Bridging Research and Management in Lake Okeechobee

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Two research programs currently being administered and conducted by staff at the South Florida Water Management District (SFWMD) illustrate the value of research to the management of water resources. The first program is the Lake Okeechobee Regulation Schedule Study (LORSS), a descriptive study examining the effects of lake level on system structure and function. The second one is the Buck Island Agroecology Research Program, an experimental study that examines the effects of beef cattle ranching practices on phosphorus runoff in the watershed. Both these programs involve three elements that are critical to the successful integration of research and management: (1) research objectives are developed in concert with concerned parties and to provide answers to key management issues; (2) research is based on rigorous scientific principles and sound experimental design; and (3) results are communicated in a timely and useful fashion to a wide audience.

The Lake Okeechobee regulation schedule determines the timing and quantity of water that must be released from the lake when the stage exceeds a certain level, which varies according to season (i.e., a lower stage is permitted in the spring prior to hurricane season, whereas a higher stage is allowed in the fall). The current lake regulation schedule (Run 25-3) ranges in lake stage from 15.60 to 16.75 ft NGVD. A review of the regulation schedule was initiated by the Jacksonville District of the US Army Corps of Engineers (USACE) in 1995. The purpose of this review is to determine if a regulation schedule could be devised to better meet the needs of the lake's ecology, while simultaneously adhering to the needs of the USACE and not requiring any structural modifications to the Hoover Dike and its associated canals and water control structures. As a part of LORSS, the USACE will prepare an Environmental Impact Statement, which will describe, in part, potential environmental effects to fish and wildlife resources due to the proposed alternative schedules.

In order to generate the environmental information necessary for the impact statement, and also to gain a better understanding of lake ecology, staff from the District, USACE, and the Florida Game and Fresh Water Fish Commission (FGFWFC) are collaborating on a research program with two main objectives: (1) collection of baseline biotic data in the littoral zone of Lake Okeechobee to assess the influence of water level fluctuations and hydroperiod on the community structure of different biota; and (2) determination of habitat preference of biotic communities of the Lake Okeechobee littoral zone, and evaluation of water level and hydroperiod upon preferred habitats. USACE is responsible for generating wildlife data, including birds, amphibians, and reptiles, FGFWFC is responsible for collecting data on fish and invertebrates, and the District is responsible for providing information on vegetation coverage, and storing and analyzing the data in GIS format. This collaborative effort will provide critical information on how stage influences biota in the lake littoral zone. In addition, results from this project will be used to generate new hypotheses on how littoral zone structure and function are affected by lake stage, which can then be tested by controlled experiments.

The focus of the Buck Island Agroecology Research Program is to determine which beef cattle stocking rates will maximize cattle production but minimize P runoff from the watershed. Watersheds located north of Lake Okeechobee are devoted largely to agricultural activates, such as dairy and beef cattle operations (Flaig and Havens 1995). Phosphorus load associated with runoff from these agricultural sources ultimately enters the lake. As a result, Lake Okeechobee's total phosphorus concentration has increased from about 50 mg/L in the early 1970s to approximately 90 mg/L at present (James et al. 1995). One consequence of higher nutrient concentrations was an increased frequency and intensity of algal blooms. Agricultural Best Management Practices (BMPs) have been developed and implemented at the dairies, resulting in dramatic reductions in total P concentrations (Havens et al. 1996). However, the target for P load from the watershed, as mandated by the Surface Water Improvement and Management (SWIM) Act, is still being exceeded. Attention is now turning to how we can reduce runoff from beef cattle operations.

A cooperative research project is being undertaken with the following partners: the District, University of Florida's Institute of Food and Agricultural Sciences (IFAS), Archbold Biological Station, Florida Cattleman's Association, and Natural Resource Conservation Service. The project consists of 16 field-scale experimental pastures, that are fenced and ditched separately from each other, so that all surface water runoff can be captured and analyzed. Eight pastures are constructed on summer pasture land and eight are constructed on winter pasture land. The experimental design for the first phase of this project involves four different stocking rate treatments on the eight summer pastures, resulting in two replicate pastures per treatment. Grazing animals will be rotated between the same summer pasture plots and winter range plots. Surface runoff will be collected and analyzed for water quality parameters. Information on optimal beef cattle stocking rates will be disseminated to beef cattle ranchers in the form of extension publications and public workshops.

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28. The Role of Research in Everglades and Florida Bay Restoration

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This presentation will focus on five major research programs and how the information from them is uses, or will be used, to make decisions affecting Everglades and Florida Bay restoration. Information on these research programs and how their results will be used are detailed in the following table.

Research Program	Products of research program for use in decision making
Settlement research	1. Allowable Everglades Agricultural Area (EAA) loads and Stormwater research Treatment Area (STA) sizing
Class III Phosphorus Threshold Research	1. "No imbalance" (Class III) nutrient concentrations will be defined for Water Conservation Areas WCA1, WCA2, WCA3, and ENP, as required by the Consent Decree and the Everglades Forever Act, and as needed by DEP for Environmental Regulation Commission and EPA review/approval. 2. Hydroperiods (and nutrient interactions) for use in determining minimum flows and levels, as required by State of Florida law. 3. Understanding of processes that affect nutrient uptake and retention in wetlands, wetland plant spread and competition. Data will be used for Storm Water Treatment Area operation, Everglades Landscape Model, South Florida Water Quality Model, Wetlands Water Quality Model, minimum flows and levels determinations, and the USCOE Central and South Florida Flood Control Restudy.
Minimum flows and levels research	1. Recommended hydroperiods / hydropatterns that will optimize wading bird breeding and foraging success. Also will supply Everglades Landscape Model (ELM)/Across Trophic Level System Simulation (ATLASS) models with data needed for predicting effects of water management scenarios.
Everglades Landscape Model	1. Calibrated and validated spatial model for predicting the effects of water management decisions (nutrients, hydroperiods, levee removal etc.) on long-term freshwater and estuarine landscape vegetation patterns and succession.
South Florida Water Quality Model	1. Calibrated and validated spatial model for predicting the effects of nutrient management decisions on the short term fate and transport of nutrients throughout the District. 2. Wasteload allocation tool for determining load reductions necessary to achieve downstream phosphorus threshold concentrations.

Florida Bay Research and Monitoring	1. Recommended salinity levels for restoration, through stable isotope research. 2. Relative importance of nutrient flux from mangrove transition zone to Florida Bay, compared to other sources. 3. Optimal salinity and nutrient conditions for sustaining seagrass. 4. Synoptic water quality data for Florida Bay for analysis of trends due to management actions.

29. Research as the Only Logical Foundation for Environmental Management

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The concept of *environmental management* is not only arrogant, but usually misleading, because, clearly, the best *management* is the least possible intervention into ecosystem structure and function and the whole-hearted embracing of natural processes. These natural processes are so complex and, in almost all cases, the data base on ecosystems so inadequate that manipulation of the structure/function foundation of a given ecosystem is usually a poorly designed trial and error exercise. It is little wonder that there are so few successes in environmental management and that the world is replete with environments under stress from human intervention that has exponentially expanded in space and accelerated in time since settlement (i. e. post-aboriginal times). The proof of this pudding is that if post-settlement human intervention is removed or redirected, systems recover, at least to some extent, toward some presettlement condition; witness Lake Washington, Washington and Gull Lake, Michigan. These are examples where the problem was exported across ecosystem boundaries (Puget sound and the Kalamazoo River respectively).

The premise here is that environmental management (and I vastly prefer *ecosystem stewardship*) should be at least as successful as human medicine and transportation (especially space and air travel). The sequence for these last two human endeavors is basic research (how things work) - technology transfer (converting knowledge of how things work to some potential application) - applying the technology-translated application to some human-defined need (fixing some malfunction in the case of medicine or extending some capability in the case of transportation).

Managers and environmentalists alike proclaim "we already know what's wrong, let's just fix it". "Knowing " what is wrong in no way implies basic knowledge how it works. As in medicine and transportation, the overwhelming majority of public funds for environmental problems should be invested in understanding how things work - basic research. Funds from the profit-driven private sector should finance the tech transfer and application. The fruits of basic ecosystem research hold the promise for immense profits when applied to environmental problems, many of which are now or soon will be life threatening. Trial and error medicine and transportation vehicle design are kept to a minimum - why should ecosystem management be different?

Methods used to Acquire the Information

The methods are simple enough, but they are time consuming. They are the hypothesis-driven scientific process of discovery. In ecosystem research, this is, of necessity, multidisciplinary. The time lag between basic research results and real world application can be long and frustrating. Without a profit-hungry technology transfer establishment there is little to be done to shorten the delay. Managers who complain that ecosystem scientists don't conduct research relevant to their problems have totally missed the point. If the scientist has an obligation to society in general, and to managers in particular, as a scientist, it is to conduct basic question-driven research, not research driven by questions devised by managers.

In the medical analogy, the question was how is the message for protein synthesis encoded in DNA? not how can we cure cancer? This is why genetic biochemists (basic researchers) and not clinicians (managers) are awarded Nobel Prizes.

Basic measures of ecosystem structure and function:

A number of measures at the ecosystem level are useful for assessing overall structure and function and would be expected to be sensitive to system changes. Among these are: 1) the balance between autotrophy and heterotrophy, that is, whether or not the ecosystem is a source or sink, or at balance annually, for organic carbon; 2) the concentration of nutrients and/or their ratios limiting carbon cycling (production and turnover) in the ecosystem; and 3) the basic components and transfers in system food webs that have been measured so as to allow for the identification of keystone taxa and essential transfer rates. Although knowledge about such system attributes are not directly transferable to the application arena, such understanding is the prerequisite for successful management.

Dynamics of populations of special concern:

More often, the measures are of particular populations (e. g. a sport fish) or communities (e. g. wading birds) that represent indicators of an healthy system to managers and the public. Examples of this more limited approach to understanding ecosystems are: 1) sport and commercial species (fishing, hunting, pet trade); 2) recreational (charismatic) species that are the subjects of viewing (e. g. bird watching) and largely non-destructive use; and 3) endangered species which are usually surrogates for habitat destruction and/or loss.

Key Findings

The Kissimmee River Restoration project, the largest physical river restoration ever attempted, provides a good example of the need for basic research, the management (restoration) objectives, and the potential for linking research findings to the restoration process, or adaptive management.

The almost universal failing of aquatic ecosystem management programs , whether focused on the entire system by way of concern for, for example, general water quality or focus on a particular component resource such as fish, has been to start from an initial poor data base and not to collect adequate data after alteration to allow evaluation of whether the project succeeded or failed. In addition, evaluation requires that some measure of success has been accepted. In restoration projects, this is embodied in the question "restore to what?" and entails the selection of some reference condition, actual or conceptual.

The ecological portion of the Kissimmee River Restoration Project includes proposed conceptual reference conditions based on the literature and best professional judgment (e. g. see Vol. 3 No. 3 - entire issue of J. Restoration Ecol. 1995). Base line data (i.e. prior to restoration) are being collected in sections of the river to be restored as well as reaches above and below them.

Conclusions and Recommendations

If managers want to be successful, it is essential that they aggressively insist on the strongest possible basic research effort. The irony is that managers are usually the leading proponents of limiting funding for basic research. The basic premise here is that knowledge is power. The more that is known about the structure and function of a given ecosystem, the higher the probability that a management activity will actually "improve" the managed system, i.e. drive it in the direction of presettlement condition and/or maintain it in its present condition if that is desirable.

30. Interagency Research on the Mercury Problem in South Florida.

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The 1994 Florida Everglades Forever Act (EFA) codifies agreements reached in a mediated settlement of the 1989 lawsuit filed by the Federal Government against the State of Florida and the South Florida Water Management District for failing to protect Everglades water quality. The EFA-mandated Everglades Construction Project (ECP) is intended to restore a more natural water routing, timing, quantity, and quality to the remnant Everglades. The attainment of a total phosphorus (TP) threshold concentration for no biological imbalance is to be accomplished in two phases. In Phase 1, which is to be completed by 2003, changes in best management practices in the Everglades Agricultural Area (EAA), in combination with the construction and operation of 43,000 acres of filter marshes called stormwater treatment areas (STAs), are intended to reduce the TP concentrations in stormwater runoff from the Everglades Agricultural Area (EAA) down to 50 ppb. In Phase 2, supplemental technologies will then achieve the TP threshold concentration. The costs of Phase 1, excluding on-site BMPs, is anticipated to be about $0.75 billion, while that of Phase 2 another $0.25-0.5 billion.

Mercury is bioaccumulating in sport fish in most portions of the Everglades to concentrations that exceed the Florida's no consumption advisory level of 1.5 mg/Kg. Comments on the ECP PEIS received to date from the Miccosukee Indian Tribe (MIT), the Everglades Coalition (EC), and the Sugar Cane Growers Cooperative (SCGC) indicate that mercury will be an issue in anticipated administrative challenges. In aggregate, these comments allege an unreasonable risk to the public health or the environment from three phenomena: (1) accumulation of mercury in accreting peat to hazardous concentrations (Superfund effect); (2) accumulation of mercury in fish and birds living in the STAs to concentrations that will eventually significantly exceed those in the fish and birds living in the portions of the Everglades that the STAs are designed to emulate (reservoir effect); (3) accumulation of mercury in fish and birds living downstream of the STAs to concentrations that will eventually significantly exceed present concentrations through an inverse relationship between TP in water and mercury in fish (nutrient effect).

The Everglades Nutrient Removal (ENR) Project is a 3,818-acre demonstration-scale STA constructed on former farmland and located at the northwest corner of the Arthur R. Marshall Loxahatchee National Wildlife Refuge (Refuge) in Palm Beach County, Florida. It is expected to remove up to 75 percent TP in up to one-third of the stormwater runoff from the EAA that would otherwise flow untreated through the S-5A pump station into the Refuge, an Outstanding Florida Water. The primary mechanisms of phosphorus removal are expected to be particle settling and storage in accumulating undecomposed plant biomass (peat) originating primarily with cattail (typha spp.). In December 1991, concerns were raised by the Governor's Mercury in Fish and Wildlife Task Force that the flooding of farmlands in the Everglades watershed could create conditions that would favor the methylation of mercury released from oxidized peat soils. As a consequence, State and Federal permits for the ENR Project contain extensive mercury monitoring and research requirements. Interim authorization to discharge was received from the U.S. Environmental Protection Agency (USEPA) in August 1994 while the mercury-related challenges from the EC, the MIT, and the SCGC were heard. These challenges are still pending.

The results of the first two years of mercury mass balance and bioaccumulation studies demonstrate that the ENR Project removed between 50 and 75 percent of the total mercury (THg) load and about 75 percent of the methylmercury (MeHg) load entering through the inflow pump. The flow-weighted annual average outflow concentration of THg was about 1 ng/L, much less than the Florida Class III Water Quality Standard of 12 ng/L. The age-adjusted mean concentrations of THg in age class 3 largemouth bass from the ENR Project interior and outflow are significantly lower than the Florida action level of 0.5 mg/Kg and the fish collected from the L-7 canal reference site. Mercury concentrations in ENR Project sediment appear to be decreasing rather than increasing with time. Results of the first two years of studies in the downstream marshes indicate that hydrology and water chemistry unrelated to TP are likely to have a more significant impact on mercury methylation and bioaccumulation than TP and that, even if the nutrient effect occurs, it is likely to be offset by reductions in THg and MeHg loads from the operation of the STAs. Thus, all three categories of mercury-related challenges have been adequately addressed, ensuring that the ECP will go forward as scheduled. Because it has been determined that more than 95 percent of the mercury entering the Everglades is from atmospheric deposition, the research effort will now place greater emphasis on assessing the benefits of local and regional controls of mercury sources while continuing process-level research and model development and testing.

Acknowledgements: The District's ENR Project mercury studies are being performed under a Cooperative Agreement (FDEP SP335/SFWMDC-6663/4) with the FDEP. This includes a $219,242 matching grant from the USEPA Region 4 and in-kind services for mercury analysis by FDEP. Process-level biogeochemical and bioaccumulation research is being performed by or for the U.S. Geological Survey (USGS), USEPA's Office of Research and Development (ORD), the Wisconsin Department of Natural Resources (WDNR), and the District. Fish spatial studies are being conducted by the Florida Game and Fresh Water Fish Commission with District and FDEP support. The District is providing logistics support to USGS, USEPA, and WDNR under an agreement with USGS. The scoping-level mercury marsh and bioaccumulation models are being developed by USEPA's ORD with District input. The Florida Atmospheric Mercury Study (FAMS) was funded primarily by FDEP, the Electric Power Research Institute, and the Florida Power and Light. The District sponsored an ENR FAMS site. Air source and deposition studies are being conducted by USEPA and FDEP with

industry cooperation. From 1994-97 the District collected biweekly samples at seven structures for USEPA Region 4.

31. The Effects of Mechanical Harvesting of Floating Plant Tussock Communities on Water Quality in Lake Istokpoga, Florida

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The effects of harvesting floating plant tussock communities by mechanical methods on selected water quality parameters in Lake Istokpoga, Florida were examined. Dissolved oxygen, temperature, pH, conductivity, turbidity, chlorophyll a, and nutrients (nitrogen and phosphorus) were compared under pre-harvest, harvest and post-harvest conditions. Water quality data were compared between one tussock harvest site and three reference sites (30m, 61m, and 91 m away from the harvested plot). Very minor, although statistically detectable ($p<0.05$) DO differences occurred at harvest site. Chlorophyll a, total nitrogen and total phosphorus concentrations decreased significantly during the harvest. Loadings of total nitrogen concentrations in Lake Istokpoga could be reduced by harvesting of floating plant communities in the littoral areas. A significant increase in turbidity and dissolved solids occurred during mechanical harvesting in both the harvested plot and the reference site 30 m away.

Harvesting by mechanical means at Lake Istokpoga reduced the total floating tussock biomass significantly in the test plots. This is consistent with reported effects of harvesting by other studies. Multiple harvesting has shown some promise for increasing the possibility of long-term control of aquatic vegetation. This test at Lake Istokpoga was conducted under operational conditions and there is no reason to believe that results would not apply to larger tussock removal projects. Given the plant density harvested, it seems likely that the turbidity effects observed up to 30 m from the harvesting are likely to result from such harvesting for other commonly performed small area harvesting operations. The harvesting need not be a weapon of destruction, but a tool to build more useful and diverse aquatic systems.

32. Using GPS to Survey Aquatic Plants

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Reedy Creek Improvement District (RCID) Environmental Services Laboratory surveys aquatic vegetation annually for the purpose of monitoring aquatic plants. Aquatic plants are surveyed in the field by boat. In the past, the locations of aquatic plants were designated on aerial maps by hand using letters to symbolize each plant species. In the lab, transfer lettering was used to produce the finished map. The function of transferring each letter onto a mylar aerial map and copying the finished map onto bluelines for distribution was a time-consuming process. More recently, vegetation data was digitized into a geographical information system to produce more professional looking maps.

A custom interface was designed for the annual aquatic plant mapping project utilizing ArcView, a Geographical Information System (GIS), and the Direct Global Positioning System (GPS) for ArcView. The Aquatic Plant Module consists of two major components: a mobile field application with a pen tablet to collect data; and database administration using a personal computer (PC). Database subsets are easily uploaded to the pen tablet for access in the field. During field collection, the Aquatic Plant Module displays a map of the selected lake system and the GPS location on that map. The GPS location uses fixed satellites, and is more accurate than assuming the location on the aerial maps. A quadrant of the lake can be selected and the module displays approximately 3 m. by 3 m. (10 ft. X 10 ft.) cells for inspection. The program allows the species or common names of plants found in that quadrant to be selected. Primary, secondary and tertiary plants may be selected and entered for each cell. Field surveys using GPS requires more man-hours than the method previously described, but this time is offset by the time saved in the lab.

Upon return to the lab, the data is downloaded from the pen tablet to the PC. The main database is updated, and data analysis and mapping of the aquatic plants takes place. The aquatic plant database may be queried, viewed and mapped using the ArcView software. At present, this software is being used by RCID to map aquatic vegetation found within the 27,000 acre Reedy Creek Improvement District. Software and hardware challenges (particularly random access memory) had to be addressed during the initial test period in 1996. Initially, this process has taken more time than the old method because debugging was required. However, after debugging, the actual mapping portion of the Aquatic Plant Module will dramatically reduce the time required to produce the vegetation maps in the lab.

GIS will provide much more information than simple vegetation maps. The aquatic plant database can be compared to the data in the laboratory database (such as nutrient concentrations and fish population data), as well as to county and state databases. Population data, land use, roads, lake systems and other county and state databases may be linked geographically to the aquatic plant database. The ability to easily analyze trends over space and time, and to compare the aquatic plant database to other databases makes the GIS system more valuable than the vegetation maps of the past. Therefore, although the extra time in the field may negate the time saved in the lab, the finished product provides more usable information.

33. Economic Fishery Valuation of Vegetation Communities in Lake Okeechobee Florida

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Increases in the demand for water and its uses have led to a number of problems associated with aquatic system management in Lake Okeechobee and other water bodies throughout Florida. Eutrophication, which is accelerated by excess nitrogen and phosphorus loading, and the stabilization of water levels has resulted in changes in water quality, aquatic macrophyte assemblages, and fish community dynamics. Native aquatic macrophytes are especially sensitive to these changes and are often displaced by undesirable exotic and invasive native plant species. Resource managers must balance the advantages and disadvantages of both native and exotic vegetation communities and determine management strategies that may affect the health of native vegetation communities.

Water managers often place a monetary value on an acre-foot of water within a system in terms of the water's agricultural and urban uses outside the system and then employ these values to justify the need for regulation of water level regimes and other changes to the water system. An economic value of about $500 is placed on an acre-ft of water in Lake Okeechobee as that water is used in the Everglades Agricultural Area. Wegener and Holcomb (1972) recognized the need for assigning monetary values to natural resources within the system, such as its fishery, that are dependent on water resource demands of that system. Determination of economic value of aquatic vegetation from recreational, commercial, and ecological standpoints allows biologists to express fisheries data in terms of economic worth when considering water-use policies. To that end, we described a method of economic fisheries valuation and defined those values for vegetation communities abundant in Florida.

Vegetated areas of Lake Okeechobee were sampled with block nets (0.08 hectare) and Wegener rings (4.0 m^2) from 1989 - 1991 to estimate fish abundance and biomass. Vegetation types included Illinois pondweed (*Potamogeton illinoensis*), hydrilla (*Hydrilla verticillata*), eel-grass (*Vallisneria americana*), bulrush (*Scirpus californicus* and *S. validus*), and yellow water-lily (*Nymphaea mexicana*). Data were used in conjunction with economic impact data of known-cause fish kill events, Rule 17-11.01 (Animal Damage Valuation), Chapter 403, Florida Statutes (using guidelines specified by the American Fisheries Society Pollution Committee), to estimate monetary fishery values of these vegetation communities. These values provide market prices for all species of fresh water fishes, assuming a live fish has equal value of a fish killed in a pollution event. Economic value, expressed as total impact in US dollars per hectare, was calculated by adding the replacement value, recreational value, and commercial value for each fish species. All economic values were expressed in US dollars per hectare.

Mean total impact values per hectare of vegetated area ranged from $44,626 for Illinois pondweed to $59,738 for hydrilla. Replacement economic values made up at least 88.9%

of the total impact value in the valuation of all vegetation types. Recreational values per hectare of vegetated area ranged from $447 for eel-grass to $5,378 for bulrush. Commercial values contributed nominally to the total impact values, constituting no more than 0.06% in the valuation of each vegetation type. Fish species that provided the greatest economic value were bluefin killifish (*Lucania goodei*), eastern mosquitofish (*Gambusia holbrooki*), bluegill (*Lepomis macrochirus*), largemouth bass (*Micropertus salmoides*), and redear sunfish (*L. microlophus*).

Each vegetation community examined as a whole unit had similar ecological worth as measured by replacement value; however, monetary values of individual fish species demonstrated differences in the ecological and recreational values of each vegetation community. The high replacement values of non-game forage species, such as the cyprinodontids and poecilids, in all vegetation communities reflect their importance to the ecology of the vegetated littoral zone. Eel-grass and Illinois pondweed provided valuable habitat for juvenile game and forage fishes. Yellow water-lily, which grows in stagnant, poor quality water, served as important habitat for poecilids and other environmentally tolerant fishes that serve as forage for fish and wildlife species. Bulrush, hydrilla, and Illinois pondweed account for the majority of the recreational fishery value (primarily from largemouth bass and bluegill). Bulrush recreational impact value was over 4 times greater than other vegetation communities and indicates its importance as game fish habitat.

Economic valuation validates the importance of vegetated littoral areas to this lake and other lakes' fisheries and ecological existence. The 4 native vegetation communities, with 5,786 ha of areal coverage on Lake Okeechobee, totaled over $283 million in total economic value and $21 million in recreational economic value. Hydrilla, the primary submerged exotic vegetation species in Lake Okeechobee with an areal coverage of 3,348 ha, accounted for $200 million in total economic value and $4 million in recreational economic value.

Development of economic fishery values quantifies the role of vegetation communities as fish habitat and enables scientists to express fisheries dynamics in terms the general public can more easily comprehend. Management implications of this economic fishery valuation technique include, but are not limited to: expression of fisheries data in more public-friendly monetary terms, counterbalance against claims of water's economic value outside the system when changes in water and habitat management within the system are being considered, mitigation of habitat loss due to development or destructive water management practices, and justification of economic benefits due to aquatic vegetation restoration.

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34. Evaluation of Alternatives for the Control of Invasive Exotic Plants in Lake Jackson

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Between 1987 and 1996, seven treatments using the herbicide fluridone (trade name Sonar) were conducted in Lake Jackson to control a hydrilla population which threatened to overwhelm the lake. Concerns were raised, however, about potential environmental effects of these treatments and whether the expense of the program was justified. Additionally, it has been suggested that alternative control strategies may offer comparative advantages. This document characterizes the problem of invasive exotic plants as it relates to Lake Jackson, describes alternatives available for addressing the problem, suggests criteria by which the alternatives can be evaluated, and offers an evaluation of the alternatives. The evaluation uses three broad criteria:

· environmental effects;

· human benefit; and

· cost.

This assessment is based primarily on existing literature and discussions with a number of individuals with expertise in aquatic plant management and the Lake Jackson system. Because some evaluation criteria are inherently intangible, and because prioritization of criteria may require value choices, the evaluation offered is not suggested to be final or conclusive, but rather is intended to provide a basis with which policy-makers and the interested public can weigh alternatives and achieve an acceptable consensus.

Several species of invasive exotic plants present in Lake Jackson are capable of adversely affecting environmental resources and associated human benefits. Uncontrolled invasive plant populations may displace native plants, eliminate open water, reduce functional space within the water column, and alter the natural benthic environment. The most troublesome of these plants in Lake Jackson are hydrilla (*Hydrilla verticillata*), waterhyacinth (*Eichhornia crassipes*), and alligatorweed (*Alternanthera philoxeroides*). Alligatorweed and waterhyacinth populations have been effectively and economically controlled using biological control agents and limited maintenance spraying, respectively. The hydrilla population, on the other hand, increased dramatically in the mid-1980s and has since been controlled only by a large-scale herbicide program. Additionally, a terrestrial species, Chinese tallow (*Sapium sebiferum*), is spreading prolifically throughout the floodplain and watershed. This adaptable tree, introduced as a landscaping ornamental, threatens to outcompete and ultimately displace many native tree species in the wetlands and uplands of Lake Jackson's watershed and has thus far not been effectively controlled.

Lake Jackson has long provided a recreational and aesthetic amenity for the people of Leon County. Additionally, its reputation as an outstanding largemouth bass fishery has attracted visitors from throughout the country. The lake has historically been ecologically productive and diverse, and it continues to provide important habitat for fish, invertebrates, waterfowl, reptiles, and amphibians. Since the 1950s, however, populations and coverage of aquatic macrophytes have expanded substantially. Adverse effects of invasive plants realized since Lake Jackson’s hydrilla population practically exploded in 1986 include:

· the displacement of submergent native plants from much of the lake's benthic habitat;

· seasonally reduced open water;

· hindered recreational activities;

· degraded residential and recreational aesthetics; and

· effects on fish and benthic invertebrate populations.

All state hydrilla and waterhyacinth control activities in the lake ceased in October 1995. Through 1993, the costs of these activities were shared by Florida Department of Environmental Protection (DEP) and the U.S. Army Corps of Engineers (USACE). Leon County contributed half the cost of the herbicides used in 1994. Recently, however, DEP determined that no more state funds may be used for aquatic plant management in Lake Jackson. This determination was based upon Section 369.22 (3), Florida Statutes, which makes aquatic plant management in intracounty waterbodies the responsibility of local governments or special districts. Thus, it is evident that aquatic plant management in Lake Jackson will remain largely dependent on the resources and decisions of local government.

Several alternatives for the control of hydrilla are considered: resuming herbicide applications, stocking triploid grass carp (*Ctenopharyngodon idella*), mechanical harvesting, and no action. None of these alternatives, however, can be implemented without substantial monetary expenditures and/or environmental impacts. This lack of a truly satisfactory alternative, unfortunately, appears to be an unavoidable characteristic of the problem. A fluridone treatment program would be perpetual, may facilitate the cycling of nutrients within the system, and may contribute to sediment destabilization and habitat alteration. Mechanical harvesting would be extremely expensive, also perpetual, would cause direct losses to native animal and plant populations, and would likely release hydrocarbon pollutants. Stocking grass carp may severely impact or eliminate native plant communities and cause associated impacts to water and sediment quality and fish and wildlife.

Biological control (other than grass carp) and utilization of future natural lake drawdowns for aquatic plant management are also considered and discussed. These alternatives, however, are currently incapable of providing reliable, predictable, or consistent hydrilla control and are therefore not included in a comparative evaluation with the other alternatives. Biological control, primarily using insects imported from native ranges of target plants, has proven highly effective against alligatorweed, but has thus far demonstrated very limited utility against hydrilla and waterhyacinth. Lake drawdowns may be exploited through such activities as removal of enriched sediments, plant biomass, and other organic material, potentially resulting in effective short-term invasive plant control. The extent, timing, and frequency of these naturally-occurring events, however, are uncontrollable for Lake Jackson. If they become feasible, drawdown and biocontrol strategies may be implemented experimentally as part of an integrated plant management effort.

It is important to note that none of the aquatic plant management alternatives discussed address what is commonly considered the underlying cause of most of Lake Jackson’s problems: excessive anthropogenic nutrient enrichment. Aquatic macrophyte (native as well as exotic) coverage has increased considerably over the last several decades primarily because of this enrichment. Considerable consensus exists that a comprehensive restoration of Lake Jackson’s environment, including exotic plant control, requires a substantial reduction in the flow of nutrients now entering the system via urban stormwater runoff. Additionally, because pollutants released over the past several decades remain in the sediments and plant biomass of this closed basin, it would be helpful if nutrient-enriched sediments and plant biomass were removed during future lake drawdowns. Long-term control of invasive aquatic plants therefore depends on the level of public commitment that is made to protecting and restoring the lake and must be evaluated in the context of overall lake management.

Achieving a consensus about aquatic plant management requires that priorities be clearly identified. Possible objectives of minimizing cost, preserving native aquatic habitat, and maintaining the system for diverse human benefits do not individually suggest the same alternative. A fluridone program, along with continued maintenance control of waterhyacinth, appears to be the only alternative now available which can potentially maintain both native plants and human benefits. Such a program requires a continuing financial commitment, possibly occasionally reduced if lake drawdown or experimental biocontrol activities become feasible. No action, on the other hand, would require no public or private financial commitment. The costs of this alternative would include loss of human and environmental benefits historically provided by the lake. A modified grass carp program could maintain open water and possibly result in some savings over fluridone. This alternative, however, could potentially profoundly alter the system by eliminating most aquatic plants, including natives. Large-scale harvesting is likely to be beyond the financial resources available and may result in some direct environmental impacts. Whatever method is employed, it is important to consistently pursue maintenance control. Increased costs and adverse environmental impacts would probably result if control activities lapse and then resume years later, allowing hydrilla and/or waterhyacinth populations to significantly expand in the interim.

35. Topographic and Volumetric Analysis of the Everglades Nutrient Removal Project Using a Geographic Information System

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The Everglades Nutrient Removal Project is a 3700-acre constructed freshwater wetland that is designed to remove excess nutrients, particularly phosphorus, from agricultural storm water runoff before it enters the Florida Everglades. The primary method of phosphorus removal is expected to be nutrient uptake by rooted and floating vegetation, and the subsequent deposition of peat as the vegetation dies and decays (Guardo et al. 1995).

South Florida Water Management District scientists hypothesize that the hydraulic loading rate, defined as the input volume of water per unit surface area, and mean water depth, may determine the efficacy of phosphorus removal (Guardo et al. 1995). To insure accurate water volume and water depth estimates, a geographic information system was used to create a three dimensional topographic model, also called a digital elevation model, of the Everglades Nutrient Removal site. Each cell in the project area was modeled separately, then all the cells were merged together to create a composite surface model of the area. The topography was modeled using a triangulated irregular network generated from a set of approximately 500 surveyed spot elevations. A triangulated irregular network is a vector data structure, specifically designed to model continuous surfaces, that consists of triangular plates derived from a Delaunay triangulation of non systematic sampling points (Burrough 1986). This data structure retains all the input data values and uses linear interpolation to estimate elevations that fall between surveyed data points.

The results of the analysis were compared with an earlier effort to model the site using fewer surveyed data points and a raster data structure. The large number of data points available for this analysis, and their even spatial distribution, resulted in the construction of an acceptable surface model(Clarke 1995). The current vector analysis indicates that the Everglades Nutrient Removal site has approximately 1700 acre-feet of additional water storage capacity when water surface elevation (stage) is maintained between 10.0 ft. and 14.0 ft. NGVD. This new estimate of storage capacity will allow District hydrodynamic modelers to refine their hydraulic loading rate calculations, optimizing the P removal efficiency of the Everglades nutrient Removal Project.

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36. Revitalizing the Headwaters: A Critical Link in the Restoration of Ecological Integrity of the Kissimmee River

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The Central and Southern Florida Flood Control Project modified the physical configuration, hydrology and ecology of both the upper and lower Kissimmee River basins. The Kissimmee River and floodplain were channelized and transformed into a series of impoundments, while the river's headwater lakes were connected by canals and divided into water storage reservoirs with water control structures that regulate lake stages and discharge regimes according to flood control schedules and operation rules.

The broad array of environmental impacts resulting from the flood control project provided the impetus for a restoration initiative that led to a comprehensive plan for restoring the ecological integrity of the river/floodplain ecosystem. Due to impacts of flood control regulation on the hydrologic characteristics of the basin, particularly discharge regimes, restoration of ecological integrity requires a watershed perspective. Restoration will be accomplished through dechannelization of the central 35 km of river/floodplain ecosystem and reestablishment of historic stage and discharge characteristics in the headwater basin. This presentation discusses the development and contributions of the headwaters component of the restoration plan.

37. An Approach to Evaluating Surface-Groundwater Interactions: A Field Study of the Kissimmee River Restoration Area

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Although channelization of the Kissimmee River succeeded in providing flood control protection for the region south of Orlando, it drastically altered the river's hydropattern and profoundly impacted wildlife and fish habitat in the river-floodplain ecosystem. The Kissimmee River Restoration Project will partially restore the 103-mile meandering river that existed prior to its conversion to the C-38 flood control canal.

Low dissolved oxygen concentrations are the principal water quality problem within the channelized system. During summer and fall months, DO concentrations commonly fall below 2 mg/L throughout the water column. These low levels are stressful, if not lethal, to most fish and invertebrate species (Toth 1993). They also appear to be leading to long-term degradation of the system's remaining fishery resources by limiting production of intolerant game fish species and shifting the competitive environment in favor of tolerant and less desirable species like gar and bowfin (Florida Game and Fresh Water Fish Commission 1991, and Miller 1992; cited in Toth 1993).

A study by Belanger et al. (1994) showed that groundwater inputs to C-38 can adversely affect DO concentrations in the canal under certain hydrologic conditions. The deep prism of C-38 allows large inputs of groundwater, especially at the upper ends of the canal's five pools, where large head differences can develop between the canal's water level and the groundwater table at low canal stages. Levels of ammonium-nitrogen, BOD, and COD in this groundwater are high enough to represent a significant oxygen demand via seepage or interflow, and could contribute to DO sags during the warmer months. After restoration, groundwater should have less influence on the river's water quality. By establishing a more natural hydrologic regime and channel morphometry, the restoration project is expected to lead to improved dissolved oxygen regimes.

As part of the restoration project's evaluation program, water quality studies include monitoring of DO in the river and restored floodplain, and analysis of factors that affect oxygen balance under existing and future conditions. To understand the factors affecting DO, a study was designed to examine the influence of the surficial aquifer on the canal and remnant river channels, and the effect of restoration on this interaction. For this study, a long-term, groundwater monitoring network has been established on the Kissimmee River floodplain. Groundwater flow and quality will be monitored in the middle reach of the river to determine how surface-groundwater exchange is affected by restoring the river's natural, historic flow-path. In this section of river, where canal backfilling and river channel restoration will begin in 1999, groundwater-producing zones will be monitored continuously at four sites along C-38 and the remnant river channels. In the river's upper reach, the canal will remain unaltered to maintain the current level of flood protection. Two additional sites will be monitored in this upper reach to allow comparisons with the sites downstream in the restored area.

Each site consists of a transect of six to ten shallow wells ranging in depth from 4 ft to 115 ft. Water levels in these wells will be recorded with pressure transducers and datalogging equipment. Water quality (DO, specific conductance, temperature, pH) will be monitored continuously in some wells. Other equipment will be deployed to measure stage and water quality in the adjacent channel, seepage into the channel, and local rainfall. Additional water quality sampling will be conducted for phosphorus, nitrogen, organic carbon, sulfide, iron, manganese, BOD, Eh, and various ions.

Water level measurements from the monitoring wells will be used in conjunction with canal stage and permeability data to estimate seepage through flow-net analysis. Permeability data will be estimated through a combination of: slug testing of monitor wells, direct measurement of split-spoon samples, and grain-size analyses. Seepage estimates from the flow net analysis will be compared to direct methods of measuring groundwater flux using seepage meters and temporary piezometers placed in the channel. Preliminary examination of material obtained from the wells indicates that an upper permeable zone (0-22 ft) overlies a semi-permeable confining layer (22-60 ft). Underneath the confining layer is another permeable zone that is under flowing artesian pressure. An upward gradient exists that could contribute groundwater to C-38 and the remnant river channels. The excavation of C-38 has almost certainly increased groundwater/surface water interactions. This field study should be able to document the decreased groundwater discharges to surface water that are anticipated with the restoration of the more natural hydrologic regime and channel morphometry.

The experience gained from this work should be relevant to other situations where knowledge of surface-groundwater exchange is important to the management of Florida lakes and streams.

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38. Fisheries of the Channelized Kissimmee River (Florida)

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Prior to channelization, the Kissimmee River was composed of a meandering, channel that flowed 166 km between Lake Kissimmee and Lake Okeechobee, Florida. The river was a highly productive riverine/wetland system augmented by a 1.5 to 3.0 km wide floodplain that became linked with the river during periods of high discharge. As a part of a larger flood control project for central and southern Florida by the USCOE in the 1960's, the Kissimmee River was channelized into a 80-km box-cut canal (C-38) separated into five stair-step impoundments. Channelization and associated hydrologic changes of the Kissimmee River resulted in loss of 13,000 hectares of wetlands and 55 km of river channel habitat. Remaining river channels and backwater habitats rapidly degraded as lack of water flow caused accumulation of organic sediments, encroachment of dense vegetative growth, and dissolved oxygen lags during summer and fall.

In an effort to return the river to a more natural condition, the U.S. Congress passed the Water Resources Development Act in 1992, which authorized Kissimmee River restoration. The proposed restoration project, which will begin construction in 1998, includes backfilling 35 km of C-38 canal, recarving 14 km of river channel, removing 2 water control structures, and leveling berms along the canal. The plan will, in theory, restore flow regimes to historic river channels and recreate seasonal water fluctuations onto the floodplain.

In order to evaluate the river's fishery under channelized conditions, fish communities were sampled with electrofishing gear. Study parameters included species composition, relative abundance, and size structure of selected species. Gear consisted of a 5.5-meter jon boat outfitted with a 5-kilowatt generator, Coffelt electrofishing unit (Model #VVP-15), and cable electrodes. Pulsed AC current was utilized. Fish were separated by species, counted, and weighed. All fish species, except Florida gar (*Lepisosteus platyrhincus*) and bowfin (*Amia calva*), were measured to the nearest mm (total length; TL). Mean catch per unit effort (CPUE) values, fish/min and g/min, were calculated for individual species and all species combined. Percent frequency distributions by 2-cm length groups were calculated for important game fish species, bluegill (*Lepomis macrochirus*), redear sunfish (*L. microlophus*), and largemouth bass (*Micropterus salmoides*).

Forty-three fish species representing 17 families were collected from 1987 to 1995. Fish assemblages were indicative of moderate quality habitat accentuated by stabilized water levels, negligible flow, and seasonal dissolved oxygen lags. Dominant species included Florida gar, bowfin, eastern mosquitofish [*Gambusia holbrooki*] (tolerant of low dissolved oxygen/stagnant water conditions), bluegill, largemouth bass, and redear sunfish (adapted to lentic environments). Length-frequencies for bluegill, redear sunfish, and largemouth bass were indicative of low numbers of harvestable-size fish.

Catch rate comparison by impoundment area (pool) revealed Pool B, the only pool to be partially restored (flow diversions in remnant channels and water level fluctuations), had highest abundances of restoration-desirable species (largemouth bass, bluegill, redear sunfish, warmouth [*L. gulosus*], spotted sunfish [*L. punctatus*], and dollar sunfish [*L. marginatus*]). Pools A and C, impoundment areas which have undergone the greatest degradation, had the lowest abundance and biomass values for centrarchid species.

Restoration of a functioning floodplain with reconnection of the floodplain to the river channel is essential for restoration of all components of the riverine floodplain ecosystem, including the channel littoral area and broadleaf marsh, wet prairie, and wetland shrub communities. Interactions between the channel and floodplain, reestablishment of complex floodplain habitat, enhanced densities of forage fish and aquatic invertebrates, and improved dissolved oxygen availability, all of which are dependent on reintroduction of historic flow regimes and amelioration of channel habitat, are essential factors for restoration of the Kissimmee River's fisheries. The absence of minimum flow throughout the year and a more natural hydrologic scheme that results in water level fluctuations throughout the river floodplain is the greatest hinderance to the reestablishment of healthy fish and wildlife populations. Fish communities will not change until hydrologic conditions and the entire ecosystem approach historical conditions.

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39. Preparing And Using Shared Vision Models For The Apalachicola-Chattahoochee-Flint Watershed

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The Apalachicola-Chattahoochee-Flint watershed lies in the southeastern United States covering nearly 20,000 square miles. About three-fourths of the basin lies in the state of Georgia and the balance is split nearly evenly between the states of Alabama and Florida. The watershed empties into the Gulf of Mexico and spans a diverse array of landscapes ranging from the Appalachian Mountains to the Piedmont to the Gulf Coastal Plain.

The Apalachicola River is the lower segment of the basin and is formed by the joining of the Flint and Chattahoochee rivers at the Florida border. It empties into Apalachicola Bay. The Chattahoochee River begins just below the North Carolina border and flows past Atlanta to the Alabama/Georgia border and follows the border (actually vice versa) to where it meets the Flint. Waters in the Chattahoochee originate primarily from surface runoff and the basin has 14 reservoirs: some privately owned and some federally owned. The largest of these, Lake Lanier, has about two-thirds of the conservation storage capacity of the basin but impounds only 10 percent of the basin. Consequently, the watershed is capable of being highly regulated in its upper reaches but not in its lower reaches.

The Flint River originates just below the City of Atlanta, flows over the fall line and then through the karst region of southwest Georgia until it meets up with the Chattahoochee. There are no storage reservoirs on the Flint and there is a significant ground water contribution to its base flow. The groundwater which flows into the Flint is used extensively for agricultural irrigation in southwest Georgia.

People use the waters of the basin for diverse purposes. These range from reservoir-based recreation and fishing in the upper reaches to hydropower production at locations throughout the basin to water supply and wastewater dilution for the Atlanta metropolitan area. The basin is also used for water-based commerce in the lower segments of the river. In Florida the prominent uses are natural resource-based including a seafood and tourist industry associated with its estuary.

Because of the abundant rainfall there has been a widespread perception in the region that there was ample water for all needs in the future. Several droughts in the 1980s began to change this perception. In 1989 the Corps of Engineers proposed to reallocate water in storage at Lake Lanier from hydropower releases to municipal supply for Metropolitan Atlanta and released revised reservoir control manuals for the federal reservoirs in the basin. The State of Georgia also was actively pursuing a regional reservoir construction program to further secure the Atlanta region's long-term water supply needs. This program included the proposed construction of a regional reservoir in the Alabama-Coosa-Tallapoosa basin just before the Alabama border. The State of Alabama reacted to this situation by suing the Corps for failure to comply with the National Environmental Policy Act. Florida was poised to join Alabama in this suit and Georgia to join the Corps and the so-called "Water Wars" were about to begin and the perception of abundant water changed.

The parties ultimately chose to address their differences through a negotiated agreement rather than through litigation. Critical aspects of the negotiated agreement include provisions which called for the states to consider creation of an interstate coordinating mechanism to deal with water resources issues and the conduct of a long-term comprehensive water resources study of the basin. The agreement pertained to both the Apalachicola-Chattahoochee-Flint (ACF) and Alabama-Coosa-Tallapoosa (ACT) basins Although the balance of this paper focuses solely on the prior basin, a parallel and connected process is also ongoing for the ACT basin.

With regard to the interstate mechanism, as of March 1997, the Alabama and Georgia legislatures ratified language establishing a river basin commission and it is anticipated that identical legislation will be passed by Florida by the end of April. The same legislation must then be passed by the U.S. Congress for the commission to be created. A key provision in the legislation calls for the establishment of an allocation formula for the waters of the basin. Failure to adopt such a formula by December 1998 will result in the commission terminating. The Comprehensive Study has led to both the collection of data essential for developing an allocation formula and to the development of tools which can be used to evaluate the data and estimate potential impacts from alternative management and usage scenarios, as well as adoption of the commission.

One of these tools which should prove to be crucial to this process is called a shared vision model. The ACF shared vision model is simply a representation of reality which was jointly developed by the three states and the Corps of Engineers. In this case, the model is simulation of river flow in the ACF basin. The shared vision model process is distinguished from typical model development processes in that key stakeholders and decision-makers are provided the opportunity to be involved in development of the tool rather than being presented a tool which was developed in isolation by technical experts. The intent is that through more intimate involvement in tool development the probability that the tool will be used to make management decisions are enhanced.

From Florida’s perspective, the intent in developing this tool was to have a model which 1) provided a good representation of the basin, 2) which was highly flexible so it could be used to evaluate a broad range of management and demand scenarios and 3) which was accessible to a broad range of users and interest groups.

Key interests which have been integrally involved in developing this model include representatives of each state, representatives from the Corps of Engineers, representatives of hydropower interests and metropolitan Atlanta. Other interests have been involved to a lesser extent. The involvement of such a diverse group in model development has helped to ensure that the model does not provide results which are biased in favor of one interest group. Florida has taken steps to coordinate model development with a group of Florida stakeholders to both get their input and help ensure that a broader range of people will be able to utilize the tool once its development was completed. This group has met on a monthly basis for the past several years.

The shared vision model of the Apalachicola-Chattahoochee-Flint basin was developed as a tool which allows people to evaluate alternative management options and demand scenarios from a basinwide context. It is focuses predominantly on water quantity issues and utilizes a monthly time-step. The basin was divided into broad reaches. Individual withdrawals and returns were assigned to reaches by state representatives as was seen to be appropriate. The demands and withdrawals for each reach were then aggregated for usage in the shared vision model. Forecasts of future demands were made by an independent consultant.

The shared vision model is intended to be used for the screening of a broad array of water management alternatives with the hopes of developing a more manageable set of well defined options. These options will then be evaluated through other models which have been developed at a more refined level. HEC-5, for instance, will be used to evaluate alternatives at a daily time step if their evaluation through the shared vision models suggests such an evaluation is warranted. The shared vision model uses two computer software platforms: Stella and Excel. Stella is an object-oriented program which is used to calculate flows at various checkpoints once demand scenarios and management options are defined. The graphical interfaces provided with this program allow users to easily set a variety of parameters.

Florida has taken several additional steps to improve access of stakeholders and decision-makers to model results. Output data has been translated from absolute values into difference statistics. Decision-makers can thereby readily interpret the changes from the historical patterns instead of being forced to review absolute numbers without the relationships being clarified.

The shared vision model provides water users, managers and decision-makers with an opportunity to proactively determine the future use of the ACF system. The tool can be used to create a common understanding of the demands on the system and the impact of those demands while at the same time providing an opportunity for a greater understanding and awareness of the various interests of the involved parties.

40. The Wakodahatchee Wetlands, Palm Beach County, Florida

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The Palm Beach County Water Utilities Department (PBCWUD) recently converted nine existing wastewater percolation ponds into constructed treatment wetlands at the former site of the System 3 Regional Utility. Appropriately, the wetlands have been renamed the Wakodahatchee, or Seminole for "created waters".

Originally conceived in 1992 as a demonstration of the beneficial reuse of reclaimed water, the Wakodahatchee Wetlands have been designed to: reduce PBCWUD reliance on deep injection well (DIW) disposal of effluent; create significant wildlife habitat accessible to the public in a park-like setting; maintain biological diversity and open space in a highly developed landscape; recharge local water supplies through infiltration to the surficial aquifer; establish treatment wetland design criteria and experience within the County; and provide limited public use for passive recreational activities.

The Wakodahatchee Wetlands are an important aspect of the 15-million gallon per day (mgd) Phase II expansion nearing completion at the South Region Water Reclamation Facility, which has a current capacity of 15 mgd. The County currently disposes of the treated effluent by DIW. Specific Condition No. 4(b) of FDEP Permit No. CD 50-254576 for the Phase II expansion included the construction of created wetlands in the list of effluent disposal facilities to be permitted. The Wakodahatchee Wetlands are located west of Delray Beach at 13026 Jog Road, Delray Beach, 33484, about 1 mile east of the county's South Region Water Reclamation Facility (SRWRF), midway between Boynton Beach Boulevard and Atlantic Avenue, just west of the Delray Villas subdivision.

Design, Performance and Operation

In limited operation since 1972, the percolation ponds at the former System 3 Regional Utility were modified between November 1995 and October 1996 at a cost of $2.85 million into eight emergent marsh wetlands, interspersed with broad areas of open water and islands of wildlife habitat. Wetland area totals 39 acres, with individual wetland cells ranging from 2.3 acres to 10.9 acres. Most of the marsh area is designed to operate at an average depth of 0.5 foot, but may be operated normally at depths to 1.5 feet. Total volume of water within the wetland is ~20 million gallons at the normal pool elevation. The average length to width ratio is ~3:1. The total site hydraulic loading rate varies from 0.9 cm/d at flows of 0.5 mgd, to 4.6 cm/day for flows of 2 mgd. Nominal detention time varies from a maximum of 40 days at 0.5 mgd of flow to 10 days at 2 mgd. A total of 28 deep zones and 8 habitat islands are included. Snags and perching posts were added for wildlife use.

Secondary effluent is pumped from the SRWRF to a splitter box, which distributes the flow to six parallel ponds. Effluent from Ponds B, C, D, E and F flows to a collector channel and then to terminal collector Pond I. The sixth parallel pond (AG) discharges in series to Pond H, which in turn discharges to Pond I. All wetland effluent is then pumped to an on-site DIW for disposal during the first year of operational monitoring. Pending FDEP approval, the treated wetland effluent will be discharged to the adjacent L-30 Canal for surficial aquifer recharge. About 70% of the wetland area is vegetated by native emergent, forested, and transitional wetland species designed to emulate native south Florida wetland plant communities. Emergent marsh zones are composed of bulrush, duck-potato, arrowhead, spikerush, fireflag, and pickerelweed. Herbaceous species planted at the upper edge of the marsh zone include sawgrass, Fakhahatchee grass, and Gulf muhlygrass. Forested species also planted at marsh edge include cypress, pond apple, Carolina willow, red maple, and buttonbush. As expected, duckweed has become naturally ubiquitous throughout the wetland. Cattails were not planted and their anticipated colonization is being controlled. Native upland plant species have been planted on the site berms, and include dahoon holly, sabal palm, saw palmetto, cocoplum, live oak, mahogany, and slash pine. Melaleuca and Brazilian pepper were removed from the site prior to construction. A mile-long boardwalk was constructed with gazebos and informative signs for easy public access and educational use. Parking spaces are provided at the adjacent County complex.

Expected wetland performance was estimated using the first order, area-based model developed by R. Kadlec and R. Knight (CRC Press, Boca Raton, 1996). BOD, TSS, TN and TP are expected to be decreased to concentrations typically associated with advanced waste treatment. At inflow rates of 0.5 mgd, discharge parameter concentrations are expected to be reduced to background levels (~5 mg/L) for BOD and TSS, 2.0 mg/L TN, and 0.5 mg/L TP. At inflow rates of 1.0 mgd, parameters are expected to approximate similar background levels for BOD and TSS, but higher nutrient concentrations of 3.4 mg/L TN, and 1.6 mg/L TP. Initial monitoring results obtained in February 1997 match these expected values, despite the early stage in plant growth and cover. At an average wetland application rate of 1.2 mgd, wetland discharge concentrations averaged ~6 mg/L BOD, ~10 mg/L TSS, ~4 mg/L TN and ~1 mg/L TP. About 0.5 mgd of effluent is lost to infiltration and evaporation.

41. An Investigation of Periphyton Nutrient Limitation in the Marsh and Marsh/Open Water Interface Areas of Lake Okeechobee

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Periphyton may account for a significant portion of primary productivity in shallow lakes, where light can reach the lake bottom. Abundant macrophytes in shallow lakes also can increase the amount of colonizable area for periphyton. When periphyton becomes abundant, it may remove significant amounts of nutrients from the water column that may otherwise be available to phytoplankton. The large marsh and marsh/open water interface areas in Lake Okeechobee are places where light often penetrates to the bottom and macrophytes are abundant. In these areas, periphyton likely reaches maximal abundance and may be able to prevent or reduce the frequency of phytoplankton blooms (Phlips et al. 1993a, Havens et al. 1996).

Periphyton research has important lake management implications. Steinman et al. (1997) indicated that periphyton can seasonally account for a significant portion of the primary producer biomass in the marsh and marsh/open water interface areas of Lake Okeechobee. Their study examined physical and water column variables to characterize factors that coincided with periphyton biomass. However, no studies have assessed the role of nutrients in limiting periphyton biomass in Lake Okeechobee. The purpose of this research was to determine whether periphyton biomass, measured as chlorophyll a, was limited by nitrogen (N), phosphorus (P), or co-limited by both, in the marsh and marsh/open water interface areas of Lake Okeechobee. In addition, we examined the importance of nutrient limitation relative to station location and seasonality.

Stations were selected for study in the north, west and southern marsh/open water interface region. A fourth station was located deep in the western littoral marsh. A square 3’ X 3’ PVC frame containing 16 nutrient diffusing substrates and a light and temperature logger were placed at each site. The four treatments included: nutrient agar only (control - C), and nutrient agar spiked with either N, P or both N+P (NP) for final concentrations of 0.1M N and P. The agar was poured into clay pots, (approximately 155 mL internal volume) which served as the diffusing substrates. Four replicates of each treatment were positioned above each frame. The pots were incubated for 21 days at roughly 0.5m above the sediment surface of each station. The studies were repeated on a quarterly basis. The marsh/open water interface stations (north, west and south) were studied five times, while the marsh station was studied four times. Physical and chemical variables and phytoplankton biomass (measured as chlorophyll a) also were measured on a weekly basis during the three week incubation period. After retrieving the frames, periphyton were scraped from each pot and chlorophyll a concentrations were determined spectrophotometrically.

Statistical analyses indicated that all three factors, nutrient treatment, station location and seasonality were highly significant ($p<0.001$) in explaining the variability in periphyton biomass. Location had the most pronounced effect on periphyton biomass. The effect of station location on periphyton biomass was significant in 8 out of 12 possible comparisons between the stations. Periphyton biomass at the marsh and north stations was significantly higher than at the west and south stations.

The effect of seasonality on periphyton biomass was significant in 38 out of 80 possible comparisons (twenty comparisons for each station times four stations). Seasonality had the biggest effect on periphyton biomass at the north station and had no effect at the marsh station. The effect of seasonality on periphyton biomass was similar at the west and south stations.

Nutrients (usually N) limited periphyton biomass at the marsh station, while a combination of nutrients N and P and seasonal effects (including possible light limitation) co-limited periphyton biomass at the north station. Seasonal effects (possibly light limitation) and not nutrients appear to have limited periphyton biomass at the west and south stations. Nutrient limitation of the periphyton at the north and marsh stations during this study are consistent with results obtained for phytoplankton in the marsh/open water interface of Lake Okeechobee (Phlips et al. 1995b) and suggest that periphyton and phytoplankton are competing for nutrients in this region of the lake (Phlips et al. 1995a). Lack of nutrient limitation of the periphyton at the west and south stations during this study contradicts the results obtained for phytoplankton (Phlips et al. 1995a) and periphyton (Havens et al. 1996) in this region of Lake Okeechobee. Unusually high lake stage resulting in poor light penetration to the lake bottom throughout the study period may have contributed to the lack of periphyton response to nutrients at the west and south stations.

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42. Contribution of Roosting Cormorants to the Nutrient Budget of Lake Adair (Orlando Florida).

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Lake Adair is a 10 hectare lake located near downtown Orlando Florida, with a mean depth of 3.9 m. The current trophic state could be described as hypereutrophic with mean total phosphorus and nitrogen concentrations of 177 ug/L and 1.46 mg/L respectively based on 1995 and 1996 data. The mean chlorophyll- a concentration was 72 mg/m^3 with a maximum value of 202 mg/m^3. Due to a trend of increasing nutrient levels and frequent spring time blooms of blue-green algae in Lake Adair, a diagnostic study was implemented to quantify nutrient inputs to the lake. In conjunction with the nutrient budget, a hydrologic analysis was done to allow the use of nutrient models to predict effects of reductions in nutrient inputs to the lake on in-lake concentrations.

Nutrient and hydrologic inputs to the lake which were evaluated included stormwater runoff, groundwater baseflow through stormwater conveyance systems, discharge water from an upstream lake and groundwater seepage through the lake bottom. In addition, the nutrient input from the droppings of double-crested cormorants, *Phalacrocorax auritus*, was evaluated. In order to determine nutrient loading from the several hundred migratory cormorants which roost on the lake, pan experiments were done to determine the quantity and nutrient content of the droppings. From those results a mass loading rate of phosphorus and nitrogen from the roost was determined. Analysis of cormorant droppings revealed high concentrations of phosphorus and nitrogen. The phosphorus concentration in 7 samples averaged 7.7 % on a dry weight basis. Nitrogen concentration in 7 samples had a mean value 13.4 % on a dry weight basis. The loading rate of phosphorus from the cormorants was estimated to be 613.9 kg $year^{-1}$ and represented 73 % of the of the total phosphorus loading to Lake Adair which was estimated to be 841.3 kg $year^{-1}$. The second largest source of phosphorus loading to the lake was groundwater seepage/internal loading estimated at 93.8 kg year-1. These inputs were grouped together because data was collected with seepage meters that do not differentiate between the two sources. Stormwater runoff from the 91 hectare watershed contributed 92.6 kg $year^{-1}$ of phosphorus. Phosphorus loading from upstream lake overflows and stormline baseflows contributed only 20.7 kg $year^{-1}$ and 10.4 kg $year^{-1}$ respectively. Nitrogen loading to Lake Adair was estimated to be 3181.6 kg $year^{-1}$ with the cormorants contributing 1147.5 kg $year^{-1}$ or 36.1% of the loading. The second largest source of nitrogen loading was groundwater seepage/internal loading at 708.0 kg $year^{-1}$, followed by stormwater runoff which contributed 561.1 kg $year^{-1}$. Nitrogen loading from upstream lake overflows and stormline baseflows was estimated at 364.8 kg $year^{-1}$ and 346.8 kg $year^{-1}$ respectively.

Phosphorus modeling using the Vollenweider equation and data collected at Lake Adair predicted in-lake lake phosphorus concentration of 166 ug/L. This value agreed well with empirical data. The Vollenweider equation predicted a phosphorus concentration of 80 ug/L by removing the 613.9 kg $year^{-1}$ phosphorus loading associated with the cormorants. Even though Lake Adair would still be considered eutrophic without the birds, the water quality would be expected to improve and the frequency of severe algae blooms should

decrease. A phosphorus concentration of 157 ug/L was the predicted result of removing the 92.6 kg $year^{-1}$ phosphorus loading associated with stormwater runoff. Reducing this input would be very expensive and result in minimal changes in water quality.

Relocation of cormorants from roosting sites is relatively easy using pyrotechnic devices, but decisions must be made to manage exclusively to provide wildlife habitat or whether water quality problems such as algae blooms are a priority. There also appears to be a general lack of data on nutrient loading to water bodies from cormorants or other large piscivorous birds. Lake Adair may not be typical because it is a small urban lake with a large population of cormorants, but this study indicates that nutrient loading from birds should not be overlooked when performing diagnostic studies on lakes.

43. Lake Bioassessment Development For Florida

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In an effort to help the states comply with the biological portion of the Clean Water Act, in 1989 the Environmental Protection Agency (EPA) developed the first of a series of bioassessment protocols-the "Rapid Bioassessment Protocols for Use in Streams and Rivers" (Plafkin et al., 1989). In 1991, the Florida Department of Environmental Protection (DEP) established a Bioassessment/Biocriteria Committee to oversee and coordinate the development of bioassessment protocols patterned after those of the EPA. The committee's mission statement, "Using biological indicators to assess ecosystem health, identify problems, and offer solutions," even though current, had its roots in 1948, when a predecessor agency to DEP chose to use aquatic macroinvertebrates as tools for monitoring and evaluating water quality. Thus, Florida realized early that "resident biota in a watershed function as continual natural monitors of environmental quality, responding to the effects of both episodic as well as cumulative pollution and habitat alteration" (Barbour *et al*, 1996).

The Stream Condition Index (SCI) was finalized in 1996 as a tool for assessing problems with nonpoint source pollution in Florida streams. The SCI consists of the integration of 7 metrics-"a characteristic of the biota that changes in some predictable way with increased human influence." The metrics include number of taxa, number of EPT, number of Chironomidae, % dominant taxon, % Diptera, Florida Index, and % filterers.

The SCI was developed within the context of ecoregions-areas of relative homogeneity based on natural water chemistry, soils, physiography, lake hydrology, vegetation, and land cover. For streams, 13 ecoregions were delineated; examination of the macroinvertebrate communities, however, culled them down to 3 bioregions.

A similar tool, the Lake Condition Index (LCI), is also being developed for lakes using ecoregions or lake regions. Maps delineating 47 lake regions have been completed; as with the stream ecoregions, however, they appear to group into 3 bioregions by macroinvertebrate communities according to sediment type (sandy, transitional, muddy) as evaluated through multidimensional scaling analysis. As with the SCI, reference sites-lakes representing the region and having the highest biological potential for the particular region-were compared with test lakes-potentially impaired lakes within the same region.

Sampling from 1993 to 1995 evolved to consist of 12 composited petite ponar grabs in lakes smaller than 1,000 acres taken from the sublittoral zone (2 to 4 meters deep). In larger lakes, a maximum of 48 grabs was composited into 4 discrete samples. After standardizing to a 100-organism subsample, data consisted of 235 observations: 155 lakes, 37 lake regions, 180 summer and 55 winter observations, and 108 reference and 47 test lakes.

Of the 30 metrics tested, 8 proved to discriminate well between reference and test lakes. Box-and-whisker plots (see Figure 1) were used to evaluate the differences in metric values among lake bioregions and lake types. The metrics represent measures of macroinvertebrate community structure and function and consisted of richness measures (number of taxa; number of Ephemeroptera, Trichoptera, and Odonata [ETO]), composition measures (Shannon-Wiener Index, % dominant taxon, % ETO), a tolerance measure (Hulbert's Lake Condition Index), and trophic measures (% collector-gatherers, % collector-filterers). These lake bioassessments also appear to be most powerful when a macroinvertebrate index is used with traditional eutrophication measures (Secchi depth, chlorophyll a, or a Trophic State Index from these).

The final metrics, the overall LCI, and the metric and LCI scoring still have to be decided, and the land-use and watershed GIS mapping and nonpoint source discharge information still need to be done for both reference and test lakes. The 1996 data for an additional 80 lakes will also be analyzed to help make these decisions.

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44. State of the Lakes of the Coastal Ridge of Palm Beach County

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A one-year evaluation was undertaken of the natural resources of the chain-of-lakes system in eastern Palm Beach County (Palm Beach County Dept. Environmental Resources Management 1996). The waterbodies are natural freshwater lakes that lie perched along the western slope of the coastal ridge. Included in the study were Pine Lake, Lake Clarke, Lake Osborne, Lake Ida, Lake Eden, and their connecting waters. Diagnosis of the current status of the lake system was based on analysis of existing databases from local, state, and federal sources, and from a field monitoring program that measured physical, chemical, and biological parameters of the lakes and land use patterns of their watersheds.

The lakes have been altered considerably from their original character as the result of: 1) channelization of the flowing waters that fed and drained the lakes and elimination of natural surface water fluctuation regimes; 2) encroachment of urban and residential growth onto associated riparian areas, wetlands, and floodplains; 3) the establishment of exotic vegetation, fish, and molluscan species that have disrupted ecosystem function; and 4) degradation of water quality due to nutrient enrichment and bacterial contamination as discharges of domestic and agricultural wastes have increased.

The disappearance of littoral zones and shoreline wetlands in the chain-of-lakes system has been extensive, with well over 50% of the wetland area extant in 1883 missing from the present shoreline configuration. Attendant with the loss of vegetated littoral zones and wetlands is the loss of the functionality they served as biological filters, and the loss of fish and wildlife habitat they provided. This loss of habitat is reflected in a fish community that is imbalanced in its overrepresentation of rough fishes such as gizzard shad and gar.

Although historical detail is sparse, the lakes are presumed to have been originally shallow. All of the lakes in the chain have been deepened by dredging. Depth is again being lost through sediment deposition and from the accumulation on the lake floors of the products of excessive aquatic plant growth. The sediments likely originate as suspended sediments carried by inflowing waters (canals and outfalls). Comparison of a bathymetric survey conducted as a part of this study with one conducted in 1986 shows a loss of 30-59% of lake volume in Lakes Ide, Eden, and the south lobe of Lake Osborne.

Water quality in the chain-of-lakes system has improved from the 1970's and early 80's are regulatory activities and upgrades in waste treatment facilities have eliminated point-source discharges. Water quality is still impaired, however, as reflected in very high nutrient concentrations, bacterial contamination, reduced dissolved oxygen concentrations, and low water transparency. Mean annual Secchi depth of the lakes is 1.1 m. Dissolved oxygen concentrations throughout the water column in Pine Lake, Lake Clarke, and Lakes Ida and Eden were below 5.0 mg/L in summer of 1995. Since 1990, total coliform bacterial counts in Lake Osborne and its inflowing water violated state

water quality criteria on 20% of quarterly sampling events. Nutrient enrichment has led to occasional algal bloom problems in the lakes. Lack of a correlation between water transparency and chlorophyll a found in this study suggests that light is not limiting to algae, and that the poor water transparency of the lakes reflects contributions of both organic and inorganic particles to the suspended load. Ratios of total nitrogen to total phosphorus were often less than 10, suggesting that algal growth in the lakes may be limited by nitrogen.

Excessive growth of macrophytes, particularly of exotic species such as hydrilla and water lettuce, is problematic in the chain-of-lakes. Hydrilla blanketed the surface of Lake Osborne in the 1980's but has been largely brought under control since then through chemical treatment. At present it has escaped control in Lakes Ida and Eden. A new exotic species, the Asian species *Hygrophila polysperma* , has been detected throughout the system. Exotic species other than nuisance aquatic plants have also become established in the system. Brazilian pepper, melaleuca, long-ear acacia, and Australian pine line much of the undeveloped shorelines of the lakes and connecting canals. Twenty-six percent of the 31 fish species present are exotics that have been intentionally or accidentally introduced to the area outside their natural ranges. Exotic molluscan species include the gastropod *Melanoides tuberculata* and the pelecypod *Corbicula manilensis*.

Based on results of this study, a draft management plan has been developed for the lake system that addresses restoration of aquatic and wetland communities and their habitats, protection and improvement of water quality, control of nuisance macrophyte biomass, maintenance and enhancement of fisheries resources, and enhancement of environmental awareness and community participation in the lake protection process. One of the key programs in the management plan calls for restoration and enhancement of littoral zones and shoreline wetlands covering 8.5 miles of shoreline within publicly owned portions of the lakes. A pilot project by county staff that created a 3-acre wetland on the western shore of Lake Ida demonstrated the promise of this approach for restoring natural plant and animal species diversity and enhancing fishery resources.

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45. Florida LAKEWATCH: A Teamwork Approach

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There are more than 500 volunteer aquatic monitoring programs listed in the 1994 National Directory of Volunteer Environmental Monitoring Programs in the United States. The U.S. Environmental Protection Agency (USEPA) is supporting volunteer monitoring by providing funds in many cases and by partially funding The Volunteer Monitor, a national newsletter (free subscriptions available by calling 415-255-8049). The Florida LAKEWATCH Program through the University of Florida's Department of Fisheries and Aquatic Sciences in the Institute of Food and Agricultural Sciences (IFAS), is one of several citizen monitoring efforts in Florida. Florida LAKEWATCH (FLW) addresses several problems associated with water management in Florida:

(a) Little baseline data exists on Florida's waters.

(b) Historically, citizens' roles in water management are limited to complaint or litigation, which often puts them in adversarial positions with regulatory agencies and government.

(c) No arena exists for resolving conflicts between diverse interest groups which are often rooted in a lack of communication and/or in a proliferation of misinformation.

FLW addresses these problems by facilitating a working partnership among a host of pre-existing resources. As a result of this simple, cost-effective approach, FLW is able to provide much-needed data on Florida waters and facilitate more productive relationships among interest groups by;

· recruiting, training, certifying, equipping, and monitoring volunteers who use their own boats for sampling on approximately 600 diverse water bodies statewide once per month for Total Nitrogen, Total Phosphorus, Chlorophyll a, and Secchi Disk depth. The cost-effectiveness of using volunteers enables the monitoring of a large number of water bodies that would otherwise be prohibitively expensive.

· utilizing University of Florida's (UF) pre-existing water chemistry laboratory to analyze samples, thereby networking the general public with the academic researchers. This research does not end up in a report on a shelf, but instead cycles back to the lake users.

· entering results into STORET, a pre-existing state database, accessible to all government agencies. Florida Department of Environmental Protection (FDEP) required that the Florida LAKEWATCH volunteers be tested. In 1991, data collected by citizen volunteers were compared to data collected by professional biologists in a side-by-side blind test for 125 individual lakes twice. There was no significant difference between values (except for some differences in the Secchi Disk readings on 11 lakes). After the FDEP reviewed the results of this test, FLW data was the first citizen-collected data permitted inclusion in STORET.

· using a computer database and communications network at UF's Institute of Food and Agricultural Sciences (IFAS), making these data readily available to the public and professionals in convenient formats. Anyone can request LAKEWATCH data (phone 352-392-9617 ext. 228) in tabular, graphical, or spreadsheet forms, in either hard copy or on computer disk -- facilitating the analysis of long-term trends, patterns, and cycles.

Florida LAKEWATCH responded to over 600 requests for data in 1996, not counting the annual distribution of individual results to all our volunteers.

Data requests come from regulatory agencies, government, environmental groups, schools, researchers, and citizens. For example, LAKEWATCH data is routinely used in FDEP's 305(b) Report to the USEPA. It was used in: "Florida Freshwater Plants: a Handbook of Common Aquatic Plants in Florida Lakes," by Hoyer, et al.; and Handbook of Common Freshwater Fish in Florida Lakes," by Hoyer, et al. The USEPA has been using Florida LAKEWATCH data to develop a map of Florida lake regions. Eagle Eye, Inc., a group of high school students at Walker Memorial Junior Academy in Avon Park, use the data in their science, mathematics, and computer classes. Consulting firms use it, too; for example, Professional Engineering Consultants, Inc. relied on it for their report to the City of Ocoee on the city lakes. Citizens use the data in many ways; for instance it has been used to evaluate the decrease in water clarity that can be expected if grass carp are stocked in Lake Ola in Orange County. The City of Altamonte Springs and the Lakes Region Lakes Management District (in Winter Haven area) both routinely use FLW data in evaluating strategies for managing flood waters.

· partnering with a host of diverse groups and agencies, often resulting in their stepping outside their traditional roles. For example, Water Management Districts, realtors, homeowner associations, environmental groups, state parks, middle and high schools, fire stations, and city/county municipalities provide statewide water sample collection centers, courier services, meeting places, mail lists, secretarial help, and local contacts to facilitate volunteer monitoring. Many even provide personnel. For example, Hillsborough County has a full-time LAKEWATCH coordinator on staff and the City of Orlando Stormwater Bureau has assigned a staff member to shepherd the program on over 40 of the city's lakes.

· using university students, a previously-untapped source of expertise, to perform aquatic studies increases the depth of data that can be obtained economically. Because Florida LAKEWATCH is directed through the University of Florida, students have been used for various projects, including making bathymetric maps on more than 60 lakes and conducting aquatic plant surveys on several hundred lakes statewide.

· responding to special issues, thus enhancing productivity of agencies. Example: in response to a notable increase in water clarity during some summers in the Harris chain of lakes in Lake County, LAKEWATCH volunteers have been specially trained to obtain and preserve water samples every other day during this event so that the relative abundance of diatoms can be evaluated as a possible cause of the clearing.

· developing a communication/education network between governmental regulatory agencies and diverse, not-easily-targeted segments of the public. By coordinating approximately 20 meetings per year in different areas of the state, encompassing diverse groups including agri-business, realtors/developers, environmental groups, eco-tourism, schools, state parks, 4-H Clubs, National Forests, Aquatic Preserves, boaters, anglers, campers, golfers, Stormwater Utility Bureaus, regulatory agencies, legislators, and city/county governments - FLW provides forums for discussion, education, and problem solving. For example, in Highlands County, FLW brought a variety of interest groups together for a one-day seminar in which participants formulated what they defined as the problems in Lake Istokpoga.

While it would be unrealistic to claim that FLW can solve all water problems, it is hoped that FLW's teamwork approach is at least a step in the direction of assembling the necessary tools -- both scientific and human.

46. The Unique Challenges of Studying Rodman Reservoir (Ocklawaha River)

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Rodman Reservoir, a part of the ill-fated Cross Florida Barge Canal (CFBC), has been the center of controversy since its creation in 1968. Although work on the CFBC was halted in 1971, the controversy continues over the fate of the reservoir. In 1993, the Florida Legislature passed Florida Law 93-213 which mandated the Florida Department of Environ-mental Protection (FDEP) to study the environmental and economic impacts associated with the various alternatives being considered for Rodman Reservoir. These alternatives range from retaining the reservoir to removing Rodman Dam and restoring the Ocklawaha River. The St. Johns River Water Management District (SJRWMD) was mandated to conduct these studies; FDEP provided funding. Environmental Consulting & Technology, Inc. (ECT), under contract to SJRWMD, conducted five of these studies: 1) detailed bathymetric and sediment thickness surveys; 2) a study of the physico-chemical characteristics of sediments; 3) a characterization of the Ocklawaha River flood-plain under the reservoir; 4) a study of the water quality in the reservoir and the Lower Ocklawaha River; and 5) a study to predict -forest successional stages in the floodplain presently inundated by Rodman Dam in the event of dam removal and river restoration.

Rodman Reservoir presents unique obstacles to conducting field studies. These obstacles include the size of the reservoir (9,000 acres); shallow water; densely packed standing and felled cypress trees; thick aquatic vegetation; the very irregular geometry of both the shoreline and the submerged features of the reservoir; and very soft, flocculent sediments. Each of these challenges, how they were met, and some of the significant findings are discussed below.

The bathymetric and sediment characterization field studies were conducted within the lacustrine and transition zones of the reservoir, which comprised about 6,000 acres or approximately 67 percent of the total area. The shallow depths, dense aquatic vegetation, and felled, semi-floating cypress logs provided formidable obstacles for vessels. Air boats proved to be the best overall boat for about 90 percent of the reservoir because of their extreme shallow draft and high maneuver-ability. In those areas of the reservoir where dense stands of dying cypress trees still remain, a narrow-beam boat equipped with an outboard motor proved to be the best choice for maneuvering between the closely-spaced trees.

The large size of the reservoir and its irregular inverted "L" shaped shoreline, precluded the use of highly accurate, line-of-sight navigation systems. We opted to use global positioning systems (GPS). Although GPS is still a line-of-sight system, satellites high off the horizon are more easily seen by the GPS receiver than a shore-based system. We increased accuracy to about ±6 feet by operating the GPS in the differential mode or DGPS. Realtime differential corrections require that the DGPS receiver not only receive the signals from the satellites but a reference station as well. For this project, we used the commercially available Acc-Q-Point® differential service. Now that the U.S. Coast

Guard's reference stations are operational at Egmont Key and other locations around Florida, this second option for differential service is now available.

Perhaps the single most challenging obstacle that Rodman Reservoir presented was the dense growths of emergent and submergent aquatic macrophytes such as *Hydrilla*. Standard survey-grade fathometers operate at high frequencies where aquatic vegetation is opaque to the acoustic energy emitted by the fathometer's transducer. We tried lower frequencies (<50--kilohertz) but with no success. Lower frequency, high-power systems such as subbottom profilers will penetrate the vegetation, however, the topmost flocculent layer of sediment is equally transparent and, therefore, cannot be detected. Our solution was to employ a graduated sounding rod using a light source and a photoelectric sensor connected to a buzzer to indicate the exact moment that the sounding rod reached the water-sediment interface. The photoelectric sensor, a Model 10 Sludge Gun® manufactured by Markland Specialty Engineering, Ltd., made detection of the water-sediment interface virtually unambiguous. Nonetheless, this method is very time consuming and we could not locate the precise *top-of-hill* or *bottom-of-slope*. Because of the large size of the reservoir and the number of sampling points needed (5,000), we used two boats with two people each operating about 10 to 12 hours a day, 7 days a week, for 2 months to complete the bathymetry survey. Currently, there is no method that will permit continuous depth measurement with dense growths of submerged aquatic vegetation.

The complex geometry of the reservoir shoreline and the submerged Ocklawaha River channel also presented some unique challenges in preparing the bathymetric chart. The problem was to accurately represent the bathymetry from discrete sampling points taken over a very irregular bottom. Triangular interpolation network- or TIN-based contouring programs, commonly used by land surveyors, work exceptionally well if the *ideal* points can be selected in the field. Unfortunately, in bathymetric surveys in water bodies like Rodman Reservoir, these features are beneath the water. Data collected as discrete points are usually best contoured with a program that employs Kriging, or similar interpolation and smoothing routine, which looks at neighboring data to calculate representative depths for established grid points. Contour plots were, therefore, prepared using Golden Software's Surfer® program with Kriging and the linear variogram model. Surfer® is capable of accounting for anisotropy and worked well when examining small areas of the reservoir. It was impractical to consider anisotropy when contouring the entire reservoir because of the serpentine nature of the relict Ocklawaha River channel.

Sediment sampling also presented some unique field challenges. Because of the high water content and very soft nature of the sediments, gravity corers and standard piston corers generally would not work in Rod-man Reservoir. Therefore, we used a piston corer which was a modified version of a corer originally designed by the University of Florida (and now commercially available from Aquatic Research Instruments). In a standard piston corer, the piston is immobilized almost immediately upon contact with the water-sediment interface. Because Rodman Reservoir sediments are too soft to stop the piston at the interface, the piston must be immobilized using a tether line. This requires measuring water depth prior to sediment coring. The resulting core was virtually undisturbed and typically clearly showed the water-sediment interface and one or more strata.

Some of the study results are summarized below:

· The lacustrine and transition zones of the reservoir have a mean water depth of about 8.4 feet, a maximum depth of 31 feet, with a volume of about 2.19 billion cubic feet or 50,275 acre-feet.

· Soft, recent sediments cover 5,136 acres in the lacustrine and transition zones of the reservoir (86 percent) with an average thickness of 1.08 feet and an estimated volume of 240 million cubic feet.

· These sediments were 80 percent water, high in volatile solids (37 percent of the solids), with total Kjeldahl nitrogen and phosphorus concentrations of 13.3 and 0.8 grams per kilogram-dry weight, and only a few metals were detected at levels above the method detection limit.

· Submerged features such as berms and spoil piles on either side of the CFBC remain, and the relict river and stream channels are still detectable.

· The reservoir (or more specifically the macrophytes in the reservoir) is acting like a nutrient scrubber or sink removing as much as 90 percent of the dissolved nitrate + nitrite.

· If the dam were removed, dissolved nitrate + nitrite and phosphorus loadings downstream are expected to increase by about 690 and 280 per-cent, respectively.

Alphabetical Listing of Abstracts
1997 Meeting of FLMS

Abstract titles are in alphabetical order by the primary author. Paper numbers indicate the chronological order in which the papers were presented.

Abtew, Wossenu, Linda Lindstrom and Stuart Van Horn, SFWMD, Importance of Monitoring Network Design and Mass Balance Analysis for Best Management of Watersheds and Water Bodies, Paper 15

Alam, Shawn, Florida Game and Fresh Water Fish Commission, The Effects of Mechanical Harvesting of Floating Plant Tussock Communities on Water Quality in Lake Istokpoga Florida, Paper 31

Bachmann, Roger, Mark Hoyer and Daniel Canfield, Fisheries and Aquatic Sciences, Can Watershed Management Restore Shallow Florida Lakes? Paper 8

Bays, James S. et al., CH2MHill, Inc., Tampa, FL, The Wakodahatchee Wetlands, Palm Beach County, Florida, Paper 40

Bodle, Mike, South Florida Water Management District, Management of Aquatic Plants in the Kissimmee Chain of Lakes, Paper 4

Brady, Mark, SFWMD, Topographic and Volumnetric Analysis of the Everglades Nutrient Removal Project using GIS, Paper 35

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