LAND-BASED SOURCES OF POLLUTION LOCAL ACTION STRATEGY COMBINED PROJECTS 1 & 2

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LIST OF ACRONYMS

ABH	Adaptive Bleaching Hypothesis
BC EPD	Broward County Environmental Protection Department
CBOD	Biodegradable Organics
CERP	Comprehensive Everglades Restoration Plan
EDC	Endocrine Disrupting Chemical
ENR	Everglades Nutrient Removal
ENSO	El Niño-Southern Oscillation
EPA	Everglades Protection Area
FDEP	Florida Department of Environmental Protection
GBR	Great Barrier Reef
HSP	Heat Shock Protein
IGBP	International Geosphere-biosphere Program
IRL	Indian River Lagoon
LAB	Long-chain Linear Alkylbenzene
LAS	Local Action Strategy
LBSP	Land-based Sources of Pollution
LCS	Lagrangian Coherent Structures
LOICZ	Land-ocean Interactions in the Coastal Zone
MAA	Mycosporine-like Amino Acid
MGD	Million Gallons per Day
NAH	Non-aromatic Hydrocarbon
NAP	National Action Plan
NPDES	National Pollutant Elimination System
OPA	Oil Pollution Act
PAH	Polycyclic Aromatic Hydrocarbon
PCB	Polychlorinated Biphenyl
POP	Persistent Organic Pollutant
PPCP	Pharmaceutical and Personal Care Product
SCOR	Scientific Committee on Oceanic Research
SDWA	Safe Drinking Water Act
SEFCRI	Southeast Florida Coral Reef Initiative
SEFLOE	Southeast Florida Ocean Outfall Experiment
SFWMD	South Florida Water Management District
SGD	Submarine Groundwater Discharge
SST	Sea Surface Temperature
SWIM	Surface Water Improvement and Management
TBT	Tribunyl Tin
TMDL	Total Maximum Daily Load
TSS	Total Suspended Solids
US EPA	United States Environmental Protection Agency
USCRTF	United States Coral Reef Task Force
USGS	United States Geological Survey
YBD	Yellow Band Disease

1. EXECUTIVE SUMMARY

There is growing concern over the degradation of coral reefs throughout the world, and especially throughout Southeast Florida. The National Action Plan of the United States Coral Reef Task Force (USCRTF) has provided guidance on the conservation of coral reefs. A team of agency and non-agency marine resource scientists, professionals, users and stakeholders, coordinated by Florida DEP and the FFWCC formed the Southeast Florida Coral Reef Initiative (SEFCRI). The SEFCRI team developed local action strategies for the reefs of southeast Florida. One of the four focus groups, Land Based Sources of Pollution, was charged to produce a technical document which combined the efforts of two projects into one effort. This document is the result of that effort. Goals have included assimilation of existing published information regarding quantity and sources of pollutants, evaluation of the relative contributions of point and non-point sources to local coral reef ecosystems, and a review of existing water quality laws and regulations on the federal, state, and local levels to determine which, if any, are applicable to coral reef ecosystems.

Project objectives have included:

- Develop a list of probable land-based sources of pollution to Southeast Florida coral reef communities.
- Collect and review existing literature reports as readily available in the peer reviewed and grey literature that quantify and characterize these sources.
- Identify, as possible, the relative contributions of these sources, including point and non-point, or information gaps that prevent identification
- Assemble a list of applicable federal, state, and local water quality standards.
- Review relevant coral reef and pollution literature to quantify and characterize regional southeast Florida pollutants and their sources.
- Compile a list of recommendations regarding future research and possible modifications/additions to existing regulations.

The pollutants identified for this project include: nutrients, heavy metals, pharmaceuticals/organics, herbicides/pesticides, salinity, carbon dioxide, temperature, turbidity, sedimentation, and disease/pathogens/viruses/bacteria. Upon review of peer-reviewed literature it has been discovered that very little research has been conducted in Southeast Florida regarding the individual effects of these pollutants on coral reefs. However, general findings on each of the individual pollutants, based on global research, can be applied the local level. Most of these pollutants are not present individually in marine waters, and many can act synergistically with one another. However, little to no information is available on the synergistic effects pollutants on coral reef communities in SE Florida or on a global scale. General findings for each pollutant are as follows:

Nutrients

Increases in dissolved inorganic nutrients may reduce coral calcification rates, reduce fertilization success, and promote the growth of macroalgae which compete with coral for space. There is ongoing discussion among researchers regarding the balance of herbivory and nutrients.

Heavy Metals

While many heavy metals are biologically essential to coral reefs, they can become toxic if their concentrations exceed a certain threshold values. Above these threshold values many heavy metals have detrimental effects of coral fertilization and larval settlement success. Current research interests are focusing on determining the processes by which corals accumulate, transport and store heavy metals.

Pharmaceuticals/Organics

There is growing concern regarding Emergent Pollutants like pharmaceutical and organic compounds in marine environments. Much of the research on organic compounds has focused on oil spills and dispersants in combination with oil spills. Small scale chronic spills may be more toxic than single large scale spills. Exposure to organic pollutants increases coral mortality and may cause reduced fecundity in some species. Dispersants used to treat oil spills may actually exacerbate these effects.

Pharmaceutical products like lotions, fragrances, medications and synthetic hormones that are washed off and/or flushed away may end up in marine environments. Although this is a relatively new area of study, researchers have found that estrogens, in particular, are present in marine waters and are biologically active in coral. Exposure to these contaminants is likely to cause tissue thickening, reduced skeletal growth, and reduced fecundity.

Herbicides/Pesticides

Herbicides and pesticides are widely used and can be introduced into marine environments through terrestrial runoff and marine antifouling paints. These chemicals and their degradation products can be highly toxic at very low concentrations. Herbicides and pesticides are known to inhibit coral photosynthesis and may cause reduced fertilization success and resulting significant changes in community structure.

Salinity

Reef coral are able to adapt to certain physical stresses. However, changes in salinity have been shown to cause sublethal effects. These include a significant reduction in photosynthetic ability in zooxanthellae and inhibition of coral ability to adapt to other stressors. Lower salinity levels may inhibit a corals ability to survive exposure to elevated temperatures. Large fluctuations in salinity may also lead to increased coral mortality.

Carbon Dioxide

Calcification of coral is controlled by the saturation of seawater with aragonite. An increase in the partial pressure of carbon dioxide can have a negative effect on coral calcification due to a decrease in the aragonite saturation state. Decreased coral calcification rates will make coral more susceptible to mechanical damage, such as storms and bioerosion, as well as make them less capable of responding to sea level rise or competing with other faster growing organisms for light and space.

Temperature

There has been much concern regarding the response of coral to elevated sea water temperatures. One of the most prominent concerns is large scale coral bleaching events caused by increased temperature and solar radiation. It has been suggested that most coral are unable to adapt quickly enough to cope with the predicted rate of temperature increase. In addition to coral bleaching, reductions in fecundity, and primary production, as well as increases and decreases of coral calcification rates can also occur in response to elevated sea water temperatures.

Turbidity

Turbidity naturally varies in time and space because it is related to physical forces acting on the seabed as well as terrestrial runoff. Increased terrestrial sediment runoff or physical activities such as dredging operations lead to increased turbidity. Increased turbidity reduces water clarity which subsequently reduces light availability and coral photosynthesis.

Sedimentation

Sedimentation can cause coral mortality by inhibition of feeding, and physically smothering or burying the coral. Sedimentation can also decrease coral growth rates through shading or abrasion. Effects of sedimentation also include increased respiration and mucus production, as well as decreased photosynthesis, reproduction and larval survival rates.

Disease/Pathogens/Viruses/Bacteria

There have been 18 coral diseases described to date. Of these, four have been reported globally while the other fourteen are confined to the Caribbean area. There is limited knowledge regarding modes of infection and disease transmission. It has been proposed that some disease-causing organisms may be deposited into local oceans via atmospheric dust transported from Africa, however, linking the components of this dust to any specific disease has proved a difficult task.

Potential local sources of pollutants have been identified as wastewater outfalls, inlets, coastal ocean processes/seasonal upwelling, submarine groundwater discharge, effects of Everglades restoration, and carbon dioxide rise. Existing reports in both peer-reviewed and grey literature that quantify and characterize these sources included monitoring reports, coral reef studies, hydrodynamic studies, water quality studies, geochemical cycling studies, hydrogeologic studies, and permit reviews. In general, there was little information on potential sources of pollutants that were specific to Southeast Florida. The records that were specific to Southeast Florida were for outfalls. These records contained data collected by each of the wastewater treatment facilities as part their NPDES permits. General findings for each potential source are as follows:

Outfalls

When evaluating the potential impact of outfalls, monitoring performed at wastewater treatment plants should be taken into consideration. Annual monitoring reports of the outfalls of southeast Florida are available, however, the physical oceanography of coastal waters must also be thoroughly understood in order to track the movement of effluent water. Understanding how discharged effluent undergoes dispersion, mixing, and dilution in the ocean is particularly important for the risk assessment of outfalls.

Inlets

Research associated with inlets focused on estuaries and rivers; addressing the hydrodynamics of the system. Research on pollutant inputs from inlet discharges is largely overlooked in the literature, especially in southeast Florida waters.

Coastal Ocean Processes/Seasonal Upwelling

There is not a clear understanding of costal ocean processes and upwelling along the southeast Florida coast. No existing studies focus on coastal ocean processes as a potential source of pollution to coastal waters in this region. Episodic delivery of nutrients to coral reef systems through both coastal ocean processes and upwelling events warrant additional study.

Submarine Groundwater Discharge

There is very little data available on the quantity and composition of groundwater entering the coastal ocean by way of submarine groundwater discharge onto the reefs off southeast Florida. New technologies and models are needed in order to estimate fluxes and differentiate between factors that influence submarine groundwater discharge so this source of pollutants to coral reef communities can be quantified.

Effects of Everglades Restoration

The Comprehensive Everglades Restoration Plan (CERP) will result in the increased delivery of freshwater and sediments to Florida Bay, Biscayne Bay, and the Florida Keys. There have been some concerns that CERP will reduce the amount of freshwater flowing into freshwater canals and estuarine systems in the southeast Florida region which may lead to local hypersalinization. This may also lead to a buildup of contaminants within the canals that could lead to high levels being flushed out during drainage events. Some potential benefits of a reduction of freshwater flows to areas north of Biscayne Bay include: tabilization of estuarine salinity regimes and increased seagrass distribution. Changes brought about to the environment by the CERP program need to be investigated to the fullest extent in order to determine the impacts to southeast Florida coastal waters.

Carbon Dioxide Rise

The effects of rising carbon dioxide in the atmosphere on ocean alkalinity as well as coral calcification need to be thoroughly understood. Climatic changes due to carbon dioxide rise and fluctuations in sea surface temperatures have had both positive and negative effects on a local scale. At present, there is no basis for predicting widespread deleterious effects. Laboratory studies need to be applied to larger spatial and temporal scales to address global issues of climate change.

A listing of applicable federal, state and local water quality standards has been compiled. Overall there are some regulations that define water quality standards. However, coral reef ecosystems are not considered specifically in water quality regulations. No numeric criteria for water quality in coral reef systems has been established which causes difficulty in determining management/enforcement strategies and responsibilities.

Recommendations from this investigation include identifying directions for future research and possible amendments or additions to the existing regulations. Additional interdisciplinary research needs to be conducted which specifically examines the effects of multiple stressors. Researchers should also focus on quantifying the relative contributions of potential sources of pollutants in Southeast Florida. Before any regulations can be imposed to reduce pollutant loadings to coral reefs, researchers need to develop numerical criteria for acceptable levels of each contaminant in marine waters, and more specifically on the reefs. We further propose that coastal waters that contain coral reefs in Southeast Florida should be considered for an Outstanding Florida Water designation. For additional information on Outstanding Florida Waters, refer to section 7.3.2.1 Florida Statues, Chapter 403 Environmental Control. Doing so would provide guidance to regulatory agencies and designate special protection to the reefs. Protections would include water quality standards and permitting practices already in place for other Outstanding Florida Waters. The outcome of this designation would provide a coordinated plan to address causes of coral reef degradation and provide a roadmap for successful conservation and management.

2. INTRODUCTION TO SEFCRI

The United States Coral Reef Task Force (USCRTF) was formed in June 1998 by the Presidential Executive Order #13089 in order to “lead, coordinate, and strengthen U.S. government actions to better preserve and protect coral reef ecosystems” (Federal Register 1998). The purpose of the Presidential Executive Order is to increase protection of the U.S. coral reefs by mandating that all Federal agencies whose actions may affect coral reef ecosystems: (a) identify their actions that may affect coral reef ecosystems; (b) utilize programs and authorities to protect and enhance the conditions of these ecosystems; and (c) as permitted by law, ensure that any authorized actions will not degrade the conditions of coral reef ecosystems. In 2000, the USCRTF adopted the National Action Plan (NAP) to Coral Reef Conservation in order to address the most pressing threats to coral reefs in the United States. The two aims of the NAP are “to understand coral reef ecosystems and the natural and anthropogenic processes that determine their health and viability; and to quickly reduce the adverse impacts of human activities on coral reefs and associated ecosystems” (United States Department of the Interior and United States Department of Commerce 2000). There are thirteen distinct goals of the NAP and they include: mapping; assessments, inventories, and monitoring; strategic research; social and economic factors; marine protected areas; sustainable fishing; managing coastal impacts; reduce pollution; restoration; outreach and education; international threats; international trade; and coordination, accountability, and partnerships. This long-term plan serves as a framework for the priorities, strategies, and implementation of plans the Task Force (United States Department of the Interior and United States Department of Commerce 2000).

In 2002, the USCRTF produced a document, A National Coral Reef Action Strategy (National Action Strategy) in order to address priorities and strategies in the short term. The "Puerto Rico Resolution" was also adopted in 2002 by the USCRTF and called for the development of Local Action Strategies (LAS) by each of the seven member U.S. states, territories, and commonwealths (United States Coral Reef Task Force 2002). The LAS are strategies driven by local groups for collaborative and cooperative action among federal, state, territory, and non-governmental partners in order to identify and implement priority actions to reduce key threats to coral reefs. Six threats were prioritized from the thirteen goals of the NAS for local action: over-fishing, land-based sources of pollution, recreational overuse and misuse, lack of public awareness, climate change and coral bleaching, and disease (Florida Department of Environmental Protection et al. 2004).

The Local Action Strategy in Florida was named the Southeast Florida Coral Reef Initiative (SEFCRI), which is comprised of Miami-Dade, Broward, Palm Beach, and Martin Counties. Within the SEFCRI group are four teams each responsible for addressing one of the four focus areas of concern: Awareness and Appreciation; Fishing, Diving, and Other Uses; Land-based Sources of Pollution and Water Quality; and Maritime Industry and Coastal Impacts (Florida Department of Environmental Protection et al. 2004). Projects 1 and 2 are products of the Land-based Sources of Pollution (LBSP) focus group. These two projects were combined into one effort. This document is the result of this effort.

3. STATEMENT OF PURPOSE

The purpose of this project is to review existing data reports (as readily available in the gray and published literature), to provide information on quantities and sources of pollution; to identify and discuss the relative contributions of point and non-point sources; to review federal, state, and local water quality standards applicable to coral reef communities; and to conduct literature searches to identify the links between pollution and coral reef communities.

This project consisted of five tasks. Task 1 included compiling a list of pollutants, defining why each pollutant was considered important, and using this list as a guideline to search relevant coral reef and pollution literature. This effort focused primarily on stony corals, octocorals, reef associated sponges, and macroalgae. This literature search covered primarily peer-reviewed articles. A bibliography of the annotated citations can be found at the end of this document.

Task 2 involved identifying specific sources of pollutants and the concentrations of these pollutants in coastal waters of South Florida, based on the list of pollutants and literature findings in Task 1. The sources investigated include: wastewater outfalls, inlets, coastal ocean processes/upwelling, submarine groundwater discharge, effects of Everglades restoration, and carbon dioxide rise. Information on pollutant sources was found primarily in gray literature.

Task 3 was a review of federal, state, and local water quality standards. Initial contacts of regulatory, research, and conservation agency staff was done to determine whether any existing water quality standards had been identified, evaluated, or researched relative to coral reefs. An initial compilation of existing land-based water quality standards was done using this compiled information.

Tasks 4 and 5 consisted of developing this document which combines all previously mentioned tasks. This document identified data gaps and made recommendations to help alleviate these gaps for South Florida waters.

4. POLLUTANTS

4.1. Overview

A stressor is considered to be any kind of input, process or activity that impacts on the functioning of an ecosystem over time. Stressors can be naturally occurring events, e.g. hurricanes, El Niño-Southern Oscillation (ENSO) or be related to human activities (Moss et al. 2005). A pollutant is defined as an anthropogenic stressor. Pollutants may include synthetic/man-made substances and/or elevated loadings of constituents already present in the system (nutrients, metals and sediments). Pollutant levels become unacceptable when they result in detrimental changes to an organism or the biological community (Kruczynski 2002). Synergistic and cumulative effects of natural and human stressors on a system will result in the degradation of habitat and loss of ecosystem function. The pollutant categories identified for the purpose of this project are: nutrients, heavy metals, pharmaceuticals/organics, herbicides/pesticides, salinity, carbon dioxide, temperature, turbidity, sedimentation, and disease/pathogens/viruses/bacteria.

4.2. Pollutant Definitions

4.2.1. Nutrients

A nutrient is defined as any substance, element, or compound that is assimilated and necessary for growth, development, and reproduction. Nutrients as pollutants are any element or compound, such as phosphorus or nitrogen, that fuels abnormally high organic growth in aquatic ecosystems (e.g. eutrophication of a lake) (Howarth et al. 2000). Changes in nutrient concentrations alter nutrient ratios. Changes in nutrient ratios may not increase total biomass but can influence community composition and diversity.

4.2.2. Heavy Metals

Bodies of water naturally contain different amounts of various metals (copper, mercury, lead, cadmium, arsenic, chromium, nickel, zinc, manganese, magnesium, and iron). Metals may exist as dissolved ions in the water column, or may precipitate out as particles in the sediment. A number of metal ion species are important trace element components of vital to physiological pathways in flora and fauna. Metals are considered pollutants when their concentrations reach a level that is toxic to organisms. For example, high concentrations of heavy metals have been implicated in having adverse effects on urchin larval development (Quiniuo et al. 1999). In some cases metals, such as iron, act as a limiting micronutrient. Excess concentrations of this metal act as a pollutant and may stimulate growth of one species over another.

4.2.3. Pharmaceuticals/Organics

Pharmaceutical and personal care products, (PPCPs) are substances containing pharmaceutical drugs and or the metabolite compounds of these drugs. PPCPs are a diverse group of chemicals that include all human and veterinary drugs (e.g. prescription or over the counter), diagnostic agents (e.g. X-ray contrast media), “nutraceuticals” (e.g. bioactive food supplements such as huperzine A), and other consumer chemicals, such as fragrances (e.g. synthetic musks) and sun-screen agents (e.g. methylbenzylidene camphor). PPCPs are considered pollutants because many have biochemical mechanisms of action outside the scope of their intended purpose. These “side effects” may be harmless to the subjects of their intended use, but highly toxic to flora and fauna that receive incidental exposure via waste disposal (Daughton 2003). For example, some pharmaceutical compounds are known endocrine disrupting chemicals (EDCs), which have been implicated in adversely affecting reproduction of marine fauna.

Organic compounds as pollutants are referred to as persistent organic pollutants. Persistent organic pollutants (POPs) are chemical substances that persist in the environment, bioaccumulate through the food web, and pose a risk of causing adverse effects to human health and the environment" (United Nations Environment Programme 1999). Some examples include, hydrocarbons (petroleum products), non-aromatic hydrocarbons (NAHs), long-chain linear alkylbenzenes (LABs), polycyclic aromatic hydrocarbons (PAHs), organochlorine pesticides (e.g. DDTs) and polychlorinated biphenyls (PCBs).

4.2.4. Herbicides/Pesticides

In agriculture, the term "pesticide" is often used as an umbrella term that includes all pest control chemicals including herbicides (weeds), insecticides (insects), fungicides (fungi), nematocides (nematodes), and rodenticides (vertebrate poisons). Several components of pesticides can be considered pollutants including: the active ingredient in the pesticide; contaminants in the active ingredient; additives (wetting agents, diluents or solvents, extenders, adhesives, buffers, preservatives and emulsifiers); and/or degradation of the active ingredient (Ongley 1996). These factors have been shown to negatively affect seagrass productivity and have been implicated in localized mangrove die back (Haynes et al. 2000; Duke et al. 2005).

4.2.5. Salinity

Salinity is a measure of the saltiness or dissolved salt content of a body of water. Salinity is an important ecological factor influencing the types of organisms able to survive in a certain body of water (Wikipedia Webpage 2005. http://en.wikipedia.org). Changes in salinity combined with other factors, compound stress on coral reefs (Sakami 2000).

4.2.6. Carbon Dioxide

Carbon dioxide is an atmospheric gas composed of one carbon and two oxygen atoms which results from the oxidation of organic matter if sufficient amounts of oxygen are present. The Earth's oceans contain huge reservoirs of carbon dioxide as bicarbonate and carbonate ions (Wikipedia Webpage. 2006. http://en.wikipedia.org). Increases in carbon dioxide may fuel the greenhouse effect, warm the atmosphere, and disrupt the natural carbon cycle. Coral reefs are threatened because increased atmospheric carbon dioxide can decrease the saturation state of aragonite in surface waters; a mineral that coral calcification is dependent on (Kleypas et al. 1999).

4.2.7. Temperature

Temperature is the measure of the hot or coldness of a body or environment (Wordnet Database Webpage. 2006. http://wordnet.princeton.edu). Temperature is considered a pollutant/stressor in marine systems when abnormal fluctuations in ocean temperatures lead to degradation of habitat and loss of function of that system (e.g. coral bleaching). Loss of habitat and function may be directly related to elevated temperatures or be a consequence of synergistic effects with other pollutants or stressors. Bleaching is the loss of algal symbionts and/or their pigments as the result of environmental stresses such as: decreased salinity, increased temperature, decreased temperature, disease, exposure at low tide, sedimentation, absence of light, and solar radiation, or a combination of these factors (Fitt et al. 2001).

4.2.8. Turbidity

Turbidity is a measure of water clarity. It is an optical property based on the amount of light reflected by suspended particles in water. The term turbidity simply refers to the decrease in water clarity due to particles in suspension (Telesnicki and

Goldberg 1995). Turbidity cannot be directly equated to total suspended load because small particles will reflect more light than the same amount of large particles and white particles reflect more light than dark-colored particles. Highly turbid waters have a large number of scattering particulates and visibility is reduced. Topsoil and land degradation lead to excessive levels of turbidity in receiving waters and to off-site ecological and physical impacts. Turbidity limits penetration of sunlight into the water column, thereby limiting photosynthetic ability leading to habitat degradation (Ongley 1996).

4.2.9. Sedimentation

Sediment is any particulate matter that can be transported by fluid flow and eventually deposited as a layer of solid particles on the bed or bottom of a body of water. Sedimentation is the deposition by settling of a suspended material (Wikipedia Webpage. 2006. http://en.wikipedia.org). Sediments are the primary carrier of absorbed chemicals into aquatic environment (Ongley 1996). Excessive sedimentation can blanket substrate reducing suitable habit for colonization of benthic organisms such as corals. Sedimentation can also depress rates of photosynthesis and enhances respiration and mucus production. As coral growth rate declines, zooxanthellae are expelled and the underlying tissue dies (Philipp and Fabricius 2003).

4.2.10. Disease/Pathogens/Viruses/Bacteria

A pathogen is a biological agent that can cause disease in its host. Pathogens are considered an infectious agent. An infection is the colonization of a host organism by a foreign species which negatively affects the host. Many pathogens are bacteria. Bacteria are a major group of microscopic prokaryotic organisms. Viruses are also considered pathogens. A virus is a small particle that infects cells in biological organisms and can also cause disease (Wikipedia Webpage. 2006. http://en.wikipedia.org).

4.3. Pollutant General Findings

4.3.1. Nutrients

Nutrients are considered a pollutant when elevated concentrations have a negative effect on coral reef systems. Increases in dissolved inorganic nutrients have been shown to reduce coral calcification rates, reduce fertilization success, and possibly promote the growth of macroalgae that compete for space with corals (Fabricus 2005). Various research activities conducted by Lapointe and colleagues (1997, 2004, 2005a, 2005b) have shown that increased nitrogen (N) and/or phosphorous (P) concentrations can cause an increase in macroalgal production resulting in an increase in harmful algal blooms.

The abundance of *Clionid* sponges has also been shown to increase with increased nutrient concentrations (Rose and Risk 1985; Summarco 1996; Holmes et al. 2000). Declines in coral cover have been associated with increased density of *Clionid* sponges along a Florida reef tract (Ward-Paige et al. 2005). There is some discussion regarding the relative importance of nutrification (increased nutrient concentrations) versus herbivory. Several studies have indicated that with normal herbivory rates, moderate nutrification would not result in a change in algal community structure or biomass (McCook 1999; Szmant 2002). Others have shown that herbivory had little effect on reducing the biomass of harmful algae while nutrient enrichment caused a significant increase in algal biomass that would then out compete the existing corals (Lapointe et al. 2004). McClanahan et al. (2005) suggest there is a complicated interaction between herbivory, nutrients, and organic matter affecting coral reefs.

There is consensus that nutrients are being introduced into marine systems via runoff, sewage discharge, and other anthropogenic activities, and that the concentrations of these nutrients tend to decrease with distance from the shoreline. In some regions of the world, it has been shown that most or all of the nutrients that enter the coastal waters are immediately taken up by microbes and never reach the reef system. Nutrient budget calculations have indicated that microbial mineralization rates exceed the total nutrient load in these places (Alongi and McKinnon 2005). Estimates of N and P demand by phytoplankton in nearshore waters shows that daily water column nutrient demand far exceeds the average daily amount supplied by benthic mineralization, river input, upwelling events and sewage discharges combined near the Great Barrier Reef (GBR) (Furnas et al. 2005). Pulses of nutrients due to episodic events may exceed phytoplankton demand, supplying excess nutrients to the reef (Furnas et al. 2005).

4.3.2. Heavy Metals

Many heavy metals, or trace metals, are biologically essential to coral reefs, however, these metals can become toxic of their concentrations increase above a certain threshold value (Great Barrier Reef Marine Park Authority Webpage. 2006. http://www.gbrmpa. gov.au/corpsite/key_issues/water_quality/principal_influences.html). Elevated metal concentrations have been shown to have negative impact on coral fecundity (Negri and Heyward 2001; Reichelt-Brushett and Harrison 2005; Reichelt-Brushett and Michalek 2005; Victor and Richmond 2005). Several studies have also shown the detrimental effects of heavy metals on coral fertilization and larval settlement success (Reichelt-Brushett 2000; Reichelt-Brushett and Harrison 2005; Reichelt-Brushett and Michalek 2005). Copper, lead, zinc, cadmium, and nickel had significant effects on fertilization success on scleractinian coral, with copper being the most toxic. The EC 50 (concentration that reduces fertilization rate by 50% relative to a control group) for copper was between 15 and 40 ugl-1 (Reichelt-Bruschett and Harrison 2005). Copper (Cu) also caused a significant decrease in fertilization rates in a laboratory study by Victor and

Richmond (2005). A study by Negri and Heyward (2001) also indicated that copper inhibited fertilization, even at concentrations close to acceptable levels given by the United States Environmental Protection Agency (US EPA) guidelines.

Additional research has focused on the mechanisms by which corals accumulate, transport, and store metals. Coral take up and store different metals in different compartments including: the polyps, zooxanthellae, and the skeleton (Esslemont et al. 2000). Bastidas and Garcia (2004) suggested that coral polyps actively diverted mercury (Hg) to other coral compartments as a method of detoxification. Others have suggested that some coral may intentionally bleach, using expulsion of symbiotes as a means of eliminating heavy metals from the coral (Peters et al. 1997). Harland and Brown (1989) also showed a marked decrease in symbiont concentration in *Porites lutea* as a result of exposure to elevated iron (Fe) concentrations.

Pollution by heavy metals can also interfere with reef building processes. Carbonic anhydrase (an enzyme used in building carbonate skeleton) activity has been found to decrease with increased heavy metal concentrations in coral colonies and sea anemones (Gilbert and Guzman 2001). Reduced growth rates, measured by linear extension and calcium carbonate accumulation, were observed in colonies of *Pocillopora damicornis* near a tin smelter. The researchers suggested that increased metal concentrations inhibit chitin synthetase production, the enzyme used for calcification (Howard and Brown 1987). Another study by Howard and Brown (1984) indicated that heavy metals are being incorporated into coral through feeding and are subsequently being deposited into coral skeletal tissues, compromising the integrity of the coral structure and making it more susceptible to mechanical and physical damages.

4.3.3. Pharmaceuticals/Organics

Organic pollution occurs when organic hydrocarbons, NAHs, LABs, and PAHs are released into the environment via sewage effluent, terrestrial runoff, ballast water discharge, or oil spills (Peters et al. 1997). Much of the research on organic pollutants has focused on the effects of oil spills and oil spills combined with dispersants on reefs (Peters et al. 1981; Dodge et al. 1984, 1985; Wyers et al. 1986;).

Research suggests that small scale chronic oil spills may be more toxic than single large scale spills and that dispersants in combination with oil caused increased tissue death and bleaching events in coral (Peters et al. 1997). A by Dodge et al. (1985) indicated that short term exposure to a chemically dispersed oil spill resulted in changes in coral calcification rates and prominent signs of stress for a short period of time. *Manicina areolata* colonies that were exposed to fuel oil treatments for a period of three months showed signs of hydrocarbon contamination even after being transferred to clean seawater for two weeks. Exposure to hydrocarbons caused tissue atrophy, degeneration, and reduced fecundity (Peters et al. 1981).

Exposure to organic pollutants increases mortality rates and may cause reduced fecundity of some coral species, and that chemical dispersants do little to improve the situation and may actually exacerbate the condition (Peters et al. 1981; Dodge et al.1985; Peters et al. 1997).

The effect of pharmaceutical products on coral reef communities is a relatively new area of study (Isidori et al. 2005). Pharmaceutical products, like lotions, fragrances, medications, and synthetic hormones that are washed off and/or flushed away may end up in marine environments. In a field study, Atkinson et al. (2003) measured the concentrations of steroidal estrogens at 20 sites in the waters surrounding the United States. Estrogen concentrations varied from undetectable in the open ocean to approximately 2000 pg/l near the Florida and Delaware coasts. Less than 20% of estrogens per week measured in the water column were found to be deposited in the sediments while 80% remained in the water column. The authors suggest that estrogens could easily leach from septic fields and groundwater into the surrounding marine environment. Mean estrogen concentrations at twelve of the sites were above 300 pg/l; the concentration at which coral begin to take up estrogen from the surrounding water column (Atkinson et al. 2003).

The effects of steroidal estrogens on coral communities are generally unknown (Atkinson et al. 2003). However, laboratory studies by Tarrant et al. (2004) have indicated that exposure to estradiol caused a 29% reduction in the number of egg-sperm bundles released by *Montipora capitata* colonies compared to control groups. *Porites compressa* grew significantly slower than controls, with 13-24% reduced growth rates, when exposed to estrone (Tarrant et al. 2004). Tarrant et al. (2004) also found that coral treated with estrone had thicker tissues. Based on these studies, the authors suggested that estrogens are biologically active in corals, and that exposure is likely to cause tissue thickening, reduced skeletal growth, and reduced fecundity (Tarrant et al. 2004).

4.3.4. Herbicides/Pesticides

Herbicides and pesticides are widely used and can be introduced into marine environments via terrestrial runoff (Olafson 1978), via vessel antifouling paints (Connelly et al. 2001). These chemicals, as well as their degradation products, can be extremely harmful to corals in very low concentrations. Tributyl tin (TBT) has been found to cause detrimental effects to coral reefs in concentrations below 0.5ng/l, and is said to be the most toxic substance ever introduced to the environment (Goldberg 1986; Maguire 1987). In an effort to reduce TBT pollution, new copper-based antifouling paints like Irgarol 1051 have been developed (Dahl and Blank 1996). These new antifouling paints are also toxic to coral (Dahl and Blank 1996; Owen et al. 2002). A study by Dahl and Blanck (1996) indicated that periphyton photosynthetic ability was significantly reduced within hours of exposure to Irgarol 1051, and that long term exposure (weeks) yielded significant changes in community structure. Irgarol 1051 is present in tropical marine waters and inhibits coral photosynthesis and zooxanthellae carbon 14 (^{14}C) incorporation (Owen et al. 2002).

Studies show increasing levels of pesticides in nearly 100% of coral in the GBR and reefs off the Florida Keys (Peters et al. 1997). Chemicals like TBT, diuron, atrazine, and other organochlorines caused a significant decrease in photosynthetic activity and zooxanthellae incorporation on coral reefs (Raberg et al. 2003; Jones and Kerswel 2003; Harrington et al. 2005). Many of these compounds have high solubility and relatively long half-lives especially diuron (Negri et al. 2005). Diuron is of concern because it interferes with photosynthesis by inhibiting photosystem II and could affect fertilization if introduced by a flood event that corresponded to a mass spawning event (Negri et al. 2005).

Researchers agree that herbicides and pesticides are toxic not only coral reefs and marine ecosystems in general (Konstantinou and Albanis 2004, Moss et al. 2005). Some current research efforts are focused on determining concentrations of these compounds in the marine environment and making recommendations regarding water quality guidelines that specifically limit or ban these chemicals, particularly near coral reefs (Konstantinou and Albanis 2004; Moss et al. 2005).

4.3.5. Salinity

Reef corals were previously considered to be dependent on a narrow range of environmental conditions to survive (Coles and Jokiel 1978), but results within the last twenty years suggest they can adapt to physical stresses more than previously believed (Muthiga and Szmant 1987). A few studies have dealt with the effects of sublethal salinity changes to corals (Coles and Jokiel 1978; Muthiga and Szmant 1987; Moberg et al. 1997). Findings of Muthiga and Szmant (1987) showed that an increase in salinity from 32 to 42 ppt causes no change in respiration, but did cause a significant reduction in photosynthesis. These sublethal effects of salinity stress were shown in the Florida coral, *Siderastrea siderea* (Muthiga and Szmant 1987). In *Porites lutea* and *Pocillopora damicornis*, photosynthesis to respiration ratios were significantly lowered in both species when exposed to sudden salinity drops (hours) from ambient 30 psu to 20 and 10 psu with *P. lutea* being slightly less affected (Moberg et al. 1997).

Salinity and temperature may have synergistic effects on corals. Coles and Jokiel (1978) show that low salinity reduces a coral's ability to survive during short term exposure to elevated temperatures. Coles and Jokiel (1978) also suggest that slight increases in resistance to thermal stress may be imparted by small increases in salinity above normal salinity values. Jokiel et al. (1993) investigated the effects of storm floods on ocean salinity in 1987 which reduced salinities to 15 psu in the surface waters of Kaneohe Bay, Hawaii. Findings showed that colonies of *Pocillopora damicornis* and *Montipora verrucosa* suffered total mortality when the salinity remained below 20 psu for more than 5 days.

The bulk of studies annotated for this project examined large variations in salinity over a short incubation time (hours-days). A few studies did examine the effects of long term exposure to changes in salinity. Hoegh-Guldberg and Smith (1989) studied the export of zooxanthellae under a small change in salinity (5 psu) during an incubation time of 20 days. This experiment also showed that extreme increases and decreases in temperature and salinity were always lethal (Hoegh-Guldberg and Smith 1989). Synergistic effects from multiple stressors are frequently discussed in the literature, but there are relatively few experimental studies on the effects of multiple stressors on corals (but see Sakami 2000; Alutoin et al. 2001). Alutoin et al. (2001) studied the effects of copper and reduced salinity acting simultaneously on the hermatypic coral *Porites lutea*. Sakami (2000) studied the effects of temperature, irradiation, salinity and inorganic nitrogen concentration on two strains of zooxanthellae isolated from the corals *Pocillopora damicornis* and *Montipora verrucosa*. Overall, low irradiation and high temperature reduced tolerance against low salinity. Also, gross photosynthesis per cell was unaffected and cellular chlorophyll a content and cell density increased with ammonium enrichment up to 20 micromoles per day. Experiments like this can help to clarify the effects of multiple environmental stresses on corals.

4.3.6. Carbon Dioxide

The metabolism of organic (photosynthesis and respiration) and inorganic (precipitation and dissolution of calcium carbonate) carbon are the two major biological processes affecting the carbon cycle of marine organisms (Leclercq et al. 2002). Coral reefs are of interest because calcification and photosynthesis are physiologically linked (Leclercq et al. 2002). Scleractinian corals, calcifying algae, and coral reef communities exhibit an increased rate of calcium carbonate deposition during the daylight period (Leclercq et al. 2002). Both processes utilize dissolved inorganic carbon and respond to changes in environmental parameters such as light and temperature (Leclercq et al. 2002). The partial pressure of carbon dioxide ($p\mathrm{CO}_2$) increases in the atmosphere due to anthropogenic inputs of carbon dioxide (Reynaud et al. 2003). This has important consequences on the Earth’s climate, including air temperature, which has risen by 0.6 °C between 1880 and 2000 (Reynaud et al. 2003).

It is now well established that calcification of corals is controlled by the saturation of seawater with respect to aragonite (Gattuso et al. 1999a; Langdon et al. 2000; Leclercq et al. 2002). An increase in the partial pressure of CO_2 can have a negative effect on coral and reef community calcification rates due to a decrease in the aragonite saturation state (Gattuso et al. 1998; Kleypas et al. 1999; Langdon et al. 2000; Marubini et al. 2001). These studies found that a doubling of CO_2 resulted in an 11-40% decline in calcification in corals and coralline algae measured over time periods ranging from 3 hours to 2 years. A decrease in coral calcification means that corals will be less able to; respond to sea level rise, and compete with faster growing organisms for space and light. They will also be more susceptible to storm damage and bioerosion, as well as other forms of stress, i.e. disease, bleaching, overfishing, pesticides, fertilizers, and sedimentation (Langdon et al. 2003).

Some experimental evidence has been published that predicts changes in coral calcification rates when exposed to elevated $p\mathrm{CO}_2$ and its biogeochemical significance (Gattuso et al. 1999a; Kleypas et al. 1999). The consensus is that calcification rates will decrease by 14-30% by 2100 (Gattuso et al. 1999a; Kleypas et al. 1999).

Coral reef ecosystems are negatively affected by an increase in both temperature and $p\mathrm{CO}_2$ (Reynaud et al. 2003). Increased temperature leads to the loss of zooxanthellae, or to a decrease in chlorophyll content per algal cell (Reynaud et al. 2003). Reynaud et al. (2003) found calcification decreased by 50% when temperature and $p\mathrm{CO}_2$ were both elevated, but calcification did not change in response to an increased $p\mathrm{CO}_2$ under normal temperature conditions.

The exchange of CO_2 between the ocean and the atmosphere is controlled by complex physical and biological processes (Bates 2002). In coral reef ecosystems, the balance of biological processes such as calcium carbonate ($CaCO_3$) formation and organic carbon production can lead to CO_2 being retained in the oceanic environment (sink of CO_2) or returned to the atmosphere through gas exchange (source of CO_2) (Bates 2002). Some studies have demonstrated that coral-dominated reefs are sources of CO_2 to the surrounding waters (Ware et al. 1991; Gattuso et al. 1999b). Other studies have suggested that macroalgal-dominated reefs systems are sinks for CO_2, but in a recent review, Gattuso et al. (1999b) found that "average" coral reef flats are sources of CO_2 to the atmosphere. Whether coral reef ecosystems act as sources or sinks of CO_2 seems to depend on the balance of two processes: organic carbon production by macroalgae and $CaCO_3$ production by corals. This was illustrated by Bates (2002) who found that a Bermuda coral reef system acted as both an oceanic sink and source of CO_2 depending on the season and community make-up (i.e., coral-dominated vs. macroalgal-dominated ecosystem) and the pre-existing air-sea CO_2 disequilibrium of waters surrounding the reef system.

Human activities increase atmospheric CO_2 partial pressure mostly through fossil fuel utilization, cement production and biomass burning (Gattuso et al. 1998). Most concerns regarding rising concentrations of atmospheric CO_2 center on how it will affect climate change (Gattuso and Buddemeier 2000). However, there have been many indications of negative biological responses in the marine environment (Gattuso and Buddemeier 2000).

4.3.7. Temperature

Substantial loss of coral cover has occurred throughout the world's coral reefs as a result of anomalously warm water due to global warming and thermal anomalies such as the El Niño-Southern Oscillation (ENSO) over the past three decades (Brown 1997;

Goreau et al. 2000; Aronson et al. 2002). Concern over the future of the world's coral reefs has increased in the face of rising sea surface temperatures (McClanahan et al. 2004). Hoegh-Guldberg (1999) concluded that most corals could not adapt quickly enough to cope with the predicted rate of rise in sea surface temperatures predicted by various climate-change models. These models predict that sea surface temperatures will exceed the current thermal tolerance of corals on the Great Barrier Reef by the year 2020 (Hoegh-Guldberg 1999).

During the last decade, the effects of elevated seawater temperatures on coral reef communities have received attention in coral reef literature (Nordemar et al. 2003). Predicting the effects that rising sea surface temperatures (SSTs) will have on local coral reef communities is hampered by a lack of thorough understanding of the capacity of corals to acclimate to local temperature regimes (Jokiel and Coles 1990; Hughes et al. 2003). One established consequence of elevated SSTs on coral reefs has been bleaching. Bleaching is defined as the loss of algal symbionts and/or their pigments, a classic response of corals to a variety of environmental stresses including elevated SSTs (Fitt et al. 2001). Bleaching of corals is a global phenomenon that is possibly linked to global climate change and increasing ocean temperatures (Brown 1997; Hoegh-Guldberg 1999).

Large-scale bleaching is not attributed only to elevated sea surface temperatures, but also to increased solar radiation (Hoegh-Guldberg and Smith 1989; Brown et al. 1994; Brown 1997; Salih et al. 1997; Hoegh-Guldberg 1999; Fitt et al. 2001; Lesser and Farrell 2004). Stress responses of corals to elevated seawater temperature involve malfunctioning algal photosystems (Salih et al. 1997; Fitt et al. 2001), reduced primary production (Porter et al. 1999), altered respiration (Porter et al. 1999; Fitt et al. 2001), coral bleaching (Brown 1997; Loya et al. 2001; Fitt et al. 2001), reduced fecundity

(Szmant and Gassman 1990) and calcification (Howe and Marshall 2002; Reynaud et al. 2003). Lesser and Farrel (2004) examined the synergistic role of solar radiation on thermally induced stress and subsequent bleaching in *Montastraea faveolata.* Under high solar radiation and elevated temperature conditions: photosystem II fluorescence in the zooxanthellae, photosynthetic pigments, and mycosporine-like amino acids (MAAs) were depressed. Host DNA damage was exacerbated under high light conditions. Thermal stress during exposure to high irradiance caused damage to photosystem II ability and carbon fixation in the zooxanthellae. It also caused DNA damage, apoptosis, and necrosis in the host tissue (Lesser and Farrell 2004).

The adaptive bleaching hypothesis (ABH) states that the loss of zooxanthellae may allow other representative algae to re-establish a symbiosis with the host coral species, creating a new holobiont (also known as ecospecies or host-symbiont unit) (Fautin and Buddemeier 2004). This hypothesis makes five assumptions: (1) multiple types of both zooxanthellae and host species commonly exist; (2) a diversity of photosymbionts can live with many hosts, and vice-versa; (3) different host-symbiont combinations may differ physiologically in aspects that affect the survival of the holobiont, host, and symbiont; (4) bleaching provides the opportunity for repopulation of a host with different dominant photosymbionts; and (5) stress-sensitive holobionts have competitive advantages in the absence of stress which implies a reversion to stress-prone combinations under non-stressful conditions (Fautin and Buddemeier 2004). The adaptive bleaching hypothesis has potential importance in determining the outcomes of non-lethal bleaching and set the possible path for how some symbiont communities might be able to recover (Fautin and Buddemeier 2004).

There have been some efforts to investigate interactions between other common stressors and elevated temperature (e.g. Berkelmans and Oliver 1999; Porter et al. 1999; Nordemar et al. 2003; Schlöder and D'Croz 2004). Several authors have described the influence of nutrients and high temperature together as a potential stressor for the coral-zooxanthellae symbiosis (e.g. Nordemar et al. 2003; Schlöder and D'Croz 2004). Impacts of global warming often coincide with various common anthropogenic disturbances, resulting in pollution (Nordemar et al. 2003). Nordemar et al. (2003) investigated the physiological response of *Porites cylindrica* when exposed to elevated seawater temperature in combination with enrichment of dissolved inorganic nutrients. Findings showed that corals on nutrient-exposed reefs may be more stressed during periods of elevated temperature, compared to corals in more pristine areas.

Loya et al. (2001) suggested that *Pocillopora damicornis* and *Stylophora pistillata* in Okinawa, Japan are bleaching-susceptible species that show high mortality under conditions of elevated sea surface temperature. Investigating a large number of corals, McClanahan et al. (2004) showed a clear species-dependence in bleaching susceptibility and mortality in the Great Barrier Reef (GBR) and Kenyan Reef. These reports have provided essential information on inter-species differences in bleaching tolerance, but do not account for intra-species differences that have been observed in the field (Brown 1997). Nakamura and Yamasaki (2005) further investigated *Pocillopora damicornis* and *Stylophora pistillata* in order to determine if water flow was a mitigating factor for bleaching. They found that although bleaching was observed with elevated sea surface temperatures, both species showed a shorter period or no visible bleaching under flow conditions; in addition, better colony growth was observed under flow conditions when compared to still conditions (Nakamura and Yamasaki 2005).

Reduced temperatures can also cause corals to bleach (Hoegh-Guldberg et al.

2005). Hoegh-Guldberg et al. (2005) investigated cold stress on the southern GBR which resulted in a mass bleaching event. Exposure to cold stress led to the complete loss of photosynthetic efficiency by photosystem II and death of the exposed coral (Hoegh-Guldberg et al. 2005).

Temperature is also an important factor affecting calcification rate in corals (Howe and Marshall 2002). Calcification in reef corals generally increases with temperature, with maximum growth reported within the range of 25-28°C (Jokiel and

Coles 1977; Coles and Jokiel 1978). Corals generally calcify most rapidly close to the maximum summer temperature, however, prolonged increases of 1-2°C above this will impair skeletal growth (Jokiel and Coles 1977; Coles and Jokiel 1978). Howe and Marshall (2002) investigated whether calcification rates in the temperate coral, *Plesiastrea*, changed with temperature in a similar manner to tropical reef corals, and whether calcification was retarded in relatively cold waters. Findings showed calcification in the temperate coral *Plesiastrea* was lower than in tropical reef corals, but followed a similar trend with a trend towards higher rates at higher temperatures, ~18°C (Howe and Marshall 2002).

There is overwhelming evidence in the literature to suggest temperature changes negatively affect coral reefs. Even under moderate greenhouse scenarios, present and future increases in sea temperature are likely to have severe effects on the world's coral reefs within 20-30 years (Hoegh-Guldberg 1999). Mass bleaching of corals is a major contributing factor to their degradation worldwide (Brown 1997; Hoegh-Guldberg 1999). If the mortality of reef building corals continues to increase, changes in the distribution of corals will occur and is likely to have detrimental effects on the health of coral reefs world-wide (Hoegh-Guldberg 1999).

4.3.8. Turbidity

Turbidity is a transient phenomenon that is temporally and spatially variable because it is related to physical forces acting on the sea bed (Larcombe and Woolfe 1999) as well as terrestrial runoff which results in light reduction in the water column (Fabricius

2005). The term turbidity simply refers to the decrease in water clarity due to particles in suspension (Telesnicki and Goldberg 1995).

Benthic communities in nearshore marine environments are subject to large natural variations in turbidity (Rogers 1990). Extreme elevation in turbidity levels can cause stress in many organisms (Rogers 1990). The photosynthetic and respiratory responses of two coral species common to Florida waters, *Dichocoenia stokesii* and *Meandrina meandrites*, were examined under conditions of elevated turbidity for three weeks (Telesnicki and Goldberg 1995). Turbidity ranges were tested and compared to controls with the highest range corresponding with the Florida standard for coastal water turbidity, 29 Nephelometric Turbidity Units (NTU) (Telesnicki and Goldberg 1995). Results showed high levels of mucus production of both species and reduced photosynthesis to respiration ratios when exposed to the high turbidity levels (Telesnicki and Goldberg 1995). These results suggest that turbidity-related water quality as presently defined in South Florida (29 NTU set by FDEP using a turbidimeter) is not a conservative value and may result in short term stress and long term decline for some coral species (Telesnicki and Goldberg 1995). Orpin et al. (2004) state that researchers and managers seeking to understand the responses of inshore ecosystems to turbidity in order to minimize the potential impacts of anthropogenic disturbances should incorporate a turbidity safety margin, i.e. any turbidity increase above the natural regime should be under conditions that pose minimal environmental risk. Natural turbidity regimes are highly variable in space and time (Larcombe et al. 1995) which complicates any assessment of ecological stress on coral assemblages and their responses (Anthony and Fabricius 2000). Orpin et al. (2004) measured the natural variability in turbidity on the

Central GBR, and recommended using one standard deviation from ambient conditions as a possible conservative upper limit of an acceptable projected increase in turbidity.

4.3.9. Sedimentation

Sediment accumulation describes an increase in thickness of a sediment body caused by addition of material at its upper surface (Larcombe and Woolfe 1999). Sedimentation is an important physical parameter that influences coral growth and community composition and is considered a significant potential mechanism leading to reef degradation (Rogers 1990; Riegl 1995). Normal sediment loading levels on fringing reefs have been quoted as ranging from ~5 mg/l (Larcombe et al. 1995) to <10 mg/l (Rogers 1990). Rogers (1990) reviewed the responses of corals and reef organisms to sedimentation and emphasized the need for measures of physical processes to compliment organism and ecosystem responses and for long-term data sets.

Sedimentation can affect corals in several different ways: (1) it can cause their death by smothering or burial (Loya 1976; Cortés and Risk 1985; Riegl 1995; Fabricius and Wolanski 2000; Nugues and Roberts 2003a; Philipp and Fabricius 2003); (2) it can decrease adult coral growth by abrasion, shading or resuspension (Dodge et al. 1974; Loya 1976; Anthony 1999); (3) it can depress zooxanthellae densities and photosynthetic activity, and increase respiration and mucus production (Riegl and Branch 1995; Yentsch et al. 2002; Philipp and Fabricius 2003); and (4) it can reduce coral reproduction, coral larval settlement, and early survival (Hodgson 1990; Babcock and Davies 1991; Hunte and Wittenberg 1992; Stafford-Smith 1993; Gilmour 1999).

Sedimentation of the suspended particles out of the water column can smother epibenthic organisms (Rogers 1990; Stafford-Smith 1993; Fabricius and Wolanski 2000). However, some corals enhance their chances of survival by cleaning off deposits before they cause damage. Corals remove sediment through active and passive sediment rejection (Stafford-Smith 1993; Riegl 1995). Active rejection includes polyp expansion, tentacular and cilliary movement, sediment ingestion and mucus formation. This mechanism is often used by scleractinian corals (Stafford-Smith 1993). Passive rejection relies on water movement and gravity to shed sediment and is used by alcyonacean corals (Riegl 1995). The effectiveness of the two strategies, active vs. passive, is dependent on the degree of turbulence in the reef zone and community composition. Many corals can tolerate exposure to short term sedimentation events, but extended exposure will eventually cause death of all colonies (Riegl and Branch 1995).

4.3.10. Disease/Pathogens/Viruses/Bacterias

One of the most important and least understood aspects of coral reef degradation is the relationship between coral disease incidence, effects on corals, and environmental conditions (Richardson 1998). There is an understanding of the relationship between thermal-induced bleaching for both coral and zooxanthellae physiologies (Fitt et al. 2001) due to the clear connection between coral bleaching and increased seawater temperature (Brown 1997). However, there is little known concerning the many diseases affecting corals (Richardson 1998).

Within the last 30 years, the number of coral diseases has increased from 2 to 18 (Sutherland et al. 2004). In the last decade, there has been a considerable increase in the number of different coral diseases described (Bruckner 2002; Sutherland et al. 2004). Of the 18 diseases described to date, 4 are reported globally: black band disease, white plague-like diseases, shut-down reaction, and skeletal anomalies; 9 are found exclusively in the Caribbean: white band Types I and II, white plague Types I, II, and III, aspergillosis, white pox, yellow blotch/band, dark spots; and 6 are endemic to the Indo-

Pacific: yellow band (YBD), skeleton eroding band, pink-line syndrome, fungal-protozoan syndrome, *Vibrio shiloi*-induced bleaching, and *Vibrio coralliilyticus*-induced bleaching and disease (Sutherland et al. 2004). However, there is a lack of knowledge about the causative agents of many diseases affecting corals (Richardson 1998).

New diseases are responsible for significant mortality in many coral species (Sutherland et al. 2004). Many hypotheses have been proposed to explain the decline of coral reefs, but none adequately explain the lack of recovery or the wide distribution of coral diseases (Garrison et al. 2003). Elevated temperatures and transport of aeolian dust from Saharan Africa, leading to a decline in water quality, have been proposed as potential causal agents of coral disease (Harvell et al. 2002; Garrison et al. 2003). It has also been suggested that transmission of pathogens by predators can exacerbate disease outbreaks among remnant populations (Williams and Miller 2005). However, studies to date have been hampered by the multitude of confounding factors such as lack of experimental studies and limited knowledge about reservoirs and modes of disease transmission (Harvell et al. 2002; Sutherland et al. 2004).

Hundreds of millions of tons of dust transported annually from Africa and Asia to the Americas may be adversely affecting coral reef ecosystems by carrying microorganisms (bacteria, viruses, and fungi), macro- and micronutrients, trace metals, and organic contaminants which are deposited into the oceans (Shinn et al. 2000; Ryan 2001; Griffin et al. 2002; Garrison et al. 2003). Linking components of the dust to specific diseases is a difficult task, and proponents of the dust hypothesis have had to rely on circumstantial evidence (Ryan 2001).

It is now known that some coral diseases are associated with high water temperature: black band disease (Kuta and Richardson 2002), plague (Richardson et al.

1998), dark spots disease (Borger 2005), and yellow blotch/band disease (Cervino et al. 2004a, Cervino et al. 2004b). One syndrome currently affecting many corals is dark spots syndrome or "dark spots disease" (Borger 2005). A study conducted by Borger (2005) performed long-term monitoring of affected colonies over time. Findings showed that the presence of dark spots syndrome is a stress response to elevated water temperatures (Borger 2005). Cervino et al. (2004b) investigated the factors leading to yellow blotch/band disease which affects the major reef-building Caribbean corals *Montastrea* spp. Elevated water temperatures increased the rate of YBD spreading and induced greater coral mortality (Cervino et al. 2004b). Furthermore, YBD did not produce the same physiological response observed in corals undergoing temperature-related bleaching (Cervino et al. 2004b).

Members of the genus *Vibrio* are common marine bacteria (Cervino et al. 2004b). A member of this genus, *Vibrio coralyticus* was isolated for study by Ben-Haim and Rosenberg (2002). *Vibrio coralyticus* was determined to be a temperature-dependent bacterial pathogen of the coral *Pocillopora damicornis* and caused rapid destruction of coral tissue within 2 weeks of exposure (Ben-Haim and Rosenberg 2002). Direct contact between infected tissue and healthy corals caused transmission of the disease, demonstrating its infectious nature (Ben-Haim and Rosenberg 2002).

Marine virology has been transformed in recent years following the discovery of their overwhelming presence in seawater, so it is surprising that they have not been implicated in coral disease, coral bleaching events or general coral reef health (e.g., Harvell et al. 1999). Wilson et al. (2005) investigated virus-like particles in stressed and non-stressed corals and found that elevated temperatures increases virus abundance. In 1995, a virulent disease, called white plague type II, killed up to 38% of *Dichocoenia* *stokesi* colonies in the Florida Keys (Richardson et al. 1998). Since then, this disease has spread throughout the Caribbean and affected most coral species (Nugues 2002). Nugues et al. (2004) found the green calcareous alga *Halimeda opuntia* present at the origin of infection on coral colonies in the Netherlands Antilles. Nugues et al. (2004) investigated the link between the presence of *Halimeda* and white plague incidence and found that physical contact to the macroalga can trigger the white plague disease and suggested that this connection could account for the elevated incidence of coral over the past decades. *Halimeda* is one of several genera of macroalgae that has increased in abundance in the Caribbean over the last 2 decades (Hughes 1994).

Coral disease is becoming more widespread but knowledge of its reservoirs, transmission, pathogenesis, and epizootiology remains limited (Sutherland et al. 2004). An inability to identify most causative agents and a lack of standard epidemiological data for diseased populations limits the ability of researchers to identify host-pathogen interactions, analyze changes in disease dynamics, and assess the impact of diseases on host populations and associated communities in the oceans (Harvell et al. 1999).

5. POTENTIAL SOURCES

5.1. Overview

In order to determine which of the identified pollutants are actually or potentially present in the coastal waters of southeast Florida, probable sources were identified for investigation. The potential sources included: wastewater outfalls, inlets, coastal ocean processes/seasonal upwelling, submarine groundwater discharge, effects of Everglades restoration, and carbon dioxide rise. Information gathered in the grey literature included: monitoring reports, reef-related studies, hydrodynamic studies, water quality studies, geochemical cycling studies, hydrogeology studies and permit reviews. After potential sources were identified, available information was gathered to determine the presence and/or concentrations of pollutants affecting southeast Florida coral reef communities in coastal waters.

5.2. Potential Sources General Findings

5.2.1. Outfalls

The four methods of effluent disposal in Florida are: ocean outfalls, surface discharges, deep well injection, and reuse (Bloetscher and Gokgoz 2001). A common practice of coastal cities is the use of ocean outfalls for disposal of domestic and industrial effluents (Huang et al. 1994). In Florida there are six open ocean outfalls spanning Dade, Broward, and Palm Beach counties as shown in Figure 1 (Bloetscher and Gokgoz 2001). Table 1 shows characteristics for the six outfalls. Ocean outfall use requires secondary treatment of the effluent (Bloetscher and Gokgoz 2001). This involves the removal of biodegradable organics (CBOD) and suspended solids through activated sludge processes, fixed film reactors, extended aeration, or modifications/combinations of these (Bloetscher and Gokgoz 2001). As stated in the Florida Administrative Code, secondary treatment of water for release from outfalls must achieve an effluent discharge of no more than 30 mg/L CBOD and 30 mg/L total suspended solids (TSS) or 85% removal of these pollutants from the influent, whichever is more stringent (Bloetscher and Gokgoz 2001).

Initial dilution is an important characteristic in outfall design and environment impact assessment of effluent discharges (Proni et al. 1994). Environmental factors affecting initial dilution include parameters such as: currents, water depth above discharge, and density stratification (Huang et al. 1994). Effluent parameters affecting initial dilution include: effluent discharge rate, effluent density, and outfall outlet (diffuser) geometry (Huang et al. 1994). For both economic feasibility and marine environmental protection, it is essential to develop realistic initial dilution design criteria for water quality management (Huang et al. 1994). Huang et al. (1994) propose a probabilistic approach to initial dilution from field data for the Hollywood and Miami-Central outfalls. This approach is presented as an improvement to the "worst case approach" where each factor affecting the initial dilution is taken at the worst 10 percentile on cumulative frequency distributions (Huang et al. 1994). The advantage of the probabilistic approach is that the statistics of initial dilution can be obtained so that the exposure risk level can be estimated from the cumulative probability of initial dilution, and outfall design criteria or water quality standards for initial dilutions can be set statistically (Huang et al. 1994).

The Southeast Florida Ocean Outfall Experiment (SEFLOE) studies were initiated in the early 1990's. These studies provided a significant amount of information concerning the mixing, dispersion, and dilution of wastewater plumes originating from the six southeast Florida ocean outfalls. The SEFLOE I study focused on characterizing initial and farfield dilution properties on ocean outfall plumes using acoustical backscatter techniques, determining the nutrient and bacterial content of the effluent and receiving waters, characterizing marine conditions, and evaluating concerns about nondegradable substances in the discharged treated effluent. Physical, chemical, and biological data were collected during the project and these data were used to characterize the outfall plumes and current environmental conditions. The SEFLOE II study continued to improve understanding of year-round physical oceanographic conditions at four ocean outfalls off southeast Florida (Miami-Dade Central, Miami-Dade North, Hollywood, and Broward). These outfalls discharge secondary treated domestic sewage (Carr et al. 2000). Both the Miami-Dade Central and Miami-Dade North outfalls have multi-port diffusers as shown in Table 5-1, while the Hollywood and Broward outfalls have single port outlets (Carr et al. 2000). This study aimed to define rapid dilution and mixing zones through modeling of near-field and farfield conditions to determine if the outfalls were contributing to unreasonable degradation of the local marine environment (Carr et al. 2000). Monitoring of nutrient concentrations in the effluent plumes was performed along with examination of the toxic characteristics of the receiving water/effluent mixture with and without chlorination, as well as measurements of the diluted wastewater to determine if it met water-quality standards for priority pollutants, bacteria, oil, and grease (EPA 2003). Plant effluents were analyzed for 126 priority pollutants and findings showed that the outfalls are "environmentally acceptable" and "create no unreasonable degradation" to the marine environment in southeast Florida based on the fact that none of the pollutants detected exceeded the acute toxicity criteria listed under the State of Florida Maximum Allowable Effluent Level (Carr et al. 2000).

The southeast Florida outfalls discharge along the western boundary of the Florida Current. This is a fast-flowing current with maximum speeds occurring in the Florida

Strait between southeast Florida and the Bahamas, in the vicinity of the southeast Florida outfalls. Maximum current speeds measured at the outfall sites during the SEFLOE studies were measured to be 60 to 70 centimeters per second; the speed and strength of the Florida Current causes effluent plumes to be rapidly dispursed (Huang et al. 1998; EPA 2003). From the SEFLOE studies, three mixing zone models were developed and are currently available for analysis of outfall mixing: CORMIX, PLUMES, and OMZA (Huang et al. 1998). Huang et al. (1998) evaluated these models using field data of the Hollywood and Miami-Dade Central outfalls obtained during the SEFLOE II project. Both nearfield and farfield (up to 800 m range from outfall) measurements were derived from dye and salinity studies. Findings showed reasonable agreement with field data for initial dilution predictions from all three models (Huang et al. 1998). Farfield predictions for dye concentrations from the three models were not consistent and only OMZA predictions showed good agreement with field data (Huang et al. 1998).

Iverson and Corcoran (1976) performed an off-shore environmental study in Broward County to investigate whether secondary treated effluent released by the outfalls was degrading the environment and whether this treatment should be upgraded to the level of advanced wastewater treatment. Findings showed that the presence of other sources of pollution (i.e. coastal runoff, fuel from vessels, boats without sewage holding tanks) around the outfalls made it difficult to measure the sole effect of the effluent. Improvements in the current methods could be made to remedy this problem. Overall conclusions were that some environmental degradation was present, however, the ecology of the area was healthy. Evidence showed that high levels of chemical pollutants in the water column were not solely the result of outfall effluent but also boat pollution and coastal runoff. Secondary treatment of sewage was adequate even at high levels of effluent flow and reduced current. However, environmental damage may result if the level of effluent flow is increased dramatically and the current flow is also greatly reduced at the same time.

An environmental assessment conducted by Fisher (1980) was performed to determine if the presence of the North Broward (Pompano) outfall and its discharge has had any effect on the physical conditions of the surrounding environment. Nine sites were tested around the terminus of the outfall pipe with one site acting as the control. Analysis of grain size distribution was done to determine if bottom sediment consistency had remained the unchanged. Sediment analysis was performed to look for the presence of selected trace metals, pesticides, and PCB's attributed to the discharge. Results of the grain size distribution analysis showed no significant difference between the control site and the outfall site. The chemical analysis of bottom sediments showed no pesticides or PCB's above the detection limits. Comparison of chemical analyses of the study in 1980 with one performed in 1978-79 shows slight increases for cadmium, chromium, lead, zinc, and nickel with no change or decreases for copper, iron and all chlorinated hydrocarbons. Chromium showed a significant decrease at the terminus of the outfall, lead at the terminus is twice the amount of other sites surrounding the terminus, and nickel showed a high concentration at the easternmost and deepest site. Overall, no changes had occurred in the consistency of bottom sediments between control and outfall samples. Differences (positive or negative) observed for the trace metals, pesticides, and PCB's may or may not have been real; the variability may occur naturally in the sediment. No visual changes in the outfall environment were observed.

The Broward County Environmental Quality Control Board (1981) produced an annual update on the environmental assessment of the north and south regional wastewater outfalls in Broward County. This annual update discussed two wastewater treatment plants in Broward County: the North Regional Wastewater Treatment Plant, with discharge out of the Pompano outfall; and the South Regional Wastewater Treatment Plant, with discharge out the Hollywood outfall. A study was conducted to determine if the effluent from these outfalls had effects on the physical conditions of the surrounding environment through visual diver observation, bivalve collection, and photographic documentation. Six sites were studied for three experimental areas and three "control" areas. Control areas were considered areas not under the direct influence of an outfall discharge. Bivalves were collected and examined for the presence of zinc, cadmium, PCB's and pesticides. Examination the bivalve tissue samples for pesticides and PCB's contained less than the minimum detection limits in all cases. The minimum detection limit for cadmium was 0.25 mg/kg. Seven of the 24 samples were reported as less than the detection limit for cadmium while the remained of samples were above the minimum detection limit. Statistical analysis showed site 3 (onshore, south side of North Regional Discharge outfall) to have a significantly greater mean zinc value than the other sites. Site 4 (offshore, ~3 miles south of the Pompano outfall) had a significantly higher mean cadmium value than the other sites. Since site 3 was close to the Hillsboro inlet it was presumably under a greater influence from land runoff and tidal exchange and this could have been the reason for the zinc content. Overall, one sample from each site resulted in no detection of pesticides of PCB's. Examination of four samples from each of the six sites for zinc and cadmium showed that bivalves from the shoal area south of the Hillsboro Inlet had significantly higher zinc content and animals from the third reef due west of Commercial Blvd. contained significantly higher amounts of cadmium. The results implied that urban runoff is the probable source of these measured differences.

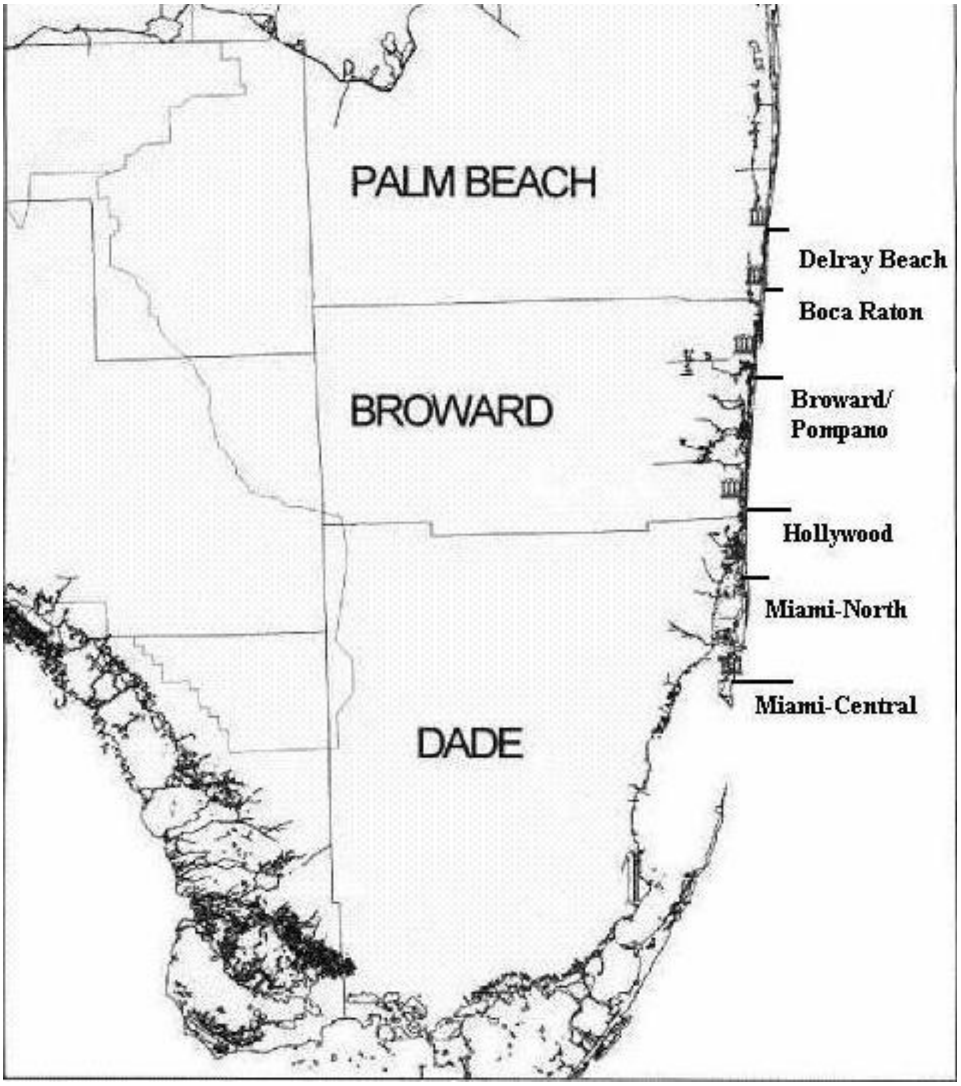
The six wastewater treatment plants that discharge effluent through their associated outfalls (Miami Central, Miami North, Hollywood, Broward/Pompano, Boca Raton, and Delray) are required to measure and report a number of parameters to the Florida Department of Environmental Protection (FDEP) as a part of their individual National Pollutant Elimination System (NPDES) permits. The data presented below span a 5 year period, January 2000 to August 2005 (obtained from the Florida Department of Environmental Protection (FDEP) Linda Horne and Lisa Self per. comm. 2006). The wastewater treatment plants were required to take water samples from the effluent before it entered the outfall pipe and report on a variety and sometimes dissimilar set of parameters depending on their individual permit requirements. However, all plants did sample and report total nitrogen (TN) and total phosphorus (TP) concentrations in plant effluent. TN and TP values were obtained from composite effluent samples collected over a 24 hour period once a month from each of the plants. Treatment facilities were not required to sample end of pipe discharges nor the ocean water near the outfalls during this time period (2000-2005). There were no additional sampling requirements and numeric limits have not yet been established for maximum allowable concentrations of nutrients in the effluent exiting the wastewater treatment plants. The US EPA does provide technical guidance on nutrient criteria for estuarine and coastal marine waters to the states, but it is up to each state to develop its own water quality standards for these parameters (United States Environmental Protection Agency 2001). The FDEP has set up a Nutrient Criteria Technical Advisory Committee which is presently working on establishing criteria for fresh water systems. Coastal and marine criteria will be established after freshwater criteria have been developed. (http://www.dep.state.fl.us/water/wqssp/nutrients/index.htm, Kevin Carter Broward County's Environmental Protection Department (BC EPD) per. comm. 2006).

Flow rates were measured on a continuous basis and reported to the FDEP as a monthly average flow. Flow rates varied over time as well as between the six plants (Fig. 2). The lowest flows were at the two most northerly plants, Delray and Boca Raton, with flow rates between ~ 15-22 million gallons/day (MGD). The two Broward County treatment plants had intermediate flows which varied between 20 to 45 MGD. The Miami-Dade treatment plants had the highest and most variable monthly flows rates. Flows ranged ~62 MGD to over 150 MGD.

A comparison of average monthly flow and total N and P concentrations in effluent samples collected at each of the plants did not show any clear relationship between flow rate and nutrient levels (Fig. 3a and b). (Please note that on 08/31/00, a TN value of 193 mg/l was measured at the Boca Raton facility and on 09/30/00, a TP value of 54 mg/l was also measured at the Boca Raton plant. These two values are noted but not shown on figures 3-6 as they appear to be anomalous). A comparison of TN and TP concentrations between the different facilities suggests median TN values in the effluent from the six facilities were similar, ranging from 16.17 mg/l to 18.45 mg/l. Median TP values were more variable, ranging from 0.7 mg/l at the Boca Raton facility to a high of 1.68 mg/l at the Miami North plant. The data suggests that flow (MGD) will likely be an important consideration when estimating the mass loads for these facilities (Fig. 4a and b).

Mass load estimates for total nitrogen and phosphorus were calculated using treatment plant effluent concentrations and average monthly flow rates from each of the six plants Mass Load Estimate = Flow (MGD) x Concentration of TN or TP (mg/l) x Conversion Factor. The conversion factor = 8.64 (lb/gal) (United States Environmental Protection Agency 1998; Mississippi River/Gulf of MexicoWatershed Nutrient Task Force 2001).

These mass load estimates are discharge loads and not equivalent to loads delivered to the reefs offshore SE Florida. Physical and biological processes will strongly impact loading levels as the effluent travels through and exits the outfalls and mixes with the surrounding sea water. To establish delivered loads, delivery factors need to be applied to the discharged load in order to assess attenuation factors as loads mix into the local environment (United States Environmental Protection Agency 1998; Mississippi River/Gulf of MexicoWatershed Nutrient Task Force 2001). Mass load estimates for both the Miami Central and Miami North facilities appear to be consistently higher than the other four plants (Fig. 5a and b). Mass load estimates varied over time with no obvious pattern for these two facilities. A more detailed examination of mass load estimates from the 4 other facilities (Delray, Boca Raton, Broward/Pompano, and Hollywood) suggests that in general, that mass load estimates for both TN and TP were higher at the two Broward facilities compared to the Delray and Boca Raton plants, though the data is variable (Fig. 6a and b). No clear trends in TN load estimates were apparent at any of the plants (Fig. 6a). TP mass load estimates for the two Broward facilities appeared to increase with time over the last several months of 2005, however, there is a gap in the data between September 2000 and March 2003 (Fig. 6b). Mass load estimates from the Delray and Boca Raton facilities were somewhat variable but typically had the lowest loadings of the six facilities. No discernible trends were noted for either TN or TP load estimates for these facilities (Fig. 6a and b).



Map taken from Christie (1997) with revisions. Distance of outfall pipes from shore is not to scale.

Figure 1: Map of Southeast Florida Ocean Outfalls

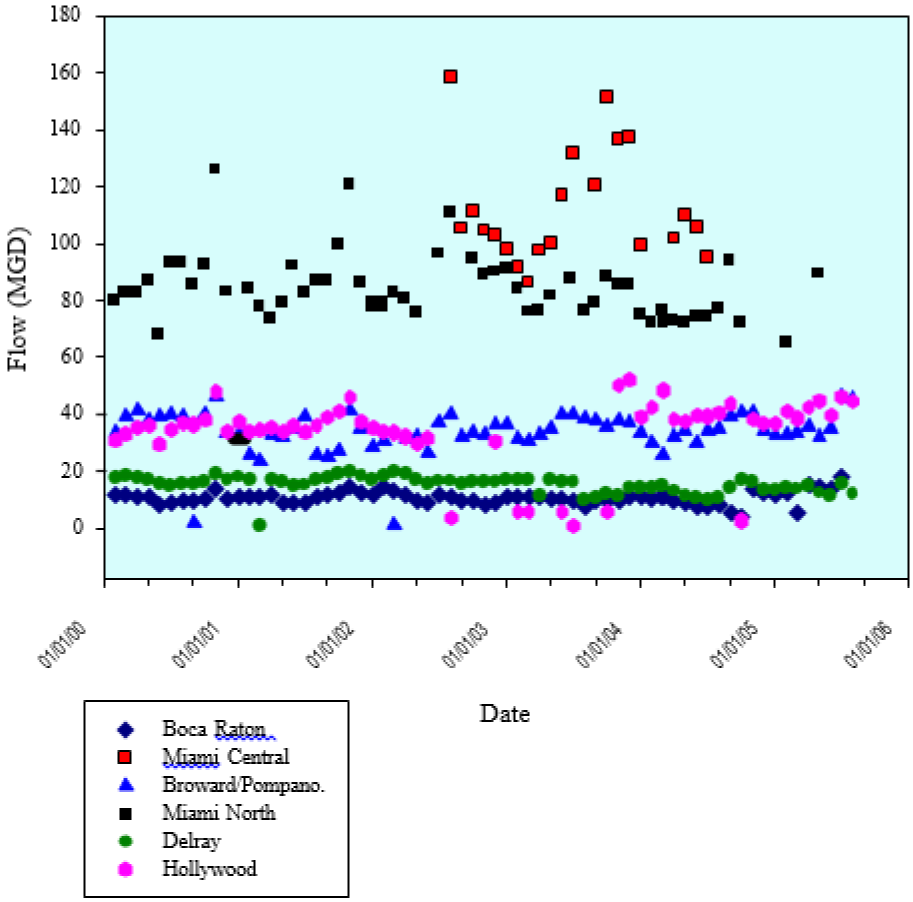
Table 1: Characteristics of Southeast Florida Ocean Outfalls

Characteristics	**Miami-Dade Central**	**Miami-Dade North**	**Hollywood**	**Broward (Pompano)**	**Boca Raton**	**Delray Beach**
Outfall Pipe: Distance (ft)	18971	11091	100987	7052	5016	5297
Off Shore (m)	5730	3350	3050	2130	1515	1600
Discharge depth (m)	28.2	29.0	28.5	32.5	29.0	29.0
S-Single Port M-Multiport	M	M	S	S	S	S
Number of ports	5	12	1	1	1	1
Diameter of ports (m)	1.22	0.61	1.52	1.37	0.76	n/a
Spacing of ports (m)	9.8	12.2	0	0	0	0
Port orientation	vertical	horizontal	horizontal	horizontal	n/a	n/a
Permitted Discharge Capacity	143 MGD	112.5 MGD	47.5 MGD*	66 MGD	17.5 MGD	24.0 MGD

* Combined permitted flow for Hollywood, Cooper City, and Davie WWTP's

Table represents data from the following: (Proni et al. 1994; Christie 1997; Huang et al. 1998; EPA 2003; Fergen et al. 2004)

Figure 2: Effluent flow rates over a 5 year period, (2000-2005) from each of the six wastewater facilities that discharge effluent through ocean outfalls off the coast of southeast Florida



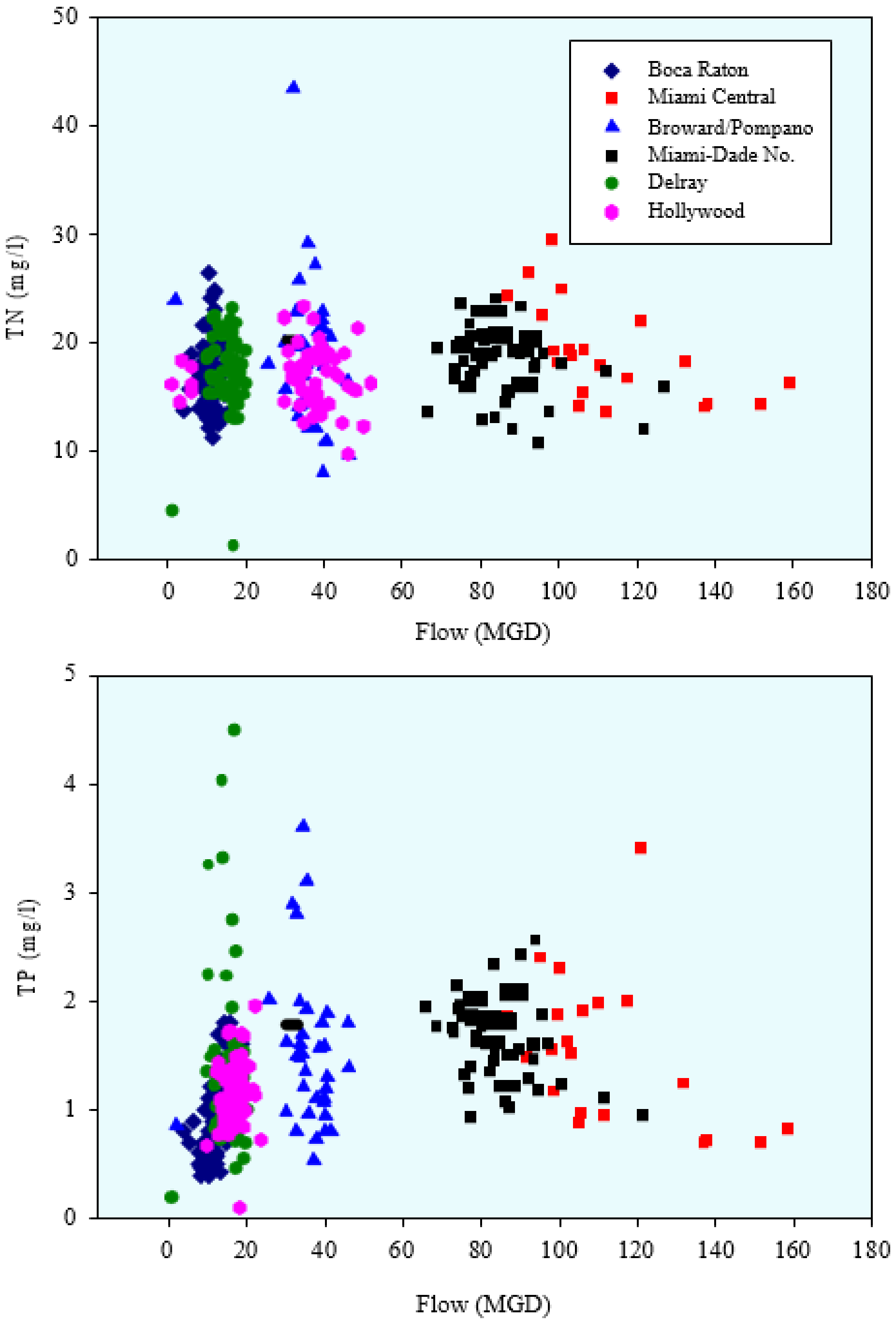


Figure 3a and b: Total nitrogen (TN) and total phosphorus (TP) concentrations as a function of flow rates from the 6 wastewater treatment facilities. The legend is the same for both plots.

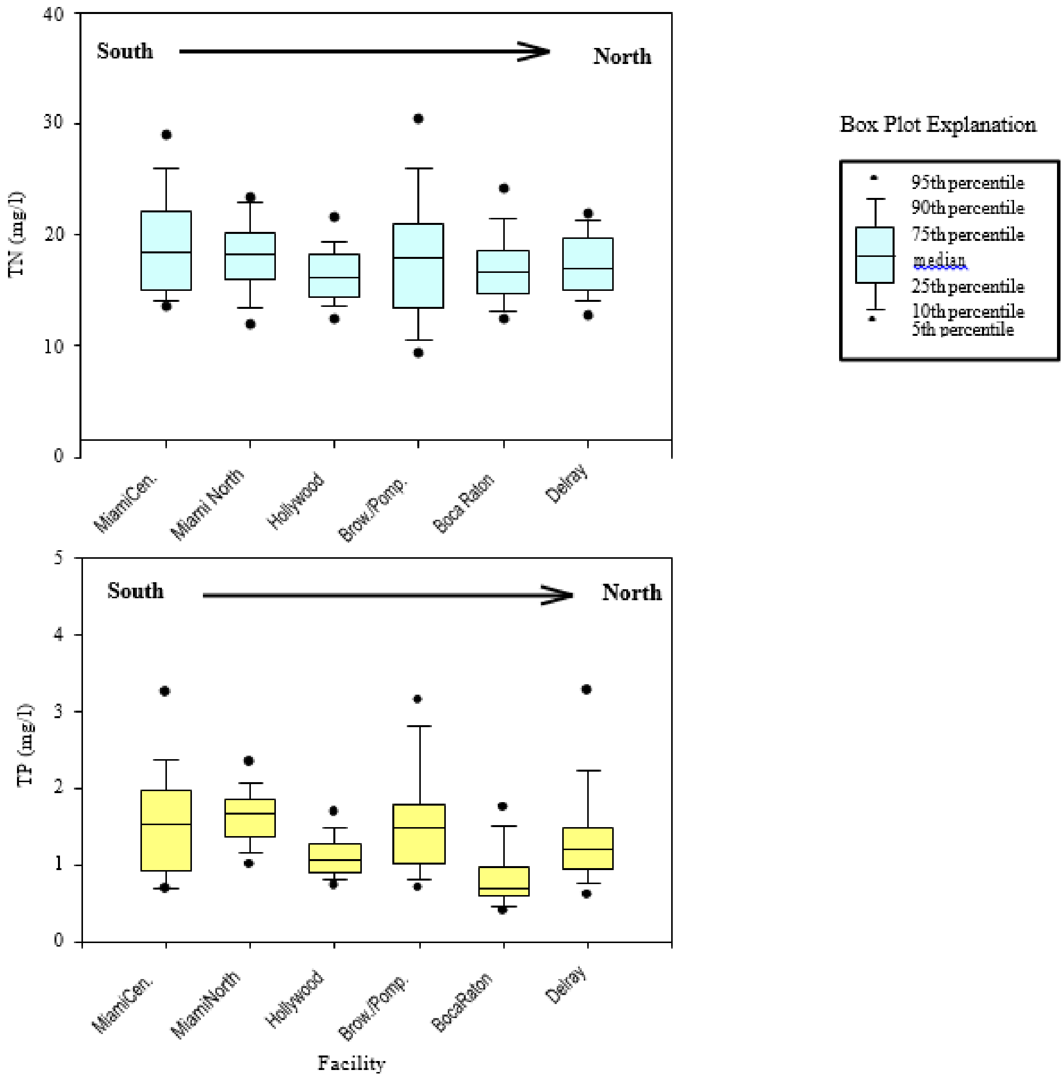


Figure 4a and b: Total nitrogen (TN) and total phosphorus (TP) concentrations (mg/l) for the six wastewater facilities discharging effluent through the ocean outfalls. January 2000 thru August 2005.

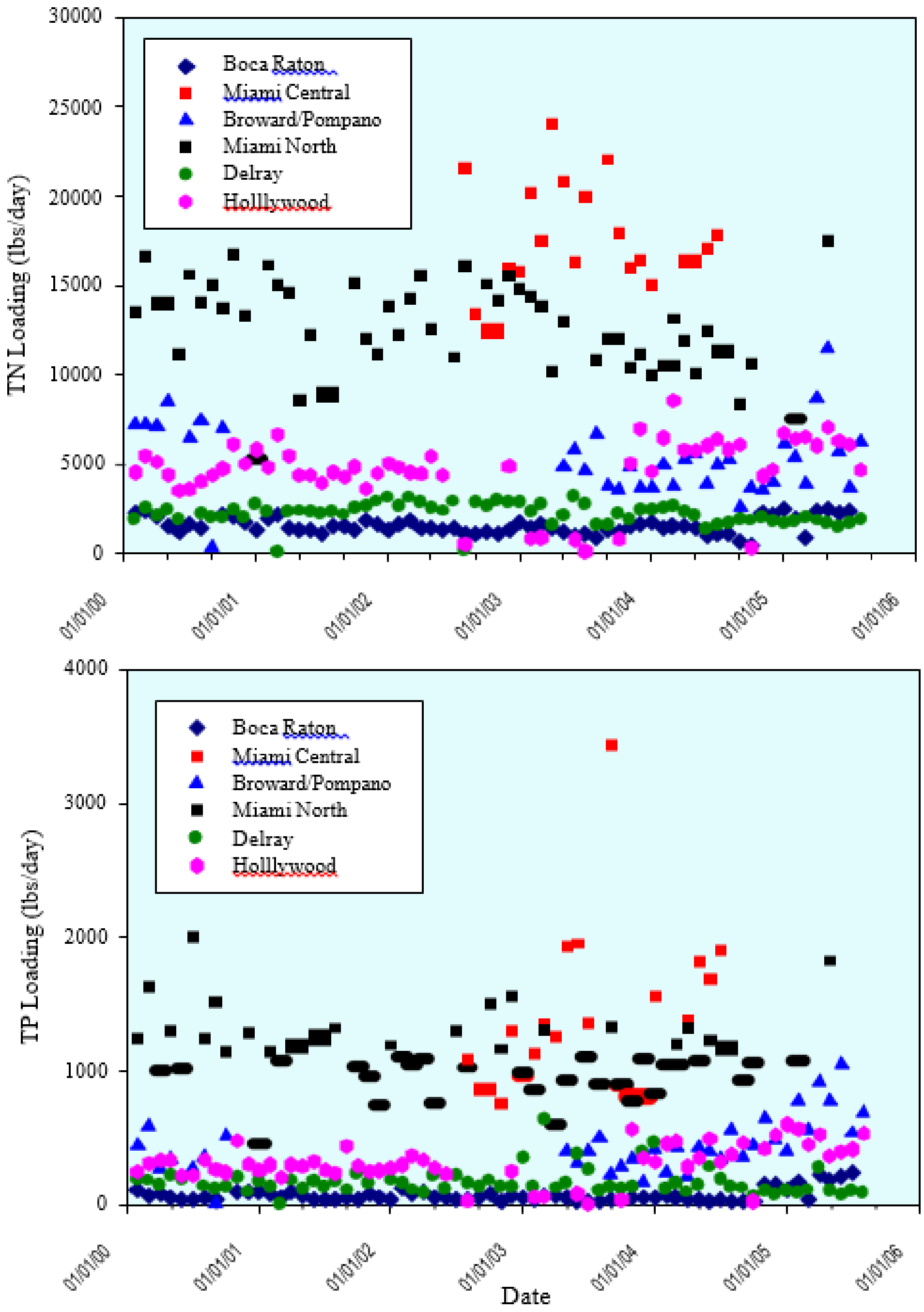


Figure 5a and b: Mass load estimates for total nitrogen (TN) and total phosphorus (TP) were calculated from TN and TP concentrations in effluent collected at each facility prior to the effluent being discharged through the outfalls of the six wastewater treatment facilities. These mass load estimates are discharge loads from the facilities and should not be considered delivery loads to the coral reefs off SE Florida. The two Miami-Dade facilities had consistently higher discharge loads compared to the four other facilities. Please note a TN concentration of 193 mg/l on 08/31/00, and a TP value of 54 mg/l measured 09/30/00 at the Boca Raton plant were not used to calculate the loadings in Figures 5 and 6 as they appear to be anomalous.

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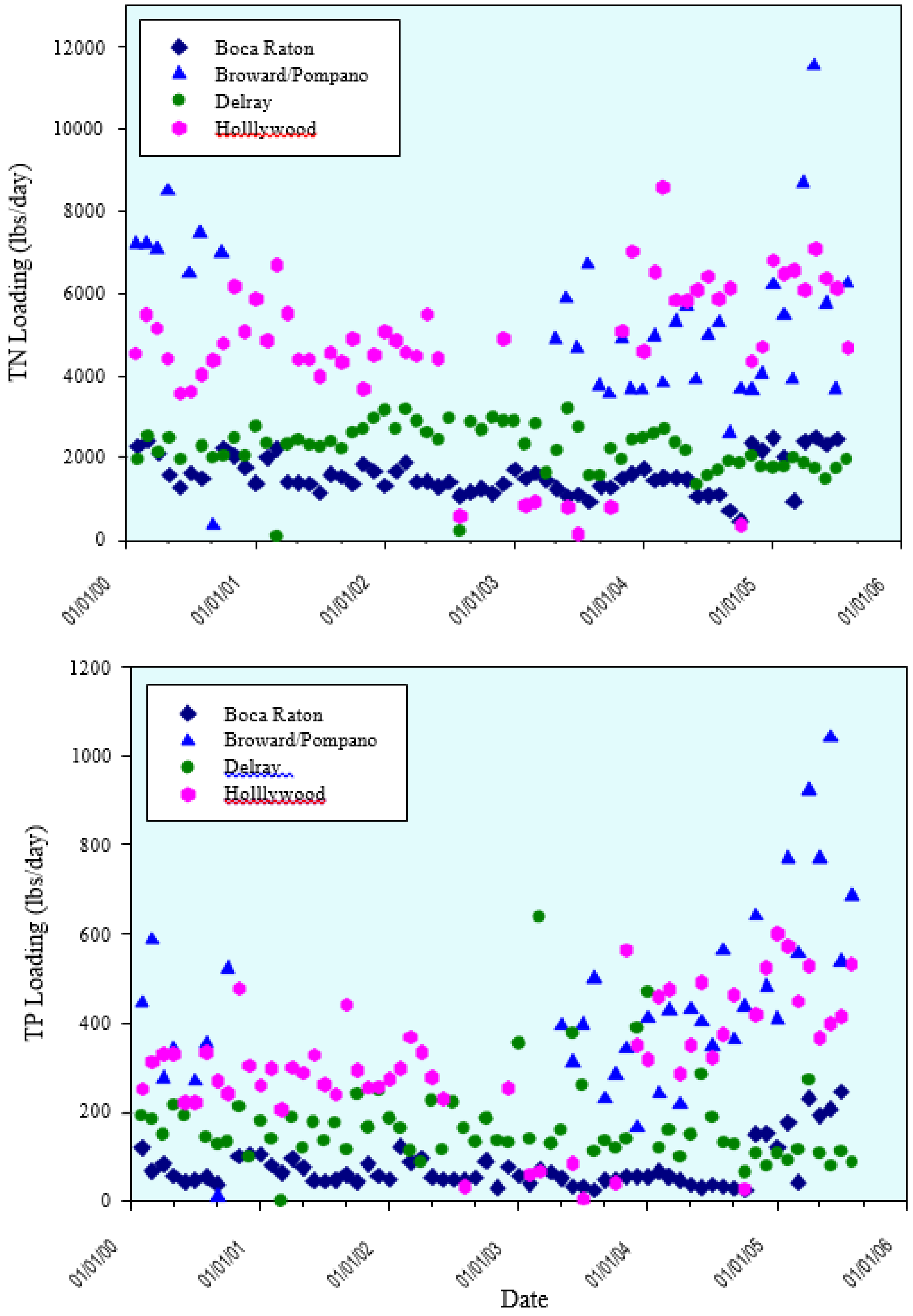
Figure 6 and b: Mass load estimates for total nitrogen (TN) and total phosphorus (TP) from the Hollywood, Broward/Pompano, Boca Raton and Delray facilities only.



5.2.2. Inlets

Inlets located within our area of study include: Jupiter, Lake Worth, Boynton, Boca Raton, and Hillsboro Inlets; Port Everglades, and Port of Miami as shown in Figure 7. Inlets are an important component to water dynamics in southeast Florida, however, there is a lack of detailed information on the hydrodynamic regimes as well as the composition of the waters moving through them.

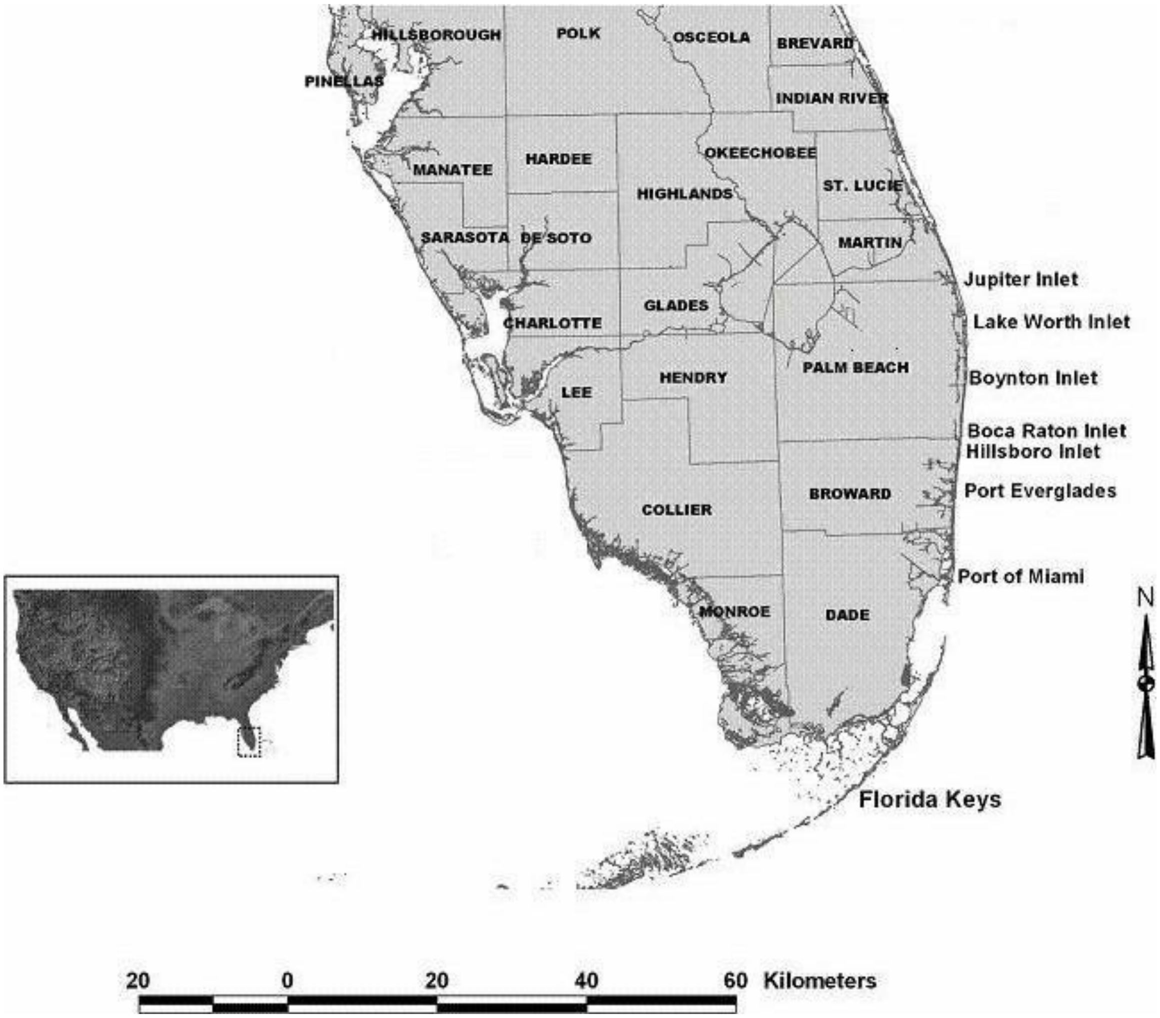
Broward County's Environmental Protection Department (BC EPD) does have some data on the chemical, biological and physical characteristics of surface waters entering two of the inlets; Port Everglades and the Hillsboro Inlet. BC EPD has maintained a surface water quality network since 1972. This network contains sites located within the primary freshwater canals, remnant major rivers and the Intercoastal Waterway (ICW) as shown in Figure 8. The initial impetus for establishing this surface water quality monitoring network was to monitor the effects of discharging effluent from wastewater treatment plants into these waterways. Direct discharge of effluent into surface waters stopped in 1988 so emphasis shifted to identifying ambient water quality conditions (Broward County Department of Planning and Environmental Protection 2001). Sites are sampled on a quarterly basis and since 1992 the following parameters have been sampled: nutrients, bacteria, chlorophyll *a*, total organic carbon, dissolved oxygen (DO), pH, temperature, and specific conductivity. Data from all ambient sites is entered into the State and National Storet databases. A detailed report on surface water quality in Broward County from 1972 through 1997 can be found in the "Broward County, Florida Historical Atlas: 1972-1997 Technical Report TR: 01-03. The atlas is now being updated by the BC EPD to include data collected since 1997.

The following research provides examples of work being done on inlets along the east coast of Florida. Tidal inlets and bays behind them are subject to a wide range of forces that create unique hydrodynamic conditions. Understanding of sedimentation and scour patterns within inlets can be improved by resolving circulation patterns; for instance, tidal motion will dominate the flow of an inlet (Militello and Zarillo 2000). Militello and Zarillo (2000) investigated tidal motion and inlet processes in Ponce de Leon Inlet by field measurements and a depth-integrated hydrodynamic numerical model. Water level and current were measured at six locations spanning the ebb shoal, inlet, and bay channels. Findings revealed the inlet was flood dominated (Militello and Zarillo 2000).

The Indian River Lagoon (IRL) system extends from Ponce de Leon Inlet to Jupiter Inlet is comprised of three interconnected estuarine lagoons: the Mosquito Lagoon, the Banana River Lagoon, and the Indian River Lagoon (subdivided into north and south regions) (Sigua et al. 2000). The IRL system is a biogeographic transition zone rich in habitats and high species diversity (Sigua et al. 2000). It receives inputs of salt water from the ocean through inlets and fresh water from direct precipitation, groundwater seepage, surface runoff, and discharges from creeks and streams (Sigua et al. 2000). Sigua et al. (2000) describe site-specific differences and temporal variability of water quality and nutrient loading distributions at various segments of the IRL system. The authors determined that long-term monitoring of living resources, sediments, and surface water quality in the IRL is useful information to resource managers and decision-makers. Overall recommendations were: (1) to develop water quality management priorities and plans that direct pollution control resources toward point and non-point sources; and (2) implement water quality management programs such as establishing limits for point and non-point sources (Sigua et al. 2000).

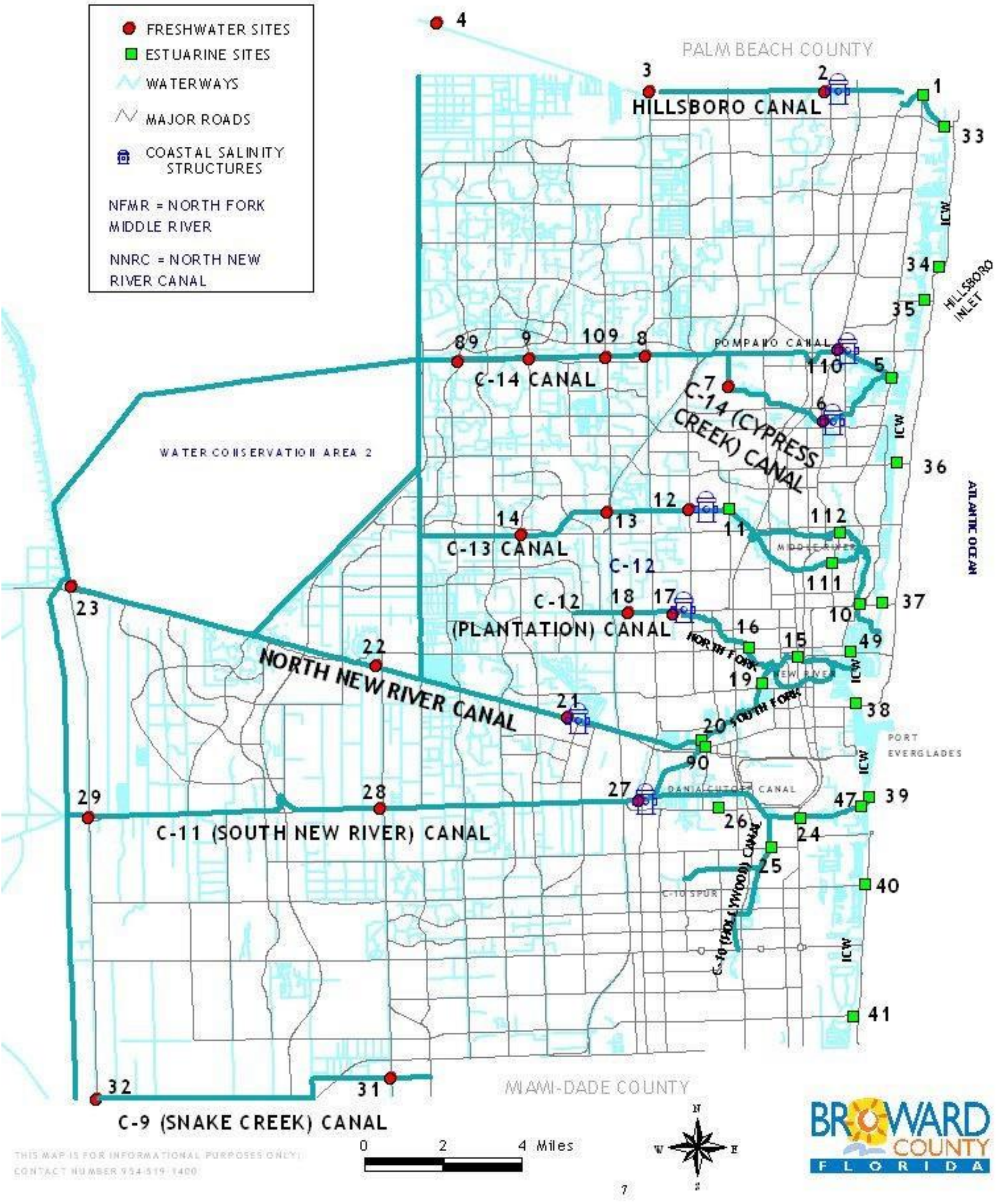
South Florida, particularly Biscayne Bay and the Ten Thousand Islands are considered to have some of the most unique estuarine areas on the United States (Macauley et al. 2002). Over this century, the South Florida ecosystem has been subjected to loss of wetland acreage, expansion of agricultural and urban areas, and wide- spread runoff control through canals and flood control gates (Macauley et al. 2002). The climate and geographical location of South Florida makes it a desirable area for human population; with an expected increase to 8 million people by 2010 (Macauley et al. 2002). The estuarine system of South Florida includes mangrove fringes, barrier islands, shallow bays, and large embayments (e.g. Tampa, Biscayne, and Florida Bays) (Macauley et al. 2002). Each system supports a unique plant and animal community that can potentially be impacted by anthropogenic materials transported from inland activities (Macauley et al. 2002).

Figure 7: Map of Southeast Florida Inlets



Map taken from Finkl and Charlier (2003) with revisions.

Figure 8: Map of Broward County's surface water quality network



5.2.3. Coastal Ocean Processes/Seasonal Upwelling

The coastal region along with its adjacent waters represent a dynamic system subject to complex and interlinked processes, including currents, mixing, eddies, tidal bores, upwelling events, and atmospheric deposition (Jahnke et al. 2002). Ekman transport, tidal jets, nearshore winds, and internal tidal bores are all processes that can result in upwelling (Leichter and Miller 1999). No studies were found that specifically focused on coastal processes in southeast Florida, however, the following studies were completed in nearby regions and have applications to local systems. Jahnke et al. (2002) estimate that approximately 90% of the nutrient input to the South Atlantic Bight region comes from upwelling events caused by the Gulf Stream current. High frequency upwelling near Conch Reef in the Florida Keys is influenced by the meandering Florida Current (Leichter and Miller 1999). The authors suggested that these upwelling events are a key source of nutrients and suspended particulate matter to the reef. Upwelling also delivers colder water to the surface and can cause temperature stress to coral (Leichter and Miller 1999).

Internal tidal bores, caused by breaking of internal waves, are also typical of coastal systems (Leichter et al. 1996 and 2003). Internal tidal bores cause striking and recurrent variations in nutrient concentrations, temperature and salinity to Conch Reef (Leichter et al. 1996 and 2003). Physical forcing of subthermocline waters is likely to deliver elevated concentrations of N and P which may contribute to phase shifts and algal dominance (Leichter et al. 1996 and 2003).

Atmospheric deposition occurs when pollutants in the air fall on the land on in the water. Air pollution can be deposition into water bodies either directly from the air onto the surface of the water, or through indirect deposition where pollutants settle on land and are carried into a water body by runoff or through natural processes such as movement of groundwater through the soil. One source of atmospheric deposition pollution is African dust (Ryan 2001; Griffin et al. 2002; Garrison et al. 2003). African dust is lifted into the Earth's atmosphere every year carrying particles containing herbicides, pesticides, and a number of microorganisms (Griffin et al. 2002). Yet the potential impacts of African dust pollution on the marine and terrestrial environments remain unknown. Thus far, findings have been presented as a working hypothesis in need of further testing (Ryan 2001).

Due to the effects of coastal ocean processes, pollutants in coastal surface waters may persist near the shoreline instead of being transported offshore. Lagrangian mechanisms are responsible for chaotic mixing in turbulent flows and determine the spread of contaminants at the ocean's surface (Lekein et al. 2005). Lagrangian motion is highly dependent on the initial conditions (exact time and location) under which the contaminant is released (Lekein et al. 2005). Lekein et al. (2005) used very high frequency radar to locate Lagrangian coherent structures (LCS) which are hidden amongst the surface currents along the Hollywood, Florida coastline. The barrier point, where LCS intersects the coastline, can be used to minimize the effects of coastal pollution (Lekein et al. 2005). Lekein et al. (2005) introduced an automated prediction algorithm which determined that the impacts of releasing pollutants into the coastal area would be considerably reduced if they were released at a time when the Lagrangian coherent structures were south of the release site. This would allow contaminants to be promptly transported away from the coastal system, reducing the local effects of the pollutant (Lekein et al. 2005).

5.2.4. Submarine Groundwater Discharge

Burnett et al. (2003) defined submarine groundwater discharge (SGD) as "any and all flow of water on continental margins from the seabed to the coastal ocean regardless of fluid composition or driving force." Direct groundwater flow into the ocean occurs through springs and seeps in nearshore regions (Scientific Committee on Oceanic Research (SCOR) Land-Ocean Interactions in the Coastal Zone (LOICZ) 2004). Since SGD eventually ends up in the coastal ocean, any contaminant that is picked up along the way will ultimately become a marine pollution problem and may contribute to poor water quality and algal blooms (Corbett et al. 2001).

Studies have presented compelling evidence that direct groundwater flow to the ocean can be a significant source of nutrients in some areas (Scientific Committee on Oceanic Research (SCOR) Land-Ocean Interactions in the Coastal Zone (LOICZ) 2004). In areas with a shallow freshwater system, where sewage treatment systems are normally less than 1 meter above the water table, nutrients and bacteria are prone to leaching and can easily pollute the groundwater (Corbett et al. 2001). This may cause a marine contamination problem when the groundwater enters the coastal system (Corbett et al. 2001). There have been a limited number of studies that examine the effects of SGD in southeast Florida. Finkl and Charlier (2003) found that SGD causes an increase in nutrients to the Florida Reef Tract through the Biscayne Aquifer. Estimated nutrient fluxes from SGD to the Palm Beach coast were 5727 metric tons per year of phosphorus and 414 metric tons per year of nitrogen (Finkl and Charlier 2003). Corbett et al. (1999) also measured elevated nitrogen concentrations along the shoreline of Florida Bay, and suggested groundwater seepage as the source. Swarzenski et al. (2001) found nutrient concentrations to be 3-5 times higher in seepage water over the Indian River Lagoon, indicating that SGD is important to the coastal nutrient budget. Nutrients like N and P can operate as fertilizers to nutrient-poor surface waters (Corbett et al. 2001). However, if supplied in excess, these nutrients may degrade water quality and stimulate growth of harmful algal blooms (Corbett et al. 2001).

In an effort to quantify the input of nutrients from SGD, the Scientific Committee on Oceanic Research (SCOR) and the Land-Ocean Interactions in the Coastal Zone (LOICZ) Project of the International Geosphere-Biosphere Program (IGBP) have established a working group of experts to specifically examine groundwater discharge into the coastal zone (Scientific Committee on Oceanic Research (SCOR) Land-Ocean Interactions in the Coastal Zone (LOICZ) 2004). Much of the research is centered on determining groundwater flux estimates as well as flow and exchange with coastal systems through the use of radioactive or other tracer techniques. Groundwater concentrations of radioactive tracers are altered by interactions with seawater in coastal aquifers allowing researchers to determine SGD flux and differentiate groundwater from surface water (Paytan et al. 2006). Swarzenski et al. (2003) determined seepage rates into the IRL using isotope rations, nutrients, chloride concentrations, conductivity, pH, temperature, and dissolved oxygen levels. Seepage rates were between 3 and 100 ml/m^2/min during the dry season and 22-144 ml/m^2/min in the wet season (Swarzenski et al. 2001). The authors suggest that there may be a connection between increased rainfall and increased SGD (Swarzenski et al. 2001). Paul et al. (1996) used bacteriophages as tracers to determine that if wastewater were injected into a subsurface well near the Florida Keys, it would quickly mix with surface waters (within 10-53 hours) where it could then be transported to the reef system and may contribute to nitrification. Depending on the water table and hydraulic features of an area, SGD as a nutrient source can have highly localized to regional consequences (Paerl 1997).

5.2.5. *Effects of Everglades Restoration*

Approximately 40% of the water that originally flowed from Lake Okeechobee into the Florida Everglades is directly diverted into the Gulf of Mexico (Schaffranek 1999). The Comprehensive Everglades Restoration Plan (CERP) was designed to restore the flow of this freshwater to the Everglades and prevent it from being lost to tide (United States Army Corps of Engineers Jacksonville District, South Florida Water Management District 1999). The estimated time to complete CERP is more than 30 years and an associated cost is $7.8 billion (United States Army Corps of Engineers Jacksonville District, South Florida Water Management District 1999). Water quality criteria for the Everglades Protection Area (EPA) are specified by the Florida Administration Code (Weaver and Payne 2004). During a 2004 study, Weaver and Payne found evidence of fifteen pesticides, including atrazine, chlorpyrifos ethyl, and diazinon at inflows throughout the region. Dissolved oxygen was also identified as a concern, with levels below the recommended 5 mg/l (Weaver and Payne 2004). The authors suggested that dissolved oxygen in this area is depressed by nutrient enrichment possibly due to groundwater seepage.

The Everglades is an oligotrophic system; and even small increases in nutrient concentrations, especially phosphorus (P), can have significant deleterious effects on the ecosystem. These findings have led the Florida Department of Environmental Protection (FDEP) to suggest a total phosphorus (TP) criterion of 10 ug/l (Weaver and Payne 2004). Weaver and Payne (2004) determined TP concentrations during 2003 ranged from 14.8 ug/l near the northern inflow at Arthur R. Marshall Loxahatchee National Wildlife Refuge, to 4.6 ug/l at the southern end of the interior of the Everglades National Park. The authors suggested that this gradient is due to P rich runoff from the Everglades Agricultural Area in the northern portion of the system. Total nitrogen (TN) concentration exhibited a similar gradient to TP, with concentrations ranging from 0.9 2.2 ug/l in the north (Weaver and Payne 2004).

Recognition of the importance of phosphorus concentrations in controlling the ecosystem structure has led to the Everglades Nutrient Removal (ENR) project (Guardo 1999). The ENR project was developed to remove nutrients from agricultural and stormwater runoff before the water enters the South Florida region and the Everglades Protection Area (EPA) (Guardo 1999). The ENR project, which was designed by the South Florida Water Management District (SFWMD), mainly focused on the reduction of P (Guardo 1999). Treatment consists of exposing runoff water to emergent or submerged aquatic vegetation which apply natural biogeochemical processes to sequester nutrients, reducing the total outflow of P (Guardo 1999; Juston and DeBusk 2005).

The changes instituted by the CERP have altered the amount and composition of freshwater flowing through the Everglades, into the Florida Bay (Rudnick et al. 1999). A study by Lirman et al. (2003) indicated that increased delivery of freshwater and sediments from CERP could to cause a reduction in coral diversity, abundance and survivorship in Biscayne Bay. Results of a 26 year study off Broward County also indicated that there was significant correlation of growth with salinity. Analysis of growth bands showed increased freshwater input was correlated with decreased growth rates in stony coral (Dodge and Helmle 2003). Reefs off Broward County are especially affected because they are already located near the extreme northern end of their habitat range causing them to be more susceptible changing environmental conditions (Dodge and Helmle 2003).

Waters flowing out of the EPA are also enriched with nutrients (Rudnick et al. 1999; Porter and Porter 2002). In an effort to make certain that this water is of proper quantity and quality, state and federal authorities have developed and are implementing several projects as a part of the CERP. If not treated, increased quantities of nutrient rich fresh waters from the EPAs will be pumped into Florida Bay at the southern extent of the Everglades, and likely cause an increase in algal blooms and exacerbate already present ecological problems (Porter and Porter 2002).

5.2.6. Carbon Dioxide Rise

Rising atmospheric carbon dioxide (CO_2) concentrations are expected to lead to a significant global climatic change with fossil fuels as a major contributor to this increase (Tans et al. 1990). Dissolved inorganic carbon occurs in three basic forms: carbon dioxide ($CO_2 + H_2CO_3$), bicarbonate (HCO_{3-}), and carbonate ion (CO_3) (Kleypas et al. 1999). Under normal seawater conditions (pH 8.0 to 8.2), HCO_{3-} is roughly 6 to 10 times CO_3 (Kleypas et al. 1999). When CO_2 dissolves in seawater, less than 1% remains as CO_2 and most dissociates into HCO_{3-} and CO_3, and the acid formed by dissolution of CO_2 in seawater lowers the pH so that some CO_3 combines with H^+ to form HCO_{3-}; thus, the addition of fossil fuel CO_2 decreases CO_3 (Kleypas et al. 1999).

Organisms and ecosystems respond to their local environment without regard for the ultimate cause of environmental conditions (Smith and Buddemeier 1992). Understanding the global carbon cycle requires a better knowledge of carbon sinks and sources, but large uncertainties remain unknown (Tans et al. 1990). Often it is not possible to distinguish between the effects of climate change, natural environment variability, or anthropogenic alteration; effects may be interactive, or a single stress may have multiple sources (Smith and Buddemeier 1992). A major characteristic of coral reefs is the precipitation of substantial quantities of calcium carbonate from the overlying water which modifies the chemical balance of the local marine CO_2 system (Smith and Buddemeier 1992). Estimates of increased atmospheric carbon dioxide (CO_2) invasion into the upper ocean are modeled and discussed (Smith and Buddemeier 1992). There is still uncertainty on the quantity of CO_2 invasion into the ocean, however, it is reasonably well understood in comparison to other aspects of the global carbon budget (Broecker et al. 1979; Tans et al. 1990).

Despite the potential for a link between oceanic CO_2 composition and the process of calcification, there is limited information about the responses of reef organisms to changes in the carbonate saturation state (Smith and Buddemeier 1992). The partial pressure of CO_2 (pCO_2) increases in the atmosphere due to anthropogenic inputs of carbon dioxide (Reynaud et al. 2003). This has important consequences on the Earth's climate, including air temperature, which has risen by 0.6 °C between 1880 and 2000 (Houghton et al. 2001). Coral reef ecosystems are negatively affected by the increase of both temperature and pCO_2 (Reynaud et al. 2003). Increased temperature leads to the loss of zooxanthellae, or to a decrease in chlorophyll content per algal cell (Reynaud et al. 2003). Reynaud et al. (2003) found calcification decreased by 50% when temperature and pCO_2 were both elevated, but calcification under normal temperature did not change in response to an increased pCO_2.

As calcification decreases, the ability of reefs to keep up with rising sea level may diminish, skeletal density may decrease, and the mineralogy of calcifying organisms may shift toward the less soluble mineral phases (Smith and Buddemeier 1992). The aragonite saturation state decreases as a function of decreasing pH and it has been estimated that a doubling of the preindustrial pCO_2 could reduce tropical sea surface carbonate saturation levels to about two-thirds of present values (Smith and Buddemeier 1992). The fate of CO_2 in the coral reef ecosystem is subject to seasonal changes and the annual balance of CO_2 in such systems is uncertain (Bates 2002). The effect of a change in seawater on calcification has very important evolutionary and ecological consequences because carbonates vary over time and space (Marubini et al. 2003). Past, present, and future changes in sea water carbonate chemistry may have implications for rates of photosynthetic CO_2 fixation (photosynthesis) and calcium carbonate precipitation (calcification) for marine organisms and ecosystems (Gattuso et al. 1998).

6. POLLUTANTS AND POTENTIAL SOURCES DATA GAPS

6.1. Overview

After reviewing the available literature, data and information gaps have been identified. The decline of coral cover and species diversity in South Florida cannot necessarily be attributed to a single factor, but most likely involve multiple stressors. Information on the duration and frequency of exposure to multiple stressors is required before a meaningful relationship between stressors and subsequent ecosystem decline can be established. Studies investigating the synergistic effects of pollutants are lacking in the literature yet are necessary to accurately characterize the effects on the coral reef community. It is especially important to conduct experiments examining the long-term effects of environmentally realistic stresses on coral growth and survival.

Monitoring is an essential part of research and its design and implementation should be one of the highest priorities in the research community. A focus of the administrative problem is the need for long-term, regionally integrated, and stable yet technically evolving data acquisition programs. One of the greatest challenges is the need for funding and research institutions to develop an effectively coordinated approach to problems (Smith and Buddemeier 1992).

The majority of the research done regarding these pollutants has been conducted in Caribbean, Australia, Asian-Pacific, and Hawaii. Most of the studies taking place off the coast of Florida have been focused in the Florida Keys and Biscayne Bay. Less attention has been paid to the coral reef communities off the southeast coast of Florida.

6.2. Nutrients

Coral reef degradation resulting from nutrient enrichment is of growing concern, however, there is limited in situ evidence on the effects of nutrient enrichment on coral reefs (Koop et al. 2001). Increased concentrations of nutrients may lead to increased growth of macroalgae which could lead to a phase shift from coral to algal dominated reefs (Koop et al. 2001). The actual concentrations required to initiate this phase shift are still unknown (Koop et al. 2001). Another gap in nutrient research lies in determining the amount of nutrients that are taken up by phytoplankton and microorganisms prior to reaching the reef system (Nixon et al. 1986). It is not yet known whether the nutrient budget allows for excess nutrients that could contribute to overgrowth of reefs by macroalgae. Nutrient budget calculations by Alongi and McKinnon (2005) have indicated that microbial mineralization rates exceeded the total nutrient load near the GBR. A better understanding of the mechanisms of nutrient transport is also needed. Coastal ocean processes, currents, upwelling, etc. all affect the way nutrients are transported offshore. These are complicated processes which require intense scrutiny before any generalization can be made to say where nutrients are going once they enter coastal waters. The geography and oceanography of the coastal zone may also restrict offshore transport of nutrients (Alongi and McKinnon 2005). Concentrations of dissolved nutrients in the water column should be combined with measurements of nutrient inputs, consumption, and turnover rates to quantify nutrient flow through the food chain to the point where it affects coral reefs (Furnas et al. 2005).

There is still a great deal of discussion regarding the relative roles of nutrients vs. herbivory. Moderate increases in nutrients can substantially increase coral susceptibility to bleaching and disease, but are not sufficient to cause coral phase shifts. (Szmant 2002; Bruno et al. 2003). Lapointe et al. (2004) suggested that nutrients had a greater effect on macroalgal biomass (specifically *Digenea simplex*) than herbivory. There is a complicated interaction between herbivory, nutrients, and organic matter affecting coral reefs (McClanahan et al. 2005). Future management decisions should focus on protecting and or restoring herbivore populations and reducing terrigenous runoff of nutrients (McCook 1999).

6.3. Heavy Metals

There are few studies on the effects of heavy metals on coral reefs, however, those that are available focus on using corals as bioindicators of heavy metal pollution in marine waters (Howard and Brown 1984). Although there was some success with this approach (Dodge and Gilbert 1984; Bastidas and Garcia 1999; David 2002), most findings were inconclusive and did not determine the effects of metals on the coral community. Another area of study focused on the impacts of heavy metals on coral health and reproduction. Elevated metal concentrations have been shown to have negative impact on coral fecundity, reproduction, and recruitment (Negri and Heyward 2001; Reichelt-Brushett and Harrison 2005; Reichelt-Brushett and Michalek 2005; Victor and Richmond 2005). Copper, lead, zinc, cadmium, and nickel had a significant effect on fertilization success on scleractinian coral, with copper being the most toxic (Reichelt- Brushett and Harrison 2005; Reichelt-Brushett and Michalek 2005). The use of fertilization success in determining the effects of heavy metals on coral is limited and the mechanisms of toxicity are not clearly understood (Reichelt-Brushett and Harrison 2005; Reichelt-Brushett and Michalek 2005; Victor and Richmond 2005). Future research should focus on determining levels of metals that have toxicological effects on coral (Reichelt-Brushett and Harrison 2005). Another information gap is the lack of data on the uptake and storage of metals within coral. While there is some information on how coral take up heavy metals out of the water column, the transport and storage of these metals within the organism remains unclear (Howard and Brown 1986; Peters et al. 1997; Esslemont et al. 2000). Several studies have focused on measuring heavy metal concentrations in sediments, waters, and coral (Brown and Holley 1982; Howard and Brown 1986, 1987; Esslemont et al. 2000). However, these parameters are usually not measured at the same time in the same location (Peters et al. 1997). Therefore, it is difficult to correlate the amounts of metals in sediments and water column to the amounts found in coral tissues.

6.4. Pharmaceuticals/Organics

Advances in technology and improved analytical capabilities have directed scientists to the study of xenobiotic compounds as a pollutant in marine systems (Wu 1999). This is a relatively new and growing area of research so there is less information available compared to some of the other pollutants listed in this report.

Since 1998, the U.S. Geological Survey (USGS) has been developing analytical techniques to measure pharmaceutical contaminants in the marine environment (Kolpin et al. 2002). Some of those that are most common contaminants include cholesterol, caffeine, prescription drugs and hormones and sterols. Not much information is available regarding the persistence and degradation of these chemicals in the marine environment; or the possible interactions with non-target aquatic organisms (Isidori et al. 2005). Atkinson et al. (2003) measured estrogen concentrations present in sewage at injection wells, coastal, and offshore waters around the U.S., including regions near the Florida Keys. Estrogen was undetectable in the open ocean, but increased to approximately 2,000 pg/l near Key West (Atkinson et al. 2003). The authors stated that the impacts of estrogens on corals were, at this point, unknown (Atkinson et al. 2003). Other studies conducted by Tarrant et al. 2004 indicated that exposure of *Montipora capitata* to estradiol caused a 29% reduction in the number of egg-sperm bundles compared to controls. Colonies of *Porites compressa* exposed to estrone grew significantly slower than control groups, estrone exposure also caused tissue thickening in one of the experiments. (Tarrant et al. 2004). The authors suggested that future research focus on determining dose-response relationships as well as effects of exposure to different types of estrogen (Tarrant et al. 2004). Research regarding other pharmaceutical compounds should focus on identifying concentrations of the compounds and their derivatives as well as assessing their impacts to coral reefs and marine ecosystems in general (Isidori et al. 2005).

Another area of research regarding xenobiotic compounds includes work on organic hydrocarbons like those found in oil spills (Peters et al. 1981; Dodge et al. 1984). Studies indicated that small scale chronic spills may be more toxic than single large scale spills (Peters et al. 1997). Petroleum products released by oil spills remaining near the surface of the water may never contact the reef directly, however, these compounds can still affect developing larvae which tend to float near the surface (Peters et al. 1997). Some studies have focused on the toxicity of oil spills in combination with dispersants (Dodge et al. 1984, 1985; Wyers et al. 1986). Research suggests that oil spills treated with dispersants may be more toxic than spills that are left untreated (Peters et al. 1997). Other literature addressing organic pollution focuses on the possibility of coral recovery from organic pollution. While some research indicates that coral may be able to recover from some organic pollution if the pollutant were to be removed and the coral were grown in clean seawater (Wyers et al. 1986); a study by Peters et al. (1981) has shown that coral colonies exposed to fuel oil for three months still exhibited hydrocarbon contamination even after being transferred to clean seawater for two weeks.

Xenobiotic compounds are found in the marine environment in very low concentrations (Wu 1999). The long term effects of these compounds are not well understood (Wu 1999). Much of the available knowledge on the subject is a result of short term laboratory studies which have exposed a single species to a constant high concentration of one compound (Peters et al. 1997; Wu 1999). The authors suggest that these short term studies cannot accurately predict the long term ecological effects in the field (Peters et al. 1997; Wu 1999). As with many of the other pollutants, transport mechanisms, uptake and storage methods will be important to understand in order to better establish the possible effects of these chemicals on reefs.

6.5. Herbicides/Pesticides

Studies show increasing levels of pesticides, particularly lindane, DDT, and chlordane in nearly 100% of corals in the Great Barrier Reef and reefs off the Florida Keys (Peters et al. 1997). In general, data on pollutants and biological responses is much more complete for temperate marine and freshwater systems (Peters et al. 1997). It has not yet been established if the fate and transport of pollutants in tropical marine systems is similar to that of temperate systems (Peters et al. 1997). Sources of herbicides and pesticides include agricultural runoff and antifouling paints (Jones and Kerswell 2003). One of the main ways that herbicides and pesticides can negatively affect coral is by interfering with photosynthesis (Raberg et al. 2003, Jones and Kerswel 2003, and Harrington et al. 2005). Agricultural runoff can introduce sedimentation in combination with herbicides and pesticides (Harrington et al. 2005). Harrington et al. (2005) suggested that the effects of sedimentation on crustose coralline algae are significantly enhanced in combination with increased concentrations of diuron.

Prior to being banned in 1990, TBT was the most common compound found in antifouling paints (Connelly et al. 2001). Researchers have stated that TBT is the most toxic substance ever introduced to the environment (Goldberg 1986; Maguire 1987). Organic booster biocides have since been introduced as an alternative to TBT (Konstantinou and Albanis 2004). These include copper based antifouling agents like

Irgarol 1051 and diuron (Konstantinou and Albanis 2004). Several studies have indicated that these compounds are also toxic to coral (Dahl and Blank 1996; Owen et al. 2002; Jones and Kerswel 2003; Jones et al. 2003). The chronic effects of these compounds are unknown and difficult to determine (Konstantinou and Albanis 2004). Authors suggest that further research should be conducted to determine these effects as well as concentrations and effects of potentially toxic degradation products of these chemicals (Konstantinou and Albanis 2004).

Despite widespread usage of chemical herbicides and pesticides there is relatively little data on the long term environmental effects on coral and other marine organisms (Haynes et al. 2000; Raberg et al. 2003). Data on toxic pollutant levels that cause adverse effects in the field are limited (Peters et al. 1997). Additionally, studies on multiple stressors and their interactions with herbicides and pesticides are limited (Raberg et al. 2003). Future research should focus on synergistic effects as well as effects on coral reproduction and larval settlement (Raberg et al. 2003).

6.6. Salinity

So far, salinity fluctuations have not been considered a serious threat to coral reefs in most areas. However, there is a growing concern regarding the detrimental role salinity fluctuations play in the survivorship of already stressed coral reef organisms or organisms existing in marginal environments. The ability of corals in marginal habitats to survive both short- and long-term salinity fluctuations is a growing area of research essential for their persistence in such environments. For example, sub-optimal salinity patterns can persist in the near-shore environment of coastal lagoons like Biscayne Bay for several days due to canal runoff or storm events (Manzello and Lirman 2003).

Long-term low-level stress salinity studies are needed in order to assess the potential impact of salinity fluctuations on coral reef communities, especially those in marginal habitats or under stress. Porter et al. (1999) studied the combined effects of temperature and salinity in Florida Bay and found exposure to elevated temperatures and salinities after 36 hours caused coral mortality (Porter et al. 1999). Similar experiments focus on short (hours) exposure times. Further research into the effects of multiple stressors combined with salinity fluctuations should be investigated. Many environmental factors affect coral reefs and fluctuations in salinity should not be overlooked.

6.7. Carbon Dioxide and Carbon Dioxide Rise

Given the uncertainties of the global CO_2 budget, it is important that the role of coral reefs in global carbon cycles should be accurately understood (Ware et al. 1991). In their review of calcification and CO_2, Gattuso and Buddemeier (2000) make the following recommendations for future CO_2 research: the role of photosynthetically coupled calcification in the global carbon cycle, and its sensitivity to ocean chemistry requires further exploration; marine biological responses to high levels of CO_2 should be researched in the long-term; and interactions of CO_2 with other environmental changes such as increased temperature and nutrient concentrations should be investigated. Kleypas et al. (1999) suggest that reduced reef calcification warrants a much closer look at the biogeochemistry of shallow water carbonate secretors. Better quantification of the calcification-saturation relationship through laboratory and field studies as well as examination of geologic records is needed. Climatic changes and fluctuations in sea surface temperatures may have positive or negative effects on a local scale. At present, there is no basis for predicting widespread deleterious effects. For example, little is known about the effects of increasing UV exposure and the decrease of carbonate saturation state (Smith and Buddemeier 1992).

Human-related stress differs from naturally induced stress due to its increased frequency and variable intensity. The long-term impacts of altering natural disturbance regimes needs to be better understood in order to address issues encountered regarding biodiversity and cumulative impacts to the coral reef community. Many CO_2 studies take place in the laboratory using a mesocosm within which CO_2 can be manipulated. This is inherently different from a natural reef for many reasons including the lack of a water-motion regime. However, there is still a need to pursue experimental studies using controlled environmental conditions to unravel the response of corals to global environmental changes.

The scientific community needs to find better ways for integration across disciplinary boundaries as well as across time and space scales within disciplines. Reef research has long been dominated by biologists and geologists, yet climate and stresses induced by climate change are defined and studied in physical and chemical terms. A concerted effort to match studies of physical/chemical forcing with the biological/geological responses is the only way to synthesize an effective approach to global change issues (Smith and Buddemeier 1992).

6.8. Temperature

Increased sea-surface temperatures are correlated with mass coral bleaching events; however, the cellular mechanism behind this phenomenon remains uncertain (Downs et al. 2002). Coral bleaching is typically used as an indicator of the upper thermal limit for a coral species, however, Fitt et al. (2001) suggest bleaching bears little relationship to physiological processes occurring in corals and their symbionts. In other words, corals appear to experience the physiological stress of reduced tissue biomass and loss of algal symbionts weeks to months before the human eye can detect any signal of stress. If bleaching is going to be used as a proxy for death in studies of thermal limits for corals, it is necessary to unequivocally link the sublethal bleaching (which sometimes corals recover from) response to the point of death of the coral. Exposure times, and irradiances, and temperatures used in experiments must be specified if experiments in the laboratory are to have any relevance to the natural world.

The ability of corals to adapt to episodes of bleaching is not known; whether tolerance against bleaching depends on properties of the host or the zooxanthellae, or a combination of both is unknown, nor is it clear whether they relate to genetic or phenotypic differences in zooxanthellae (Brown 1997). It remains unknown as to the processes by which symbiont shifts occur in coral populations and whether there could be differential mortality of coral hosts and/or bleaching-induced symbiont change (Baker et al. 2004). Numerous documents from a variety of geographical areas report on wide-scale coral bleaching resulting in mass mortality, but only a few studies have presented detailed quantitative data on community structure and species diversity before and after a bleaching event (Loya et al. 2001). This has limited the ability to project long-term effects of coral community structures. Research on the induced synthesis of heat shock proteins (HSPs) has increased as a result of widespread bleaching episodes. Robbart et al. 2004 addressed the hypothesis that variable HSP expression following an ENSO event may be important in determining the ability of certain coral species to recover (Robbart et al. 2004). Such differences in resilience following a large-scale event such as an ENSO may drive change in coral species abundance patterns (Robbart et al. 2004).

Coral bleaching does not always result in mortality. A number of studies have documented coral recovery from a bleaching event. The adaptive bleaching hypothesis

(ABH) states that the loss of zooxanthellae may allow other representative algae to re establish a symbiosis with the host coral species, creating a new holobiont (also known as ecospecies or host-symbiont unit) (Fautin and Buddemeier 2004). Another hypothesis for this phenomenon is that the outcome of mortality or recovery is determined by the extent of oxidative damage experienced by the coral, however, further research is needed to support this (Downs et al. 2002). Even with moderate predictions, present and future increases in sea surface temperature are likely to have severe effects on coral reef systems. A better understanding of the capacity for corals and zooxanthellae to adapt to rapid and on-going changes is required. Given the central role of corals and zooxanthellae in the structure and function of coral reefs, these changes are likely to have severe and negative effects on the heath of coral reefs world-wide.

The ecological and economic effects of these changes have not been adequately assessed and should be a priority for research (Hoegh-Guldberg 1999). The need to implement long-term, international monitoring programs for coral reef ecosystems has been documented and supported by many scientists in the field of research. Major goals for this field of research should be to determine the ability of reefs to recover from stress, develop and amplify methods of restoring damaged coral reef habitats, and study the effects of large-scale bleaching and mortality on ecological services provided by coral reef systems (Goreau et al. 2000).

6.9. Turbidity

Turbidity in the marine environment has been long overlooked by the scientific community. Research on particles in the marine environment has focused primarily on sedimentation rather than turbidity. Assessment of turbidity of inshore ecosystems should address two questions: (1) what constitutes a significant increase in turbidity? and

(2) what is the turbidity threshold above which significant environmental change is expected? These factors are critical for researchers and managers to understand when seeking to establish thresholds or trigger levels (Orpin et al. 2004). Turbidity effects are infrequently examined, and then only at extremely high levels for short periods of time or in association with toxic byproducts.

While some studies have addressed the problems of turbidity on coral assemblages, findings have been inconsistent. The turbidity regime in the marine environment can have a significant effect on the energetics of corals. Exposure time to high-turbidity levels is a crucial factor in determining ecological stress (Anthony and Fabricius 2000). Few studies have attempted to quantify this stress as a function of turbidity exposure. Orpin et al. (2004) suggest weather forecasts (wind monitoring stations) as a cost effective and empirically based field tool that could provide environmental managers with a way to forecast the likely range of ambient turbidity. Availability of light in the water column decreases with increased concentration of suspended particles.

Historic data on water clarity in tropical coastal marine systems is sparse. The records that do exist are from areas where research stations are located or in areas of extreme pollution. Given the strong link between turbidity, light reduction and lower depth limits for coral reefs, more research is needed to understand conditions leading to long-term changes in water clarity in coastal systems (Fabricius 2005).

6.10. Sedimentation

Along with turbidity, sedimentation has been long overlooked by the scientific community and the majority of research done on this topic has been performed within the last fifteen years. It is generally accepted that high rates of sedimentation lead to smothering and death of coral polyps, but the impact of low level accumulation is unknown. Sedimentation is considered a major cause of coral degradation; however, the impact of sedimentation on coral-algal interactions has been largely overlooked. Nugues and Roberts (2003a) suggest that algal overgrowth in high sediment conditions may not be an important cause of mortality, but that sedimentation and algae act synergistically to lead to coral decline. Sedimentation may cause reef decline by: (1) directly causing mortality through sediment burial and smothering; then (2) suppressing the regrowth of surviving adult colonies and the settlement of new recruits through increased competition with algae. Further research is needed to clarify this connection.

Corals have the ability to survive the death of parts of their living tissue due to sedimentation. However, much remains to be learned about the significance of partial mortality and whether it can be used as a rapid and effective means of detecting sediment stress on coral reefs (Nugues and Roberts 2003b).

More rigorous, comprehensive research is needed to quantify the response of individual reef organisms and the reef system as a whole to sedimentation from dredging and runoff. Emphasis should be on changes in abundance and spatial arrangement of dominant benthic organisms so scientists can effectively assess changes and trends on coral reefs. Standardization of monitoring methods and long-term data sets are necessary for this to happen (Rogers 1990).

Additional research is needed on the threshold levels for reef species above which sedimentation has lethal effects for a particular species and above which normal functioning of the reef ceases. The limit between high and low sediment accumulation is poorly defined due to hydrodynamic interactions in the environment such as: magnitude, rate, duration, and timing, all which add to the complexity of its measurement (Thomas and Ridd 2005).

6.11. Disease/Pathogens/Viruses/Bacteria

There is a lack of knowledge about the causative agents of many diseases affecting corals and their symbiotic algae. The ongoing characterization of coral diseases is important to identify coral disease pathogens to determine possible treatment or prevention. New areas of research include: discerning mechanisms of aspergillosis resistance in sea fans, applying molecular technology to confirm identities of pathogens in outbreaks, manipulating corals to trigger disease occurrence, and determining if any relationship exists between increased nutrients and disease occurrence (Richardson 1998). Anthropogenic inputs such as organic carbon (starch, lactose, arabinose, and mannose) and nutrient loading are also becoming increasingly important in relating species-specific and carbon-specific pathologies and rates of mortality (Kuntz et al. 2005). While declines in corals have led to the identification of some diseases, impacts of these diseases are poorly understood. Future research will indicate whether plague- like signs in coral species represent a single disease condition by a single pathogen, or if plague-like diseases represent different diseases caused by a variety of pathogens (Sutherland et al. 2004).

The occurrence of pathogenic human enteric viruses in marine waters is not well characterized. Any understanding of this topic has been hampered by a limited number of studies, lack of available and accurate detection assays, and erroneous assumptions regarding virus viability and infectivity. The contamination of marine waters with viruses should be considered an important issue (Griffin et al. 2003).

Declines in Caribbean coral reefs due to black band disease and coral bleaching have occurred during peak years of African dust loading. Linking components of dust to specific diseases is difficult because scientists have yet to identify the causative agents for the vast majority of coral diseases. While researches are involved in exploring the potential impacts of African dust, any findings are presented as a working hypothesis in need of further testing (Ryan 2001).

Very few studies focus on the physiological impairments of the coral host and its symbiont that relate specifically to pathogenic stress. An understanding between the stability between the coral host and its symbiotic zooxanthellae is germane to understanding homeostasis within this relationship. Integrating the links between thermal expulsion and coral diseases may provide a better understanding of the cellular mechanisms that induce the breakdown of the coral and zooxanthellae. It is imperative to distinguish between the mechanisms of coral bleaching and coral disease infection for accurate field measurements of reef health (Cervino et al. 2004a).

Disease occurrence in the oceans is on the rise. Most new diseases occur by host shifts and not the emergence of new microorganisms. Contributing to the emergence of diseases is a long-term warming trend coupled with human activities. The inability to identify most causative agents and lack of standard epidemiological data for diseased populations limit the ability to examine host-pathogen interactions, to analyze changes in disease dynamics, and to assess the impact of diseases on host populations worldwide. There is an urgent need for interdisciplinary studies of marine diseases, focusing on the development of better molecular and computational tools and understanding the mechanisms of disease resistance in marine organisms (Harvell et al. 1999).

6.12. Outfalls

The initial dilution of effluent discharges is an important characteristic for determining environmental impact. For economic feasibility and marine environmental protection, it is essential to develop realistic initial dilution design criteria or standards for water quality management (Huang et al. 1994). The Florida Current plays a major role in the mixing and dispersing of effluent plumes. Physical oceanography of coastal waters must be thoroughly understood in order to track the movement of effluent water.

Theories on the initial mixing of outfall plumes has been established, however, these theories were mainly compared with laboratory experiments and verification of these theories with field data is rare (Proni et al. 1994). Mixing zone models have been developed (CORMIX, PLUMES, and OMZA) but minimal research has shown the accuracy of their predictive ability in repetitive studies (Huang et al. 1998).

Surveys on water quality parameters in treatment plants in south Florida have been performed which indicate that routinely monitored constituents are at allowable levels (Bloetscher and Gokgoz 2001), however, the fate of pesticides, solvents, and cleaners is less well studied. Further research and better analytical techniques are necessary to understand their impacts and detect concentrations that may exist in south Florida wastewater treatment plants.

Factors that decrease risk from ocean outfalls include the rapid dispersal and dilution of plumes by the Florida Current (EPA 2003) but also the distance of the outfalls from land; the lowest risk outfalls are farthest from land (Miami-Dade Central outfall) while the highest risk outfalls are closest to land (Boca Raton, Del Ray Beach outfalls). While the use of multi-port diffusers appears to aid in dispersal of the effluent compared to single-port diffusers, discharging the effluent at a faster speed appears to also increase the rate of dispersal and dilution (EPA 2003).

While evaluating the potential impacts of the southeast Florida ocean outfall discharges on the marine environment, South Florida wastewater utilities and regulatory agencies need to recognize that additional information is needed to develop conditions for outfall permitting. Understanding how discharged effluent undergoes dispersion, mixing, and dilution in the ocean is particularly important for the risk assessment of outfalls. In order to maintain that outfalls are not causing environmental degradation, active sampling and pretreatment inspections should be ongoing; sampling techniques should also be cohesive among the different cities in southeast Florida for testing of their respective outfalls; and laboratory tests should be maintained for comparison to field work.

6.13. Inlets

Research in the field of inlets is lacking in Florida, especially along the southeast coast. The flow of water movement associated with inlets, as well as the make-up of this water is largely unknown. Existing research deals mostly with estuaries, canals and rivers in other areas of Florida as well as addresses hydrodynamics and water quality issues (Militello and Zarillo 2000; Sigua et al. 2000; Macauley et al. 2002). The South Florida Water Management District maintains a database of historical and current hydrologic, meteorologic, and hydrogeologic water quality data collected at the ir coastal salinity control structures (fire hydrants in Fig. 8) (South Florida Water Management District (SFWMD): DBHYDRO Water hydrological and quality data. 2006. http://www.sfwmd.gov/org/ema/dbhydro/index.html). The coastal salinity control structure are located several miles inland and separate the freshwater portion of the system from the saline part. Data from these structures could be used to calculate loadings into the estuarine portion of the canal system. Characterization of pollutant concentrations in inlet discharges and quantification of flow rates into and out of the inlets is an area largely overlooked in the literature. In order to quantify the relative and absolute magnitudes of pollutant discharges into the coastal ocean off southeast Florida, physical, and biogeochemical processes characterizing those waters must be investigated such as:

hydrodynamic data, sediments, surface water quality, living organisms, and the benthic community. Inlets are an important component to the complex waterway system of southeast Florida and they should not be ignored by the scientific community.

6.14. Coastal Ocean Processes/Seasonal Upwelling

The fundamental processes that control coastal dynamics operate over a wide range of space and time scales (Jahnke et al. 2002). The study of these processes has been recognized as a crucial step in the understanding of any marine system (Jahnke et al. 2002). In order to determine the fate of anthropogenic materials that are introduced into the coastal system, long term measurements of boundary layer and seabed parameters are necessary (Jahnke et al. 2002). This is because much of the transport and dispersal of these materials is often episodic and occurs in the near-bottom boundary layer (Jahnke et al. 2002). The authors also suggested that continuous measurements of all coastal conditions be undertaken, an integrated coastal observatory system was proposed (Jahnke et al. 2002).

Upwelling events are a key source of nutrients and suspended particulate matter to some coral reefs (Leichter and Miller 1999; Jahnke et al. 2002). Upwelling also delivers colder water to the surface and can cause temperature stress to coral (Leichter and Miller 1999). However, there is also some evidence that localized upwelling events may actually help to relieve heat stress in some coral species (Grimsditch and Salm 2005). Ekman transport, tidal jets, near shore winds, and internal tidal bores are all processes that can result in upwelling (Leichter and Miller 1999). The biological and ecological effects of upwelling events are not well understood (Leichter and Miller 1999). Internal tidal bores can introduce cooler, nutrient rich, high salinity water from below the thermocline to coral reefs (Letichter et al. 1996; Leichter et al. 2003). The authors suggest that there is a critical need to understand coastal dynamics and their consequences for coral and other marine ecosystems (Leichter et al. 2003).

Again, there are no studies that focused specifically on coastal ocean processes as a source of pollutants to the southeast Florida region.

6.15. Submarine Groundwater Discharge

The amount of water and dissolved constituents released by submarine groundwater discharge (SGD) into the coastal ocean is unknown due to the difficulty involved in measuring it (Corbett et al. 2001). There are three ways available to describe SGD, modeling, direct physical measurement, and tracer techniques (Corbet et al. 2001; Burnett et al. 2003). In each of these situations there are many assumptions made in the calculations, and very rarely are any two or more approaches used within the same study (Burnett et al. 2003). The authors suggest that new technologies and modeling strategies need to be developed in order to estimate fluxes and differentiate between the factors that influence SGD (Burnett et al. 2003).

Studies have presented compelling evidence that direct groundwater flow to the ocean can be a significant source of nutrients in some areas (Scientific Committee on Oceanic Research (SCOR) Land-Ocean Interactions in the Coastal Zone (LOICZ) 2004). According to Payton et al. (2006) nutrient concentrations were higher in groundwater than in coastal waters near the Florida Keys by one to two orders of magnitude. The contribution from SGD was highly variable between samples due to the many factors that influence SGD, but there was a general concentration gradient for nutrients with concentrations being highest near the shoreline (Paytan et al. 2006). The authors noted, however, that the reef tract off the Florida Keys is several kilometers offshore and therefore it is not clear whether the groundwater is ever being transported all the way to the reef (Paytan et al. 2006)

Submarine groundwater discharge (SGD) may also be a source of pathogens, bacteria and other chemicals (Corbett et al. 2001; Paytan et al. 2006). Since SGD eventually ends up in the coastal ocean, any contaminant that is picked up along the way will ultimately become a marine pollution problem and may contribute to poor water quality and algal blooms (Corbett et al. 2001). The sources of pollutants to the groundwater, mechanisms that enhance SGD, and the impacts on coral reefs all need to be further evaluated (Paytan et al. 2006). Researchers suggest that specific pollutant fluxes and pathways need to be studied in direct relation to their effects on coral reefs (Paytan et al. 2006). It is also important to note that no studies were found that specifically center on the effects of SGD in southeast Florida.

6.16. Effects of Everglades Restoration

The Comprehensive Everglades Restoration Plan (CERP) was designed to restore the flow of this freshwater to the Everglades and prevent it from being lost to tide (United States Army Corps of Engineers Jacksonville District, South Florida Water Management District 1999). CERP will also restore a more natural historic flow of water to Biscayne Bay. This will result in increased delivery of freshwater and sediments to Florida Bay, Biscayne Bay, and the Florida Keys (Lirman et al. 2003). Increasing the amount of freshwater also means decreasing salinity. Lirman et al. (2003) suggests that the flow be delivered via overland flows rather than canals in order to reduce the localized impacts of salinity fluctuations. Waters flowing out of the EPA (Everglades Protected Area) due to CERP are also enriched with nutrients and runoff from the Everglades Agricultural Area (Rudnick et al. 1999; Porter and Porter 2002). In an effort to reduce the concentrations of nutrients, the Everglades Nutrient Removal (ENR) project was established (Guardo 1999). Studies regarding the effectiveness of this project have centered on the removal of phosphorus (P). Although the total outflow of P was reduced in the studies, it was not reduced to the desired concentration of ≤ 10 µg/l (Juston and DeBusk 2005). It has been suggested that since the ENR is made up of different cells with different treatment characteristics, each cell needs to be analyzed separately to gain a better understanding of the effectiveness of the system (Guardo 1999).

There have been some concerns that CERP will actually reduce the amount of freshwater flowing into estuarine systems in the southeast Florida region which may lead to local hypersalinization. This may also lead to a buildup of contaminants within the canals that could lead to high levels being flushed out during drainage events. There has been no research found that addresses these concerns at this time.

7. REVIEW OF FEDERAL, STATE AND LOCAL WATER QUALITY STANDARDS

7.1. Overview

Task 3 of SEFCRI Land-based Sources of Pollution and Water Quality Local Action Strategy involves the location, identification, and review of federal, state, and local water quality laws. The environmental laws, regulations, and ordinances that contain water quality standards and criteria on the federal, state, regional and local levels have been reviewed. The review was expanded to include other laws and regulations that could be construed to be used or applied to protect coral reefs from land based sources of pollution. These include laws that include prohibitions and laws that address damages to natural resources.

Each regulatory document was evaluated to determine: whether coral reefs were specifically addressed, whether marine resources were addressed, whether there were specific quantitative or qualitative water quality standards, and whether there were any planning or prohibition clauses that would allow for current or future application to coral reefs. When a law was found that could be applied, it was analyzed and pertinent sections are included in the Appendices of the report.

In addition to finding promulgated and published laws, contacts were attempted with regulatory, research, and conservation agency staff to determine whether any existing water quality standards have been identified, evaluated, or researched specific to coral reefs.

7.2. Federal Laws & Regulations

Federal Water Pollution Control Act (Clean Water Act)

33 United States Code (U.S.C.) 1251 et. seq.

Sections 101, 303, 304, 305, 319, 401, 402, 403

Code of Federal Regulations, Part 131

7.2.1. Clean Water Act

See APPENDIX 1, Code of Federal Regulations See APPENDIX 2

The main federal law that addresses surface water quality standards is the Federal Water Pollution Control Act which is also known as the Clean Water Act (CWA). The CWA has five main elements: (1) a system that creates minimum effluents standards based on an industrial category, (2) water quality standards, (3) a discharge program that creates a permitting system for standards and enforcement, (4) special provisions for problems such as toxic chemicals and oil spills, and (5) grants and loans for treatment facilities that are publicly owned.

The first main element is based on assessments and guidelines that have been developed for each industry. Effluent limitations and guidelines have been developed by assessments and information gathered from industrial facilities.

Water quality standards are set based on Sections 303 and 304. They have been developed primarily based on state activities under the guidelines of the Code of Federal Regulations, Part 131, Water Quality Standards (Appendix 2), which provides federal guidance and requirements to states based on the goal of designating the use of water bodies and then accordingly developing an appropriate standard. The water quality standards are standards for the overall quality of water. Waters are classified by their beneficial use and standards are developed for that use. States are required to establish water quality standards for the beneficial use of water bodies in the state.

Discharge regulatory requirements of the law apply primarily to industrial and municipal dischargers. The concept is that all discharges into waters of the United States are prohibited unless authorized by a permit. The permitting authority can be delegated to the states. The Act uses both the water quality standards and technology based effluent limitations to protect water quality. The permit for point source industrial municipal and storm water discharges to surface water is called the National Pollutant Discharge Elimination System (NPDES) and is outlined in Section 402 of the CWA.

The CWA, Section 305(a) requires that states assess water bodies and produce an inventory report on the conditions of state waters including the identification of point sources, a description of non-point sources and programs that are needed to control each category of pollution. Waters that are not meeting the criteria for designated uses are called impaired waters. Under CWA Section 303(d) the state must develop a list of impaired waters. Thermal pollution is also addressed to identify where controls are not stringent enough to protect populations of shellfish, fish and wildlife. This is known as the 303(d) List. States are required to develop total maximum daily loads (TMDL) that specify limits for the addition of pollutants responsible for water quality impairment. A TMDL specifies the maximum amount of a pollutant that can go into a water body for the water body to meet water quality standards. EPA approves or disapproves impaired water lists and TMDLs submitted by the state. States are required to have an EPA approved continuing planning process that provides for periodic updates of the requirements for assessing impaired waters and TMDLs.

Section 304 of the CWA establishes a requirement of publishing water quality criteria on the kind and extent of effects on health and welfare to plankton, fish, shellfish, wildlife, plant life, shorelines, beaches, esthetics and recreation from pollutants, on the concentration and dispersal of pollutants and their effects on biological community diversity, productivity, stability, eutrophication, sedimentation for receiving water bodies. Under this provision the EPA must also provide information on the restoration, maintenance, of the chemical, physical, biological integrity of waters as well as factors needed to protect and propagate shellfish, fish, and wildlife, and on the measurement, and classification of water quality.

Section 319 of the CWA was an added during the 1987 when it was recognized that the effluent and permitting provisions of CWA addressing point sources were not sufficient to improve water quality without strengthening the approach to non-point source pollution. This section directs states to develop reports and management plans that address non-point sources. Management plans are approved by EPA and states are encouraged to develop these on a watershed basis. Approved plans are eligible for federal implementation grants.

Application to Coral Reef Water Quality

The applicable existing provisions of the CWA can be applied, even though there is no explicit language addressing the coral reef resources. However, the language of the water quality provisions is clear in their application to waters where coral reefs occur. Section 101 states the goal of water quality which provides for protection and propagation of fish, shellfish, and wildlife and provides for recreation in and on the water. In addressing the creation of the water quality standards of Section 303, standards are to be based on use and take into account the use and value “for public water supplies, propagation of fish and wildlife, recreational purposes …” Section 303(i) specifically addresses aspects of Coastal Recreation Water Quality criteria and standards for coastal recreation waters of the state. Section 304, in addressing the development of information and guidelines, also specifies the applicability to plankton, fish, shellfish….shorelines, beaches etc. The water quality inventory in Section 305(a)(1) refers to taking into account tidal variations of all navigable waters including waters of the contiguous zone.

Coral reefs are found in water that is navigable and some reefs may be located in the contiguous zone.

7.2.2. Safe Drinking Water Act

The Safe Drinking Water Act (SDWA) provides standards for drinking water to protect against natural and manmade contaminants. Initially, the focus of the Act was for treatment of drinking water. Later amendments in 1986 and 1996 focused on protection of drinking water sources including surface and groundwater. Local laws including zoning and local pollution prohibition laws exist to protect sources of drinking water. Some of these laws include water quality criteria.

Application to Coral Reef Water Quality

SDWA is not drafted to protect general surface water quality. However, any of the local pollution prohibitions that address surface or ground water quality may benefit marine and reef resources by reduction of pollutants.

7.3. State Laws

Florida Constitution

Florida Statutes, 403, 376, 373, 380

7.3.1. Florida Constitution

Article II, Section 7 of the Florida Constitution provides for abatement of water pollution and conservation and protection of Florida’s natural resources and scenic beauty. This provides for the statutory basis for those sections of the Florida Statutes that protect water resources and other natural resources including coral reefs.

ARTICLE II: GENERAL PROVISIONS

SECTION 7. Natural resources and scenic beauty.

(a) It shall be the policy of the state to conserve and protect its natural resources and scenic beauty. Adequate provision shall be made by law for the abatement of air and water pollution and of excessive and unnecessary noise and for the conservation and protection of natural resources.

7.3.2. Florida Statues

7.3.2.1. Chapter 403, Environmental Control

Chapter 403 is known as the Florida Air and Water Pollution Control Act. This act addresses water, air and noise. The legislative declaration recognizes pollution of water as harmful, including harm to aquatic life. The public policy of the state is declared to "conserve the waters of the state and to protect, maintain, and improve the quality thereof for public water supplies, for the propagation of wildlife and fish and other aquatic life, and for domestic, agricultural, industrial, recreational, and other beneficial uses and to prove that no wastes be discharged into any waters of the state" without treatment. The legislative declaration includes for the provision of a statewide program of air and water pollution prevention and "for the securing and maintenance for appropriate levels of air and water quality." The Department empowered to carry out this declaration is the Florida Department of Environmental Protection (FDEP) under the police powers of the state. The FDEP is designated as the state water quality protection agency.

Chapter 403 defines pollution as "the presence in the outdoor atmosphere or waters of the state of any substances, contaminants, noise, or man-made or human-induced impairment of air or waters or alteration of the chemical, physical, biological, or radiological integrity of air or water in quantities or at levels which are or may be potentially harmful or injurious to human health or welfare, animal or plant life…." Waters are defined to include "rivers, lakes, streams, springs, impoundments, wetlands and other waters or water bodies that include fresh, saline, tidal, surface, or underground waters."

The FDEP is empowered to control and prohibit pollution of air and water by law and rules that the department promulgates. The department is charged with developing a "comprehensive program for the prevention, abatement, and control of the waters of the state". Chapter 403 allows for the grouping of water into classes.

The FDEP is also charged with establishing water quality standards for the state. The department is also charged with establishing and administering a program for "restoration and preservation of bodies of water within the state" and to establish "Outstanding Florida Waters" which are a special category of waters that warrant special protection. In addition to these waters the department is charged with adopting rules allowing for stricter permitting within aquatic preserves, areas of critical state concern and other waters subject to the provisions under Chapter 380, Florida Statutes. Under Section 403.062 the department has general control and supervision of waters that include coastal waters when pollution may affect public health or interests of the public.

Application to Coral Reef Water Quality

The statute does not specifically address water quality as it relates to coral reef resources. However, the statute specifically includes saline, coastal and tidal waters where coral reefs occur.

There is no limitation on location or kind of pollution sources nor is there a distinction made in the origins of the pollution sources as being land or water based. There is no language that excludes seepage either from land based surface or ground water, or a direct water pollution source.

There are four program areas that are applicable to waters surrounding the reefs:

Water Quality Standards, (Section 403.061(10) & 403.061(11), and Total Maximum Daily Loads, (Section 403.067) Ocean Outfalls (Section 403.085) and National Pollutant Discharge Elimination System (NPDES, Section 403.0885).

7.3.2.2. Water Quality Standards

i. Florida Statute Section 403.061(10)

Section 403.061(10) provides the FDEP with authority to develop a program to prevent, abate and control the waters of the state. It provides for the grouping of state waters into classes based on present and future beneficial use.

ii. Florida Statute Section 403.061(11)

Section 403.061(11) provides FDEP with the authority to establish ambient water quality standards. These standards appear in Florida Administrative Code (F.A.C. Chapter 62-302).

iii. Florida Administrative Code Chapter 62-302, Surface Water Quality Standards

All surface waters of the state are classified into Class I (potable water supplies), Class II (shellfish propagation or harvesting), Class III (recreation, propagation and maintenance of a healthy, well-balanced population of fish and wildlife, Class IV (agricultural water supplies), Class V (navigation, utility an industrial use). Some waters, including many waters where coral reefs are located, have additional special designations and protection. These waters receive highest protection and include: Outstanding Florida Waters, Outstanding National Resource Waters. Under F.A.C. in these waters, there can be no degradation of water quality. Coastal waters that are not included in these special designations are classified as Class III waters. Southern Florida, where reefs may occur, that have special designation include: Biscayne National Park, Dry Tortugas National

Park, Everglades National Park, Crocodile Lake National Wildlife Refuge, Green Heron National Wildlife Refuge, Hobe Sound National Wildlife Refuge, Key West National Wildlife Refuge, Bahia Honda State Park, Bill Baggs Cape Florida State Recreation Area, John Pennekamp Coral Reef State Park, Long Key State Recreation Area, Windley Key Fossil Reef State Geological Site, San Pedro State Underwater Archeological Preserve.

Without a non-degradation designation waters would be classified as Class III, predominantly marine waters. This classification applies even when reefs may occur in these waters. The quantitative water quality criteria tables (Table 2) in Chapter 62 302.530 follow:

Table 2: 62-302.530 Criteria for Surface Water Quality Classifications

Parameter	Units	Class I: Potable Water Supply	Class II: Shellfish Propagation or Harvesting	Class III: Fresh	Class III: Marine	Class IV: Agricultural Water Supplies	Class V: Navigation, Utility and Industrial Use
(1) Alkalinity	Milligrams/L as CaCO3	Shall not be depressed below 20		Shall not be depressed below 20		≤ 600	
(2) Aluminum	Milligrams/L		≤ 1.5		≤ 1.5		
(3) Ammonia (un-ionized)	Milligrams/L as NH3	≤ 0.02		≤ 0.02			
(4) Antimony	Micrograms/L	≤ 14.0	≤ 4,300	≤ 4,300	≤ 4,300		
(5) (a) Arsenic (total)	Micrograms/L	≤ 10	≤ 50	≤ 50	≤ 50	≤ 50	≤ 50
(5) (b) Arsenic (trivalent)	Micrograms/L measured as total recoverable Arsenic		≤ 36		≤ 36		

Notes: (1) "In H" means the natural logarithm of total hardness expressed as milligrams/L of CaC0:3 For metals criteria involving equations with hardness, the hardness shall be set at 25 mg/L if actual hardnessis< 25 mg/L and set at 400 mgi\.if actual hardness is> 400 mgi\. (2) This criterion is protective of human heallh not of aquatic life (3) For application of dissolved metals criteria see 62-302 500(2) (d) FA C

Parameter	Units	Class I: Potable Water Supply	Class II: Shellfish Propagation or Harvesting	Class III: Fresh	Class III: Marine	Class IV: Agricultural Water Supplies	Class V: Navigation, Utility and Industrial Use
(6) Bacteriological Quality (Fecal Coliform Bacteria)	Number per 100 ml (Most Probable Number (MPN) or Membrane Filter (MF))	MPN or MF counts shall not exceed a monthly average of 200, nor exceed 400 in 10% of the samples, nor exceed 800 on any one day. Monthly averages shall be expressed as geometric means based on a minimum of 5 samples taken over a 30 day period.	MPN shall not exceed a median value of 14 with not more than 10% of the samples exceeding 43, nor exceed 800 on any one day.	MPN or MF counts shall not exceed a monthly average of 200, nor exceed 400 in 10% of the samples, nor exceed 800 on any one day. Monthly averages shall be expressed as geometric means based on a minimum of 10 samples taken over a 30 day period.	MPN or MF counts shall not exceed a monthly average of 200, nor exceed 400 in 10% of the samples, nor exceed 800 on any one day. Monthly averages shall be expressed as geometric means based on a minimum of 10 samples taken over a 30 day period.		
(7) Barium	Milligrams/L	≤					
(8) Benzene	Micrograms/L	≤ 1.18	≤ 71.28 annual avg.	≤ 71.28 annual avg.	≤ 71.28 annual avg.		
(9) Beryllium	Micrograms/L	≤ 0.0077 annual avg.	≤ 0.13 annual avg.	≤ 0.13 annual avg.	≤ 0.13 annual avg.	≤ 100 in waters with a hardness in mg/L of CaCO3 of less than 250 and shall not exceed 500 in harder waters	

Notes: (1) "In H" means the natural logarithm of total hardness expressed as milligrams/L of CaC0:3   For metals criteria involving equations with hardness, the hardness shall be set at 25 mg/L if actual hardnessis< 25 mg/L and set at 400 mgi\.if actual hardness is> 400 mgi\. (2) This criterion is protective of human heallh not of aquatic life (3) For application of dissolved metals criteria see 62-302 500(2) (d) FA C

Parameter	Units	Class I: Potable Water Supply	Class II: Shellfish Propagation or Harvesting	Class III: Fresh	Class III: Marine	Class IV: Agricultural Water Supplies	Class V: Navigation, Utility and Industrial Use
(15) Cadmium	Micrograms/L See Notes (1) and (3).	Cd < $e^{(0.7409[\ln H]-4.719)}$	< 8.8	Cd ≤ $e^{(0.7409[\ln H]-4.719)}$	< 8.8		
(16) Carbon tetra-chloride	Micrograms/L	≤ 0.25 annual avg.; 3.0 max	≤ 4.42 annual avg.	≤ 4.42 annual avg.	≤ 4.42 annual avg.		
(17) Chlorides	Milligrams/L	≤ 250	Not increased more than 10% above normal back-ground. Normal daily and seasonal fluctuations shall be maintained.		Not increased more than 10% above normal back-ground. Normal daily and seasonal fluctuations shall be maintained.		In predominantlymarine waters, not increased more than 10% above normal back-ground. Normal daily and seasonal fluctuations shall be maintained.
(18) Chlorine (total residual)	Milligrams/L	≤ 0.01	≤ 0.01	≤ 0.01	≤ 0.01		
(19) (a) Chromium (trivalent)	Micrograms/L measured as total recoverable Chromium See Notes (1) and (3).	Cr (III) ≤ $e^{(0.819[\ln H]+0.6848)}$		Cr (III) ≤ $e^{(0.819[\ln H]+0.6848)}$		Cr (III) ≤ $e^{(0.819[\ln H]+0.6848)}$	In predominantly fresh waters, ≤ $e^{(0.819[\ln H]+0.6848)}$

Notes: (1) "In H" means the natural logarithm of total hardness expressed as milligrams/L of CaC0:3 For metals criteria involving equations with hardness, the hardness shall be set at 25 mg/L if actual hardnessis< 25 mg/L and set at 400 mgi\.if actual hardness is> 400 mgi\. (2) This criterion is protective of human heallh not of aquatic life (3) For application of dissolved metals criteria see 62-302 500(2) (d) FA C

Parameter	Units	Class I: Potable Water Supply	Class II: Shellfish Propagation or Harvesting	Class III: Fresh	Class III: Marine	Class IV: Agricultural Water Supplies	Class V: Navigation, Utility and Industrial Use
(19) (b) Chromium (hexavalent)	Micrograms/L See Note (3)	≤ 11	≤ 50	≤ 11	≤ 50	≤ 11	In predominantly fresh waters, ≤11. In predominantly marine waters, ≤ 50
(20) Chronic Toxicity (see definition in Section 62-302.200(4), F.A.C. and also see below, "Substances in concentrations which...")							
(21) Color, etc. (see also Minimum Criteria, Odor, Phenols, etc.)	Color, odor, and taste producing substances and other deleterious substances, including other chemical compounds attributable to domestic wastes, industrial wastes, and other wastes					Only suchamountsas will not render the waters unsuitable for agricultural irrigation, livestock watering, industrial cooling, industrial process water supply purposes, or fish survival.	

Notes: (1) "In H" means the natural logarithm of total hardness expressed as milligrams/L of CaC0:3   For metals criteria involving equations with hardness, the hardness shall be set at 25 mg/L if actual hardnessis< 25 mg/L and set at 400 mgi\.if actual hardness is> 400 mgi\. (2) This criterion is protective of human heallh not of aquatic life (3) For application of dissolved metals criteria see 62-302 500(2) (d) FA C

Parameter	Units	Class I: Potable Water Supply	Class II: Shellfish Propagation or Harvesting	Class III: Fresh	Class III: Marine	Class IV: Agricultural Water Supplies	Class V: Navigation, Utility and Industrial Use
(22) Conductance, Specific	Micromhos/cm	Shall not be increased more than 50% above background or to 1275, whichever is greater.		Shall not be increased more than 50% above background or to 1275, whichever is greater.		Shall not be increased more than 50% above background or to 1275, whichever is greater.	Shall not exceed 4,000
(23) Copper	Micrograms/L See Notes (1) and (3).	$\mathrm{Cu} \le e^{(0.8545[\mathrm{lnH}]-1.702)}$	≤ 3.7	$\mathrm{Cu} \le e^{(0.8545[\mathrm{lnH}]-1.702)}$	≤ 3.7	≤ 500	≤ 500
(24) Cyanide	Micrograms/L	≤ 5.2	≤ 1.0	≤ 5.2	≤ 1.0	≤ 5.0	≤ 5.0
(25) Definitions (see Section 62-302.200, F.A.C.)							
(26) Detergents	Milligrams/L	≤ 0.5	≤ 0.5	≤ 0.5	≤ 0.5	≤ 0.5	≤ 0.5
(27) 1,1-Dichloro-ethylene (1,1-dichloroethene)	Micrograms/L	≤ 0.057 annual avg.; ≤ 7.0 max	≤ 3.2 annual avg.	≤ 3.2 annual avg.	≤ 3.2 annual avg.		
(28) Dichloromethane (methylene chloride)	Micrograms/L	≤ 4.65 annual avg.	≤ 1,580 annual avg.	≤ 1,580 annual avg.	≤ 1,580 annual avg.		
(29) 2,4-Dinitro-toluene	Micrograms/L	≤ 0.11 annual avg.	≤ 9.1 annual avg.	≤ 9.1 annual avg.	≤ 9.1 annual avg.		

Notes: (1) "In H" means the natural logarithm of total hardness expressed as milligrams/L of CaC0:3 For metals criteria involving equations with hardness, the hardness shall be set at 25 mg/L if actual hardnessis< 25 mg/L and set at 400 mgi\.if actual hardness is> 400 mgi\. (2) This criterion is protective of human heallh not of aquatic life (3) For application of dissolved metals criteria see 62-302 500(2) (d) FA C

Parameter	Units	Class I: Potable Water Supply	Class II: Shellfish Propagation or Harvesting	Class III: Fresh	Class III: Marine	Class IV: Agricultural Water Supplies	Class V: Navigation, Utility and Industrial Use
(30) Dissolved Oxygen	Milligrams/L	Shall not be less than 5.0. Normal daily and seasonal fluctuations above this level shall be maintained.	Shall not average less than 5.0 in a 24-hour period and shall never be less than 4.0. Normal daily and seasonal fluctuations above these levels shall be maintained.	Shall not be less than 5.0. Normal daily and seasonal fluctuations above these levels shall be maintained.	Shall not average less than 5.0 in a 24-hour period and shall never be less than 4.0. Normal daily and seasonal fluctuations above these levels shall be maintained.	Shall not average less than 4.0 in a 24-hour period and shall never be less than 3.0.	Shall not be less than 0.3, fifty percent of the time on an annual basis for flows greater than or equal to 250 cubic feet per second and shall never be less than 0.1. Normal daily and seasonal fluctuations above these levels shall be maintained.
(31) Dissolved Solids	Milligrams/L	≤ 500 as a monthly avg.; ≤ 1,000 max					
(32) Fluorides	Milligrams/L	≤ 1.5	≤ 1.5	≤ 10.0	≤ 5.0	≤ 10.0	≤ 10.0
(33) "Free Froms" (see Minimum Criteria in Section 62-302.500, F.A.C.)							

Notes: (1) "In H" means the natural logarithm of total hardness expressed as milligrams/L of CaC0:3 For metals criteria involving equations with hardness, the hardness shall be set at 25 mg/L if actual hardnessis< 25 mg/L and set at 400 mgi\.if actual hardness is> 400 mgi\. (2) This criterion is protective of human heallh not of aquatic life (3) For application of dissolved metals criteria see 62-302 500(2) (d) FA C

Parameter	Units	Class I: Potable Water Supply	Class II: Shellfish Propagation or Harvesting	Class III: Fresh	Class III: Marine	Class IV: Agricultural Water Supplies	Class V: Navigation, Utility and Industrial Use
(34) "General Criteria" (see Section 62-302.500, F.A.C. and individual criteria)							
(35) (a) Halometh-anes (Total trihalomethanes) (total of bromoform, chlorodibromomethane, dichlorobromome- thane, and chloro-form). Individual halomethanes shall not exceed (b)1. to (b)5. below.	Micrograms/L	<80					
(35) (b) 1. Halomethanes (individual): Bromoform	Micrograms/L	≤ 4.3 annual avg.	≤ 360 annual avg.	≤ 360 annual avg.	≤ 360 annual avg.		
(35) (b) 2. Halomethanes (individual): Chlorodibromomethane	Micrograms/L	≤ 0.41 annual avg.	≤ 34 annual avg.	≤ 34 annual avg.	≤ 34 annual avg.		

Notes: (1) "In H" means the natural logarithm of total hardness expressed as milligrams/L of CaC0:3 For metals criteria involving equations with hardness, the hardness shall be set at 25 mg/L if actual hardnessis< 25 mg/L and set at 400 mgi\.if actual hardness is> 400 mgi\. (2) This criterion is protective of human heallh not of aquatic life (3) For application of dissolved metals criteria see 62-302 500(2) (d) FA C

Parameter	Units	Class I: Potable Water Supply	Class II: Shellfish Propagation or Harvesting	Class III: Fresh	Class III: Marine	Class IV: Agricultural Water Supplies	Class V: Navigation, Utility and Industrial Use
(35) (b) 3. Halomethanes (individual): Chloroform	Micrograms/L	≤ 5.67 annual avg.	≤ 470.8 annual avg.	≤ 470.8 annual avg.	≤ 470.8 annual avg.		
(35) (b) 4. Halomethanes (individual): Chloromethane (methyl chloride)	Micrograms/L	≤ 5.67 annual avg.	≤ 470.8 annual avg.	≤ 470.8 annual avg.	≤ 470.8 annual avg.		
(35) (b) 5. Halomethanes (individual): Dichlorobromomethane	Micrograms/L	≤ 0.27 annual avg.	≤ 22 annual avg.	≤ 22 annual avg.	≤ 22 annual avg.		
(36) Hexachlorobutadiene	Micrograms/L	≤ 0.45 annual avg.	≤ 49.7 annual avg.	≤ 49.7 annual avg.	≤ 49.7 annual avg.		
(37) Imbalance (see Nutrients)							
(38) Iron	Milligrams/L	< 1.0	≤ 0.3	≤ 1.0	≤ 0.3	≤ 1.0	
(39) Lead	Micrograms/L See Notes (1) and (3).	Pb ≤ e(1.273[lnH]- 4.705);	≤ 8.5	Pb ≤ e(1.273 [lnH] - 4.705);	≤ 8.5	≤ 50	≤ 50
(40) Manganese	Milligrams/L		≤ 0.1				
(41) Mercury	Micrograms/L	0.012	0.025	0.012	0.025	≤ 0.2	≤ 0.2

Notes: (1) "In H" means the natural logarithm of total hardness expressed as milligrams/L of CaC0:3 For metals criteria involving equations with hardness, the hardness shall be set at 25 mg/L if actual hardnessis< 25 mg/L and set at 400 mgi\.if actual hardness is> 400 mgi\. (2) This criterion is protective of human heallh not of aquatic life (3) For application of dissolved metals criteria see 62-302 500(2) (d) FA C

Parameter	Units	Class I: Potable Water Supply	Class II: Shellfish Propagation or Harvesting	Class III: Fresh	Class III: Marine	Class IV: Agricultural Water Supplies	Class V: Navigation, Utility and Industrial Use
(42) Minimum Criteria (see Section 62-302. 500, F.A.C.)							
(43) Mixing Zones (See Section 62-4.244 , F.A.C.)							
(44) Nickel	Micrograms/L See Notes (1) and (3).	$\text{Ni} \le e^{(0.846[\ln H]+0.0584)}$	≤ 8.3	$\text{Ni} \le e^{(0.846[\ln H]+0.0584)}$	≤ 8.3	≤ 100	
(45) Nitrate	Milligrams/L as N	≤ 10 or that concentration that exceeds the nutrient criteria					
(46) Nuisance Species		Substances in concentrations which result in the dominance of nuisance species: none shall be present.					
(47) (a) Nutrients		The discharge of nutrients shall continue to be limited as needed to prevent violations of other standards contained in this chapter. Man-induced nutrient enrichment (total nitrogen or total phosphorus) shall be considered degradation in relation to the provisions of Sections 62-302.300, 62-302.700, and 62-4.242, F.A.C.					
(47) (b) Nutrients		In no case shall nutrient concentrations of a body of water be altered so as to cause an imbalance in natural populations of aquatic flora or fauna.					

Notes: (1) "In H" means the natural logarithm of total hardness expressed as milligrams/L of CaC0:3 For metals criteria involving equations with hardness, the hardness shall be set at 25 mg/L if actual hardnessis< 25 mg/L and set at 400 mgi\.if actual hardness is> 400 mgi\. (2) This criterion is protective of human heallh not of aquatic life (3) For application of dissolved metals criteria see 62-302 500(2) (d) FA C

Parameter	Units	Class I: Potable Water Supply	Class II: Shellfish Propagation or Harvesting	Class III: Fresh	Class III: Marine	Class IV: Agricultural Water Supplies	Class V: Navigation, Utility and Industrial Use
(48) Odor (also see Color, Minimum Criteria, Phenolic Compounds, etc.)	Threshold odor number		Shall not exceed 24 at 60 degrees C as a daily average.				Odor producingsubstances: only in such amounts as will not unreasonably interfere with use of the water for the designated purpose of this classifi-cation.
(49) (a) Oils and Greases	Milligrams/L	Dissolvedoremulsified oils and greases shall not exceed 5.0	Dissolved or emulsified oils and greases shall not exceed 5.0	Dissolved or emulsified oils and greases shall not exceed 5.0	Dissolved or emulsified oils and greases shall not exceed 5.0	Dissolved or emulsified oils and greases shall not exceed 5.0	Dissolved or emulsified oils and greases shall not exceed 10.0
(49) (b) Oils and Greases		No undissolved oil, or visible oil defined as iridescence, shall be present so as to cause taste or odor, or other-wise interfere with the beneficial use of waters.					
(50) Pesticides and Herbicides							
(50) (a) 2,4,5-TP	Micrograms/L	≤10					
(50) (b) 2-4-D	Micrograms/L	≤100					
(50) (c) Aldrin	Micrograms/L	≤ .00013 annual avg.; 3.0 max	≤ .00014 annual avg.; 1.3 max	≤ .00014 annual avg.; 3.0 max	≤ .00014 annual avg.; 1.3 max		
(50) (d) Beta-hexachlorocyclo-hexane (b-BHC)	Micrograms/L	≤ 0.014 annual avg.	≤ 0.046 annual avg.	≤ 0.046 annual avg.	≤ 0.046 annual avg.		

Notes: (1) "In H" means the natural logarithm of total hardness expressed as milligrams/L of CaC0:3   For metals criteria involving equations with hardness, the hardness shall be set at 25 mg/L if actual hardnessis< 25 mg/L and set at 400 mgi\.if actual hardness is> 400 mgi\. (2) This criterion is protective of human heallh not of aquatic life (3) For application of dissolved metals criteria see 62-302 500(2) (d) FA C

Parameter	Units	Class I: Potable Water Supply	Class II: Shellfish Propagation or Harvesting	Class III: Fresh	Class III: Marine	Class IV: Agricultural Water Supplies	Class V: Navigation, Utility and Industrial Use
(50) (e) Chlordane	Micrograms/L	≤ 0.00058 annual avg.; 0.0043 max	≤ 0.00059 annual avg.; 0.004 max	≤ 0.00059 annual avg.; 0.0043 max	≤ 0.00059 annual avg.; 0.004 max		
(50) (f) DDT	Micrograms/L	≤ 0.00059 annual avg.; 0.001 max	≤ 0.00059 annual avg.; 0.001 max	≤ 0.00059 annual avg.; 0.001 max	≤ 0.00059 annual avg.; 0.001 max		
(50) (g) Demeton	Micrograms/L	≤ 0.1	≤ 0.1	≤ 0.1	≤ 0.1		
(50) (h) Dieldrin	Micrograms/L	≤ 0.00014 annual avg.; 0.0019 max	≤ 0.00014 annual avg.; 0.0019 max	≤ 0.00014 annual avg.; 0.0019 max	≤ 0.00014 annual avg.; 0.0019 max		
(50) (i) Endosulfan,	Micrograms/L	≤ 0.056	≤ 0.0087	≤ 0.056	≤ 0.0087		
(50) (j) Endrin	Micrograms/L	≤ 0.0023	≤ 0.0023	≤ 0.0023	≤ 0.0023		
(50) (k) Guthion	Micrograms/L	≤ 0.01	≤ 0.01	≤ 0.01	≤ 0.01		
(50) (l) Heptachlor	Micrograms/L	≤ 0.00021 annual avg.; 0.0038 max	≤ 0.00021 annual avg.; 0.0036 max	≤ 0.00021 annual avg.; 0.0038 max	≤ 0.00021 annual avg.; 0.0036 max		
(50) (m) Lindane (g-benzene hexachloride)	Micrograms/L	≤ 0.019 annual avg.; 0.08 max	≤ 0.063 annual avg.; 0.16 max	≤ 0.063 annual avg.; 0.08 max	≤ 0.063. annual avg.; 0.16 max		
(50) (n) Malathion	Micrograms/L	≤ 0.1	≤ 0.1	≤ 0.1	≤ 0.1		
(50) (o) Methoxychlor	Micrograms/L	≤ 0.03	≤ 0.03	≤ 0.03	≤ 0.03		
(50) (p) Mirex	Micrograms/L	≤ 0.001	≤ 0.001	≤ 0.001	≤ 0.001		
(50) (q) Parathion	Micrograms/L	≤ 0.04	≤ 0.04	≤ 0.04	≤ 0.04		

Notes: (1) "In H" means the natural logarithm of total hardness expressed as milligrams/L of CaC0:3 For metals criteria involving equations with hardness, the hardness shall be set at 25 mg/L if actual hardnessis< 25 mg/L and set at 400 mgi\.if actual hardness is> 400 mgi\. (2) This criterion is protective of human heallh not of aquatic life (3) For application of dissolved metals criteria see 62-302 500(2) (d) FA C

Parameter	Units	Class I: Potable Water Supply	Class II: Shellfish Propagation or Harvesting	Class III: Fresh	Class III: Marine	Class IV: Agricultural Water Supplies	Class V: Navigation, Utility and Industrial Use
(50) (r) Toxaphene	Micrograms/L	≤ 0.0002	≤ 0.0002	≤ 0.0002	≤ 0.0002		
(51) (a) pH (Class I and Class IV Waters)	Standard Units	Shall not vary more than one unit above or below natural background provided that the pH is not lowered to less than 6 units or raised above 8.5 units. If natural background is less than 6 units, the pH shall not vary below natural background or vary more than one unit above natural background. If natural background is higher than 8.5 units, the pH shall not vary above natural background or vary more than one unit below background.					
(51) (b) pH (Class II Waters)	Standard Units	Shall not vary more than one unit above or below natural background of coastal waters as defined in Section 62-302.520(3)(b), F.A.C., or more than two-tenths unit above or below natural background of open waters as defined in Section 62-302.520(3)(f), F.A.C., provided that the pH is not lowered to less than 6.5 units or raised above 8.5 units. If natural background is less than 6.5 units, the pH shall not vary below natural background or vary more than one unit above natural background for coastal waters or more than two-tenths unit above natural background for open waters. If natural background is higher than 8.5 units, the pH shall not vary above natural background or vary more than one unit below natural background of coastal waters or more than two-tenths unit below natural background of open waters.					
(51) (c) pH (Class III Waters)	Standard Units	Shall not vary more than one unit above or below natural background of predominantly fresh waters and coastal waters as defined in Section 62-302.520(3)(b), F.A.C. or more than two-tenths unit above or below natural background of open waters as defined in Section 62-302.520(3)(f), F.A.C., provided that the pH is not lowered to less than 6 units in predominantly fresh waters, or less than 6.5 units in predominantly marine waters, or raised above 8.5 units. If natural background is less than 6 units, in predominantly fresh waters or 6.5 units in predominantly marine waters, the pH shall not vary below natural background or vary more than one unit above natural background of predominantly fresh waters and coastal waters, or more than two-tenths unit above natural background of open waters. If natural background is higher than 8.5 units, the pH shall not vary above natural background or vary more than one unit below natural background of predominantly fresh waters and coastal waters, or more than two-tenths unit below natural background of open waters.					
(51) (d) pH (Class V Waters)	Standard Units	Not lower than 5.0 nor greater than 9.5 except certain swamp waters which may be as low as 4.5.					
(52) (a) Phenolic Compounds: Total		Phenolic compounds other than those produced by the natural decay of plant material, listed or unlisted, shall not taint the flesh of edible fish or shellfish or produce objectionable taste or odor in a drinking water supply.					

Notes: (1) "In H" means the natural logarithm of total hardness expressed as milligrams/L of CaC0:3   For metals criteria involving equations with hardness, the hardness shall be set at 25 mg/L if actual hardnessis< 25 mg/L and set at 400 mgi\.if actual hardness is> 400 mgi\. (2) This criterion is protective of human heallh not of aquatic life (3) For application of dissolved metals criteria see 62-302 500(2) (d) FA C

Parameter	Units	Class I: Potable Water Supply	Class II: Shellfish Propagation or Harvesting	Class III: Fresh	Class III: Marine	Class IV: Agricultural Water Supplies	Class V: Navigation, Utility and Industrial Use
(52) (b) Total Chlorinated Phenols and Chlorinated Cresols	Micrograms/L	1. The total of all chlorinated phenols, and chlorinated cresols, except as set forth in (c) 1. to (c) 4. below, shall not exceed 1.0 unless higher values are shown not to be chronically toxic. Such higher values shall be approved in writing by the Secretary. 2. The compounds listed in (c) 1. to (c) 6. below shall not exceed the limits specified for each compound.					1. The total of the following Phenolic compounds shall not exceed 50: a) Chlorinated phenols; b) Chlorinated cresols; and c) 2,4-dinitrophenol.
(52) (c) 1. Phenolic Compound: 2-chlorophenol	Micrograms/L	≤ 120	< 400 See Note (2).	< 400 See Note (2).	< 400 See Note (2).	< 400 See Note (2).	
(52)(c) 2. Phenolic Compound: 2,4-dichlorophenol	Micrograms/L	<93 See Note (2).	< 790 See Note (2).	< 790 See Note (2).	< 790 See Note (2).	< 790 See Note (2).	
(52) (c) 3. Phenolic Compound: Pentachlorophenol	Micrograms/L	≤ 30 max; ≤ 0.28 annual avg; ≤ e(1.005[pH]-5.29)	≤ 7.9	≤ 30 max; ≤ 8.2 annual avg; ≤ e(1.005[pH]-5.29)	≤ 7.9	≤ 30	
(52)(c) 4. Phenolic Compound: 2,4,6-trichlorophenol	Micrograms/L	≤ 2.1 annual avg.	≤ 6.5 annual avg.	≤ 6.5 annual avg.	≤ 6.5 annual avg.	≤ 6.5 annual avg.	

Notes: (1) "In H" means the natural logarithm of total hardness expressed as milligrams/L of CaC0:3 For metals criteria involving equations with hardness, the hardness shall be set at 25 mg/L if actual hardnessis< 25 mg/L and set at 400 mgi\.if actual hardness is> 400 mgi\. (2) This criterion is protective of human heallh not of aquatic life (3) For application of dissolved metals criteria see 62-302 500(2) (d) FA C

Parameter	Units	Class I: Potable Water Supply	Class II: Shellfish Propagation or Harvesting	Class III: Fresh	Class III: Marine	Class IV: Agricultural Water Supplies	Class V: Navigation, Utility and Industrial Use
(52) (c) 5. Phenolic Compound: 2,4-dinitrophenol	Milligrams/L	≤ 0.0697 See Note (2).	≤ 14.26 See Note (2).	≤ 14.26 See Note (2).	≤ 14.26 See Note (2).	≤ 14.26 See Note (2).	
(52) (c) 6. Phenolic Compound: Phenol	Milligrams/L	≤ 0.3	≤ 0.3	≤ 0.3	≤ 0.3	≤ 0.3	≤ 0.3
(53) Phosphorus (Elemental)	Micrograms/L		≤ 0.1		≤ 0.1		
(54) Phthalate Esters	Micrograms/L	≤ 3.0		≤ 3.0			
(55) Polychlorinated Biphenyls (PCBs)	Micrograms/L	≤ 0.000044 annual avg.; 0.014 max	≤ 0.000045 annual avg.; 0.03 max	≤ 0.000045 annual avg.; 0.014 max	≤ 0.000045 annual avg.; 0.03 max		

Notes: (1) "In H" means the natural logarithm of total hardness expressed as milligrams/L of CaC0:3   For metals criteria involving equations with hardness, the hardness shall be set at 25 mg/L if actual hardnessis< 25 mg/L and set at 400 mgi\.if actual hardness is> 400 mgi\. (2) This criterion is protective of human heallh not of aquatic life (3) For application of dissolved metals criteria see 62-302 500(2) (d) FA C

Parameter	Units	Class I: Potable Water Supply	Class II: Shellfish Propagation or Harvesting	Class III: Fresh	Class III: Marine	Class IV: Agricultural Water Supplies	Class V: Navigation, Utility and Industrial Use
(56) (a) Polycyclic Aromatic Hydrocarbons (PAHs). Total of: Acenaphthylene; Benzo(a)anthracene; Benzo(a)pyrene; Benzo(b)fluoranthene; Benzo-(ghi)perylene; Benzo(k)fluoranth-ene; Chrysene; Dibenzo-(a,h)anthracene; Indeno(1,2,3-cd)pyrene; and Phenanthrene	Micrograms/L	≤ 0.0028 annual avg.	≤ 0.031 annual avg.	≤ 0.031annual avg.	≤ 0.031 annual avg.		
(56) (b) 1 (Individual PAHs): Acenaphthene	Milligrams/L	<1.2 See Note (2).	< 2.7 See Note (2).	< 2.7 See Note (2).	< 2.7 See Note (2).		
(56)(b) 2. (Individual PAHs): Anthracene	Milligrams/L	<9.6 See Note (2).	< 110 See Note (2).	< 110 See Note (2).	< 110 See Note (2).		

Notes: (1) "In H" means the natural logarithm of total hardness expressed as milligrams/L of CaC0:3 For metals criteria involving equations with hardness, the hardness shall be set at 25 mg/L if actual hardnessis< 25 mg/L and set at 400 mgi\.if actual hardness is> 400 mgi\. (2) This criterion is protective of human heallh not of aquatic life (3) For application of dissolved metals criteria see 62-302 500(2) (d) FA C

Parameter	Units	Class I: Potable Water Supply	Class II: Shellfish Propagation or Harvesting	Class III: Fresh	Class III: Marine	Class IV: Agricultural Water Supplies	Class V: Navigation, Utility and Industrial Use
(56) (b) 3. (Individual PAHs): Fluoranthene	Milligrams/L	<0.3 See Note (2).	< 0.370 See Note (2).	< 0.370 See Note (2).	< 0.370 See Note (2).		
(56) (b) 4. (Individual PAHs): Fluorene	Milligrams/L	<1.3 See Note (2).	< 14 See Note (2).	< 14 See Note (2).	< 14 See Note (2).		
(56) (b) 5. (Individual PAHs): Pyrene	Milligrams/L	<0.96 See Note (2).	< 11 See Note (2).	< 11 See Note (2).	< 11 See Note (2).		
(57)(a) Radioactive substances (Combined radium 226 and 228)	Picocuries/L	≤ 5	≤ 5	≤ 5	≤ 5	≤ 5	≤ 5
(57) (b) Radioactive substances (Gross alpha particle activity including radium 226, but excluding radon and uranium)	Picocuries/L	≤ 15	≤ 15	≤ 15	≤ 15	≤ 15	≤ 15
(58) Selenium	Micrograms/L	≤ 5.0	≤ 71	≤ 5.0	≤ 71		

Notes: (1) "In H" means the natural logarithm of total hardness expressed as milligrams/L of CaC0:3   For metals criteria involving equations with hardness, the hardness shall be set at 25 mg/L if actual hardnessis< 25 mg/L and set at 400 mgi\.if actual hardness is> 400 mgi\. (2) This criterion is protective of human heallh not of aquatic life (3) For application of dissolved metals criteria see 62-302 500(2) (d) FA C

Parameter	Units	Class I: Potable Water Supply	Class II: Shellfish Propagation or Harvesting	Class III: Fresh	Class III: Marine	Class IV: Agricultural Water Supplies	Class V: Navigation, Utility and Industrial Use
(59) Silver	Micrograms/L See Note (3).	≤ 0.07	See Minimum criteria in Section 62-302.500(1)(c)	≤ 0.07	See Minimum criteria in Section 62-302.500(1)(c)		
(60) Specific Conductance (see Conductance, Specific, above)							
(61) Substances in concentrations which injure, are chronically toxic to, or produce adverse physiological or behavioral response in humans, plants, or animals		None shall be present.					
(62) 1,1,2,2-Tetra-chloroethane	Micrograms/L	≤ 0.17 annual avg.	≤ 10.8 annual avg.	≤ 10.8 annual avg.	≤ 10.8 annual avg.		
(63) Tetrachloroethyl-ene (1,1,2,2-tetrachloroethene)	Micrograms/L	≤ 0.8 annual avg., ≤ 3.0 max	≤ 8.85 annual avg.	≤ 8.85 annual avg.	≤ 8.85 annual avg.		
(64) Thallium	Micrograms/L	< 1.7	< 6.3	< 6.3	< 6.3		

Notes: (1) "In H" means the natural logarithm of total hardness expressed as milligrams/L of CaC0:3   For metals criteria involving equations with hardness, the hardness shall be set at 25 mg/L if actual hardnessis< 25 mg/L and set at 400 mgi\.if actual hardness is> 400 mgi\. (2) This criterion is protective of human heallh not of aquatic life (3) For application of dissolved metals criteria see 62-302 500(2) (d) FA C

Parameter	Units	Class I: Potable Water Supply	Class II: Shellfish Propagation or Harvesting	Class III: Fresh	Class III: Marine	Class IV: Agricultural Water Supplies	Class V: Navigation, Utility and Industrial Use
(65) Thermal Criteria (See Section 62-302.520)							
(66) Total Dissolved Gases	Percent of the saturation value for gases at the existing atmospheric and hydrostatic pressures	≤ 110% of saturation value	≤ 110% of saturation value	≤ 110% of saturation value	≤ 110% of saturation value		
(67) ~~(~~Transparency	Depth of the com-pensation point for photosynthetic activity	Shall not be reduced by more than 10% as com-pared to the natural background value.	Shall not be reduced by more than 10% as com-pared to the natural background value.	Shall not be reduced by more than 10% as com-pared to the natural background value.	Shall not be reduced by more than 10% as com-pared to the natural background value.		
(68) Trichloroethylene (trichloroethene)	Micrograms/L	≤ 2.7 annual avg., ≤ 3.0 max	≤ 80.7 annual avg.	≤ 80.7 annual avg.	≤ 80.7 annual avg.		
(69) Turbidity	Nephelometric Turbidity Units (NTU)	≤ 29 above natural background conditions	≤ 29 above natural background conditions	≤ 29 above natural background conditions	≤ 29 above natural background conditions	≤ 29 above natural background conditions	≤ 29 above natural background conditions
(70) Zinc	Micrograms/L See Notes (1) and (3).	$Zn \leq e^{(0.8473[\ln H]+0.884)}$	< 86	$Zn \leq e^{(0.8473[\ln H]+0.884)}$	< 86	< 1,000	< 1,000

Notes: (1) "In H" means the natural logarithm of total hardness expressed as milligrams/L of CaC0:3 For metals criteria involving equations with hardness, the hardness shall be set at 25 mg/L if actual hardnessis< 25 mg/L and set at 400 mgi\.if actual hardness is> 400 mgi\. (2) This criterion is protective of human heallh not of aquatic life (3) For application of dissolved metals criteria see 62-302 500(2) (d) FA C

7.3.2.3. Total Maximum Daily Loads

Florida Statue 403.067 Establishment and implementation of maximum daily loads. In Florida, F.A.C. 62-303 defines impaired waters as when water quality assessments determine that water bodies are not meeting the water quality standards for their designated use due in whole or in part to discharges of pollutants form point and non-point sources. The designated use of water bodies in Florida are classified based on Florida Administrative Code Chapter 62-302 where the water quality standards are also defined.

7.3.2.4. Ocean Outfalls

Florida Statute 403.085, Sanitary sewage disposal units; advanced and secondary waste treatment; industrial waste, ocean outfall, inland outfall, or disposal well waste treatment. This prohibits sanitary sewage disposal into the ocean without secondary treatment. This is not a standard, it is a prohibition.

7.3.2.5. National Pollutant Discharge Elimination System

Florida Statute 403.0855, Establishment of federally approved National Pollutant Discharge Elimination System (NPDES) Program; Chapter 62-620, Florida Administrative Code, Wastewater Facility and Activities Permitting

This is a program that has been delegated to Florida by the US EPA. The premise is that all discharges into state waters are unlawful unless authorized by a permit. The permit is an NPDES permit.

7.3.2.6. Chapter 373, Water Resources

See APPENDIX 8

Part I of Chapter 373 is the State Water Resource Plan which describes the planning duties and powers of the Department of Environmental Protection and the working plan with district water management. The water resources plan of the state includes reference to the water quality standards of FDEP. The management of water resources includes the purpose of environmental protection and the preservation and enhancement of the water quality of the state. Part IV is titled “Management and Storage of Surface Waters”. Section 373.453 is Surface Water improvement and management (SWIM) plans and programs. This provides for water management districts and other government entities to develop plans for the improvement of surface waters that need improvement, restoration, or additional protection. The language does not exclude the development of water quality criteria and standards as part of management under the SWIM plan. Section 373.4592, Everglades Improvement and Management, provides for a phosphorus limit of 10 parts per billion in the surface water of the Everglades. This is part of the Comprehensive Everglades Restoration Plan.

Application to Coral Reefs

Part VI includes the miscellaneous provisions of Chapter 373. This provides for a liberal construction of the Chapter. The SWIM plan could include activities and criteria that promote water quality to enhance reef resources.

7.3.2.7. Chapter 376, Pollutant Discharge Prevention & Removal

See APPENDIX 9

This chapter records the legislative intent of preserving and maintaining resources that include coastal waters, estuaries, tidal flats, beaches and lands adjoining the seacoast. It recognizes that pollution events may occur and provides a prohibition of pollution into waters and lands of the State in Section 376.041. The statute also provides for liability for natural resource damages caused by pollutant discharge.

Application to Coral Reefs

Coral reef ecosystems are specifically addressed in this chapter, however, the location of the reefs in coastal waters would give applicability for damages to the reef ecosystem. Pollutants are not specifically addressed in terms of any specific water quality standard.

7.3.2.8. Chapter 380, Land & Water Management

See APPENDIX 10

This law provides for the land planning framework for the State including the designation of Areas of Critical State Concern. The chapter provides the process for permitting, designating and protecting the Florida Keys, an area of Critical State Concern (Section 380.051 and Section 380.0552).

Application to Coral Reefs

This chapter (Section 380.0558) defines coral reefs as "the assemblage of corals and other organisms that are actively building three-dimensional reef structures off the southern coast of Florida. The chapter provides for the establishment of a trust fund for coral reefs and natural resources within areas of Critical State Concern. The fund is for the reimbursement of costs incurred by the Department of Environmental Protection in obtaining damages to coral reefs and other resources. This does not provide for any prohibition of pollutants nor does it include any water quality standards.

7.4. Local Laws

Broward County,

Martin County,

Miami-Dade County,

Monroe County,

Palm Beach County

7.4.1. Broward County

See APPENDIX 11

Chapter 27 of the Broward County Code is entitled “Pollution Control”. This chapter makes the distinction between surface and ground water and specifically includes marine waters in the definition of surface water. Section 27-193 is a prohibition against discharges to receiving waters that would cause quality less stringent than the water quality standards. The chapter includes marine water quality standards in Section 27-195.

F.A.C. Chapter 62-302-530 standards are incorporated by reference. Water quality standards and the prohibition could be applied in the waters where coral reefs occur in Broward County. Table 3 shows the Broward County water quality standards for marine, fresh (surface) and ground water. Unless otherwise stated, all criteria express the maximum not to be exceeded at any time. In some cases there are separate or additional limits, such as annual average criteria, which apply independently of the maximum not to be exceeded at any time. N.S. appears for compounds where no standard has been set.

Table 3: Broward County Water Quality Standards for Marine, Fresh (Surface) and Ground Water

CAS#	**COMPOUND**	**MARINE**	**FRESH**	**GROUND**
83-32-9	ACENAPHTHENE	2,700 µg/L	2,700 µg/L	N.S.
15972-60 8	ALACHLOR	N.S.	N.S.	2 µg/L
309-00-2	ALDRIN	1.3 µg/L	3.0 µg/L	1.0 µg/L total
	ALKALINITY	N.S.	Shall not be depressed	N.S.
7429-90-5	ALUMINUM	1,500 µg/L	N.S.	200 µg/L
7664-41-7	AMMONIA (UN-IONIZED)	N.S.	20 µg/L	N.S.
120-12-7	ANTHRACENE	110,000 µg/L	110,000µg/L	N.S.
7440-36-0	ANTIMONY	4,300 µg/L	4,300 µg/L	6µg/L
7440-38-2	ARSENIC (TOTAL)	50 µg/L	50 µg/L	50µg/L
7440-38-2	ARSENIC (TRIVALENT)	36 µg/L	N.S.	N.S.
1912-24-9	ATRAZINE	N.S.	N.S.	3 µg/L
7440-39-3	BARIUM	N.S.	N.S.	2,000 µg/L
71-43-2	BENZENE	71 µg/L annual average	71 µg/L annual average	1 µg/L
50-32-8	BENZO(A)PYRENE	N.S.	N.S.	0.20 µg/L
7440-41-7	BERYLLIUM	0.13 µg/L	0.13 µg/L	4µg/L
319-85-7	BETA HEXACHLOROCYCLOHEXANE	0.046µg/L annual	0.046 µg/L annual average	N.S.
	BOD 5	7,000 µg/L	5,000 µg/L	5,000µg/L
	BROMATES	100,000 µg/L	N.S.	N.S.

CAS#	**COMPOUND**	**MARINE**	**FRESH**	**GROUND**
7726-95-6	BROMINE (FREE MOLECULAR)	100µg/L	N.S.	N.S.
75-25-2	BROMOFORM	Less than or equal to 360 µg/L annual average	Less than or equal to 360 µg/L annual average	N.S.
7440-43-9	CADMIUM	5 µg/L	1 µg/L	5 µg/L
1563-66-2	CARBOFURAN	N.S.	N.S.	40 µg/L
56-23-5	CARBON TETRACHLORIDE	4.42 µg/L annual	4.42 µg/L annual average	3 µg/L
	CBOD 5	7,000 µg/L	10,000 µg/L	N.S.
57-74-9	CHLORDANE	0.004 µg/L	0.0043 µg/L	2µg/L
	CHLORIDE	10% above normal background. Normal and daily seasonal fluctuations shall be maintained	N.S.	250,000 µg/L
	CHLORINATED HYDROCARBONS (NOT OTHERWISE IDENTIFIED BY NAME)	10 µg/L	10 µg/L	10 µg/L
7782-50-5	CHLORINE (TOTAL RESIDUAL)	10 µg/L	10µg/L	1,000 µg/L
124-48-1	CHLORODIBROMOMETHANE	Less than or equal to 34 µg/L annual	Less than or equal to 34 µg/L annual	N.S.
75-01-4	CHLOROETHYLENE (VINYL CHLORIDE)	N.S.	N.S.	1µg/L
68-66-3	CHLOROFORM	Less than or equal to 470.8 µg/L annual average	Less than or equal to 470.8 µg/L annual average	N.S.

CAS#	**COMPOUND**	**MARINE**	**FRESH**	**GROUND**
74-87-3	CHLOROMETHANE (METHYL CHLORIDE)	Less than or equal to 470.8 µg/L annual average	Less than or equal to 470.8 µg/L annual average	N.S.
95-57-8	2-CHLOROPHENOL	400 µg/L	400 µg/L	N.S.
16065-831	CHROMIUM (HEXAVALENT)	50µg/L	11µg/L	N.S.
16065-831	CHROMIUM (TRIVALENT)	673,000µg/L	N.S.	N.S.
165065-831	CHROMIUM (TOTAL)	N.S.	50 µg/L	100µg/L
	COD	N.S.	N.S.	10,000 µg/L
	COLIFORM (FECAL)	A. 200 colonies per 100 ml for monthly average	A. 200 colonies per 100 ml for monthly average	A. 200 colonies per 100 ml for monthly average
		B. 400 colonies per 100 ml for 10% of samples	B. 400 colonies per 100 ml for 10% of samples	B. 400 colonies per 100 ml for 10% of samples
		C. 800 colonies per 100 ml in any sample	C. 800 colonies per 100 ml in any sample	C. 800 colonies per 100 ml in any sample
	COLIFORM (TOTAL)	A. 1,000 colonies per 100 ml for monthly average	A. 1,000 colonies per 100 ml for monthly average	1,000 colonies per 100 ml
		B. 1,000 colonies per 100 ml for 20% of samples	B. 1,000 colonies per 100 ml for 20% of samples	

CAS#	**COMPOUND**	**MARINE**	**FRESH**	**GROUND**
		C. 2,400 colonies per 100 ml in any sample	C. 2,400 colonies per 100 ml in any sample	
	COLOR	No unnatural discoloration shall be apparent except for that resulting from scientific investigation or environmental monitoring	No unnatural discoloration shall be apparent except for that resulting from scientific investigation or environmental monitoring	No unnatural discoloration
7440-50-8	COPPER	3 µg/L	3 µg/L	1,000 µg/L
	CYANIDE	1 µg/L	5 µg/L	200 µg/L
94-75-7	2,4-D (2,4-DICHLORO PHENOXYACETIC ACID)	N.S.	N.S.	70 µg/L
75-99-0	DALAPON (2,2-DICHLORO PROPIONIC ACID)	N.S.	N.S.	200 µg/L
50-29-3	DDT	0.001 µg/L	0.001 µg/L	0.1 µg/L
8065-48-3	DEMETON	0.1 µg/L	0.1 µg/L	0.1 µg/L
	DETERGENT (AS MBAS)	500 µg/L	500 µg/L	N.S.
96-12-8	DIBROMOCHLOROPROPANE (DBCP)	N.S.	N.S.	0.2µg/L
106-93-4	1,2-DIBROMOETHANE (EDB)	N.S.	N.S.	0.02 µg/L
95-50-1	1,2-DICHLOROBENZENE (o-DICHLOROBENZENE)	N.S.	N.S.	600 µg/L
106-46-7	1,4-DICHLOROBENZENE (p-DICHLOROBENZENE)	N.S.	N.S.	75 µg/L
75-09-2	DICHLOROMETHANE (METHYLENE CHLORIDE)	1,580µg/L	N.S.	N.S.

CAS#	**COMPOUND**	**MARINE**	**FRESH**	**GROUND**
75-27-4	DICHLOROBROMOMETHANE	Less than or equal to 22µg/L annual average	Less than or equal to 22 µg/L annual average	N.S.
107-06-02	1,2-DICHLOROETHANE (ETHYLENE DICHLORIDE)	N.S.	N.S.	3 µg/L
75-35-4	1,1-DICHLOROETHYLENE (VINYLIDENE CHLORIDE)	3.2µg/L	3.2 µg/L	7 µg/L
156-59-2	CIS-1,2 DICHLOROETHYLENE	N.S.	N.S.	70µg/L
156-60-5	TRANS-1,2 DICHLOROETHYLENE	N.S.	N.S.	100µg/L
75-09-2	DICHLOROMETHANE (METHYLENE CHLORIDE)	1,580µg/L	1,580 µg/L	5 µg/L
51-28-5	2,4-DICHLOROPHENOL	790 µg/L	790µg/L	N.S.
94-75-7	2,4-DICHLOROPHENOXY	N.S.	N.S.	70 µg/L
75-99-0	2,2-DICHLOROPROPIONIC ACID (DALAPON)	N.S.	N.S.	200 µg/L
78-87-5	1,2- DICHLOROPROPANE	N.S.	N.S.	5 µg/L
103-23-1	DI-(2-ETHYLHEXYL) ADIPATE	N.S.	N.S.	400µg/L
117-81-7	DI-(2-ETHYLHEXY) PHTHALATE	N.S.	N.S.	6µg/L
60-57-1	DIELDRIN	0.0019 µg/L	0.0019 µg/L	N.S.
51-28-5	2,4 - DINITROPHENOL	14,260 µg/L	14,260µg/L	N.S.
121-14-2	2,4 - DINITROTOLUENE	9.1 µg/L	9.1µg/L	N.S.
88-85-7	DINOSEB	N.S.	N.S.	7 µg/L
85-00-7	DIQUAT	N.S.	N.S.	20 µg/L

CAS#	**COMPOUND**	**MARINE**	**FRESH**	**GROUND**
115-29-7	ENDOSULFAN	0.0087 µg/L	0.003 µg/L	0.1µg/L
145-73-3	ENDOTHALL	N.S.	N.S.	100 µg/L
72-20-8	ENDRIN	0.0023 µg/L	0.0023 µg/L	2 µg/L
100-41-4	ETHYLBENZENE	N.S.	N.S.	30 µg/L
107-06-2	ETHYLENE DICHLORIDE (1,2 DICHOLOROETHANE, EDC)	N.S.	N.S.	3 µg/L
206-49-0	FLUORANTHENE	370 µg/L	370 µg/L	N.S.
86-73-7	FLUORENE	14,000 µg/L	14,000 µg/L	N.S.
	FLUORIDE	5,000 µg/L	10,000 µg/L	2,000 µg/L
58-89-9	GAMMA-HEXACHLORO CYCLOHEXANE (LINDANE)	0.004µg/L	0.01 µg/L	0.2 µg/L
1071-83-6	GLYPHOSATE (ROUNDUP)	N.S.	N.S.	700 µg/L
	GROSS ALPHA	N.S.	N.S.	15 pCi/l
86-50-0	GUTHION (AZINPHOS METHYL)	0.01 µg/L	0.01µg/L	0.1 µg/L
76-44-8	HEPTACHLOR	0.0036 µg/L	0.001 µg/L	0.4µg/L
1024-57-3	HEPTACHLOR EPOXIDE	N.S.	N.S.	0.2 µg/L
87-68-3	HEXACHLOROBUTADIENE	49.7 µg/L	49.7µg/L	N.S.
77-47-4	HEXA-CHLOROCYCLO PENTADIENE	N.S.	N.S.	50µg/L
7439-89-6	IRON	300 µg/L	1,000 µg/L	300 µg/L
7439-92-1	LEAD	5.6 µg/L	30 µg/L	15 µg/L
58-89-9	LINDANE (GAMMA-HEXA CHLOROCYCLOHEXANE)	0.004µg/L	0.01 µg/L	0.2 µg/L
121-75-5	MALATHION	0.1 µg/L	0.1 µg/L	0.1µg/L

CAS#	**COMPOUND**	**MARINE**	**FRESH**	**GROUND**
7439-96-5	MANGANESE	N.S.	N.S.	50 µg/L
7439-97-6	MERCURY	0.025 µg/L	0.012 µg/L	2µg/L
72-43-5	METHOXYCHLOR	0.03 µg/L	0.03 µg/L	40µg/L
75-09-2	METHYLENE CHLORIDE (Dichloromethane)	N.S.	N.S.	5µg/L
2385-55-5	MIREX	0.001 µg/L	0.001 µg/L	0.1 µg/L
108-90-7	MONOCHLOROBENZENE	N.S.	N.S.	100 µg/L
7440-02-0	NICKEL	8.3 µg/L	100 µg/L	100 µg/L
	NITROGEN: TOTAL NITROGEN AS N	1,500 µg/L	1,500 µg/L	N.S.
	NITRATE (as N)	N.S.	N.S.	10,000 µg/L
	NITRITE (as N)	N.S.	N.S.	1,000 µg/L
	TOTAL NITRATE + NITRITE (as N)	N.S.	N.S.	10,000 µg/L
	ODORS	N.S.	N.S.	None detectable due to sewage or industrial
	OIL AND GREASE	Dissolved or emulsified oil or grease shall not exceed 1.0 ppm; no undissolved or visible oil as iridescence shall be present	Dissolved or emulsified oil or grease shall not exceed 1.0 ppm; no undissolved or visible oil as iridescence shall be present	Dissolved or emulsified oil or grease shall not exceed 10.0 ppm; no undissolved or visible oil as iridescence shall be present
23135-220	OXAMYL	N.S.	N.S.	200 µg/L

CAS#	COMPOUND	MARINE	FRESH	GROUND
7782-44-7	OXYGEN, DISSOLVED	Daily average not less than 5,000 µg/l. Single reading never less than 4,000 µg/l	Daily average not less than 5,000µg/l. Single reading never less than 4,000 µg/l	N.S.
56-38-2	PARATHION	0.04 µg/L	0.04 µg/L	42µg/L
	PATHOGENS (excluding coliforms)	1 per gallon	1 per gallon	1 per gallon
87-86-5	PENTACHLOROPHENOL	1 µg/L	8.2 µg/L annual average	1 µg/L
127-18-4	PERC (PERCHLORO ETHYLENE, TETRACHLORO ETHYLENE,	N.S.	N.S.	3 µg/L
1918-02-1	PICLORAM	N.S.	N.S.	500 µg/L
	pH	Not less than 6.5 nor more than 8.5 Units	Not less than 6.5 nor more than 8.5 Units	Not less than 6.5 nor more than 8.5 units
108-95-2	PHENOL	300 µg/L	300 µg/L	N.S.
	PHENOLIC COMPOUNDS	N.S.	N.S.	0.1 µg/L
	PHOSPHATES (TOTAL as P)	N.S.	N.S.	10 µg/L
7723-14-0	PHOSPHORUS (TOTAL)	50 µg/L	20µg/L	N.S.
	PHTHALATE ESTERS	N.S.	3.0 µg/L	N.S.
1918-02-1	PICLORAM	N.S.	N.S.	500 µg/L
1336-36-3	POLYCHLORINATED BIPHENYLS (PCBs)	0.03µg/L	0.04 µg/L	0.5 µg/L

CAS#	**COMPOUND**	**MARINE**	**FRESH**	**GROUND**
	POLYAROMATIC HYDRO CARBONS (PAHs). Total of: Acenaphthylene, Benzo(a)anthracene, Benzo(a)pyrene, Benzo(b)fluoranthene, Benzo(ghi)perylene, Benzo(k)fluoranthene, Chrysene, Dibenzo-(a,h)- anthracene, Indeno(1,2,3-cd)pyrene, and Phenanthrene	0.031 µg/L annual average	0.031 µg/L annual average	500 µg/L
129-00-0	PYRENE	11,000 µg/L	11,000 µg/L	N.S.
	RADIOACTIVITY:			
	GROSS BETA RADIUM 226 STRONTIUM 90	1,000 pCi/L 3 pCi/L	1,000 pCi/L 3 pCi/L	1,000 pCi/l 3 pCi/l 10 pCi/l
	(in Picocuries/L)			
7782-49-2	SELENIUM	25 µg/L	5 µg/L	50 µg/L
7440-22-4	SILVER	0.05 µg/L	0.07 µg/L	100 µg/L
93-72-1	SILVEX (2,3,5-TP)	N.S.	N.S.	50 µg/L
	SOLIDS (Floating, Suspended or Settleable)	None attributable to wastes	None attributable to wastes	None attributable to wastes
122-34-9	SIMAZINE	N.S.	N.S.	4 µg/L
7440-23-5	SODIUM	N.S.	N.S.	160,000 µg/L
100-42-5	STYRENE (Vinyl Benzene)	N.S.	N.S.	100 µg/L
	SULFATE	N.S.	N.S.	250,000 µg/L
79-01-6	TCE (Trichloro-ethylene)	N.S.	N.S.	3 µg/L

CAS#	**COMPOUND**	**MARINE**	**FRESH**	**GROUND**
	TEMPERATURE	Not to be above 90°F	Not to be above 90°F	Not to be above 90°F
79-34-6	1,1,2,2-TETRA - CHLOROETHANE	10.8 µg/L	10.8µg/L	N.S.
127-18-4	TETRACHLOROETHYLENE	8.85 µg/L	8.85µg/L	3 µg/L
7440-28-0	THALLIUM	6.3 µg/L	48.0 µg/L	2 µg/L
108-88-3	TOLUENE	N.S.	N.S.	40 µg/L
	TOTAL DISSOLVED GASES	110% of saturation value at the existing atmospheric and hydrostatic pressures	110% of saturation value at the existing atmospheric and hydrostatic pressures	N.S.
	TOTAL DISSOLVED SOLIDS	N.S.	N.S.	500,000 µg/L
8001-35-2	TOXAPHENE	0.0002 µg/L	0.0002 µg/L	3µg/L
	TRANSPARENCY	Not to be reduced by more than 10% as compared to the natural background value	Not to be reduced by more than 10% as compared to the natural background value	N.S.
120-82-1	1,2,4-TRICHLORO -BENZENE	N.S.	N.S.	70 µg/L
71-55-6	1,1,1-TRICHLOROETHANE	173 µg/L	173µg/L	200 µg/L
79-01-6	TRICHLOROETHYLENE (TCE)	80.7 µg/L	80.7µg/L	3 µg/L
79-00-5	1,1,2-TRICHLOROETHANE	N.S.	N.S.	5 µg/L
88-06-2	2,4,6-TRICHLOROPHENOL	6.5 µg/L annual average	6.5µg/L annual average	N.S.

CAS#	**COMPOUND**	**MARINE**	**FRESH**	**GROUND**
	TRIHALOMETHANES, TOTAL (Total Trihalomethanes equals the sum of the concentrations of Bromodichloromethane, Chlorodibromomethane, Tribromomethane (Bromoform) and Trichloromethane (Chloroform))	N.S.	N.S.	100 µg/L
	TURBIDITY	10 NTUs	10 NTUs	10 NTUs
75-01-4	VINYL CHLORIDE	N.S.	N.S.	1µg/L
1330-20-7	XYLENES, Total	N.S.	N.S.	20 µg/L
7440-66-6	ZINC	86 µg/L	86 µg/L	5,000 µg/L

(d) *Other compounds:* If toxic or undesirable compounds other than those listed in Subsection (a), (b), or (c) of this Section, or listed compounds contained in Rules 62-302.530 and 62 520.420, F.A.C., are present, EPD, based on the latest scientific knowledge concerning toxicity and adverse effects on the intended water use, may specify limits.

(e) *Synergistic action:* Whenever evidence indicates that a combination of pollutants exerts a greater effect than the individual pollutants, the EPD may, on the basis of these findings, lower the limits established in Subsections (a), (b), or (c) of this Section.

7.4.2. Martin County

See APPENDIX 12

Chapter 67 of the Martin County Code is titled “Environmental Control”. Section 67.1 has a prohibition against a change in the beneficial use of water. The chapter does not include water quality standards. State law is specifically incorporated by reference which could be applied in the waters where coral reefs occur in Martin County.

7.4.3. Miami-Dade County See APPENDIX 13

Chapter 24 of the Miami-Dade County Code includes water quality standards in Section 24-42(4). The prohibition against violating water quality standards specifically addresses tidal salt water in Miami-Dade County where coral reefs may occur. Further, Section 24-25 incorporates the rules of the State of Florida Department of Environmental Protection and the United States Environmental Protection Agency by reference. Specific standards in this code appear in Table 4.

Table 4: Water Quality Standards for Miami- Dade County

Chemical, Physical or Biological Characteristic	***Fresh Water (water containing less than 500 ppm chlorides)***	***Tidal Salt Water (water containing more than 500 ppm chlorides)***	***Groundwater***
Dissolved oxygen (mg /l)	5 ppm during at least 10 hours per 24-hour period, never less than 4 ppm, unless acceptable data indicate that the natural background dissolved oxygen is lower than the values established herein.		
Biochemical oxygen demand (mg/l)	Shall not exceed a value which would cause dissolved oxygen to be depressed below values listed under dissolved oxygen and in no case shall be great enough to produce nuisance conditions.		
pH	6.0--8.5 1	6.0--8.5 1	6.0--8.5 1
Floating solids, settleable solids, sludge deposits	None attributable to sewage, industrial wastes or other wastes.	None attributable to sewage, industrial wastes, or other wastes.	
Oil and grease (mg/l)	15 2	15 2	15 2
Odor-producing substances	None attributable to sewage, industrial wastes, or other wastes. Threshold odor number not to exceed 24 at 60°C as a daily average.		
Temperature			
Sources permitted prior to July 1, 1972	Shall cause no environmental damage.		
Sources permitted after July 1, 1972	3° above ambient.	(June--September) 2° above ambient. (October--May) 4° above ambient.	

Chemical, Physical or Biological Characteristic	***Fresh Water (water containing less than 500 ppm chlorides)***	***Tidal Salt Water (water containing more than 500 ppm chlorides)***	***Groundwater***
Turbidity	29 NTU above background		
Ammonia (mg/l)	.5 ppm as N	.5 ppm as N	.5 ppm as N
Chlorides (mg/l)	500 3	3	500 3
Chromium (mg/l) total	.05	.05	.05
Cyanides (mg/l)	None detectable	None detectable	None detectable
Detergents (mg/l)	0.5	Insufficient to cause foaming	0.5
Fluoride (mg/l)	1.4 as F	10 as F	1.4 as F
Lead (mg/l)	0.95	0.35	0.05
Phenol (mg/l)	0.001	0.005	0.001
Zinc (mg/l)	1.0	1.0	1.0
Sulfides (mg/l)	0.2	1.0	0.2
Coliform organisms (MPN/100 ml)	1,000 4	1,000 5	50
Mercury	None detectable	None detectable	None detectable
Iron	0.3 mg/l	0.3 mg/l	0.3 mg/l
Arsenic	0.05 mg/l	0.05 mg/l	0.05 mg/l
Specific conductance	500 microohms per cm (fresh water). Not more than 100% above background, in waters other than fresh.		
Dissolved solids	Not to exceed 500 mg/l for monthly average or 1000 mg/l at any time.		

Chemical, Physical or Biological Characteristic	*Fresh Water (water containing less than 500 ppm chlorides)*	*Tidal Salt Water (water containing more than 500 ppm chlorides)*	*Groundwater*
Radioactive substances	Gross beta activity (in known absence of strontium 90 and alpha emitters), not to exceed 1000 micro-microcuries at any time.		
Other compounds	Other toxic or undesirable compounds than those listed above may occur in individual waste streams. Limits for these components may be specified by the Pollution Control Officer based on the latest scientific knowledge concerning toxicity and adverse effect of the intended water use.		
Synergistic action	Whenever scientific evidence indicates that a combination of pollutants exert a greater effect than the individual pollutants, the Pollution Control Officer may, on the basis of these findings, lower the herein established limits to the level necessary to prevent damage to the waters of the county.		

1 Shall not cause the pH of the receiving waters to vary more than 1.0 unit. When the natural background pH lies outside the limits established, the introduction of a waste shall not displace the pH of the receiving waters more than 0.5 pH units from these standards.
2 Shall not be visible, defined as iridescence, or cause taste
or odors. 3 Waste shall not increase natural background
more than 10 percent.
4 Maximum MPN/100 ml in surface water used as a drinking water supply shall be 100.
5 Maximum MPN/100 ml in a tidal water from which shellfish are harvested for human consumption shall be 70. (Ord. No. 04-214, §§ 1, 5, 12-2-04)

7.4.4. Monroe County

See APPENDIX 14

Chapter 5.5 of the Monroe County Code includes no water quality standards and does not reference State law. However, the Monroe County Code establishes "No discharge zones". These are defined as:

"*No discharge zone* means any of the areas located within State waters within the boundaries of the Florida Keys National Marine Sanctuary, as identified in Federal Register Notice 66:144, pp 38967--38969, promulgated on 26 July 2001, and as shown in Attachment A of this Ordinance."

The Federal Register Notice appears at the end of APPENDIX 14.

7.4.5. Palm Beach County

See APPENDIX 15

Chapter 11 of the Palm Beach County Code is titled "Environmental Regulation and Control". The chapter does not include water quality standards. State law is specifically incorporated by reference.

7.5. Miscellaneous Laws & Provisions

7.5.1. Endangered Species Act

See APPENDIX 16

The Endangered Species Act is a comprehensive law designed to identify, protect, conserve and recover endangered and threatened species in the United States. The Endangered Species Act uses an ecosystems approach to address habitats that will provide for recovery of species. Some identified species that utilize marine waters are: Parrot fishes, Florida Manatee, Brown Pelican, American Crocodile, Key Mud Turtle, Kemp's Ridley Sea Turtle, Leatherback Turtle, Atlantic Green Turtle, and the Hawksbill Turtle. In March 2005, National Marine Fisheries Service, and the National Oceanic and Atmospheric Administration filed a notice of a 12 month finding on a petition to add the elk horn coral, stag horn coral and fused-stag horn coral to the list of threatened and endangered species. When these additions are added to the listed species they will place the coral reef ecosystem clearly within the provisions of the act.

The act prohibits the "take" of any listed species. The term "take" under Section 3 (19) of the act "means to harass, harm, pursue, hunt, shoot, wound, kill, trap, capture, or collect, or to attempt to engage in any such conduct". Water quality degradation in the coral reef system can be construed to inflict harm to the proposed listed species, which would then give the Endangered Species Act authority over water quality at the reef system. Under Section 11(f) (Penalties and Enforcement, Regulations) there is authorization to promulgate regulations to enforce the act. Consequently, water quality could become a regulatory issue under this act.

7.5.2. National Marine Sanctuaries Act See APPENDIX 17

The National Marine Sanctuaries Act primarily functions to give the Secretary of Commerce Authority to designate portions of the marine environment as National Marine Sanctuaries. Along with the designation there is authority for management that complements existing regulatory authority. In Section 306, the act includes prohibitions against destruction or causing the loss or injury to sanctuary resources. These resources would include coral reefs within a designated National Marine Sanctuary. The act does not include water quality standards or regulations nor does it address promulgating rules for this.

7.5.3. National Marine Sanctuaries Regulations See APPENDIX 18

Under the National Marine Sanctuaries Act these regulations define the specific standards and procedures for designating an area a National Marine Sanctuary. There are no water quality standards or criteria in these regulations. Within this regulation are the regulations that implement the comprehensive management plan for the Florida Keys National Marine Sanctuary Act. Included in the regulation in Section 922.164(d)(i) is a prohibition in Ecological Reserves and Sanctuary Preservation Areas against the discharge or deposit of any material or other matter except cooling water or engine exhaust.

7.5.4. Florida Keys National Marine Sanctuary; Draft Management Report **See APPENDIX 19**

The Florida Keys National Marine Sanctuary Draft Management Report was revised in February, 2005. It is a five year review of a 1997 Management Plan and Environmental Impact Statement. It includes strategies for management for a period of five years. One management division addresses enforcement and resource protection which includes in Section 3.4.4, a Water Quality Action Plan. This plan identifies both accomplishments of the last five years as well as strategies for the next five years. The main accomplishment in the last five years has been the establishment of a prohibition for no discharges in all state waters in the Florida Keys National Marine Sanctuary and in waters surrounding the City of Key West. One of the strategies (W.5) is the development of Water Quality Standards. Until research indicates the need for more rigorous standards, Outstanding Florida Water (Florida Administrative Code Rule 62-302) standards will be used.

7.5.5. Oil Pollution Act

See APPENDIX 20 and Regulations APPENDIX 21

The Oil Pollution Act (OPA) established a liability scheme for vessels and facilities that spill oil in the United States waters. The law enumerates compensable damages, claims procedures, financial responsibility requirements and how an Oil Spill Liability Trust Fund is used. If damage from an oil spill or vessel occurs to a coral reef the OPA applies. However, the OPA does not include water quality standards.

7.5.1 Coral Reef Conservation Act

See APPENDIX 22

Among the purposes of The Coral Reef Conservation Act of 2000 is to preserve, sustain, and restore the condition of coral reef ecosystems. This law is primarily a funding law for the additional study and assessment of reefs. It does specify that management of reefs is an authorized activity under this act. Although the act does not specifically mention the development of reef specific water quality standards or regulatory programs, the development of management strategies may include regulation and enforcement.

7.5.6. Presidential Order 13089, Coral Reef Protection See APPENDIX 23

In 1998, President Clinton signed Executive Order 13089. This order addresses coral reef protection and defines the composition of a Coral Reef Task Force. Among the duties of the Task Force is an evaluation of land-based sources of pollution, and a determination of whether additional legislation is needed to carry out policies that protect coral reefs. There is no specific reference to water quality standards.

7.5.7 Natural Resources Damage Assessment

See APPENDIX 24

Natural Resources Damage Assessment authorizes the government to seek remediation of environmental damages resulting from the release of hazardous substances or pollutants or other damage to natural resources including coral reefs. The government may seek to abate the action, require restoration and recover costs as well as seek compensation for damages. There are no water quality standards identified in this law as its focus is remediation and damage liability under the Oil Pollution Act, Comprehensive Environmental Response, Compensation and Liability Act or the National Marine Sanctuaries Act.

7.5.8 **Ocean and Coastal Resources Management Act**

See APPENDIX 25

In 2005, Part IV of Chapter 161, Florida Statutes was amended to include the Ocean and Coastal Resources Act. This law creates a Council to review information that is available on the resources and also to identify information that is needed for the development of future ocean and coastal policies.

7.6. Water Quality Standards: Synthesis & Conclusion

Language addressing water quality standards or criteria for the specific purpose of protecting coral reefs is lacking in the laws and regulations. Water quality standards do exist for predominantly marine waters (State of Florida), marine waters (Broward

County) and tidal salt water (Miami-Dade County). These standards could be applied when coral reefs occur in the waters of these jurisdictions.

Other federal, state and local laws and regulations qualitatively prohibit pollution or discharge into waters, however, they do not set quantitative water quality standards. Some laws address physical or discharge damage to coral reef resources and they provide for the calculation of liability, restoration and damage. The State of Florida clearly recognizes the value of ocean, and coastal resources and in 2005 established the Florida Oceans and Coastal Resource Act which will provide for the evaluation of studies, monitoring and research efforts to protect these resources. Ultimately, this may lead to additional research and the collection of scientific data that could be the basis for water quality standards that specifically address the protection of reef systems. A strong base of water quality data will necessarily precede any legislation or rulemaking that leads to regulatory protection specific to waters where reef systems occur. The precedent for an extensive data base to support the promulgation of new laws has been experienced with the phosphorus standard promulgation for Everglades restoration. The development of this standard was contentious even with the existence of substantial data.

Perhaps the most likely practical protection to waters that harbor reefs would be the designation of these waters as Outstanding Florida Waters. For this designation to attach, the process would not necessarily require as extensive a data base that would be needed to promulgate quantitative water quality standards. However, this would serve as additional protection for these reef containing waters. It would provide for a protection from a decrease in water quality or indirect discharges.

8. RECOMMENDATIONS & CONCLUSIONS

This report has examined potential sources and types of pollutants that can negatively affect coral reef communities in the coastal waters of southeast Florida. Federal, state, and local water quality standards have also been reviewed to determine connections between existing regulations and the pollutants of interest.

Research in the field of pollutant impacts on coral reefs is weighted heavily in the areas of temperature and nutrients. Much less work has been accomplished in the areas of pharmaceuticals/organics, sedimentation, and turbidity. For all pollutants investigated, there is a lack of work done specific to southeast Florida coastal waters. Most work performed in Florida is focused mainly in Biscayne Bay and the Florida Keys area. Another major gap in research concerns the lack of studies investigating synergistic effects. Because the marine environment is extremely variable and subject to multiple stressors, such interacting effects need to be better understood. Current research focuses on the impacts of stressors to individual species. To better understand coral reef community response, research is needed at that level.

A review of the federal, state, and local water quality standards and regulations has revealed that coral reefs were not well considered. Water quality standards for this area do not exist, and any numeric criteria that do are unrelated to any possible negative impact on coral reefs. Unfortunately, the lack of scientific evidence has made it difficult to develop new or updated regulations. Information should be obtained as to the mechanism and feasibility of characterizing the coastal waters of southeast Florida, to be considered as an area of “outstanding waters”.

Due to gaps that exist in both the pollution literature and laws/regulations, a major disconnect exists; the science cannot be tied into the regulations. Overall recommendations are that the waters which surround the reef systems off the coast of southeast Florida should be considered part of outstanding Florida waters. In addition, more interdisciplinary and community level research should be done in order to investigate the synergistic effects of multiple stressors on coral reef communities.

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