

A.11 LAKE WORTH LAGOON CONCEPTUAL ECOLOGICAL MODEL

A.11.1 Model Leads

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A.11.2 Introduction

The Lake Worth Lagoon is the principal estuarine water body in Palm Beach County. Historically, Lake Worth Lagoon was a freshwater lake with drainage from swamps along its western edge. The barrier island to the east separates Lake Worth from the Atlantic Ocean. In the late 1800s, settlers arrived on the banks of Lake Worth and immediately began making changes to the lagoon environment that continue to this day. Extreme high tides, waves, high lake water levels, and storms occasionally caused the formation of temporary inlets. Several early attempts were made to create navigable inlets from the ocean, and in 1877 construction of a stable inlet was achieved. This inlet had an immediate effect on the freshwater dynamics and the lake began to change to a saltwater lagoon system. During the 1890s the completion of a navigation canal from the north end of Lake Worth Lagoon to Jupiter Inlet resulted in increased freshwater discharges to the lagoon. Also, during this decade developers began filling the wetland edges of the lagoon, an activity that continued into the 1970s.

In the early 1900s, the Atlantic Intracoastal Waterway was completed from the south end of the lagoon to Biscayne Bay. By 1915, the Port of Palm Beach created a permanent inlet four feet deep at the north end of Lake Worth Lagoon. In 1925, the inlet was deepened to 16 feet, and dredge spoils deposited in Lake Worth Lagoon resulted in the creation of Peanut Island. In 1917, the South Lake Worth Inlet was created in a failed effort to improve tidal circulation and provide flushing to the south end of the lagoon. The completion of the West Palm Beach Canal (C-51) in 1925 resulted in significant freshwater inflow to Lake Worth Lagoon and provided the drainage necessary for the development of the west shore of the lagoon.

Today, Lake Worth Lagoon is connected to the Atlantic Ocean by two permanent inlets (Figure A-36). The Lake Worth Inlet is 800 feet wide by 35 feet deep; the South Lake Worth Inlet is 130 feet wide by 6 to 12 feet deep. The Atlantic Intracoastal Waterway runs the entire length of the lagoon. Eight causeways and bridges connect the mainland to the barrier island. Twenty-eight marinas and hundreds of private docks are scattered along the shoreline. Approximately 65 percent of the shoreline is bulkheaded; only 19 percent of the shoreline remains fringed by mangroves (PBCERM 1992). While the cumulative impact of the anthropogenic activities over the past 100 years has significantly altered the Lake Worth Lagoon from its previous character and diminished its value as a healthy estuarine ecosystem, significant regionally important natural resources remain. The fish and wildlife, water quality and recreational values that remain are being identified and evaluated, for protection under the auspices of the Lake Worth Lagoon Management Plan (PBCERM and FDEP 1998).



Figure A-36: The Boundary of the Lake Worth Lagoon Conceptual Ecological Model

Recreational and commercial fish species, invertebrates, birds, species of special concern and endangered species utilize the existing natural estuarine communities of the lagoon. The West Indian manatee is an endangered marine mammal found in Florida's rivers, estuaries and inshore areas. The section of Lake Worth Lagoon just south of the Lake Worth Inlet has the greatest overall abundance of manatees during the winter season. Palm Beach County waters provide major warm water refuge and travel corridors for the entire East Coast population of manatees. Several bird sanctuaries and/or rookeries are also located in the Lake Worth Lagoon, including Bingham Islands, Bird Island, Fisherman's Island, Hunter's Island, John's Island, and Munyon Island. A list of protected plant and animal species that have been identified in Lake Worth Lagoon or are likely to naturally inhabit the lagoon was compiled in the Lake Worth Lagoon Natural Resources Inventory and Enhancement Study (Dames and Moore and PBCERM 1990). This list includes a total of 40 species including 13 plants, 1 mammal, 4 reptiles, 18 birds and 4 fishes.

Water quality, sediment quality and hydrology of the Lake Worth Lagoon reflect a highly altered and stressed environment resulting from decades of nonpoint and direct discharges from the surrounding urban development. Alterations affecting hydrology include construction of canals, channelization of natural waterways, filling, drainage, and/or impoundment of wetlands, and stabilization and creation of inlets to the Atlantic Ocean. Creation of permanent inlets to the lagoon changed its character from freshwater to estuarine. Connection of the C-51 canal led to episodic inflows of large amounts of fresh water that disrupt the estuarine biological communities of Lake Worth Lagoon.

A conceptual ecological model in the risk assessment framework has been developed for the Lake Worth Lagoon (Figure A-38). The model depicts the general pathways by which driving forces (in rectangles), particularly those related to modern human culture, affect "attributes" of the ecosystem (in hexagons) that are intrinsically important to ecosystem function or are generally viewed by humans as valuable and important to maintain. Drivers are manifested as stressors (ovals) that exert their impact on the ecosystem in various ways, or "effects" (diamonds). "Performance measures" (trapezoids) provide the parameters about the attributes that can be measured to determine the direction (positive or negative) and intensity of effects.

A.11.3 External Drivers and Ecological Stressors

Sources of ecological stressors in the Lake Worth Lagoon originate from agricultural and urban development and the concurrent construction and operation of water management systems. Sea level rise is also a factor that affects the ecology of the lagoon and must be taken into consideration during restoration efforts. The resultant major stressors to the Lake Worth Lagoon are **altered hydrology; altered estuarine salinity; elevated loads of nutrients, suspended and dissolved organic matter; input of contaminants and toxins; boating and fishing pressure; and physical alterations.**

Altered hydrology results from altered freshwater flow volume and timing. The interconnected network of canals, often across natural drainage basin boundaries, and the need to provide adequate flood protection for those areas developed as a result of the network of canals, has resulted in unnatural discharges during basin flood releases. Additionally, water withdrawals for irrigation and other water supply purposes reduce flow volumes to the lagoon during drought conditions. **Altered estuarine salinity** is a direct result of the altered hydrology but is also affected by sea level rise.

Elevated loads of nutrients, suspended and dissolved organic matter has resulted from the transformation of the lagoon drainage basin from one dominated by wetland mosaics and forested areas to urban and agricultural land uses. In addition, the drainage basin has been extended and cross-connected to

afford flood protection; however, the absence of adequate storage and treatment facilities requires delivering flood waters rapidly into the lagoon with little potential for amelioration of nutrient and dissolved organic matter loads. High peak flow rates also scour canal bottoms as well as exacerbate erosion of canal banks, thus delivering elevated suspended solids loads to the lagoon during sporadic rain-driven events.

Input of contaminants and toxins result from the establishment of pathways whereby substances commonly used within both urban and agricultural settings are delivered to the lagoon via overland flow or through canal discharges. Such substances include pesticides, metals and oils from wear and use of automobiles, as well as from other industrial and urban practices.

In addition to the construction of water management system canals, many other **physical alterations** have been made to the lagoon. These include opening and widening of inlets, dredging and maintenance of navigation channels, development of the shoreline and interior basin, and draining and filling wetlands.

The extensive basin drainage modifications made possible an increase in population and facilities along the lagoon. This has resulted in increased **boating and fishing pressure** from both recreational and commercial demands.

A.11.4 Ecological Attributes

A.11.4.1 Salinity Envelope

The Lake Worth Lagoon is a system dominated by polyhaline conditions adversely affected by large volume freshwater releases. The ideal restoration scenario may thus be to minimize perturbation from those large-scale canal discharges. Natural estuaries tend to reach a steady state where the salinity gradient remains relatively stable in position, subject to seasonal and tidal oscillations (Pickard and Emery 1990). The concept of a natural distribution of salinity gradients and variability acceptable to and supportive of aquatic life is an important prerequisite for environmental health. Mortality and/or impairment have been documented in many species exposed to salinities outside their ideal ranges (Kingsford and Gray 1996).

Prolonged discharge events may create a plume of fresh water that prevents tidal marine waters from entering the lagoon. The low salinity plume described above may act as a "plug" or barrier to successful colonization of habitats in the lagoon by many organisms. In a typical natural scenario, offshore areas provide larvae and juveniles to the lagoon, and in turn, the lagoon provides adult fish to spawn offshore. Salinity disruption or blockage could interfere with both processes. The early larval and juvenile stages are particularly vulnerable to being adversely affected by poor water conditions including lowered salinity. Organisms may potentially avoid the low salinity area, and thus delay settling in nursery habitats exposing them to enhanced risk of predation, or they may die or suffer reduced fitness due to exposure to deleterious salinity levels. Low salinity exposure may cause eggs or larvae to settle prematurely in inappropriate habitats, leading to reduced fitness or death (Forward 1989, Reagan 1985). The halocline produced by the low salinity front may cause larval organisms to gather along the edge of the plume, exacerbating the life-history risks (Kingsford and Gray 1996). The potential for deleterious effects is greater when discharges occur closer to the inlets that provide tidal marine water, because a larger portion of the lagoon is unavailable for the normal migrations of colonizing species.

A.11.4.2 Water Quality

The Lake Worth Lagoon receives major inflows of fresh water from the regional canals. The C-17 canal discharges to the upper segment of the Lake Worth Lagoon. The C-51, C-16, and C-15 canals discharge to the middle and lower segments of the lagoon (Figure A-36). While inlets provide some mechanism for flushing and restoration of salinity equilibrium, the middle and lower segments of the lagoon are subject to less circulation and have longer periods of low salinity (Zarillo 2003). Canal influences extend to nutrient and sediment loads as well.

The Lake Worth Lagoon and Palm Beach Coast Basin Status Report (FDEP 2003) contains data from a recent water quality assessment for the Lake Worth Lagoon that indicates that the northern and southern segments of the lagoon are potentially impaired for copper. The northern segment was also identified as potentially impaired for lead. The report shows that ecological data gathered for the Lake Worth Lagoon in recent years reflect the degraded state of the lagoon that have been caused by canal inflows and the altered shoreline. However, some data do indicate moderate improvement in water quality with respect to nutrients, possibly due to reductions in point source discharges. The data in the Impaired Waters Rule database was insufficient to evaluate water quality in the central segment of the lagoon.

A.11.4.3 Submerged Aquatic Vegetation

Submerged bottom resources in the Lake Worth Lagoon include seagrass beds, macro-algae, oyster habitat, corals and sponges. Seagrasses first became established in Lake Worth Lagoon when the system was converted from freshwater to marine due to the influences of permanent inlets. Many areas that would otherwise be suitable for seagrass colonization have been lost due to dredging and filling activities; however seagrasses reportedly have never been abundant (Harris et al. 1983). In general, seagrasses are most common and dense in shallow areas and in areas that maintain good water clarity due to sheltering or tidal flushing.

Seagrass beds provide habitat for myriad animals, including the juveniles of many commercially and recreationally valuable species. Like all plants, seagrasses require adequate sunlight, and this is a function of water clarity. A 1940 inventory found 4,271 acres of seagrass within the lagoon. In 1975, a survey found a mere 161 acres. However, in 2001, some 1,630 acres were documented, indicating that conditions amenable to seagrass recolonization had improved (Applied Technology and Management, Inc. 2002).

All submerged aquatic vegetation (SAV) species have a preferred and tolerable salinity range. They respond unfavorably when salinity alterations exceed these ranges. Degraded water quality and physical alterations have been shown to cause a regional decrease in coverage (Chamberlain and Doering 1998a). This decline negatively impacts fish and invertebrate communities. It also causes destabilization of sediments and a shift in primary productivity from benthic macrophytes to phytoplankton, both of which provide negative biofeedback that further affect seagrass beds.

Seagrass communities can be found throughout Lake Worth Lagoon. Six species of seagrasses are known to occur in Lake Worth Lagoon. Turtle grass (*Thalassia testudinum*) is capable of forming dense beds. Shoal grass (*Halodule wrightii*) is the most tolerant of temperature and salinity changes. Manatee grass (*Syringodium filiforme*) mixes with other species in small beds. *Halophila engelmannii*, *Halophila johnsoni*, and *Halophila decipiens* populate deeper areas. In Lake Worth Lagoon, *Halodule wrightii* is the most abundant species of seagrass in terms of coverage, and occurs primarily in shallow areas. A 2001 seagrass survey identified 70 percent of the seagrasses in the northern segment of the lagoon (Little

Lake Worth just north of North Ocean Drive), 20 percent of the seagrasses in the central segment of the lagoon (Royal Park Bridge to Ocean Avenue bridge in Lantana), and 10 percent of the seagrasses in the southern segment of the lagoon (Ocean Avenue bridge in Lantana to Ocean Avenue bridge in Boynton Beach). Corresponding seagrass coverage within each segment is 30 percent in the northern, 12 percent in the central and 15 percent in the southern segment of the lagoon. *Halophila engelmanni* was observed in a single occurrence in north Lake Worth Lagoon (PBCERM and Dames and Moore 1990).

Species of macro-algae also become attached to the bottom or form drifting mats. Seagrass and macroalgal communities are very important habitat for many marine species. Their continued survival in Lake Worth Lagoon is dependent upon protection from direct impacts and maintenance of good water quality.

While not as abundant as seagrass communities, other types of bottom resources including oyster bars, corals and sponges also provide important habitat functions for marine organisms. Oyster bars can be found in the vicinity of John D. MacArthur State Recreation Area, and in the vicinity of the Bingham Islands and at the north end of Hypoluxo Island. Corals and sponges are limited in occurrence to areas within close proximity to the inlets.

A.11.4.4 Benthic Communities

The Lake Worth Lagoon benthic community composition varies with the substrate encountered. Every animal has limits of salinity extremes and rates of salinity change beyond which the organism will not survive. Benthic organisms provide essential ecological and biological functions in the lagoon and can influence the quality of the environment. These communities filter/trap particulates, serve as refuge, and provide a food source for fish and macroinvertebrates. Benthic communities can serve as important indicators of environmental quality that respond to changes in freshwater inflow or water quality via change in cover, density or community composition. A healthy benthic community represents an important habitat that will support diverse fish and motile invertebrate populations. Degradation or loss of benthic communities will diminish the ability of the lagoon to maintain the mosaic of conditions that support high habitat diversity and productivity.

Macroinvertebrates provide an ideal measure of the response of the benthic community to environmental perturbations (Boesh and Rosenberg 1981, Reish 1986). Benthos are primarily sedentary, thus, have limited escape mechanisms to avoid disturbances (Bilyard 1987). They provide a record of effects of short and long-term environmental changes through species composition and abundance changes. Therefore, they are often used as water-quality indicators. They are relatively easy to monitor and tend to reflect the cumulative impacts of environmental perturbations, thereby providing good indicators of the changes in ecosystems over time. They have been used extensively as indicators of impacts of both pollution and natural fluctuations in the estuarine environments (Gaston et al. 1985, Bilyard 1987, Holland et al. 1987, Boesh and Rabalais 1991).

The theory underlying use of species indicators to assess water quality condition assumes that benthic assemblages, which are often comprised of a variety of species across multiple phyla, represent a range of predictable biotic responses to potential pollutant impacts. Their use in water-quality studies requires assumptions that communities remain at steady state except when influenced by human activity. Long-term studies show that natural variation over a variety of time scales often masks anthropogenic (human-induced) changes. Therefore, species indicator(s) associated with changes and shifts in biota diversity are used to assess the status of a habitat.

Benthic macroinvertebrate communities in the Lake Worth Lagoon are sensitive to bottom type, water quality and salinity fluctuations. Furthermore, the fluctuation between periods of high and low discharge causes alternating shifts between estuarine and freshwater species (Haunert and Startzman 1985). Reed (1975) reported that species diversity and species richness values from sites sampled both near canal outfalls and from mud-dominated areas were low, similar to those reported from pollution-stressed areas in other studies. Deis et al. (1983) attributed differences in macroinvertebrate community structure to physical effects arising primarily from the West Palm Beach Canal.

A.11.4.5 Fishery Species

At least 70 percent of Florida's recreationally sought fishes depend on estuaries for at least part of their life histories (Harris et al. 1983, Estevez 1998, Lindall 1973). Within the lagoon, seagrass communities provide critical refugia for juvenile fish such as redfish (*Sciaenops ocellatus*), grouper, snook (*Centropomus undecimalis*), and spotted seatrout (*Cynoscion nebulosus*).

Several studies of Lake Worth Lagoon's fish populations have been conducted over the past twenty years. A total of 261 species of fish have been collected in Lake Worth Lagoon including fish species found in the vicinity of the inlets. Both resident and transient populations are found in the lagoon, but population sizes as well as timing and nature of utilization by various species are largely unknown.

The greatest numbers of fish species have been collected near Munyon Island, northwest of Palm Beach Shores, near the Lake Worth Inlet, near Hunters Island and in the vicinity of South Lake Worth Inlet. These areas contain some of the lagoon's most diverse marine habitats and are essential nursery habitats for juvenile marine reef fishes (Gilmore et al. 1981).

The total number of species collected in Lake Worth Lagoon (195), and in the lagoon including the vicinity of the inlets (261), is comparable to the total for the Loxahatchee River area where 286 species have been collected (Christensen 1965), the Indian River Lagoon where 286 species have been collected (Gilmore et al. 1981), and Biscayne Bay where 193 species have been collected (DERM 1984).

While conclusive data documenting the population trends of various fish species in Lake Worth Lagoon are not available, it is clear from review of historical accounts and catch records that commercial and recreational fisheries resources in the lagoon have greatly declined over the past forty years (Harris et al. 1983, Lewis et al. 1985, McCray et al. 1985, WPB Fishing Club 1989, Woodburn 1961). The most likely reasons for fisheries declines are habitat destruction and water quality degradation (PBCERM and Dames and Moore 1990). Improperly regulated fish harvesting is also probably a contributing factor.

A.11.4.6 Shoreline Habitat Functionality

The ecological value of mangrove communities has been well documented in the scientific literature. Mangrove communities provide habitat for marine organisms, protect shorelines from erosion, and enhance water quality by acting as natural filters. Detrital material produced by mangroves is the basis of the food chain for South Florida's marine and estuarine ecosystems. Mangroves support fish and macroinvertebrate communities by providing protected nursery areas for fishes, crustaceans, and shellfish, and food for a multitude of important commercial and recreational marine species such as snook, snapper, tarpon, jack, sheepshead, red drum, oyster and shrimp (Harris et al. 1983, Lindall 1973). Mangrove roots act to trap sediments and prevent shoreline erosion and provide attachment surfaces for various marine organisms. Additionally, mangrove forests provide habitat for a highly diverse population of birds (Odum et al. 1982).

Mangroves are sensitive to alterations in upland drainage. In some areas, drainage for agricultural and urban development has reduced overland flows of fresh water to the mangroves. This results in an increased amount of concentrated runoff, which in turn changes the salinity balance, reduces the flushing of detritus, and washes nutrients directly into the lagoon without the benefit of filtration by the mangrove system (Estevez 1998).

Most of the Lake Worth Lagoon shoreline has been altered by dredging, filling and bulkhead construction. Between 1940 and 1975, an estimated 87 percent of shoreline mangroves were eliminated by shoreline development (Harris et al. 1983). Currently only about 19 percent of the shoreline (including islands) has fringing mangroves. Bulkheads have been constructed on approximately 65 percent of the shoreline (including canals).

A.11.4.7 Near-Shore Reef

Coral reef systems are highly oligotrophic, and potentially vulnerable to changes resulting from nutrient enrichment. Reef development is typically slow and occurs over geologic time scales, so impacts to reefs may cause ecological problems that require long time frames for recovery. The areas near North and South Lake Worth Inlets (i.e., Palm Beach and Boynton Inlets) are unique and important resources for the State of Florida. The extensive hard coral systems present within a few kilometers of the shoreline provide habitat for many marine species of socio-economic value to tourism and local fisheries. These reefs represent the most northward extension of tropical reefs on the east coast of the United States, and transition into worm reef/limestone habitat near the Jupiter Inlet (Japp and Hallock 1990). The recreational and commercial importance for this area of northern Palm Beach County cannot be overstated, and the health of Florida's reef system is of special concern. The quantity and quality of water discharged from the Lake Worth Lagoon has effects on near-shore habitats near the ocean inlets of the Lake Worth Lagoon, and changes to the water management strategies as a result of Comprehensive Everglades Restoration Plan (CERP) activities may alter the current conditions. Alteration of flows delivered to C-16, C-17 and C-51 will directly affect the transport of sediments to near-shore reef areas, as well as light penetration through alteration of watercolor and clarity. These factors may directly or indirectly affect the health of corals through a variety of mechanisms. Decreasing the volume of fresh water "put to tide" through existing water conveyances will most likely be beneficial to the overall health of these hardgrounds. System-wide effects expected as a result of the implementation of the CERP include decreased nutrient and sediment transport to these tropical reefs, and decreased color, which will improve the light regime needed by symbiotic zooxanthellae found in many sessile invertebrates (e.g., stony corals, octocorals, sponges and tunicates). Indirectly, these reef animals will benefit from an expected decrease in overgrowth by macro-algal species that readily respond to increased nutrients.

A.11.5 Ecological Effects

Critical Linkages between Stressors and Attributes/Working Hypotheses

The most significant ecological impact to the Lake Worth Lagoon is the alteration of estuarine salinity regime. Salinity is one of the principal factors influencing the distribution and abundance of organisms inhabiting estuaries (Kennish 1990). Changes in the distribution, timing and rapidity of change of salinity include low saline events, primarily due to regulatory water releases from the S-155 structure, but also include discharges from the S-41 and S-44 structures.

The large-scale water releases transport massive volumes of organic and inorganic sediments, which contribute to deposits of muck in the estuaries (Shrader 1984, Gunter and Hall 1963, Pitt 1972). The large

accumulations of muck covering the bottom of the lagoon dramatically decrease the quality and quantity of habitat for benthic macroinvertebrates, oysters and finfish. Together, altered salinity and siltation can have negative impacts to important components of estuarine and near-shore reef ecosystems, including SAV, phytoplankton, fish and macro-invertebrate communities, fish-eating birds, and reef-building polychaetes (Haunert 1988). Changes in temporal and spatial patterns of salinity envelopes can be significant stressors to fish and shellfish populations.

The above conditions are exacerbated by the loss and fragmentation of shoreline habitat and by the input of toxins, nutrients, and dissolved organics (Haunert et al. 1994). The loss and fragmentation of habitat due to human development results in the direct loss of mangrove wetlands and emergent bank vegetation upon which fish and macro-invertebrate communities depend. Increased inputs of nutrients and dissolved organics degrade water quality, contribute to the accumulation of muck, which in turn covers hard bottom habitat, and contributes to changes in phytoplankton and SAV communities. Increased levels of toxicants, from agricultural run-off, urban development and the boating industry including metals, pesticides and their residues, can cause adverse impacts to aquatic food chains leading to fish-eating birds.

The ecological effects and critical linkages described above are based on key hypotheses. The hypotheses are presented below, organized by attribute.

A.11.6 Submerged Aquatic Vegetation

Effects of Altered Salinity on Submerged Aquatic Vegetation

Tabb et al (1962) stated: “Most of the effects of man-made changes on plant and animal populations in Florida estuaries are a result of alterations in salinity and turbidity.” Altered estuarine salinity resulting from hydrologic alterations, water management practices, and sea level rise has had a negative effect on SAV and has resulted in large decreases in the spatial extent of SAV in the Lake Worth Lagoon. Different species of SAV have different desirable salinity ranges (Zieman 1982, Doering et al. 2002). When salinity falls outside of these ranges, the SAV is negatively impacted and may result in a reduction in densities and distribution (Chamberlain and Doering 1998b). Increases or decreases in salinity may give one species a competitive advantage over another (Livingston 1987).

Level of certainty - moderate

Relationships among Submerged Aquatic Vegetation, Salinity and Fishes.

Negative changes in SAV community structure and function along with changes in the natural salinity regime have resulted in a decrease in larval and adult fish recruitment into the lagoon. Fish densities are typically greater in grass bed habitat within South Florida’s estuaries and coastal lagoons than in adjacent habitats (Reid 1954, Tabb et al. 1962, Roessler 1965, Yokel 1975, Weinstein et al. 1977). The SAV beds provide protection from predation for animals living in it. The dense seagrass blades and rhizomes associated with the grasses provide cover for invertebrates and small fishes while also providing sanctuary from predators (Zieman 1982). Reduction in size and health of SAV beds effects the location, abundance and speciation of fisheries in the lagoon.

Level of certainty - moderate

Effects of Nutrients, Turbidity and Dissolved Organic Matter on Submerged Aquatic Vegetation

The input of increased levels of nutrients, dissolved organic matter and turbidity affect SAV abundance and health by increasing phytoplankton levels and water color which in turn decreases the amount of light that penetrates the water column to become available to SAV.

Level of certainty - moderate

Effects of Increased Epiphyte Growth on Submerged Aquatic Vegetation

Increased epiphyte growth can be caused by both increases in available nutrients that accelerate their growth and/or a decrease in grazing pressure. This increase in epiphytes can shade the blade of the SAV, thus decreasing the amount of light that can be absorbed by the plant and used for photosynthesis.

Level of certainty - moderate

Effects of Muck Accumulation on Submerged Aquatic Vegetation

Large deposits of highly organic, silt and clay materials, i.e., muck, have displaced normal sandy substrate in the lagoon contributing to the decrease in extent of SAV beds. SAV need suitable substrate for successful recruitment and establishment. Muck sediments are easily resuspended in the water column by boat wakes, wind and wave action, decreasing the amount of light which penetrates the water column to become available to SAV.

Level of certainty - moderate

Effects of Boating Pressure on Submerged Aquatic Vegetation

The increase in the numbers of boats in the lagoon has contributed to the decrease in extent of SAV beds. Shallow areas, which normally contain the healthiest and most abundant beds, are most likely to be impacted when boats run aground, or boat props come in close proximity to the grass beds.

Level of certainty - low

Effects of Physical Alterations in the lagoon to Submerged Aquatic Vegetation Distribution, Abundance and Health.

The physical alterations in the lagoon that have an adverse impact on SAV include the destruction of natural shoreline and replacement with hardened shoreline such as bulkhead and seawalls. As the shallow sloping shorelines are eliminated, the area available with the correct depth for SAV recruitment and growth declines.

Level of certainty - high

A.11.7 Benthic Communities

Effects of Altered Salinity Envelope on Macroinvertebrate Community

Sudden and extreme shifts in salinity lead to changes in the diversity and species composition of benthic invertebrates in the lagoon. Community composition varies with the substrate encountered, however, for any animal there are limits of salinity extremes and rates of salinity change beyond which the cells and the organs will not function (McLusky 1971).

Level of certainty – high

Effects of Elevated Nutrients on Macroinvertebrate Community

Benthic infaunal organisms are often used as indicators of perturbations in the estuarine environment because they are relatively nonmobile, short-lived, and, therefore, cannot avoid environmental problems. The response of benthic communities to alterations in sediment and water quality is relatively well understood and is often expressed as changes in community structure, density, and diversity (USEPA 1999). For example, excess nutrients can create enhanced feeding opportunities for some tolerant organisms, while eliminating niches, habitats and food supply for other sensitive organisms.

Level of certainty – moderate

Effects of Shift in Sediment Characteristics on Macroinvertebrate Community

Rapid deposition of new sediments or sudden shifting of unstable sediments during excessive stormwater discharges can make conditions inhospitable for certain classes of sessile organisms that require stability for survival and reproduction.

Level of certainty - moderate

Effects of Shift to Toxic Substances and Contaminants on Macroinvertebrate Community

Since macroinvertebrates physically live either on or in the sediments, they are directly exposed to and affected by heavy metals, pesticides and other toxins in the sediment. Many of these substances are either insoluble in water or tend to associate with particulate matter that flocculates, often resulting in concentrations much higher in the estuarine sediments than that observed within the overlying water column. This increase in toxins can cause a shift to more pollutant tolerant species. Toxins can also bioaccumulate causing a decline in the health of the communities.

Level of certainty - moderate

Effects of Shift to Anoxic and Hypoxic Conditions on Macroinvertebrate Community

Different species may be better adapted than other less tolerant types to endure low oxygen conditions. Sustained low dissolved oxygen levels will generally result in extirpation of more sensitive taxa, such as bivalves, with a resultant shift toward a macroinvertebrate community dominated by less sensitive taxa such as Oligochaeta the polychaete Capitellidae.

Level of certainty - moderate

A.11.7.1 Fishery Species

Effects of Reduced Coverage and Health of Submerged Aquatic Vegetation on Fishery Species

Economically and ecologically valuable fishery species include both fish and shellfish (e.g., lobster and shrimp). Reduction in size and health of SAV beds effects the location, abundance and speciation of fisheries in the lagoon. SAV provide nursery grounds for many fish and invertebrate communities and the destruction of these nursery grounds has a negative effect on the estuarine fish communities.

Level of certainty - moderate

Effects of Toxic Substances on Fishery Species

Toxic substances that can deleteriously affect fish health include pesticides, various heavy metals, polychlorinated biphenyls (PCBs), polycyclic aromatic hydrocarbons (PAHs), etc. These substances are delivered to the lagoon with freshwater inflows from both agricultural and urban stormwater runoff, or released in situ via various maritime activities and practices. Such substances can affect fish health either singly, additively or synergistically, such that a clear understanding of the potential ramifications of often low level concentrations is difficult. Additionally, toxic compounds can compound the effects of biological toxins produced by certain species of algae, either during blooms or during minor species shifts in algal communities, or permit opportunistic organisms to adversely affect fish health. Fish health effects include avoidance, fish abnormalities such as lesions, genetic changes, and loss of reproductive success. Documented pathways for toxic substances to affect fish health include bioaccumulation through the underlying chain of foodstuffs, direct exposure to compounds in the water column, and/or exposure to contaminated surficial sediments. Certain species of fish appear to be more prone than others to the effects of toxic materials.

Level of certainty - low

Effects of Loss of Mangrove Habitat on Fishery Species

Destruction of the mangrove shoreline that once lined large areas of the lagoon has negatively impacted fisheries. Mangroves supply a structural refuge for juvenile fish, a substrate for fish food sources, and are an important component in the detrital food chain for the lagoon. In large areas of the lagoon, natural shoreline has been lost to development.

Level of certainty – high

A.11.7.2 Shoreline Habitat Functionality

Relationship of Loss of Mangroves to Physical Alterations to the Lagoon

Physical alterations to the lagoon caused by increased population in the coastal zone has lead to the conversion of natural shoreline, both mangrove and freshwater floodplain, to seawalls, bulkheads and other types of hardened shoreline. This loss of habitat impacts many other important components of the lagoon including fisheries, crabs, benthic invertebrates and birds.

Level of certainty - high

A.11.7.3 Near-Shore Reef

Relationship of Near-Shore Reef to Altered Freshwater Flows

Increased flows may also equate with increased loads and a concomitant increased potential impact to the health and abundance of near-shore reefs. Competition is an important process determining the structure and composition of benthic communities on reefs, and competition from macro-algae is an important step during reef degradation (Mcook et al. 2001). Even slight increases in nutrients can present catastrophic consequences, and can result in blooms of macro- and filamentous algae (Lapointe 2000).

Level of certainty - low

A.11.8 Research Questions

Research questions were developed for the critical linkages discussed in Section A.11.4 and displayed in the conceptual ecological model (Figure A-38, Section A.11.9) based on relative importance to project outcome in consideration of relative certainty of those linkages. Ecological changes resulting from the reduction of stormwater discharges to the Lake Worth Lagoon will be influenced by interrelated causal relationships with low levels of certainty. All of these uncertainties involve the estimated reductions in freshwater flow and sediment loading into the lagoon. Several of these relationships are based purely on the volume, timing and distribution of the fresh water itself, while others involve reductions of nutrient, toxin, suspended solids and dissolved organic loads that are associated with discharges from the developed watershed.

Effects of Altered Salinity on Submerged Aquatic Vegetation

What effect do undesirable salinity shifts have on the diversity and community species composition of *Syringodium filiforme* and macro-algae?

Relationships among Submerged Aquatic Vegetation, Salinity and Fishes

What is the temporal utilization of SAV by fish and how is that interaction affected by salinity?

Relationship of Submerged Aquatic Vegetation to Input of Nutrients, Turbidity and Dissolved Organic Matter

What effect does increased levels of nutrients and dissolved organics have on light attenuation and its subsequent effect on the distribution, density and abundance of SAV in the Lake Worth Lagoon?

Relationship of Submerged Aquatic Vegetation to Increased Epiphyte Growth

What is the relationship of the amount of epiphyte coverage found on SAV with the location, abundance and diversity of different species in the Lake Worth Lagoon?

Relationship of Submerged Aquatic Vegetation to Accumulation of Muck

What is the present distribution of muck deposits and how do they relate to SAV reestablishment?

Relationship of Physical Alterations in the Lagoon to Submerged Aquatic Vegetation Distribution, Abundance and Health

What is the best way to reestablish SAV in areas that have been physically impacted?

Relationship of Macroinvertebrate Community Shift to Altered Salinity Envelope

What effect do undesirable salinity shifts have on the diversity and community species composition of macroinvertebrates in the lagoon?

Relationship of Macroinvertebrate Community Shift to Elevated Nutrients

What effect do elevated nutrients have on the diversity and community species composition of macroinvertebrates in the lagoon?

Relationship of Macroinvertebrate Community Shift to Sediment Characteristics

What effect do sediment characteristics have on the diversity and community species composition of macroinvertebrates in the lagoon?

Relationship of Macroinvertebrate Community Shift to Toxins and Contaminants

What effect do contaminants have on the diversity and community species composition of macroinvertebrates in the lagoon?

Relationship of Macroinvertebrate Community Shift to Anoxic and Hypoxic Conditions

What effect does oxygen regime have on the diversity and community species composition of macroinvertebrates in the lagoon?

Effects of Reduced Coverage and Health of Submerged Aquatic Vegetation on Fishery Species

What is the relationship of habitat loss and fishery species?

Effects of Increased Levels of Toxins on Fishery Species

To what extent do fish within the lagoon exhibit the abnormalities and/or lesions documented in nearby associated waters (i.e., Loxahatchee Estuary, St. Lucie Estuary and the Indian River Lagoon)? What is the functional relationship between toxins and abnormalities and/or lesions found on fish in the Lake Worth Lagoon?

Effects of Loss of Mangrove Habitat on Fishery Species

What is the effect of loss of mangrove habitat on fishery species? What is the best way to enhance or reestablish viable shoreline habitat?

Relationship of Tidal Inundation into the Lake Worth Lagoon Due to Sea Level Rise

What is the relationship of sea level rise to the lagoon's salinity regime?

Relationship of Macroinvertebrate Community Shift to Altered Salinity Envelope

What effect do undesirable salinity shifts have on the diversity and community species composition of macroinvertebrates in the Lake Worth Lagoon?

Relationship of Water Quality in Lake Worth Lagoon to Water Management

What is the quantitative link between water management and flow at the boundary of the lagoon ecosystem?

Relationship between Turbidity and Nutrient Concentrations and the Reestablishment of Seagrasses in Lake Worth Lagoon

What limits seagrass distribution in the central and southern segments of the lagoon and are changes in water management going to improve this?

Relationship between Actual Freshwater Inflow to Lake Worth Lagoon and Water Management

Is there a direct relationship between the inflow of fresh water to Lake Worth Lagoon and water management practices in the watershed?

Relationship of Habitat Loss and Estuarine Fish Communities

What is the appropriate salinity gradient to maintain from interior coastal wetlands through the near-shore zone in order to optimize the diversity and abundance of estuarine fish species in Lake Worth Lagoon?

Relationship of Freshwater Flow to Estuarine Habitat

How is estuarine habitat affected by the quantity, timing and distribution of freshwater inflow?

Relationship of Mangroves and Freshwater Inflow Changes and Sea Level Rise

What are the effects of freshwater inflow change and sea level rise on mangrove distribution?

A.11.9 Hydrologic Performance Measures

A.11.9.1 Polyhaline Pattern and Stability

Improving the timing, quantity and duration of freshwater discharges is the primary mechanism for changing salinity patterns within Lake Worth Lagoon. The goal is to moderate wet season flood releases and augment dry season inflows to provide an ecologically appropriate salinity envelope. The goal is maximize the balance, diversity and distribution of the polyhaline and stenohaline community, and to reduce to the extent possible of mesohaline conditions. The central and southern segments of the lagoon should more closely resemble conditions currently present in the northern segment.

The preliminary salinity target performance measure for the Lake Worth Lagoon is an inflow of 500 cubic feet per second (cfs) during the wet season. This inflow is expected to achieve minimum bottom salinity of 23 parts per thousand (ppt) during the wet season at a distance of 0.5 miles north of the mouth of the C-51 canal.

A target salinity envelope is being developed by the North Palm Beach Comprehensive Everglades Restoration Project Delivery Team. The team has established a Receiving Waterbodies Focus Group that will use an integrated modeling approach to develop a salinity gradient that would result in a more stable and persistent natural biological communities in the lagoon. The modeling approach will be completed by December 2003.

A.11.10 Ecological Performance Measures

A.11.10.1 Water Quality

Water quality performance measures for Lake Worth Lagoon includes the following indicators: nutrients, algal bloom frequency, and water clarity measured by photosynthetically-active radiation (PAR). Current levels of surface water nutrient (total phosphorus and total nitrogen) concentrations and loads must be maintained or reduced to historical background levels. Frequency of algal bloom occurrences must not increase. Existing water clarity must be maintained or improved in those regions where reduced water clarity is limiting growth of seagrasses. Reduce loads of nutrients, toxins, dissolved organic matter and total suspended solids that originate from agricultural and urban land use practices and are exacerbated by regulatory and flood releases during wet periods and from the enlargement of the local drainage basins.

A.11.10.2 Sediment Quality

Restoration efforts and changes in water management practices may affect the conveyance of contaminants in sediments; therefore, toxicant concentrations are also a recommended indicator for a performance measure. The target is to decrease the geographic extent and concentration of sediment contamination and decrease the extent of unstable or muck sediments, which inhibit formation of balanced benthic community.

A.11.10.3 Benthic Community

Benthic performance measures recommended for the lagoon include increased species richness, abundance and diversity of benthic species. Unstable salinity, low dissolved oxygen, presence of toxic substances and elevated concentrations of nutrients (via algal response to nutrient enrichment) can separately or in concert with one another adversely affect the composition of the lagoon's benthos. Maintenance of suitable conditions will allow establishment of sensitive groups (e.g., filter feeders such as Pelecypoda and Porifera, and grazers such as Telmatogetoninae), resulting in an overall balanced and diverse benthic community typical of that of a healthy lagoonal system.

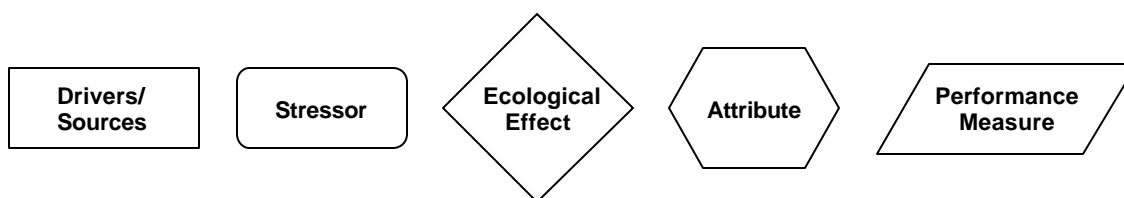
A.11.10.4 Submerged Aquatic Vegetation

The indicators for a SAV performance measure include cover, density and species composition. The target is to reestablish SAV beds in areas presently devoid of SAV, to improve cover where currently inhibited, and to maintain existing cover in areas where plants currently flourish.

A.11.10.5 Fishery Species

Indicators recommended for performance measures relative to the fish and shellfish communities include abundance, density and species composition. The overall target is to increase the diversity and density of fishery assemblages at benchmark locations in the Lake Worth Lagoon. More specifically the target is as follows:

- Increase representation of juvenile stages of reef and recreationally important fishes, including gray snapper (*Lutjanus griseus*), mutton snapper (*Lutjanus analis*), yellowtail snapper (*Ocyurus chrysurus*), lane snapper (*Lutjanus synagris*), yellowtail parrot fish (*Sparisoma rubripinne*), gag grouper (*Mycteroperca microlepis*), grunt (*Haemulon* sp.), snook (*Centropomus undecimalis*), red drum (*Sciaenops ocellata*), and spotted seatrout (*Cynoscion nebulosus*) from present baseline conditions.
- Increase abundance of mullet (*Mugil* sp.), menhaden (*Brevoortia* sp.) and anchovy (*Anchoa* sp.) based on catch per unit effort.



- Increase post-larval and juvenile densities of spotted seatrout in representative seagrass beds, particularly shoalgrass from present baseline conditions.
- Increase juvenile settlement rates of the common and fat snook (*Centropomus parallelus*) at representative sites in the Lake Worth Lagoon from present baseline conditions.
- Increase abundance of juvenile and adult red drum at representative lagoon sites from baseline conditions.

A.11.10.6 Shoreline Habitat Functionality

The indicators for a performance measure shoreline habitat functionality is the percent of restored shoreline mangrove habitat, species diversity, and quality of habitat as defined by height, depth and density of fringing mangrove stands. The target or restoration expectation is to increase spatial extent of mangrove and emergent shoreline plant communities.

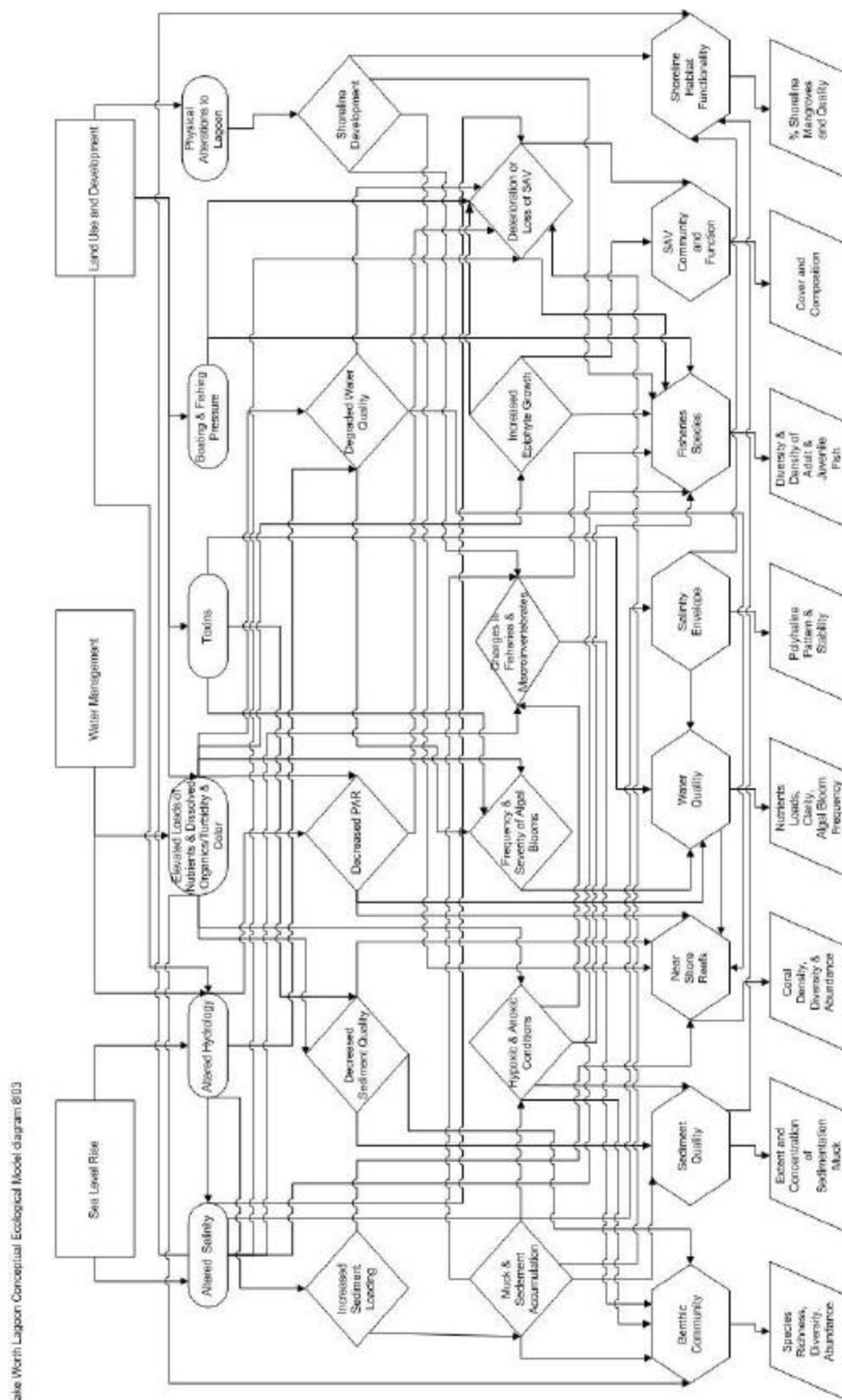
A.11.10.7 Near-Shore Reef Health

Indicators recommended for performance measures relative to the near-shore reef system include coral density, diversity and abundance. Water clarity, sediment quality and deposition rate must not inhibit or adversely affect the near-shore reef system such that there is a net loss or degradation of coral.

A.11.11 Model

The diagram for the Lake Worth Lagoon Conceptual Ecological Model is presented in Figure A-38. The key to the symbols used in the diagram is presented in Figure A-37.

Figure A-37: Key to the Symbols Used in the Following Diagram



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