Coastal Bays and Barrier Islands Conceptual Ecological Model

1. Model Leads

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2. Introduction

The coastal bays and barrier islands covered by this conceptual model are located on the southwest coast of Florida and include Estero Bay, Naples Bay, Rookery Bay, and their associated barrier islands. These coastal bays are characterized by a salinity gradient and mosaic that vary spatially with topography and that vary seasonally and inter-annually with rainwater and freshwater flow from their associated tributaries. All of the coastal bays have formed into lagoonal type estuaries by the lack of significant fresh water input and a weak tidal exchange due to the restricted size of their inlets.

Each of the bay systems has been impacted by varying degrees of hydrologic alterations and degradation of water quality. **Naples Bay** is the most severely impacted of the representative bays. The bay is heavily influenced by urban development activities, and as a result has reduced water clarity, increased concentrations of toxicants and nutrients, and reduced dissolved oxygen levels. Extensive areas of mangroves and salt marsh have been replaced by seawalls and bulkheads. Road and drainage development activities have altered the volume, quality, timing and mixing characteristics of freshwater flows reaching Naples Bay. Seasonal influxes of fresh water from the Golden Gate Canal System have greatly altered the natural salinity regime, and severely stressed the biota of the estuary. The prolonged salinity stresses have resulted in sharp declines in plankton, benthic, shellfish, and fish communities. Seagrass beds once prevalent in the bay have been replaced by bare sandy mud.

Estero Bay is also heavily influenced by urban development activities. Deteriorating water quality in the bay and tributaries, all of which are classified as Outstanding Florida Waters, has occurred concurrently with the rapid urbanization of the watershed. Seagrass beds are shrinking and are being replaced by algae; dissolved oxygen levels are decreasing below acceptable levels; and heavy metal concentrations are increasing in the tributaries due to storm water runoff from urban areas. Alteration to freshwater inflows has significantly influenced the salinity gradients and nutrient loading of the rivers and creeks that flow into the bay. The adjacent barrier islands (Estero Island, Big Hickory Island, and Black Island) have been developed and submit additional stresses to the estuary.

Rookery Bay is located at the northern end of the 10,000 Islands area, one of the largest mangrove-forested regions in the new world. Rookery Bay is one of the few remaining relatively undisturbed estuaries in Southwest Florida and is the least impacted of the representative bays. Pristine mangrove forests surround the bay's shallow waters and pine flatwoods and dry-zone scrub act as upland buffers. However, the area surrounding Rookery Bay is experiencing unprecedented urban growth rates. Roads, canals, planned unit developments, commercial projects, and agriculture represent major land-uses within the primary watersheds draining into Rookery Bay. These alterations can greatly modify the volume, timing and quality of freshwater entering this fragile estuarine ecosystem.

Mangrove forest is the dominant plant community type in the coastal bays. Four different species of mangrove tree occur in the bays. Moving progressively landward, those species are the red mangrove (*Rhizophora mangle*), black mangrove (*Avicennia germinans*), white mangrove (*Laguncularia racemosa*), and buttonwood (*Conocarpus erectus*). The most common type of the mangrove community within coastal bays is the fringe mangrove which occurs along the shorelines of the bays and their associated tributaries and waterways. All four mangrove species can be found in this mangrove community type.

Seagrasses and salt marshes are also present in the coastal bays. The seagrass beds are primarily comprised of three seagrasses: turtle grass (*Thalassia testudinum*), manatee grass (*Syringodium filiforme*), and Cuban shoal grass (*Halodule wrightii*). In areas of low salinity, such as near the mouth of freshwater rivers and creeks, widgeon grass (*Ruppia maritima*) can be found. The denser grassbeds are usually found in shallow water with a fairly constant level of salinity. Saltmarshes form a transitional community between mangroves, freshwater marshes, and salt barrens. This community becomes more dominant in the brackish upper reaches of the tidal creeks and rivers. The dominant species in this community are smooth cordgrass (*Spartina alterniflora*) in the lower zones, black needlerush (*Juncus roemarianus*) in the middle zone, and saltgrass (*Distichlis spicata*) and salt meadow cordgrass (*Spartina patens*) in the upper salt marsh zone.

The combination of subtropical climate, the lagoon configuration, and diverse habitats make coastal bays one of Southwest Florida’s most important ecological areas for vertebrate species. Approximately 40% of the state's endangered and threatened species are found within this area. The coastal bays support a variety of commercial and sport fisheries by providing nursery areas and other critical habitat. The coastal bays are also important homes for colonial waterbirds and valuable stopover areas for migratory birds.

3. External Drivers

Drivers include the major external natural and anthropogenic driving forces that have large scale influences on natural systems. Natural drivers creating potential stressors to the coastal bays include severe storms, sea level rise, and natural fluctuations in rainfall patterns. Anthropogenic drivers include urban, industrial, and agricultural development and water management practices.

NATURAL SOURCES

Climatic cycles and meteorological events

Climatic cycles and meteorological events can cause flooding or drought stressed conditions in estuaries that are similar to stressed conditions created by water management practices. Human use of water resources can also compound the problems associated with floods and drought. Major storms have significant effects on water quality and benthic habitats. Estuaries monitored after hurricanes exhibit high turbidity, increased nutrient and pollutant loading, high dissolved organic carbon, and persistent plankton blooms (Tilmant et al., 1994). Benthic communities also experience high erosion, and burial and removal of organisms during hurricanes (Thomas et al., 1962; Tilmant et al., 1994).

Sea Level Rise

Coastal bays may be significantly reconfigured during the 21st Century due to the rise of sea level which is projected to increase two feet over the next one hundred years. In combination with climatic cycles and major storm events, sea level rise will result in shoreline transgression, inland movement, and altered circulation and salinity patterns in the coastal bays. Thus functional estuaries and their ecological attributes, as influenced by the restoration of beneficial freshwater flow volume and duration, must be viewed as spatially dynamic with a long-term trend toward inland movement.

The spatially dynamic aspects of the estuaries, resulting from sea level rise and geomorphic processes, influence all of the ecological attributes and restoration expectations for the estuaries. Although sea level rise and shoreline transgression are facts, fundamental uncertainties remain regarding when and to what extent the estuaries will be reconfigured. These uncertainties pertain to rates of accretion versus erosion of mangrove soils, coastal storm berms and bay mud banks, to altered circulation and salinity patterns, and to specific spatial shifts in estuarine habitat zones (RECOVER. 2001).

ANTHROPOGENIC SOURCES

Water Management

Water Management practices, including diversion, ditching, and diking, have resulted in drastic changes to the natural surface water flow patterns in the coastal bays' watersheds. These changes have caused large fluctuations in the quantity, timing, distribution, and quality of freshwater entering the coastal bays and have had an overwhelming impact on the ecology of the estuarine systems through the alteration of the salinity regime.

Urban, Industrial, and Agricultural Development

Population growth in the watersheds of the coastal bays has been rapid and represents a potential threat to the ecological integrity of the region. Changes in land use associated with an increase in urban, industrial, and agricultural development have led to loss and fragmentation of coastal and shoreline habitat, changes in water use, and an increase in water demands. Increased development has led to increased boating pressure from both commercial and recreational boating activities and increased fishing pressure from sport and commercial fisheries. The need for coastal navigation has resulted in the dredging and the channelization in all of the coastal bays.

Urban and agriculture development has impacted the water quality in coastal bays. Sources of water quality problems may include urban stormwater runoff (e.g., lawns, golf courses, "street dust"), agricultural runoff, surface mining runoff, septic systems, discharges from Publicly Owned Treatment Works (POTWs), direct industrial discharges, landfill runoff, as well as atmospheric deposition of contaminants from varied sources (for a review of drivers, see USGS 1998, 1999). Although much of the focus (and control) has been on point sources, considerable evidence has been amassed to suggest nonpoint sources, such as urban stormwater runoff, and diffuse pathways, such as atmospheric deposition, can play very significant roles in local WQ problems. Atmospheric deposition of contaminants from varied sources (both local and distant) can be an important driver in estuarine WQ in one of two ways. Direct atmospheric deposition of a contaminant to the estuary includes loading from dry deposition and wet deposition. Indirect deposition from the atmosphere to the estuary occurs when the contaminant is initially deposited to the watershed and then transported to the estuary through runoff and tributaries and, hence, a function of water management. Along with the growing appreciation of potential impacts from atmospheric transport and deposition also comes a realization that we can no longer rely on the "dilutive effects of the ocean environment" to solve coastal pollution. Evidence has accumulated that anthropogenic contaminants, as well as natural occurring materials, in riverine discharges can be transported and have biological effects far removed from their discharge site (Rabalais et al. 1996; Goolsby, 1994, Rudnick et al., 1999). As one example, algal blooms in western Florida Bay have been linked to nutrient transport along the southwest shelf of Florida (Rudnick et al., 1999).

A recent assessment of the Florida Department of Transportation's "Florida Land Use and Cover Classification System (FLUCCS) for the Estero Bay watershed in 1995 estimated 20% of landuse was urban, 18% was agricultural with the remaining 62% undeveloped (T. Liebermann, pers. comm.). Although values differed slightly, this was not inconsistent with an earlier assessment of landuse in the watershed by PBS&J, Inc. (1999; note, basin delineations may have differed between assessment). PBS&J, Inc. (1999) also reported 101 domestic point sources (31 occurring within the Imperial River Basin) and 13 industrial point sources permitted by FDEP within the watershed. Based on 2000 FLUCCS, landuse in the Estero Bay watershed was estimated at 24% urban (and increase of 4% in 5 years), 16% agriculture and 60% undeveloped (T. Liebermann, pers. comm.). Urban landuse also increased in the five year period between 1995 and 2000 in western Collier County, going from 12% to 13%; during this same period, agriculture decreased from 1% to less than 0.5%. Various projections (e.g., http://www.colliergov.net/compplanning/; Southwest Florida Regional Planning Council; SWFFS) agree that populations in southern Lee and Collier Counties continue to grow at a significant rate.

Recent loading assessments for Estero Bay (PBS&J, Inc.1999; PBS&J and Bender, 1999; DHI, 2001) differed in approach and, not surprisingly, quantitative output; however, qualitatively, reached similar conclusions. Based on their landuse estimates, PBS&J, Inc. (1999) ranked the same three tertiary basins (out of a total of 68 tertiary basins) as having the highest loading for: 1) total runoff, 2) TP and TN and, 3) TSS (i.e., runoff water flow was calculated from precipitation data and landuse specific-runoff coefficients and areas; pollutant load rate was quantified from calculated flow and standard concentrations). Not surprisingly, these three basins, which were located within the secondary basins of Imperial River, Estero River and Six-Mile Cypress Slough, were the largest of the tertiary basins. By comparison, area-weighted rankings were highest for two tertiary basins located within Hendry Creek and a basin in Ten-mile canal (PBS&J Inc.,1999). These rankings of tertiary basins by PBS&J Inc. (1999) were consistent with the results of water quality modeling of the Estero Bay Watershed by DHI (2001) that found the greatest loading of runoff, BOD, TP and TN to the Bay was from the Imperial River. On a per unit area basis, DHI (2001) also ranked Hendry Creek highest in terms of BOD, TP and TN. Estimates of total loads to Estero Bay via the tributaries (e.g., hydrologic, TP and TN) differed by a factor of two between assessments by PBS&J and Bender (1999) and DHI (2001). A complete understanding of loading to Estero Bay will require information regarding exchange between the bay and near coastal waters (i.e., influx as well as efflux), including loads originating from Caloosahatchee River that enter the bay through Matanzas Pass. Similar loading assessments will be required for Naples Bay and coastal Collier County.

4. Ecological Stressors

Stressors are the physical or chemical changes that occur within natural systems that are brought about by the drivers, and which cause significant changes in the biological components, patterns and relationships in natural systems.

Altered Hydrology and Freshwater Inflow

Altered hydrology is one of the predominate stressors to coastal bays and includes both excessive water withdrawals and freshwater pulses. Hydrologic changes have resulted in decreased water quality, increases in turbidity and nutrient loading, altered water residence time in the estuaries, increased seagrass mortality, harmful algal blooms, and an altered salinity regime. These changes, in turn, are impacting critical estuarine biota.

Urban and agricultural development have caused drastic changes to the natural surface water flow patterns in the watersheds of the coastal bays. Historically, flow-ways in the region followed the natural drainage features made up by a series of strands, sloughs and more broadly as surface sheetflows to the tidal areas of the estuary. The historic water flows were extremely slow and deeply penetrating due to vegetation and physical geography, and hydroperiods extended well into the winter/spring dry season. However, as land areas began to be developed, the alterations resulted in a series of canals, ditches, dikes, and numerous roads that overdrained the water table and drastically altered the flow patterns of the natural drainage basins. These development events have greatly reduced the areas of functional wetlands, lowered groundwater levels, reduced aquifer recharge and contributed to concentrating the flow of stormwater runoff instead of allowing the traditional sheetflow across the land.

Altered flows into the coastal bays may affect the federally endangered West Indian manatee (*Trichechus manatus*), American crocodile (*Crocodylus acutus*), smalltooth sawfish (*Pristis pectinata*), and wood stork (*Mycteria americana*). The West Indian manatee forages, calves, and rests in the bays as well as tributaries leading into the coastal bays. Hydrologic changes may alter freshwater flows and biological conditions in the bays, which in turn may effect manatees. Changes in hydrology affects the American crocodile's use of tributaries and may affect nesting habits and success. The bays contain smalltooth sawfish habitat and excessive freshwater inflows or pulses could decrease the value of this habitat for sawfish (Seitz and Poulakis, 2002). The wood stork forages in all of the tributaries leading into the bays, and any change in hydrology in this area may affect wood stork feeding areas.

Changes in Water Quality and Increased Contaminants

Typical water quality problems in estuaries include nutrient enrichment leading to accelerated eutrophication; low dissolved oxygen (DO) levels associated with eutrophication and/or flow restrictions; toxics in the water column or sediments, particularly petroleum hydrocarbons and heavy metals from point discharges and non-point source runoff; algal blooms, which can be toxic to marine organisms and humans; and the proliferation of invasive species.

Increases in freshwater inflow from runoff as well as from point sources have also contributed to a significant decrease in water quality within the coastal bays. Major issues of concern include increased sedimentation and turbidity as well as increased nutrient loading and chemical pollution (VanArman et al., 1989).

The following examples show that many local water quality stressors have drivers both inside and outside of the study area.

Salinity

Altered salinity (often described in terms of chlorinity or specific conductance) can result from natural events, such as seasonal rainfall, major storms, rise in sea level, and by controlled releases of water when rainfall and storms lead to emergency management of upstream water sources. In the case of the latter, freshwater would be considered a pollutant.

Physical Characteristics, Major Ions, Dissolved Organic Carbon, (e.g., Turbidity, Total Suspended Solids, calcium, chlorides, specific conductance, etc.)

Dissolution of rocks and soils, wastes from wildlife and domestic animals, and agricultural and urban drainage are all sources of total dissolved solids (TDS) in surface water (and attendant changes in conductance as related to concentration of chloride, sulfate, and other major ions; for review, see Field et al. 2003, SFWMD 1999). Stormwater releases have the potential to directly or indirectly alter temperature, pH, total suspended solids, turbidity, and dissolved oxygen. Accelerated decomposition of organic matter in the historic peat deposits (due to land-use change) provides a significant source of DOC and nutrients (Wang et al., 2002).

Nutrients

Not surprisingly, the National Water-Quality Assessment (NAWQA) Program has found nutrient loads differ by land use, with the highest nitrogen and phosphorus concentrations occurring in agricultural and urban streams (USGS, 1999). These finding are consistent with assessments in south Florida that report elevated nutrient concentrations (or loads) in both agricultural and urban runoff (Drew and Schomer, 1984; Post, Buckley, Schuh, and Jernigan Inc., 1999; Post, Buckley, Schuh, and Jernigan Inc. and W. Dexter Bender and Associates, Inc., 1999; ERD 2003). South Florida's high level of agricultural productivity can be a significant driver in water quality problems as a result of various activities including the substantial usage of soil amendments, including mineral fertilizers and biosolids (USEPA, 1999), or simply due to soil disturbance (Wang et al., 2002). Accelerated decomposition of organic matter in the historic peat deposits of the Everglades (due to land-use change) has been reported to be a significant source of DOC and nutrients (Wang et al., 2002). Land use change associated with urbanization has also been found to be a significant driver in water quality problems. In an urban water quality study in North Carolina, some of the highest pollutant export rates were from new construction sites (Line et al., 2002). Housing construction was divided into two phases: construction-I (clearing, grubbing and grading) and construction-II (installation of roads, house construction, landscaping). They found that golf course, pasture and construction-I land uses had the highest export rates for phosphorus. Interestingly, of the various urban land uses, construction-II had the highest export of nitrogen. They attributed this loading from a combination of a high level of nitrogen import in the form of enriched topsoil [sod], mulch, fertilizer and immature vegetation.

In addition to stormwater runoff (end of the pipe), human activities may also be a driver via an atmospheric pathway. Nitrogen can volatilize directly from the surface of fields (dependent on application method) or can be blown off fields or roads as particles. The atmosphere can be a significant source of nitrogen in various forms (i.e., in addition to diatomic nitrogen) from a variety of sources (Pribble *et al.* 2001). These include, but are not limited to, nitrous oxides (emitted from combustion of fossil fuels) and its reactive products: nitric acid and nitrate; ammonia (emitted from soils, growing plants, manure and fertilizers) and its reactive product, ammonium; organic nitrogen compounds. Prospero et al. (1996) estimated that present day deposition on nitrogen (including ammonia) to the North Atlantic Ocean to be five times greater than pre-industrial times, primarily due to fossil fuel combustion and biomass burning. Similarly, atmospheric deposition of nitrogen (potentially from a distant source) could be a driver (external to the study area) contributing to water quality problems in southwest Florida (Squires *et al.* 1998). Although atmospheric deposition of nitrogen has been estimated to be responsible for 21% of external nitrogen loading to Tampa Bay, it is important to note that the greatest part of nonpoint nitrogen loading was attributed to urban and agricultural runoff (Pribble *et al.* 2001).

In this context, one illustration of the potential significance of direct atmospheric deposition of ammonia is its possible role in blooms of *Karenia brevis*, i.e., red tides (Steidinger et al., 1998). Alternatively, Lenes et al. (2001) make a compelling argument that long-range atmospheric transport of iron (a known growth factor) and bloom stimulation of the nitrogen fixing *Trichodesmium* could be a contributing factor to red tide outbreaks in southwest Florida, i.e., the release of the fixed nitrogen could fertilize *Karenia brevis*. Hence, this important southwest Florida issue may have external drivers not under local control. Not surprisingly, modelers remain "stymied by the chaos of unknown initial conditions" that stimulates red tides in southwest Florida (Walsh et al. 2002). Red tides have been documented along the west coast of Florida well before the “age of water management” (Geesey and Tester 1993) and will likely continue despite out best efforts. Consequently, although chlorophyll-a will likely be used as an indication of algal blooms, occurrence of red tides (*K. brevis*) will not be a performance measure (either evaluation or assessment) for the SWFFS. Nonetheless, it is conceivable that some reduction in red tide magnitude, duration, or frequency is achievable if coastal nutrification were reduced.

Toxicants

Agriculture, turfgrass systems (golf courses, turf farms, city parks and lawns) and ornamental plants require usage a wide variety of pesticides, i.e., insecticides, herbicides, and fungicides. Contrary to public perception, USGS (1999) reports that insecticides occur more frequently in urban streams than in most agricultural streams. Urban runoff has been found to contain a wide variety of other toxicants that can results in significant impacts to aquatic biota in receiving waters (Pitt, 1995). Residues of some of these pesticides have been detected in sediments and surface water at District structures at various times (Miles and Pfeuffer 1997, Pfeuffer and Matson 2002). Likewise, sediment and fish collected by the USGS National Water

Quality Assessment Program have also been found to contain pesticide residues at some locations in the central and southern Everglades (http://sofia.usgs.gov/ publications/ circular/ 1207/ summary.html, also see the NOAA shellfish contaminant network). Waterbirds collected in South Florida have also been reported to contain residues of bioaccumulative pesticides (Rumbold et al. 1996, Spalding et al. 1997, Rodgers 1997, Rumbold and Perio *in prep*). Most recently, a bird kill in excess of 800 birds occurred on Lake Apopka, possibly as a result of pesticide poisoning, after former farmlands were flooded (*The Orlando Sentinel*; March 10, 1999; *Environmental News Network*, February 19, 1999). As mentioned above, fertilizers are also extensively used in Florida. Several studies have measured heavy metals (e.g., cadmium, lead, nickel and copper; USEPA 1999) in mineral ores and resulting fertilizers. Organic and biosolid fertilizers may also have measurable concentrations of heavy metals.

Atmospheric loading is often the dominant proximate source of inorganic mercury to many water bodies, with the ultimate primary drivers being coal-fired utility boilers and municipal and medical waste incinerators (USEPA 1997a). However, the complication lies in the relationship between influx of inorganic mercury and the amount that is methylated post deposition by sulfate-reducing bacteria. The latter process is of fundamental concern because methylmercury (MeHg) is the more toxic and bioaccumulative form that can build up in the food chain to levels harmful to humans and other fish-eating animals. Environmental mercury methylation chemistry is complex. Research continues in to the interactions which enhance or inhibit methylation across a wide range of environmental conditions. Interestingly, in many areas, mercury methylation in the Everglades appears to be driven or inhibited by sulfate loading in agricultural runoff (Bates *et al.* 2002) depending on the sulfate concentrations present. If this is the case, we have two different contaminants with multiple drivers and very different pathways interacting along a concentration gradient to produce a variety of water quality results.

The principal pathway for mercury exposure to humans is through the consumption of marine fish and fish products. Yet, there remains a paucity of data on the cycling and fate of mercury in estuarine and marine systems (for a review, see Rumbold et al. 2003 and reference therein). Obviously, the natural source of sulfate in seawater in estuarine systems complicates source identification, i.e., mainland runoff of MeHg versus atmospheric deposition and *in situ* production. Studies of south Florida estuaries have found elevated levels of mercury (both the inorganic and methyl form) in surface water discharges and, more importantly, in fish (Ache et al. 2000; Adams and McMichael 2003; Evans at al. 2003, Rumbold et al. 2003). Consumption advisories for the protection of human health have been issued for select coastal species (Florida Department of Health 2003).

Water Quality - Baseline Conditions

The following describes the existing water quality conditions in Estero Bay, Naples Bay, Rookery Bay, coastal Collier County and tidal tributaries.

Concerns about water quality now has greater significance given the number of waterbodies recently designated as Outstanding Florida Water under 62-302.700 within the region. These include, but are not limited to Estero Bay and its tributaries, Wiggins Pass and Cocohatchee River System, Rookery Bay NEP and Rookery Bay Aquatic Preserve, and Cape Romano – Ten Thousand Islands State Aquatic Preserve.

In the report entitled "Estero Bay Watershed Assessment", PBS&J Inc. (1999) concluded that concentrations of total nitrogen and nitrite + nitrate in the bay's tributaries (based on data collected from 1990-1997) compared well with the median values observed in southern Florida streams. On the other hand, they concluded values of total phosphorus to be somewhat high in comparison to the statewide medians. Although constrained by the limited amount of data available in STORET at the time of their assessment, U.S. EPA (2000c) concluded that water quality was slightly better in the Estero River compared to the Imperial River (i.e., in terms of DO, BOD, and chlorophyll a), but that both tributaries only partially supported their designated uses. Based on more recent data, FDEP (2002, 2003) classified the tributaries to Estero Bay including the Imperial River, Estero River, Spring Creek, Hendry Creek, and Mullock Creek (either freshwater segment, marine segment, or both) as impaired for nutrients as measured by chlorophyll a (Chl-*a*) concentration, DO, coliforms, copper or some combination of these parameters (for methodology and legislative authority, see Impaired Surface Waters Rule [IWR], Chapter 62-303 F.A.C.). Subsequently, these waterbodies have been listed on U.S. EPA's 303d list (Table 1; U.S. EPA, 2003). Two recent assessments (Janicki Environmental, Inc. 2003; Tetra Tech, Inc. 2004) also report exceedances of state water quality standards within the Estero Bay tributaries based on an informal application of the IWR. As shown by Table 1, these two assessments show remarkable agreement with FDEP's assessment despite the fact they used different data sets (e.g., period of records, sources) and different basin boundaries (i.e., aggregation of data). The assessments found low DO to be a common problem. Several waterbodies were also shown to be of concern due to nutrients, un-ionized ammonia, and copper. The two recent assessments further reported increasing trends in a number of water quality constituents, suggesting worsening conditions. For example Janicki Environmental, Inc. (2003) found concentrations of nitrite+nitrate, orthophosphate, and turbidity were increasing and DO decreasing in Estero River. They found Hendry Creek to have increasing BOD, coliforms, TSS, and turbidity. Imperial River showed increases in TSS, turbidity and declining DO. Spring Creek showed increasing trends in orthophosphate, turbidity and declines in DO. Tenmile Canal showed increases in ammonia, coliforms, nitrite + nitrate, orthophosphate, TSS and turbidity. Tetra Tech, Inc. (2004) also reported several coastal waterbodies showing significant trends of increasing BOD, decreasing DO, and increasing turbidity or TSS. At the same time, there were some trends suggesting improving water quality in several waterbodies including decreasing concentrations of certain nitrogen species in Hendry and Spring Creek, and Imperial River as well as decreasing concentration of TP in the water body containing the Imperial River (Tetra Tech, Inc. 2004).

Unlike its tributaries, Estero Bay (proper) was found to meet designated uses by FDEP (e.g., turbidity, nutrients: Chl-*a*, DO; Table 1) and, thus, was not reported on the 303d list. Although Janicki Environmental, Inc. (2003) found DO and ammonia to be of concern within the basin overall, other assessments have also reported that the bay (proper) generally meets state water quality standards (Mitchell-Tapping 1996, PBS&J 1999, U.S. EPA 2000c, Boyer and Jones 2002, Tetra Tech, Inc. 2004). Although the results of these assessments are cause for optimism, concerns remain regarding water quality in the bay. First, although these datasets met the requirements under the IWR rule, they may not have been sufficient to accurately capture the complexity of this estuarine system. For example, using continuous recording DO probes, Mitchell-Tapping et al. (1998) observed near-dawn DO sags to less than 1 mg/L in the Bay, well below the state standard, which would not likely have been captured by routine sampling during daylight hours. Further, some have argued that because Estero Bay is divisible into two hydrologic systems, water quality assessments must be done separately on each (comments made at July 25, 2002, public meeting for Everglades West Coast Basin Status Report). The notion that the bay may be hydrologically divisible into two regions (by a line drawn through the lower portion of Julies Island) originated from Tabb et al. (1971). Subsequently, this was corroborated to a degree through scoping studies carried out by Clark (1987). Although hydrologic studies with the necessary level of detail have yet to be completed, factors that suggest complexity in the bay's circulation were articulated in the "Estero Bay Watershed Assessment" (PBSJ, 1999; page 1-4) as follows:

"…, the Bay is exceptionally shallow. Average tide range exceeds mean bay depth, meaning there is a large potential for tidal action to affect Bay circulation and flushing. Natural tributaries to Estero Bay are short, and small. Their historic flows are largely unknown, but probably were low, and changed gradually in all but the largest storm events, meaning that the eastern side of the Bay was most affected by river discharges. The Rivers have no outlet channels-- the channels end abruptly upon entering Estero Bay, further signifying relatively low discharges. Inlets from the Gulf of Mexico also are small, and dynamic. Inlets have minor channel systems penetrating into the Bay. These circumstances suggest that circulation is different during high tides than low. Circulation characteristics are largely unknown, but under study. The Bay's zones of minimal tidal exchange, or "null zones" are known. Their location, size, and chemistry will be important variables to consider in bay science and management. Finally, given the Bay's shallow nature, wind is probably an important controlling factor over circulation."

Preliminary results from an ongoing study confirm this complexity and may support independent hydrologic systems. Using salinity as a tracer, Byrne (2003) reports that water from the Caloosahatchee River enters Estero Bay through Matanzas Pass. He further reports that water entering the northeastern part of the bay travels south and mixes with water from the Estero River before flowing through Big Carlos Pass. In the south-central bay, he found that hydrologic exchange was limited and salinities increased. The Imperial River discharged both south and north; the latter ultimately making it to and out Big Hickory Pass and New Pass (Byrne, 2003).

Yet, the supposition that water quality is variable in the bay due to complex circulation patterns was weakened by a recent assessment of the bay as three different regions (upper, middle and lower bay). This assessment, by PBS&J and Bender (1999), found little difference in concentrations of nitrogen, phosphorus and chlorophyll among the three regions (based on data from the Lee County Environmental Lab for the period 1991 – 1998). However, this report failed to delineate the regions and, thus, there is uncertainty whether they adequately captured the complexity of the bay's circulation. In particular, only two stations were identified north of Julies Island and it is uncertain if these stations alone were pooled for the "upper bay". Beyond the issues of monitoring locations and how data are subsequently pooled for evaluation there is also a question about increased variability from random sampling during the flood stage (i.e., Lee County does not target either ebb or flood stage; K. Kibbey, pers. comm.); though an argument can be made that random sampling captures the "average" condition.

Because physical forces (e.g., tidal action, bathymetry, river flow, salinity gradient, density stratification, optical properties, flocculation, etc.,) interact with a variety of biological attributes (as well as chemical), estuaries tend to be relatively individualistic in their response to nutrient over enrichment. An appreciation of these interactions is essential in arriving at sound management actions, including the selection of appropriate water quality benchmarks. Most importantly, it should be understood that although Estero Bay may not be considered legally impaired based on state standards, water quality may be degraded to the point of acting as a stressor. For example, Janicki Environmental, Inc. (2003) reports that stations within the Estero Bay Basin frequently exceeded benchmarks for chlorophyll, nitrogen, phosphorous, and Secchi disk depth when criteria where based either on a U.S. EPA recommended approach (2000d, 2001) or based on research in Indian River Lagoon (Crean et al., in review). Of course, comparisons to other estuaries as a reference condition, even those located nearby, must be done cautiously. For example, Estero Bay basin ranks low (i.e., in terms of concentrations of nitrogen, phosphorous, fecal coliform bacteria, and BOD) when compared to northern Charlotte Harbor (Janicki Environmental, Inc., 2003), but high when compared to Marco Island, Naples Bay, or Rookery Bay (Boyer and Jones 2002). Ideally, one would seek out a minimally impaired reference site that is a physical analog to the Estero Bay (e.g., within an equivalent salinity regime, inflows, outflows, etc.).

Finally, incomplete knowledge regarding hydrodynamic mixing and residence time (i.e., flushing rate) in Estero Bay raises another (and more troublesome) concern. A U.S. EPA report (2001, pg. 1-16) warns that "*… a highly enriched estuarine system with a rapid flushing rate may appear to be in attainment when only the biota and dissolved oxygen are measured, but the load of nutrients being delivered downstream in its coastal discharge plume is degrading the receiving waters.*" At this point it is important to note that, due to a lack of data, FDEP (2003) was unable to determine if coastal waterbodies were meeting uses (i.e., waterbody identification (WBIDs) numbers out to three miles offshore). Tetra Tech, Inc (2004) found coastal Lee to be of concern due to nutrients; however, these findings must be interpreted cautiously due to both the way in which the data were aggregated and presented. The boundaries for the coastal waterbody were established to capture offshore sampling. However, sampling occurred more frequently nearshore and thus, the maps, as drawn, misrepresent the true extent of water quality information. Further, closer inspection of the data set for the WBID 58 (Tetra Tech, Inc. 2004) indicated that it may have included data on Sanibel River.

Although limited in number, assessments of data collected from western Collier County have also raised concerns regarding water quality. During the mid 70s, the Collier County Conservancy evaluated water quality in Naples Bay, the largest urbanized embayment within western Collier and identified three major problems: 1) lack of flushing in dead-end canals, 2) stratification of Naples Bay due to large fresh water inputs and, 3) pollutant discharge from direct stormwater runoff (Simpson, 1979). Based on data collected from 1990-1991, Grabe (1991) reported that waterbodies in highly urbanized areas of Collier County supported high phytoplankton biomass as measured by Chl-*a* and that both the Cocohatchee River and Naples Bay ranked high in nutrient concentrations; the latter especially for inorganic nitrogen. The recent assessment by FDEP found water quality has deteriorated to the point that many waterbodies failed to meet state WQS. Cocohatchee River, Barron River, Henderson Creek, Golden Gate Canal, and Gordon River were all found to be impaired (FDEP 2002, 2003) and, consequently, have all been listed on U.S. EPA's 303d list for nutrients, DO, BOD, coliforms or some combination of these parameters (Table 1). Additionally, Naples Bay was found to be imparied (FDEP 2002, 2003) and reported on the 303d list for nutrients (Table 1). More recently, the Cocohatchee River has also been reported to have elevated copper concentrations (R. Watkins, Collier County Pollution Control Department, pers. communication). Tetra Tech, Inc. (2004) found several waterbodies in western Collier (WBIDs 307, 308, 309, 305, 306, 284, 304, 300) to be of concern for DO, nutrients, ammonia, copper, iron, conductivity, and coliforms.

Further, WBID 307, which extends from Naples Bay down to Rookery Bay, was found to have increasing trends in Chl a. Collier County was outside the scope of the assessment done by Janicki Environmental, Inc. (2003).

As in the case of coastal waterbodies off the southern Lee County coast, FDEP had insufficient data to determine if coastal water off Collier County was meeting all uses (based on maps, report date of 5/22/03, downloaded on 12/16/03 from http://www.dep.state.fl.us/water/images/basin411/EWC_Parameters_8_2.pdf). By comparison, Tetra Tech, Inc. (2004) found coastal Collier (WBID 288) to be of concern for coliforms, copper, iron, and nutrients. Here again these findings must be interpreted cautiously due to both the way in which the data were aggregated and presented. Most of the sampling and observed exceedances were nearshore. Nevertheless, coastal nutrification along southwest Florida as result of loading from these rivers and creeks, is of particular local interest due to the growing public concern about its possible role in outbreaks of red tide, "Blackwater" and, more recently, red drift algae (Gillis 2003, Zollo 2002 and 2003). Although, occurrence of these types of outbreaks will not be a performance measure for the SWFFS (either evaluation or assessment), it is conceivable that some reduction in magnitude, duration, or frequency is achievable if coastal nutrification were reduced.

Although the IWR assessment is based on water column concentrations, additional information on water quality can be gained from an evaluation of sediments. An early study of sediment contamination in Estero Bay reported cadmium, chromium, lead, mercury and zinc above background concentration and considered levels a cause for concern (Clark, 1987). Alternatively, Clark (1987) reported pesticides and polychlorinated biphenyls (PCBs) were below minimum detection levels in all sediments. A re-assessment of Clark's data by Lee County showed that chromium and zinc were at natural levels (K. Kibbey, pers. comm.). Additionally Lee County Environmental Laboratory performed sediment analysis for metals at the same sites in 1989 and 1995 (K. Kibbey, pers. comm.). The additional studies showed that all metals were in the natural levels except for cadmium, lead and zinc. Mercury was not analyzed as it was not included in "A Guide to the Interpretation of Metal Concentrations in Estuarine Sediments". Cadmium increased slightly in 1989, but dropped significantly to just within natural levels in 1995. Lead remained about the same level above background concentrations for all three monitoring events, but the distribution did move towards less flushed areas in 1995. Levels of zinc increased from 1986 to 1989 to 1995. The changes in metal concentration / distribution are most likely attributed to high volumes of discharge that occurred in 1995 (K. Kibbey, pers. comm.). A more recent study by Fernandez et al. (1999), which included eight sediment cores from Estero Bay, also found several of these metals at concentrations above background. However, only chromium and copper were above the threshold effects level (TEL) and neither were above the probable effects level (PEL). Fernandez et al. (1999) also found organic toxicants in sediments from Estero Bay to be below reporting limits.

Low levels of contaminants such as trace metals, chlorinated hydrocarbons and pesticides and aromatic hydrocarbons have been documented in western Collier by studies carried out by the county (Grabe 1990, 1991, 1993), as well as other agencies (NOAA 1999). The results from a recent survey are consistent with previous reports (Grabe 1993) in that only a few locations restricted to highly developed areas in Naples Bay, Cocohatchee River, Vanderbilt Lagoon, and near the Collier Boulevard Bridge were observed to have contamination levels that may require particular attention (Gardinali 2002).

Table 1. Parameters of concern identified through either a formal or informal IWR assessment for Estero Bay watershed and coastal Collier County.

Water Segment	**Everglades Westcoast Basin (U.S. EPA 2003)**	**CHNEP Assessment (Janicki 2003)**	**SWFFS Assessment (Tetra Tech 2004)**
Estero Bay (proper)*	Meets designated uses for DO, Nutrients, turbidity (insufficient data for unionized ammonia, metals, coliforms)	DO, Ammonia*	Meets uses
Imperial River (fresh)	DO, Nutrients, coliforms	DO, Nutrients, Ammonia	DO, coliforms, Conductivity
Imperial River (marine)	Copper	-	
Hendry Creek (fresh)	DO, Nutrients	DO, Ammonia	DO, coliforms, Nutrients, Ammonia Conductivity
Hendry Creek (marine)	DO, Nutrients, coliforms	Nutrients	
Mulluck Creek (marine)	DO, Nutrients	-	DO, coliforms, Ammonia Conductivity
Estero River (fresh)	DO	DO, Ammonia	Copper, DO, coliforms
Estero River (marine)	DO, Nutrients, copper	Meets uses	
Ten Mile Canal	DO	DO, Ammonia, Nutrients	DO, coliforms, Ammonia Conductivity
Spring Creek (fresh)	DO	DO, Ammonia	DO, coliforms, Nutrients, Ammonia Copper, Lead
Spring Creek (marine)	DO, Nutrients, copper	Meets uses	
Cocohatchee River	DO, BOD, Iron, Coliforms	N/C	DO
Naples Bay	Nutrients	N/C	Copper, coliforms, Iron
Gordon River	DO, BOD, Coliforms	N/C	
Blackwater River	DO	N/C	
Henderson Creek	DO	N/C	

*Note, basin delineations vary among assessments.

1. Based on maps, report date of 5/22/03, downloaded on 12/16/03 from http://www.dep.state.fl.us/water/images/basin411/EWC_Parameters_8_2.pdf

N/C – not considered.

Habitat Alteration and Loss

Physical alterations to the coastal bays have also impacted natural habitats and the associated presence and abundance of species historically found within the coastal bays. These alterations include conversion of wetlands, mangrove removal, dredging of navigational channels, shoreline alteration from construction of seawalls and bulkheads, snagging of navigation hazards, and creation of large-scale canal communities through dredge-and-fill operations. The construction of numerous inland waterways and causeways has further altered water flow and habitat. Construction of weirs and other water control structures changes the physical dimension of the coastal bays and reduces (or eliminates) the upstream oligohaline portion of the estuaries, especially during the dry season (Chamberlain and Doering 1998a). This salinity zone is an important nursery area, feeding area, and refugia for juvenile stages of sport and commercial fishes. Construction and operation of the water control structures may interfere with migration patterns of many estuarine species, by acting as a barrier between the freshwater and saline water habitats and have historically resulted in deaths of manatees attempting to pass through these structures.

Human Use

Boating pressure from both commercial and recreational boating activities is a stressor to coastal bays through direct impacts such as seagrass scarring, physical damage to hardbottom communities, sediment resuspension, wake erosion, and construction of boating channels (O'Shea et al., 1985; Sargent et al., 1995; Ault et al., 1997). In addition, boat collisions are the leading cause of human-related manatee mortality (W. Dexter Bender and Associates 1995, FFWC 2003). Fishing pressure from sport and commercial fisheries has impacted standing stocks of many species (Post, Buckley, Schuh, and Jernigan, Inc. 1999) and in turn impacted those species that depend on fish as their primary food source.

5. Ecological Attributes

Attributes are the biological indicators or components of natural systems, which are representative of the overall ecological conditions of the system. Attributes of coastal bays include seagrasses, mollusks, shrimp, fish and birds, but also an aggregated attribute (water quality condition) that includes phytoplankton blooms and aspects of the chemical and physical condition and processes of the bays. Attributes are selected to represent the known or hypothesized effects of the stressors (e.g., seagrass extent and coverage), and the elements of the systems that have important human values (e.g., fish, oysters).

Algal Bloom Community Structure and Function

Higher trophic levels depend on a healthy distribution and abundance of phytoplankton for sustenance, growth, and reproduction. Thousands of species of microscopic algae make up the base of this marine food chain; however, a few dozen algal species produce toxins. Harmful algal blooms of these algae are commonly called red tides, since, in some cases, the tiny plants increase in abundance until they dominate the planktonic community and change the color of the water with their pigments.

Harmful algal blooms in coastal bays cause substantial environmental, societal, and economic damage. Some of the harmful effects associated with noxious algal blooms include: (1) mass mortalities of wild and farmed fish and shellfish, (2) degradation of water quality, (3) alteration of community structure due to unpalatable algae deterring grazers or due to anoxic conditions produced when blooms decay, (4) death of marine mammals, seabirds, and other animals, and (5) physiological stress and death of humans that consume water or shellfish containing concentrated algal toxins.

The occurrence of harmful algal blooms in coastal bays appears to be increasing and linked to human activity. Excessive anthropogenic nitrogen loading from extensive urban, agricultural, and industrial growth in estuarine watersheds has led to accelerating primary production (eutrophication), and has been accompanied by expanding harmful algal blooms. Other suggested causes include: global warming and changing biotic interactions; however quantitative data supporting these mechanisms are insufficient, and supportive causal links have rarely been documented.

Benthic Community Structure, and Function

Benthic communities provide essential ecological and biological functions and directly influence the quality of the environment. Benthic communities trap and filter particulates, serve as refuge, and provide a food source for birds, fish and macroinvertebrates. As the first link in the food chain, they are the initial sink for heavy metals that bioaccumulate in higher species. These communities are the “first responders” to changes in freshwater inflows and water quality. Benthic communities of the coastal bays are composed of estuarine organisms and intertidal invertebrates including various species of sand dollars, sea urchins, crabs, worms, amphipods, scallops, clams, and numerous other bivalve and gastropod species.

Benthic communities are found in both hard-bottom and soft-bottom substrates in the coastal bays. Hardbottom substrates are composed of limestone bedrock and oyster reefs, and soft bottom substrates of mixtures of sand, mud, and shell. Oyster reefs serve to decrease turbidity by trapping sediment and stabilizing erosion processes, and provide a hard substrate and habitat for many other species of invertebrates which in turn attracts predators for those species. Benthic organisms that are commonly found on the soft-bottom substrates of the coastal bays include the five-notched sand dollar (*Encope emarginata*), Florida fighting conch (*Strombus alatus*), horseshoe crab (*Limulus polyphemus*), lightning whelk (*Busycon contrarium*), beaded starfish (*Astropecten articulatus*), and black urchin (*Diadema* sp.) (U.S. Army Corps Of Engineers 1999).

Wading and Shore Bird Community Structure and Function

The coastal bays and barrier islands are important feeding grounds and breeding grounds for raptors, shore birds, and wading birds. Birds are important consumers of estuarine organisms and are potentially impacted by any stressors that affect their food base, including salinity changes, nutrient inputs, toxic compounds, and fishing pressure. As with other top predators, some of these bird species are the most vulnerable members of the ecosystem with regard to pesticide and mercury effects and are a visible indicator of estuarine health. Coastal bays and barrier islands also provide important stop-over areas to migratory songbirds.

There are eight rookery and at least six roosting islands in the coastal bays. Birds such as brown pelicans (*Pelicanus occidentalis*), magnificent frigate birds (*Fregata minor*), double-crested cormorants (*Phalacrocorax auritus*), great blue herons (*Ardea herodias*), little blue herons (*Egretta caerulea*), great egrets (*Ardea alba*), snowy egrets (*Egretta thula*), roseate spoonbills (*Ajaia ajaja*), reddish egrets (*Egretta rufescens*), and white ibis (*Eudocimus albus*) use these places for nesting or roosting. The great white heron nests on one of the mangrove islands in Estero Bay, which is believed to be the northernmost nesting site for this rare bird.

The coastal bays and barrier islands are important nesting sites for three of Florida's listed shorebird species. They are the threatened least tern (*Sterna antillarum*) and snowy plover (*Charadrius alexandrinus*), and the black skimmer (*Rynchops niger*), a species of special concern. All three species are ground-nesting birds and are extremely vulnerable to disturbance. Other shorebirds use the coastal bays and barrier islands between September and April as a wintering ground or resting stop during their annual migration

Fisheries Community Structure and Function

At least 70% 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). Seagrass beds and mangroves provide critical refugia for juvenile fish such as snapper (*Lutganus* spp.), grouper (*Epinephelus* spp. and *Mycteroperca* spp.), grunts (*Haemulon* spp.), snook (*Centropomus* spp.), Spanish mackerel (*Scomberomorus maculatus*), and spotted seatrout (*Cynoscion nebulosus*). Juvenile pink shrimp (*Penalus duorarum*), stone crab (*Menippe mercenaria*), and blue crab (*Callinectes sapidus*) are also afforded protection in these habitats. The decline in juvenile abundance and distribution of these and other species, along with the overall decline in species richness may be related to a decline in seagrass and mangrove habitat and/or a result of alterations in the salinity regime and the timing of the freshwater discharges.

Commercial and recreational fishing pressure has increased along the west coast of Florida. With this increase, there has been a decline in reported landings (Post, Buckley, Schuh, and Jernigan and W. Dexter Bender and Associates, Inc 1999). In Lee County, clear evidence for this decrease can be seen with the spotted seatrout where there has been a decline on catch-per-unit-effort from 1986 to 1995 (Bortone and Wilzbach, 1997).

Submerged Aquatic Vegetation Community Structure and Function

Submerged Aquatic Vegetation (SAV) is a key feature in the estuarine environment and provides food, substrate and shelter to hundreds of estuarine species. Rapidly growing seagrass leaves provide food for trophically higher organisms via direct herbivory or from the detrital food web. The canopy structure formed by these leaves offers shelter and protection. This combination of food source and shelter results in seagrass beds being the richest nursery areas for young stages of fish, crustaceans and shellfish, which are important to commercial and recreational industries. SAV and the organisms that live on them are important food sources in the estuarine system. Manatees, waterfowl and wading birds rely heavily on seagrass systems as forage areas. SAV also has a significant ecological role as critical habitat for, not only manatees, but also other endangered and threatened species, and species of special concern. SAV also maintains water quality by stabilizing bottom sediments and removing nutrients from the water column.

SAV habitat is at risk of degradation or destruction by a number of human and natural perturbations, including (1) dredging and filling (e.g., navigation channels, marinas), (2) construction and shading from in- and over-water structures, (3) boating impacts (e.g., prop scarrings, groundings, and anchor moorings), (4) trampling, (5) siltation, (6) severe storms, (7) altered hydrology, and (8) degradation to water quality. The degradation to water quality is a result of point source pollution (e.g., wastewater discharge, agricultural runoff), nonpoint source pollution (e.g., stormwater runoff, leaching form septic tanks), and the alteration of adjacent watersheds.

Degraded water quality, alterations to freshwater flow, boating impacts, and construction of navigational channels through Estero Bay, Naples Bay, and Rookery Bay have all had negative impacts on the seagrasses. The result has been a regional decrease of seagrass coverage. This decline negatively impacts the 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 to further affect seagrass beds. Furthermore, these impacts are expected to worsen with the rapidly expanding population of this region and the predicted increase in boating activity.

Bivalve Community Structure and Function

The American oyster (Crassostrea virginica) is a keystone species in the coastal bays and provides direct economic and environmental benefits. Oysters grow naturally in reefs which are the primary source of hard substrate and consequently support unique assemblages of organisms. Numerous studies have documented greater biodiversity associated with oyster reefs than with adjacent sedimentary habitats. Oysters filter phytoplankton, particulate organic carbon, sediments, pollutants, and microorganisms from the water column, which increases water clarity and improves light penetration. Seagrass beds, which require light, benefit from the oyster’s filtering effects and in turn support their own unique assemblages of estuarine organisms

Oysters are sensitive to salinity and siltation. Optimum salinities for oysters that will result in sustaining and enhancing oyster populations range from 15-25 ppt (Volety et al. 2003). Higher salinity levels increase negative effects from saltwater predators such as oyster drills (Hofstetter 1977, White and Wilson 1996) and the protozoan parasite *Perkinsus marinus*, commonly known as Dermo (Volety 1995), the primary oyster pathogen in the Gulf of Mexico (Soniat 1996). Dermo is estimated to have killed 80% of the oysters in a bed under optimal salinity and temperature within Chesapeake Bay (Andrews 1988). Presently, increased oligohaline conditions have limited distribution of oysters in Estero Bay and Naples Bay.

The epidemiology of Dermo disease coupled with physiological responses of oysters in relations to environmental and anthropogenic stress will yield critical information on conditions necessary for healthy oyster reefs. Salinity and water quality conditions that yield enhanced distribution of healthy oyster reefs can be used as hydrological targets for restoring and maintaining suitable salinity and water quality in the coastal bays.

Anthropogenic changes in water quality have caused the distribution of oyster reefs to shift geographically along the onshore-offshore estuarine axis. The geographic locus of maximal reef development may not be congruent among the 3 major estuaries of the coastal bays. For example, since current water management practices deliver greater volumes of freshwater during parts of the year to the Estero Bay tributaries, their oyster reefs are located further downstream when compared to those of the Rookery Bay-Henderson Creek estuary.

Mangrove Community Structure and Function

Mangrove forests are found in intertidal zones along shorelines of the coastal bays. Mangroves have been classified as keystone ecosystems (Burke and Lauenroth 1995) because they have a disproportionately strong effect on the structure of other ecosystems. They provide a number of ecological functions to estuarine communities including filtering, stabilizing, storm protection and habitat roles.

Mangroves improve water quality by filtering upland runoff and trapping waterborne sediments and debris. Mangrove roots stabilize shorelines and fine substrates, reducing turbidity, and enhancing water clarity. Mangrove forests serve as storm buffers by functioning as wind breaks and through prop root baffling of wave action.

Mangroves support fish and macro-invertebrate communities by providing breeding, feeding and nursery grounds for a multitude of important commercial and recreational marine species including grouper, spotted sea trout, snook, snapper, tarpon, jack, sheepshead, red drum, oyster, crab, and shrimp (Harris et al. 1983, Lindall 1973, Imbert et al. 2000). Mangroves have a significant ecological role as habitat for endangered and threatened species, and species of special concern. For several of these species, the habitat is critical and vital to their continued survival. Additionally, mangrove forests provide habitat for a highly diverse group of bird species (Odum et al. 1982). Unaltered mangroves contribute to the overall natural setting and visual aesthetics of Florida’s estuarine waterbodies.

Manatee Population Abundance, Distribution, and Health

Manatees often use secluded canals, creeks, embayments, and lagoons, particularly near the mouths of coastal rivers and sloughs, for feeding, resting, playing, mating, and calving (Marine Mammal Commission [MMC] 1986 and 1988). Manatees frequent coastal, estuarine, and riverine habitats and are capable of extensive north-south migrations. They are listed by both the state and federal government as an endangered species and are protected throughout their range.

Manatees can be commonly found in all of the coastal bays. In the Estero Bay, concentrations of manatees are found in the upper tidal reaches of the Hendry Creek, Mullock Creek and Ten-mile Canal. There are two borrow pits on Ten-mile Canal which act as warm water aggregation areas for manatees during winter months, and also appear to receive some year-round use. Additional manatee concentrations are found at Johnson Bay (connected to the southern end of Rookery Bay) along the eastern shoreline between Markers 14 and 20, in Rookery Bay, and at the basin adjacent to Enchanting Shores Trailer Park off Henderson Creek (http://www.floridamarine.org).

The Florida manatee population is divided into four stocks or populations: Northwest, Southwest, Atlantic, and Upper St. Johns River. Coastal bays are inhabited by individuals of the Southwest Stock which comprises approximately 42 percent of the total Florida manatee population (estimated in 2003 to include 3,113 individuals) and consists of the counties along the Gulf of Mexico from Pasco County south to Whitewater Bay in Monroe County and DeSoto, Glades, and Hendry counties (http://www.floridamarine.org). The Southwest Stock has been noted for having higher levels of watercraft-related manatee deaths and injuries and natural mortality events (*i.e.*, red tide and severe cold). According to more recent analyses by Runge *et al.* (in review), growth rates in the Southwest Stock approximate a rate of -1.1 percent per year (95 percent confidence interval of -5.4 to 2.4).

Between 1976 and 2002, 1,887 manatee deaths were recorded within the Southwest Stock. The cause of death categories include watercraft, flood gate/canal lock, other human causes, perinatal, cold stress, natural, and undetermined. The main human-related threat faced by manatees in Florida is death or serious injury from watercraft strikes. Between 1976 and 2002, watercraft-related manatee deaths accounted for 25 percent of the total mortality (O'Shea *et al.* 1985; Ackerman *et al.* 1995; FWC unpublished data).

Natural causes of death include disease, parasitism, reproductive complications, and other nonhuman-related injuries, as well as occasional exposure to cold and red tide (O'Shea *et al.* 1985; Ackerman *et al.* 1995). These natural causes of death accounted for 13 percent of all deaths between 1976 and 2002 (FWC unpublished data). Perinatal deaths accounted for 20 percent of all deaths in the same period. A prominent natural cause of death in some years is exposure to cold.

Another threat includes uncertainty in the availability of warmwater refuges as deregulation of the power industry in Florida occurs. Consequences of an increasing human population and intensive coastal development are also long-term threats to the manatee. Their survival will depend on maintaining the integrity of ecosystems and habitat sufficient to support a viable manatee population.

6. Ecological Effects

Ecological effects are the biological responses caused by the stressors. They are critical linkages between stressors and attributes.

Note: Because of unique similarities among ecological relationships of adjacent natural systems, many of the following relationships have been developed and adapted from the Ecological Effects sections presented in the Caloosahatchee Estuary and Florida Bay Conceptual Ecological Models included in the CERP Monitoring and Assessment Plan developed by the South Florida Ecosystem Restoration Working Group.

Mangroves

Relationship of Mangrove System Function and Shoreline Fragmentation

The primary human-caused impact affecting mangrove communities today are direct loss of habitat from coastal urbanization (i.e., developing waterfront property and subsequent effects of channel dredging, spoil placement, chemicals, debris, and formal landscaping). These activities have resulted in impacts to the mangrove system's ecological functionality. Mangroves carry out a number of ecological functions, including land formation (Warming, 1925; Davis, 1940), sediment stabilization, primary productivity, filtration of land runoff, and serve as habitats and nurseries for a variety of avian and estuarine species (Dawes 1998; MacNae, 1968, Odum et al., 1982).

The National Wetlands Inventory estimated a total of 272,973 hectares ([ha] 674,241 acres) of mangroves in 1982 (Lewis et al. 1985). By 1989, approximately 224,500 ha (554,515 acres) of mangroves remained in central and south Florida. The loss of mangrove productivity to Florida estuarine food chains is well documented for certain locations. Since the early 1900s, mangrove communities in South Florida have steadily disappeared (Lugo and Snedaker 1974). Statewide estimates vary on total mangrove losses. Conservative values of 3 to 5 percent were derived by Lindall and Saloman (1977); while more recent work indicates a 23 percent loss (Lewis et al. 1985).

Extensive areas of mangroves in Collier County's coastal bays were lost when dredging activities created and broadcast heavy loads of fine flocculent material that coated aerial roots and killed trees (Odum and Johannes 1975). Lee County has lost 19 percent of its original mangroves due to construction and resultant turbidity from runoff and pollution (Estevez 1981). This loss has been linked to declines in fin fish and commercial shrimping in the region (Dawes 1998).

Level of Certainty – high

Relationship of Mangrove System Productivity and Upland Flows

Mangroves are sensitive to alterations in upland drainage. Productivity in the shoreline mangrove systems can be impacted from modifications in the freshwater hydroperiod by water management practices. Alterations in the natural freshwater flow regime through diking, impounding, and flooding activities affect the salinity balance and encourage exotic vegetation growth. Australian pine (*Casuarina equisetifolia*) and Brazilian pepper (*Schinus terebinthifolius*) are two exotic plant species documented to invade mangrove communities as a result of changes in water flow.

Mangroves are highly productive natural ecosystems, and provide nutrients and shelter too many ecologically and commercially important aquatic organisms (Mitsch and Gosselink 1993, Mooney *et al.* 1995, WRI 1996). Mangrove forests have been recognized as critical nursery habitat for local species such as blue crab, snook, tarpon, and ladyfish (Odum et al. 1982, Gilmore et al. 1983, Lewis et al. 1985). However, large areas of mangroves have been lost or fragmented through dredge-and-fill activities (National Safety Council 1998, Estevez 1998)

In some areas, drainage for agricultural and urban development has drastically reduced overland flows of freshwater to the mangroves. This results in an increased amount of concentrated runoff, which in turn changes water and soil salinities, reduces the flushing of detritus, and washes nutrients directly into the coastal bays without the benefit of filtration by the mangrove system (Estevez, 1998). Changes in freshwater discharge have also altered the structure of mangrove forests. The reduction and modification of this habitat type may represent a limiting factor in total population sizes of some estuarine-dependent species (Lewis 1990).

Level of Certainty – moderate

Manatees

Relationship of Manatee Populations and Submerged Aquatic Vegetation

Manatees are herbivores that feed opportunistically on a wide variety of aquatic vegetation. Seagrass beds provide important areas for manatee foraging, calving, resting, and mating. Preferred manatee habitat in south Florida is characterized by the availability and proximity of submerged aquatic vegetation (Smith 1993). Seagrasses appear to be a staple of the manatee diet in coastal areas (Ledder 1986, Provancha and Hall 1991, Kadel and Patton 1992, Koelsch 1997, Lefebvre *et al.* 2000). Manatees usually forage in shallow grass beds that are adjacent to deeper channels (Hartman 1979, Powell and Rathbun 1984). Some manatees have been observed to return to the same seagrass beds year after year and may show preference for certain areas (USFWS 1999).

Level of Certainty – high

Relationship of Manatee Populations to Boating Pressure

The largest identified human cause of manatee deaths is collisions with watercraft and/or propellers of watercraft. Between 1976 and 2002, watercraft-related manatee deaths accounted for 25 percent of the total mortality. Over the last 25 years, manatee deaths have had an average increase of 7.2 percent per year (Ackerman *et al.* 1995; FWC unpublished data). Watercraft-related manatee deaths were lower in 1992 and 1993, but increased thereafter. From 1996 to 2002, watercraft-related manatee deaths were the highest on record, which also corresponds to an increase in the manatee population and an increase in registered watercraft.

As noted above, there has been an increasing trend in watercraft-related manatee mortality in all four stocks over the past decade. This is reflected in increases in the average annual number of watercraft-related manatee mortalities as the period over which the average is taken becomes more recent. For instance, in the Atlantic Stock, the mean observed mortality due to watercraft was 25.8 deaths per year for the period 1990-1999, 29.8 per year for the period 1993-2002, and 37 per year for the 5-year period from 1998-2002. This trend is statistically significant in all four stocks. The slope of the increase (as fit to the period 1992-2002) does not differ between the Upper St. Johns River and Northwest Stocks (5.96 percent), nor does it differ between the Atlantic and Southwest Stocks (9.53 percent). To interpret these mortality rates of increase, however, it is important to compare them to the historic growth rates (1990-1999) in each stock, to account for the increase in manatee mortalities that would be expected due to increases in manatee population size. In the Atlantic and Southwest Stocks, the rate of increase in watercraft-related manatee mortality over that period exceeded the estimated growth rate of those populations (by 8.5 percent in the Atlantic and 10.6 percent in the Southwest). In the

Northwest Stock, the rate of increase in mortality (6.0 percent) is somewhat larger than the estimated growth rate (3.7 percent).

Level of Certainty – high

Relationship of Manatee Populations to Habitat Loss

As Florida's human population increases, particularly in coastal counties, threats to preferred manatee habitat may increase. A significant threat to manatees is the loss and degradation of habitat from the combined effects of recreational and commercial boating activities, coastal construction, dredging and filling activities, alterations to freshwater flow, and pollution from sewage discharge and storm water runoff loss (MMC 1993, Smith 1993). These activities may continue to degrade habitat reducing foraging opportunities for manatees.

Other human activities may also affect manatees and their habitat. Harassment by watercraft and swimmers may drive animals away from preferred natal areas and winter refugia, and the loss of vegetation in certain areas (*e.g.*, winter foraging areas) may require manatees to travel greater distances to feed. The impact of these kinds of activities on the survival, recovery, and mortality of the species is not fully understood.

Level of Certainty – high

Relationship of Manatee Populations to Water Control Structures

The second largest human-related cause of manatee deaths is entrapment or crushing in water control structures and navigational locks and this accounts for approximately 4 percent of the total mortalities recorded between 1976 and 2002 (Ackerman *et al.* 1995; FWC unpublished data). These deaths were first recognized in the 1970s (Odell and Reynolds 1979), and steps have been taken to eliminate this source of mortality. Beginning first in the early 1980s, gate-opening procedures were modified. Annual numbers of deaths initially decreased after this modification. However, the number of deaths subsequently increased and, in 1994, a record 16 deaths were documented. Manatee mortality decreased during 2000-2002 with 14 manatee mortalities for the 3-year period.

Level of Certainty – high

Relationship of Manatees to Red Tide

Red tide has been suspected responsible in past manatee deaths. Marine mammal mortality associated with red tide is poorly known. There have been cases of porpoise moralities that have been blamed on the toxin because of their coincidence with red tide blooms (Gunter et al. 1948, Geraci 1989). Also, a link has been suggested between the death of seven manatees in 1963 and a red tide event near Fort Myers (Layne 1965, Bossart et al 1998).

In 1982, a large number of manatees died coincidentally with a red tide dinoflagellate (*Gymnodinium breve*) outbreak between February and March in Lee County, Florida (O'Shea *et al.* 1991). At least 37 manatees died, perhaps in part, due to incidental ingestion of filter-feeding tunicates that had accumulated the neurotoxin-producing dinoflagellates responsible for causing the red tide. In 1996, from March to May, at least 149 manatees died in a red tide event over a larger region of southwest Florida (Bossart *et al.* 1998; Landsberg and Steidinger 1998). Although the exact mechanism of manatee exposure to the red tide brevetoxin is unknown in the 1982 and 1996 outbreaks, ingestion, inhalation, or both are suspected (Bossart *et al.* 1998). The most recent red tide outbreak in 2003 was responsible for the deaths of 75 manatees (http://www.floridamarine.org). The critical circumstances contributing to red tide-related deaths are concentration and distribution of the red tide, timing and scale of manatee aggregations, salinity, and timing and persistence of the outbreak (Landsberg and Steidinger 1998).

Level of Certainty – high

Relationship of Manatee Populations to Cold Stress

Following a severe winter cold spell at the end of 1989, at least 46 manatee carcasses were recovered in 1990; cause of death for each was attributed to cold stress. Exposure to cold is believed to have caused many deaths in the winters of 1977, 1981, 1984, 1990, 1996, and 2001; and have been documented as early as the 19th century (Ackerman *et al*. 1995; O'Shea *et al.* 1985; FWC unpublished data).

The loss of industrial warm-water discharges can result in the deaths of individuals relying on these sites. Many Florida manatees have come to depend on warm-water outfalls from certain power plants and other industrial facilities to avoid thermal stress during periods of extreme winter cold. If warm-water discharges used regularly by manatees are disrupted or otherwise fail to provide needed warmth during the winter, animals which have learned to use them may be exposed to cold stress and perhaps die before they can find or reach alternative heat sources.

Level of Certainty – high

Fisheries

Relationship of Spotted Seatrout Populations to Salinity

Juvenile density and sport catch of spotted seatrout in the coastal bays reflect the suitability of estuarine habitat and nursery grounds as influenced by salinity. Density of post-larvae is highest at an intermediate salinity range of 20-30 ppt, and density drops when salinity exceeds 35 ppt. Juvenile density is expected to increase due to the resumption of natural volumes and timing of freshwater flow into the coastal bays, in response to a reduction in the frequency and duration of hyper-salinity events. Adult abundance and distribution based on sport Catch Per Unit Effort (CPUE) should reflect juvenile growth and survival, although that relationship is not presently known.

Level of Certainty – moderate

Relationship of Submerged Aquatic Vegetation to Juvenile Fish Abundance

A decline in the amount of seagrass habitat/coverage has occurred in Estero Bay and Rookery Bay, with an almost complete disappearance in Naples Bay. The result of this decline is a reduction in potential habitat for a number of seagrass dependent species, and especially the juvenile life stages of many estuarine dependent species (Virnstein1987, Stoner 1984, Zieman 1982). Specifically, larval gag grouper (*Mycteroperca microlepis*) use sea grass beds as settlement substrate after having hatched offshore on natural hard bottom structures. The larvae settle in the higher salinity areas of Estero Bay and Rookery Bay in the spring of each year. After attaining a size of about 60 - 80 mm TL they migrate offshore to take up residence on offshore reefs (Jory and Iverson 1989). Juvenile spotted seatrout use grass beds for protection from predation while adults feed on many of the seagrass associated species such as shrimp and smaller fishes (Pearson 1929, Miles 1950, Perret et al. 1980). Concomitant with reduction in habitat for specific life histories of selected species, the reduction in grass beds has also led to an overall reduction in species diversity of the estuaries.

Level of Certainty – moderate

Relationship of Salinity and Freshwater Discharge to Juvenile Fish

Alterations in the natural salinity regime and timing of freshwater discharges have resulted in a decline in juvenile fish abundance, distribution, and species richness. Alterations in the salinity regime places undo stress on the sensitive life history stages of many estuarine species (Emery 1957, Odum1970, Lindall 1973, Perry and McIlwain 1986, Chamberlain and Doering 1998b). While estuarine species are generally well adapted to cope with varying salinity conditions and cycles, they are not so robust as to tolerate large shifts in the timing cycle of salinity regimes. A simple case in point is the egg stage of spotted seatrout. Trout eggs are neutrally buoyant at about 20-22 ppt (Pattillo et al. 1997), and are spawned during the warmer months of the year (Lassay 1983). For these eggs to hatch, they must be exposed to sufficient salinities to remain buoyant and maintain oxygen movement across egg membranes. If large and protracted reductions in salinity were to occur during the summer months, it could lead to the reduction or elimination of an entire year-class of spotted seatrout.

Level of Certainty – moderate

Relationship of Fish Populations to Red Tide

A recent increase in the occurrence of red tide in southwest Florida has contributed to increased mortality in estuarine fishes. Red tide was first identified during a catastrophic mortality event of marine fishes and other animals that took place between November 1946 and August 1947 (Gunter et al. 1948). Since then, investigations of literature have revealed 471 years of documented, confirmed, or suspected red tide events off of Florida's west coast (www.floridamarine.org). However, due to the scarcity and historical nature of this data, it is undetermined if there has been an actual increase in occurrence or severity of red tide in Florida waters.

Red tides typically occur in late summer and early fall months but have occurred in every month of the year. They begin about 10-40 miles off shore and are transported inshore by currents and winds. These red tide blooms have been associated with invertebrate, fish, bird and marine mammal mortalities (Gunter et al. 1948, Landsberg and Steidinger 1998, Bossart et al. 1998).

Level of Certainty – moderate

Relationship of Fishing Pressure to Fish Landings

Increased fishing pressure has resulted in a decrease in the number of landings of both commercial and recreationally sought fish. Increased fishing pressure in Southwest Florida has presumably led to increases in landings and also a decrease in the catch per unit effort of the system. Unfortunately, the data on landings and effort may not be comprehensive enough historically to make such a claim but they do lead to suspicions. An alternative measure is to simultaneously examine life history features of the community of organisms that should respond should the above be true. For example, growth rates for some predators (that no longer have as many competitors for food resources) should increase. Likewise age at first reproduction might be lower as the species respond to having larger more mature individuals removed from the population. Using historical (but imprecise) data, and coupling that with more recent and more accurate fishery and life history data will help authenticate this statement.

Level of Certainty – moderate

Relationship of Submerged Aquatic Vegetation to Blue Crab Abundance

The decline in the amount of seagrass habitat/coverage has resulted in a reduction in potential habitat for blue crabs. Young crabs use seagrass beds for nursery areas, and crabs of all sizes forage in seagrasses. Shedding blue crabs conceal themselves in the vegetation until their new shells have hardened.

Level of Certainty – low

Oysters

Relationship of Oysters to Other Estuarine Species

Oyster bars provide habitat and food for numerous estuarine species including gastropod mollusks, polychaete worms, decapod crustaceans, various boring sponges, fish, and birds, including the endangered American oystercatcher (*Haematopus palliates*). The American oyster is the dominant species in the oyster reef community. There may be over 40 species of macrofauna living in oyster beds (Bahr and Lanier 1981) with the total number of species exceeding 300 (Wells 1961).

Oysters, clams, and scallops are natural components of southern estuaries and were documented to be historically abundant in the system (Estevez 1998,). Although currently less abundant (Chamberlain and Doering 1998a, Sackett 1888), they continue to be an important resource commercially and recreationally. This reduction in oyster coverage was largely due to shell mining, altered freshwater inflow, and changes in hydrodynamics. This decrease has resulted in a decrease in the oyster reef community of the estuaries.

Level of Certainty – high

Relationship of Oysters to Sediment Loads

There has been a decrease in the oyster population in the coastal bays due to increased sediment loads resulting from man induced alterations in the natural hydrology. Adult oysters have effective morphological adaptations for feeding in much higher levels of suspended solids than are usually encountered under normal conditions (Kennedy 1991). Oysters from relatively turbid estuaries appear to be capable of feeding at total solids concentrations as high as 0.4 g/l but significantly reduce their pumping rates at as low as 0.1 g/l (Loosanoff and Tommers 1948). Suspended solids may clog gills and interfere with filtering and respiration of the oysters (Cake1983). Increased sediment loads to the coastal bays as a result of increased flows from tributaries can have detrimental effects on oysters and other filter feeding bivalves.

Level of Certainty – moderate

Relationship of Salinity to Oysters

Alterations of freshwater flows from tributaries have lead to dry season increases and wet season decreases in salinity in the coastal bays. Extreme and prolonged fluctuations in salinity can have negative physiological effects on oysters.

Salinity is important in determining the distribution of coastal and estuarine bivalves. Adult oysters in the Gulf of Mexico normally occur at salinities between 10 and 30 ppt but they tolerate a salinity range of 2 to 40 ppt (Gunter and Geyer 1955). Short pulses of freshwater inflow can greatly benefit oyster populations by killing predators, such as the southern oyster drill and the welk, that cannot tolerate low salinity water (Owen 1953), while excessive freshwater inflows may kill entire populations of oysters (Gunter 1953, Schlesselman 1955, MacKenzie, 1977).

Changes in salinity can also affect the structural and functional properties of these bivalves through changes in (1) total osmotic concentration, (2) relative proportions of solutes, (3) coefficients of absorption and saturation of dissolved gases, and (4) density and viscosity (Kinne 1964). These bivalve physiological processes translate to functional processes in ecosystems (Dame 1996).

Protozoa are probably the most common cause of epizootic outbreaks that result in mass mortalities of oysters. One of the most important is Dermo, caused by a member of the phylum Apicomplexa, *Perkinsus marinus*. It is characterized by emaciation of the digestive gland of the oyster. Dermo has limits imposed by salinity and temperature (Dame 1996) and is more intense in areas of higher salinities (Burreson and Ragone 1996, Calvo et al. 1996).

Level of Certainty - moderate

SAV and Plankton

Relationship of Altered Salinity and Submerged Aquatic Vegetation

Altered estuarine salinity resulting from hydrologic alterations resulting from 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 coastal bays.

Different species of SAV have different desirable salinity ranges. 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). 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.”

Level of Certainty – high

Relationship of Nutrients to Phytoplankton and SAV

The increase of nutrients into the coastal bays from land use has had negative impacts on SAV through increased epiphytic growth on SAV and decreased light penetration which restricts the depth at which SAV can grow.

Reduction in penetration of light into the water column is often blamed for the disappearance and diminishing of previously healthy seagrass meadows. Because seagrasses are rooted plants attached to the bottom, reduced light reduces photosynthesis, growth, and reproduction. This condition is cited as a major source of seagrass decline in Florida estuarine systems (Durako 1988).

Nutrification can lead to subtle responses such as changes in communities at the species level, altered rates of biogeochemical processes (e.g., nutrient recycling, sediment oxygen demand, etc.), and shifts in seasonal patterns (i.e., spring versus summer primary production) or magnitude of variability (for review, see Cloern, 2001; USEPA 2001). Resource competition, not just in terms of N or P, but also their specific form (e.g., concentration of ammonium to nitrate) can also result in species shifts. Many organic N molecules are not readily available to phytoplankton, while many organic P molecules are, due to the activity of phosphatase enzymes (Vitousek and Howarth, 1991).

Nutrients can trigger a thick growth of epiphytes which can reduce the amount of light that can reach the surface of the seagrass blade (Murray et al. 1999). Relatively minor changes in nutrient input can lead to sharp reductions in the productivity of seagrasses, which can lead to broad habitat changes (Livingston 1984). Excess nutrients encourage growth of more nutrient tolerant species that cause undesirable effects such as mono specific communities which decrease the value for fisheries and benthic invertebrate species.

Tampa Bay National Estuary Program produced an empirical regression-based water quality model that showed strong relationship between TN load and Chl-*a* (as a measure of phytoplankton abundance and nuisance algal blooms; Janicki and Wade 1996). A similar relationship has been established for the C43 Basin / Caloosahatchee River (Janicki Environmental, Inc. 2003).

Unnaturally low ratios of silicon (Si) to P or Si:N (due to increases in P or N) are thought to favor the selection and possible ascendancy of lightly-silicified diatoms and non-diatoms (Dortch & Whitledge 1992).

Level of Certainty – moderate

Relationship of Submerged Aquatic Vegetation and Salinity to Mollusk Populations and Fish Recruitment

Negative changes in SAV community structure and function along with changes in the natural salinity regime has resulted in substantial losses of mollusk populations and a decrease in larval and adult fish recruitment into the coastal bays.

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 grass 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 interfering with the feeding efficiency of their potential predators (Zieman 1982). Reduction in size and health of SAV beds effects the location, abundance, and speciation of fisheries in the coastal bays.

Level of Certainty – low

Relationship of Current and Historical Submerged Aquatic Vegetation Coverage to Potential Distribution

The submerged aquatic vegetation in the coastal bays will increase as estuarine conditions improve. The extent of this increase depends on available area with suitable salinity, substrate, water clarity, and temperature.

Seagrasses require light for photosynthesis. A number of factors can influence water clarity and light penetration. These include color and suspended solids. The different species of SAV have distinct requirements for light. Research indicates that *Thallassia testudium*, *Halodule wrightii*, and *Syringodium filiforme* require levels of at least 10-15% of surface irradiance, while *Halophila decipiens*, *Halophila englemannii*, *Halophila johnsonii*, and *Ruppia maritima* appear to have somewhat lower requirements, perhaps as low as 2-3% of surface irradiance (URS Greiner Woodward Clyde 1999).

Most seagrasses appear to tolerate a wide range of substrate conditions. Virtually all seagrasses seem to grow on sandy or silty muds and on sands with some mud contents (Reid 1954, Voss and Voss1955, Phillips 1960) and require a sufficient depth of sediment for proper development. Substrates must also contain nutrients, especially nitrogen and phosphorous, which are available for SAV growth (Duarte 1991). The microbially mediated chemical processes in marine sediments provide a major source of these nutrients (Capone and Taylor 1980).

Each species of SAV has their own temperature and salinity tolerance ranges and their tolerance to salinity variation is similar to their temperature tolerances. *Halodule wrightii* is the most broadly euryhaline, *Thallassia testudium* is intermediate, and *Syringodium filiforme* and *Halophila* have the narrowest tolerance ranges (McMillian 1979, Zieman 1982). *Vallisneria americana* is generally a freshwater grass but can tolerate salinities of near 10 ppt. Therefore, *Vallisneria* is also an important component of the oligohaline estuarine SAV community (Twilley and Barko 1990, Adair et al. 1994, Kraemer et al. 1999).

Level of Certainty – low

Water Quality

Dissolved Oxygen

Relationship of Dissolved Oxygen to Phytoplankton and SAV

As a result of primary production, which can be stimulated by phytoplankton and SAV producing DO during daylight hours, daylight levels of DO can actually reach supersaturation levels in the presence of phytoplankton blooms or thick stands of macrophytes. However, both phytoplankton and SAV utilize DO and, in the dark, are a net sink for DO, and this can result in hypoxic and sometimes anoxic conditions (Mitchell-Tapping et al. 1998). A recent study by Pedersen et al. (2003) linked meristem anoxia and sulfide intrusion in *Thalassia testudinum*, and possible sulfide toxicity and seagrass die off, to low nighttime oxygen levels in the water column (rather than the photosynthetic history of the plant).

Level of Certainty – high

Relationship of Dissolved Oxygen to Benthic Communities and Fish Populations

Hypoxia (low dissolved oxygen) can be a significant problem in certain estuaries, especially those receiving excessive nutrient loads, impacting the health of fish and shellfish populations (USEPA 2000b). The response of fishes and invertebrates to alterations in dissolved oxygen and water quality is relatively well understood and is often expressed as changes in community structure, density, and diversity (for review, see Mitchell-Tapping et al. 1998, USEPA 1999, Breitburg 2002).

Level of Certainty – high

Relationship of Dissolved Oxygen and Sediment Chemistry

Increased nutrient loading, suspended solids and dissolved organic material from the watershed can result in higher BOD, higher sediment oxygen demand (SOD) or both and, consequently, hypoxia or even anoxia, especially when freshwater flows produce a density stratification (CDM 1998, Turner 2001). Anoxic conditions can result in altered redox conditions and altered chemistry in the sediment

Level of Certainty – moderate

Total Suspended Solids and Water Clarity (e.g., Turbidity, TSS, Color)

Relationship of Total Suspended Solids to Phytoplankton and SAV

Inorganic suspended sediments, organic nonchlorophyll-based detritus, and, of particular importance in south Florida, humic materials (McPherson et al. 1996) may reduce water clarity and shade out SAV. A statistically significant inverse correlation has been reported between the depth of the deep edge of a seagrass bed and color and turbidity in southern Indian River Lagoon. Preliminary targets have been established based on water quality observed at these deep seagrass beds (Crean et. al. in review).

Because seagrasses are rooted plants attached to the bottom, reduced light reduces photosynthesis, growth, and reproduction. This condition is cited as a major source of seagrass decline in Florida estuarine systems (Durako 1988). Under certain circumstances, dissolved organics (e.g., humics, etc.) and attendant water color and clarity have been thought to reduce undesirable algal growth under high nutrient conditions (McPherson et al. 1996). SAV need suitable substrate for successful recruitment and establishment. Deposits of silt / muck can displace or modify normal substrate in the estuary and contribute to the decrease in extent of SAV beds.

Level of Certainty – moderate

Relationship of Total Suspended Solids to Benthic Communities and Fish Populations

Suspended solids may clog gills and interfere with filtering and respiration of oysters (Cake 1983). Humic materials can influence the chemical speciation, bioavailability and, in some cases, toxicity of certain metals and organics (McCarthy et al. 1994).

Level of Certainty – moderate

Relationship of Total Suspended Solids to Shoreline Habitat functionality

Sediment load caused by dredge and fill operations and in runoff from shoreline construction has been identified as a cause of mangrove loss and salt marsh destruction.

Level of Certainty – moderate

<u>Nutrients (macro- and micronutrients)</u>

Relationship of Nutrients to Sediment Chemistry

Nutrification can lead to altered rates of biogeochemical processes (e.g., nutrient recycling, sediment oxygen demand, redox, etc. [CDM 1998, Turner 2001, Cloern 2001]), which, in turn, can lead to further changes in water quality (e.g., solubility of metals). Nutrification can also lead to saturation of soils where substrate becomes a source, and not a sink, for additional nutrients (internal loading).

Level of Certainty – moderate

<u>Toxicants</u>

Relationship of Toxicants to Benthic Communities and Fish Populations

Both acute and chronic effects have been reported for both organic and inorganic toxicants to a wide variety of aquatic species (National Toxics Rule, 57 FR 60848, December 22, 1992, USEPA 2002 and references therein, Wiener et al. 2002). Many of these substances are either insoluble in water or tend to associate with particulate matter that flocculates (i.e.,"salting-out") often resulting in concentrations much higher in the estuarine sediments than that observed within the overlying water column.

Level of Certainty – moderate

Relationship of Toxicants to Upper trophic level predators, including listed species

Persistent bioaccumulative toxicants (PBTs) can pose a risk to upper trophic level predators (USEPA 1997b)

Level of Certainty – moderate

Relationship of Toxicants to Human health

Persistent bioaccumulative toxicants (PBTs) can pose a risk to humans (USEPA 2002 and references therein).

Level of Certainty – moderate

Hydrologic Restoration and Water Quality Condition

Linkage of Watershed Hydrology to Freshwater Inflow, Circulation and Water Quality in Coastal Bays

Water quality and circulation of coastal systems are linked to inland, freshwater wetlands through a combination of diffuse overland flow, creek and river flow, and groundwater seepage. The salinity regime of coastal bays, as well as many other aspects of the coastal bays' ecosystem (water residence time, stratification, nutrient loading, etc.), depend upon the quantity, quality, timing, and distribution of freshwater inputs to the bays. Planning and implementation of ecosystem restoration requires the capability to link, through a predictive estuarine mixing model, changes in flows of associated tributaries and the consequent changes in the estuaries. These linkages have yet to be modeled and this is perhaps the highest priority need for restoration on the southwest coast.

Level of Certainty – low

7. Research Questions

Linkage of Watershed Hydrology to Freshwater Inflow

How does adjacent watershed hydrology (surface water and groundwater) relate to the inflow and estuarine mixing patterns in coastal bays?

Response of Ecological Indicators to Restored Flows

What are the key ecological indicators and how will they respond to the restoration of a more natural flow regime?

Relationship of Manatee Mortality to Red Tide

Will changes in salinity, nutrient load, and water residence time due to the restoration of the recommended estuarine salinity envelope reduce the occurrence of red tide in inland waters at times coincident to when manatees move between inland waters and estuarine waters?

Status of Manatee Populations

What is the most accurate means to estimate or detect trends in manatee population size?

Manatees and watercraft

How can management/laws/rules/signs/education help minimize collisions between manatees and watercraft? Are propeller guards or alternative means of propulsion a feasible solution to reduce recreational watercraft-related manatee mortality?

8. Hydrologic Performance Measures

The following hydrologic performance measures for the coastal bays have been adopted from the Freshwater Inflow Performance Measures for Estero Bay and the Hydrological and Ecological Performance Measures for Henderson Creek/Rookery Bay developed for the Southwest Florida Feasibility Study (SWFFS). Please review these documents for a detailed description on the methods and justifications used for the development of these performance measures.

Estero Bay

General hydrologic restoration objectives for management of Estero Bay should be to: (1) decrease the volume of wet season flows; (2) increase the volume of dry season flows; (3) increase the lag time between peak rainfall and peak flow; and (4) delay the period of little or no flows in the dry season.

The target for this criterion is to establish and maintain conditions that are favorable to sustain and enhance oyster populations in the Estero Bay estuary near the mouth of the tributaries. Target salinity for oysters for this region is 15-25 ppt. Under current water management practices, freshwater releases are unnaturally high in the summer months (July through October) and below normal during the dry, winter months (November through June). It is recommended that when freshwater releases that exceed the above recommended range are necessary, repeated pulsed releases of < 1 week duration be made during the winter months instead of sustained high releases of freshwater during summer months. High freshwater releases that exceed 1 week can cause lower salinities (< 5 ppt) creating conditions that are stressful to both oysters and oyster spat. The recommended hydrologic targets (HT) of freshwater inflow are as follows:

> ***HT 1.*** Ten Mile Canal: Minimize the number of days (or percent of year) of average canal discharge that exceed daily mean flows 215 cfs, so to reduce the frequency and duration of large harmful freshwater pulses. Freshwater pulses that exceed daily mean flows of 215 cfs, or pulses that push salinities below 5ppt at Mullock Creek station should be < 1 week.

HT 2. Ten Mile Canal: Maximize the number of days (or percent of year) of daily mean flows of 4-50 cfs, with a median of approximately 15 cfs, to improve conditions for estuarine organisms. Maintain flows that hold salinities at 15-25 ppt at Mullock Creek station.

HT 3. Estero River: Minimize the number of days (or percent of year) of average river discharge that exceed daily mean flows of 31 cfs, in order to reduce the frequency and duration of large harmful freshwater pulses. Freshwater pulses that exceed daily mean flows of 31 cfs, or pulses that push salinities below 5ppt at the Estero River salinity station should be < 1 week.

HT 4. Estero River: Maximize the number of days (or percent of year) of daily mean flows of 3-9 cfs, with a median of approximately 4 cfs, to improve conditions for estuarine organisms. Maintain flows that hold salinities at 15-25 ppt at the Estero River salinity station.

HT5. Imperial River: Minimize the number of days (or percent of year) of average river discharge that exceed daily mean flows of 94 cfs, so to reduce the frequency and duration of large harmful freshwater pulses. Freshwater pulses that exceed daily mean flows of 94 cfs, or pulses that push salinities below 5ppt at Imperial River station should be < 1 week.

HT 6. Imperial River: Maximize the number of days (or percent of year) of daily mean flows of 8-26, with a median of approximately 13 cfs, to improve conditions for estuarine organisms. Maintain flows that hold salinities at 15-25 ppt at Imperial River salinity station.

Henderson Creek/Rookery Bay

Due to the dynamic nature of estuarine environments, setting a restoration goal for freshwater inflow from Henderson Creek must account for natural changes in watershed rainfall amounts and include both physicochemical and biological endpoints. All changes should be designed to result in flow characteristics and salinity patterns approximating the more natural basin and estuary of Fakahatchee Bay, given the same rainfall pattern. The recommended hydrologic targets (HT) of freshwater inflow are as follows:

HT 1. (a) Minimize the number of days (percent of year) of average canal discharge <50cfs, measured at Weir No. 1 in Henderson creek Canal, in order to extend flow into the dry season.

HT 1. (b) Minimize the number of consecutive days, weeks, and months that daily average freshwater inflow to Henderson Creek is < 50 cfs.

HT 2. Maximize the number of days (or percent of year) of average flow between 150 - 400 cfs, measured at Weir No. 1 in Henderson Creek in order to promote salinities between 30 and 20 ppt respectively, which are ideal for oysters and oyster-reef dependent organisms.

HT 3. (a). Given similar rainfall patterns in both Henderson Creek and Fakahatchee Bay basins, the first wet season pulse of freshwater inflow into Henderson Creek should be concurrent, or not deviate by more than 2 weeks, from the first increased seasonal flows into the Fakahatchee Bay basin (as measured in the future in Fakahatchee River and/or East River).

HT 3. (b). The maximum increase in freshwater inflow to Henderson Creek should not exceed 100 % in a single day.

HT 4. Minimize the number of days that freshwater inflow to Henderson Creek exceeds 300 cfs for one day, a week, and more than a month.

9. Ecological Performance Measures

The following ecological performance measures for the coastal bays have been adopted from the Freshwater Inflow Performance Measures for Estero Bay and the Hydrological and Ecological Performance Measures for Henderson Creek/Rookery Bay developed for the Southwest Florida Feasibility Study (SWFFS).

Estero Bay

A study recently completed for the South Florida Water Management District documented the impact of water management practices on oysters and associated fish populations in the nearby Caloosahatchee River (Volety et al. 2003). In this study, laboratory exposure of adult and juvenile oysters to various salinities indicated that juvenile oysters are highly susceptible to mortality when exposed to salinity < 5 ppt for > 1 week. Although adults can tolerate salinities as low as 5 ppt for extended periods of 8 weeks, they can not tolerate salinities lower than 3 ppt. Additionally, slower growth, poor spat production, and excessive valve closure occurs at salinities below 14 ppt. Optimum salinities for oysters that will result in sustaining and enhancing oyster populations range from 15-25 ppt. The greatest oyster growth and recruitment occurs during the late spring and wet season. In the Estero Bay tributaries, extended freshwater releases during wet summer months, when salinity is normally low, can often result in low salinities (< 5 ppt) that are harmful to both adult and juvenile oysters. Based on these results, the following ecological targets (ET) have been developed:

ET 1. Within the limits of natural variability, limit to < one week the exposure of juvenile and adult oysters to salinities < 5 ppt.

ET 2. Promote and maintain salinities in the range of 15-25 ppt where oysters are located.

Henderson Creek/Rookery Bay

The proposed performance measures are based on salinity change, the relative abundance of stenohaline to euryhaline macroinvertebrates, and the physiological condition and ecological distribution of oysters for Henderson Creek relative to homologous reference sites within Fakahatchee Bay. This ongoing research is being conducted by the staff of the Rookery Bay National Estuarine Research Reserve and associated scientists at Florida Gulf Coast University. These monitoring results indicate that the proposed performance measures will provide useful indicators of altered freshwater inflow that can be used to set goals for habitat restoration.

Species inhabiting estuaries have evolved to respond to seasonal changes in freshwater input and its affect on estuarine habitat salinity to signal important life cycle stages such as reproduction and migration patterns. Although these species naturally adapted to salinity fluctuations, euryhaline species are better adapted than stenohaline species at tolerating salinity fluctuations (Serafy et al. 1997). In order to assess the affects of altered habitat salinity conditions on natural species abundance, Fakahatchee Bay was selected as a reference estuary. Previous examination of salinity conditions and watershed flow way patterns of Fakahatchee Bay suggest that this habitat is less influenced by alterations in watershed freshwater than Henderson Creek and may be representative of a natural estuarine environment. Salinity responds similarly in both Fakahatchee Bay and Henderson Creek, suggesting that the precipitation affecting both watersheds is comparable (Savarese, pers. comm.). This further justifies using Fakahatchee Bay as reference estuary.

Due to natural temporal and spatial differences in the abiotic and biotic condition of estuarine environments, the nekton species composition of any two estuaries or the same estuary from one year to the next are not likely to be identical. Within a particular biogeographic region; however, the intra-annual seasonal pattern of species composition of similar types of estuaries with similar longitudinal salinity gradients should be maintained (Whitfield 1999). Shirley et al. (In Review) found that the species composition patterns within the reference estuary, Fakahatchee Bay, varied seasonally within a year to next and were dissimilar for three out of four corresponding seasons from one year to the next. Yet, the overall pattern of species composition was maintained with the late wet and late dry season most dissimilar and the early wet and early dry season acting as transitional seasons. This result underscores the value of comparing species composition patterns of reference versus altered estuaries using data collected within the same year and season and argues against using historic datasets to set restoration targets for nekton.

The primary management goal of the Rookery Bay National Estuarine Research Reserve is to conserve natural biodiversity (FDEP 2001). Given the complex nature of estuarine systems and limitations to knowing the complete effects of altered freshwater inflow on every component of an ecosystem, a management decision has been made to use a reference site approach for setting restoration performance measures. Based studies by Shirley et al. (In Review), three recommendations can be made regarding managing watershed inflows to conserve nekton species composition: 1) water quality monitoring using near-continuous sampling is preferred over sampling at larger time scales, 2) nekton species composition patterns are a useful indicator of altered freshwater inflow and 3) comparisons of the reference and altered estuaries should be made within the same season and year.

Ecological Performance Targets (ET):

ET 1. Seasonal relative abundance of the >5mm size class of stenohaline (*Petrolishthes armatus*) and euryhaline (*Eurypanopeus depressus*) crabs, calculated as the ratio, (total *P. armatus* +1)/total *E. depressus* +1) on oyster reefs in Henderson Creek.

Target: Ratio should not be statistically different (p = 0.05) from the ratios of these species calculated from populations sampled on oyster reefs in Fakahatchee Bay.

Method: For these collections, eight artificial substrates (Hester Dendy samplers) will be deployed each month for a two-week interval on two oyster reefs within a similar region of each estuary. The estuarine region for deployment should be located in the area where oyster reef formation first occurs traveling down the estuary from the headwaters. These locations typically have similar late dry season (March, April and May) salinity conditions.

ET 2. Distribution of the eastern oyster, *Crassostrea virginica*.

Target: These metrics should be comparable in magnitude to the same homologues in Fakahatchee Bay. A characterization of Fakahatchee reefs and oysters has not occurred yet. This should occur well in advance of any restoration action. See method described in Savarese and Volety (2001).

Method: Oyster living density, standing stock, and larval recruitment should be maximized at the middle spatial homologue (homologue 3) and then decrease up- and downstream to the lower and higher homologue respectively (see Savarese and Volety 2001 for definition of homologue position). These physiologic and ecologic measures should be made twice annually, wet and dry season, at each of 5 homologues within Henderson Creek and Fakahatchee Bay.

ET 3. Amplitude, timing, and frequency of salinity fluctuations.

Target: The maximum rate of salinity change (as measured in change in ppt per hour) within a month should not exceed that measured at a reference site in Fakahatchee Bay by more than 25% during the same period. The first wet season pulse of freshwater into Henderson Creek, as defined by an hourly salinity change of 10% or greater at least 5 times in one day, should not deviate by more than 2 weeks from the day of similar salinity changes in Fakahatchee Bay.

Method: Simultaneous measurements of salinity at the same homologue in Henderson Creek as measured at the reference site in Fakahatchee Bay.

ET 4 Species composition of nekton species.

Target: Seasonal patterns in nekton species composition should be similar (75% by Bray Curtis) within Fakahatchee Bay and Henderson Creek.

Method: See methods described in Shirley et al. (In Review).

10. Water Quality Performance Measures

The SWFFS Water Quality Sub-team has developed two sets of performance measures: 1) evaluation measures (Table 2) and, 2) assessment measures (Table 3). Evaluation performance measures are used to predict the performance of a given alternative. Assessment performance measures are used to measure real responses as a basis for tracking how well the plan is meeting its goals. Targets for these performance measures are currently being developed along with tools for their assessment (for details, see SWFFS Water Quality strategy paper).

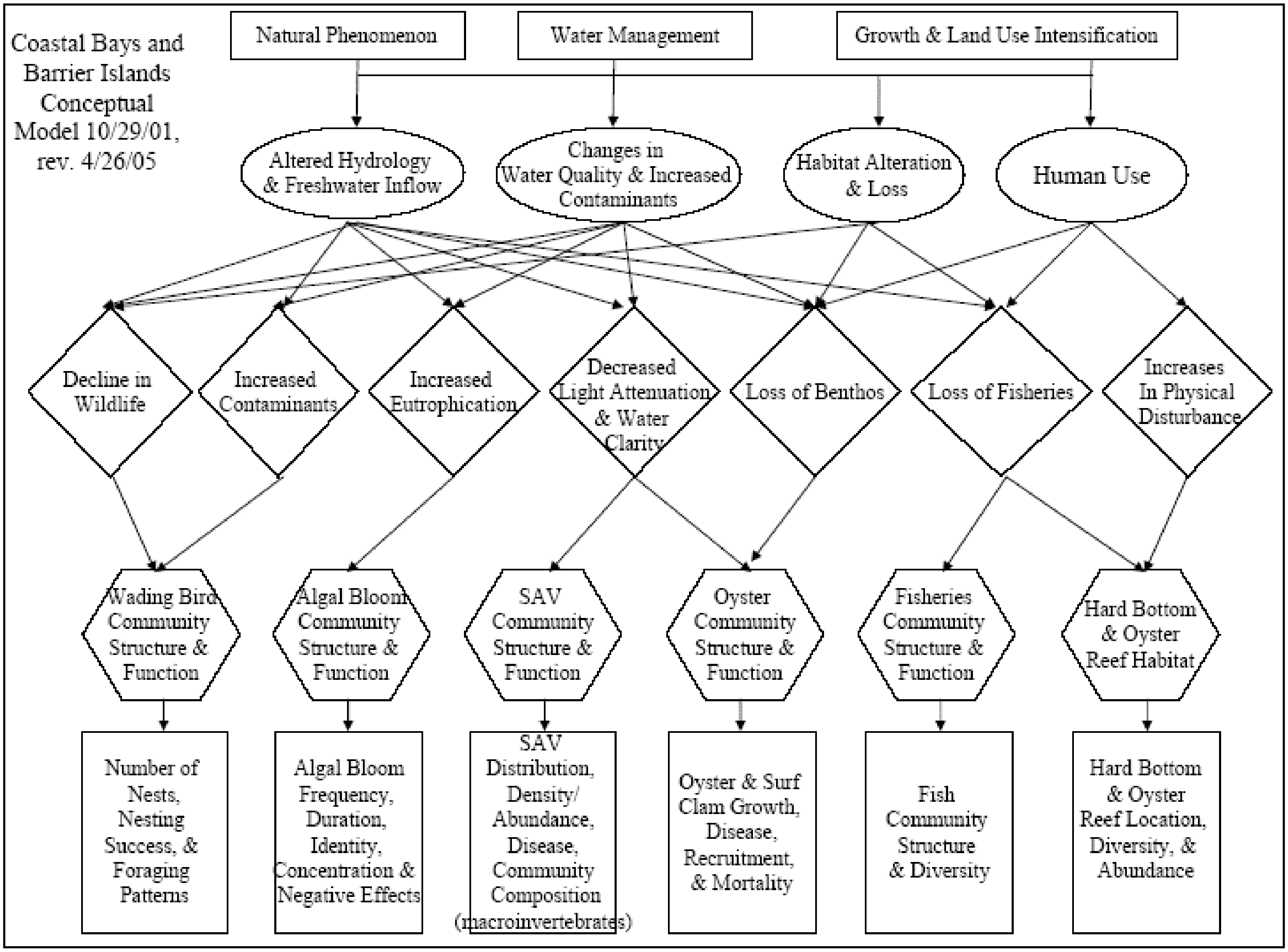
Table 2. SWFFS Water Quality Sub-Team Evaluation Performance Measures.

Evaluation Performance Measures
Dissolved Oxygen (DO)
Salinity (PSU)
Turbidity / TSS
Photosynthetically Active radiation (PAR) / Color
Chlorophyll *a* (Chl-*a*)
Total Nitrogen (TN)
Dissolved inorganic nitrogen (DIN)
Soluble Reactive Phosphorus (SRP)
Total Phosphorus (TP)

Table 3. Assessment Water Quality Performance Measures for SWFFS

Assessment Performance Measure	**Target**
Dissolved Oxygen (DO)	Project/indicator region specific
Specific Conductance	Project/indicator region specific
Salinity	Project/indicator region specific
Turbidity/ TSS / Color	Maintain or reduce to levels that support healthy flora and fauna.
Photosynthetically Active radiation (PAR) / secchi disc depth	Maintain or increase to levels that support healthy flora and fauna.
Chlorophyll a (Chl *a*)	Maintain or reduce to levels that support healthy flora and fauna.
Total Nitrogen / Ammonia Nitrogen / Total Kjeldahl Nitrogen / Nitrate / Nitrite / Dissolved inorganic nitrogen	Maintain or reduce loads and concentrations to support healthy flora and fauna.
Total Phosphorus / Ortho-phosphate/ soluble reactive phosphorus	Maintain or reduce loads and concentrations to support healthy flora and fauna.
Chloride	Project/indicator region specific
Sulfate	Project/indicator region specific
Silica	Project/indicator region specific
Pesticides	Project/indicator region specific
Trace Metals	Project/indicator region specific

11. Model



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