EVALUATION OF THE WATER QUALITY PROTECTION PROGRAM AND SCIENCE PROGRAM FOR THE FLORIDA KEYS NATIONAL MARINE SANCTUARY

Task 7
Final Report

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1.0 INTRODUCTION

1.1 Background

The Florida Keys National Marine Sanctuary (FKNMS) was designated in 1990 through the Florida Keys National Marine Sanctuary and Protection Act, Public Law 101-605. Section 8 of this act called for the U.S. EPA and the State of Florida, in consultation with the National Oceanic and Atmospheric Administration (NOAA), to develop a comprehensive Water Quality Protection Program (WQPP) for the Sanctuary. The law stated that the purpose of this program was to "recommend priority corrective actions and compliance schedules addressing point and non-point sources of pollution to restore and maintain the chemical, physical and biological integrity of the Sanctuary, including restoration and maintenance of a balanced, indigenous population of corals, shellfish, fish and wildlife, and recreational activities in and on the water." Additionally, the law assigned responsibilities for the implementation of the WQPP to the State of Florida, EPA and NOAA.

The WQPP called for adoption or revision of applicable water quality standards for the Sanctuary based on water quality criteria which may use biological monitoring or assessment methods to assure protection and restoration of the water quality, coral reefs and other living resources. The adoption of enforceable pollution control measures (such as water quality-based effluent limitations and best management practices), as well as methods to eliminate or reduce pollution from point and non-point sources, were also to be implemented.

The WQPP also called for the establishment of a comprehensive water quality monitoring program. This program would determine the sources of pollution causing or contributing to existing or anticipated pollution problems in the Sanctuary, evaluate the effectiveness of efforts to reduce or eliminate those sources of pollution, and evaluate progress toward achieving and maintaining water quality standards and toward protecting and restoring corals and other living resources.

At the time of the Sanctuary designation, many of the complex physical and biological processes in the various Keys ecosystems were not well understood. To implement the actions stated in the Florida Keys National Marine Sanctuary and Protection Act, as well as the National Marine Sanctuaries Program Amendments Act of 1992, H.R. 5617, EPA along with the state of Florida (through the Florida Department of Environmental Protection – FDEP) and NOAA initiated funding for three long-term monitoring projects to understand the status and trends in water quality, corals, and seagrass. This monitoring was initiated in 1995. In addition to the long-term monitoring projects, EPA and its partner agencies funded special studies to help identify cause-and-effect relationships among pollutants and ecological impacts. To date, the water quality, coral and seagrass long term monitoring projects have completed their 12th year and approximately 25 special studies have been funded and completed.

In support of water quality efforts in the Florida Keys, EPA has also provided funding for four environmental restoration projects in the area. Additionally, in collaboration with FDEP, EPA Region 4 provided funding for a $4.326 million Title II Construction Grant for the construction of an advanced wastewater treatment plant and sewage collection system in the Florida Keys. Further, EPA provided a $3.8 million grant to the City of Islamorada, Florida to demonstrate the centralized management of decentralized wastewater systems. In 1999 the Florida Legislature passed State Law 99.395 which set water quality treatment standards for wastewater management systems in the Florida Keys. Additionally, in 2001 the Florida Keys Water Quality Act (Public Law 106-554) was approved by the U.S. Congress and authorized the U.S Army Corps of Engineers to provide technical and financial assistance for wastewater treatment and storm water management projects to improve water quality of the FKNMS. Moreover, EPA Region 4 designated all State waters within the boundary of the FKNMS as a no discharge zone (NDZ) in June 2002 at the request of Monroe County, Florida and then Florida Governor Jeb Bush.

1.2 Report objectives

In March 2007, EPA Region 4 requested support from Battelle Memorial Institute (Battelle) to perform an objective review of the FKNMS Science Program, specifically the comprehensive long term monitoring and special studies projects associated with the WQPP for the Sanctuary, to provide recommendations and next steps to EPA for future monitoring and special studies. Battelle was asked to review the annual reports from 2000 through 2005 (2006 reports were not complete at the time) for the Coral Reef Evaluation and Monitoring Project, Seagrass Monitoring Project and Water Quality Monitoring Project. Battelle also reviewed 22 final special studies reports that had been from funding in 1995, 1997, 2003 and 2004. These reports are listed below by funding year.

Funding Year 1995

- Brand, L. 1997. Semi-Synoptic Sampling of Phytoplankton in Florida Keys National Marine Sanctuary.
- Chanton, J.P. *et al.* 1998. Use of Natural and Artificial Tracers to Detect Subsurface Flow of Contaminated Ground Water in the Florida Keys National Marine Sanctuary.
- Kump, L.R. 1998. Wastewater Nutrients in Ground Water.
- Cook, C. *et al.* 1997. Reef Corals and their Symbiotic Algae as Indictors of Nutrient Stress.
- Hanisak, M.D. 1999. Algal Tissue Nutrients as Indicators of Nutrient Enrichment in the Florida Keys.
- Lapointe, B.E. and W.R. Matzie. 1997. High Frequency Monitoring of Wastewater Nutrient Discharges and their Ecological Effects in the Florida Keys National Marine Sanctuary.
- Shinn, E.A. and A. Tihansky. 1995. Groundwater Seepage Demonstration Project.
- Smith, N.P. and P.A. Pitts. 1998. Hawk Channel Transport Study: Pathways and Processes.

Funding Year 1997

- Chanton, J.P. *et al.* 2001. Use of Artificial Tracers to Detect Subsurface Flow of Contaminated Ground Water in the Florida Keys.
- Kump, L.R. 1998. Fate of Wastewater Nutrients in Florida Keys Ground Water.
- Mueller, E., D.L. Santavy, E.C. Peters, L. MacLaughlin, J.W. Porter, K.L. Patterson and J. Campbell. 2001. Etiology and Distribution of Coral Diseases in the Florida Keys National Marine Sanctuary.
- Pierce, R.H. 1998. Effects of Mosquito Control Measures on Non-Targeted Organisms in the Florida Keys National Marine Sanctuary.
- Richardson, L. 2001. Distribution and Etiology of Two Coral Diseases in the FKNMS: Black Band and White Plague Type II, 1997-2000.
- Rose, J.B. *et al.* 1999. Viral Pathogens and Microbial Indicators in the Canals of the Florida Keys (Phase I and Phase II).
- Swart, P.K. *et al.* 2000. The Impact of Sewage-derived Nutrients on the Florida Keys National Marine Sanctuary.

Funding Year 2003

- Bertelsen, R., A. Dahood, and K. Miller. 2004. Spillover of Lobsters from Western Sambo Ecological Reserve: Scientific Report.

- Hallock Muller,P. 2006. Three New Tools for Reef Monitoring and Risk Assessment: Distinguishing Local from Global Stressors.
- Smith, S.R. and R.B. Aronson. 2006. Coral Population Structure and Dynamics in the Fully Protected Zones of the Florida Keys National Marine Sanctuary.
- Szmant, A.M. *et al.* 2004. Recruitment of *Montastraea faveolata* (species complex): Larval Dispersal, Settlement, and Post-settlement Survivorship.
- Szmant. A. 2006. Recruitment of Two Species of Reef Building Coral *Monastraea*: Factors that Effect Post-settlement Survivorship.
- Lipp, E. *et al.* 2006. Human Fecal Indicator Bacteria and Pathogenic Viruses in Offshore Reefs and Human Recreational Risk in Nearshore Waters of the Florida Keys.

Funding Year 2004

- Bertelsen, R. and K. Maxwell. 2005. Evaluation of Potential Spillover of Lobsters from the Dry Tortugas National Park to the Tortugas Ecological Reserve (North).

Four additional Special Studies projects have been funded to date, but no Final Reports were available for review and were therefore, not considered in this evaluation. These studies include:

- Glazer, 2003. Anthropogenic Effects of Queen Conch Reproductive Development in South Florida
- Harvell, 2003. Origins and Impacts of the Sea Fan Aspergillosis Epizootic Explored with Molecular and Field Techniques.
- Delgado, 2004. The Effect of Water Quality on Embryogenesis and Larval Development of Queen Conch: Implications for Recruitment to and Coastal Development of the Florida Keys.
- Riemer, 2004. Endocrine Disruptors and Pharmaceutical Metabolites in Nearshore Waters of the Florida Keys National Marine Sanctuary.

EPA also requested that Battelle review seven additional projects for which they provided financial support. These “other studies” included:

- Ault *et al.*, 2006. Building Sustainable Fisheries in Florida’s Coral Reef Ecosystem: Positive Signs in the Dry Tortugas
- Ayres Associates, 1998. Florida Keys Onsite Wastewater Nutrient Reduction Systems Demonstration Project
- Boyer *et al.*, 2004. Little Venice Water Quality Monitoring Project: Phase I Results
- Boyer and Briceno, 2006. Little Venice Water Quality Monitoring Project: Phase II Annual Report
- Cox and Hunt, 2005. Change in Size and Abundance of Caribbean Spiny Lobsters *Panulirus argus* in a Marine Reserve in the Florida Keys National Marine Sanctuary, USA. FKNMS Caribbean Spiny Lobsters
- MACTEC, 2003. Monroe County Residential Canal Inventory and Assessment
- Shinn, Reese and Reich, 1994. Fate and Pathway of Injection-Well Effluent in the Florida Keys

The scope of work from EPA also called for review of the Year 2000 Science Advisory Panel Recommendations and the 2002 Sanctuary Comprehensive Science Plan. The Year 2000 Science Advisory Panel represented an earlier activity, supported by the WQPP to review the progress and make observations and recommendations of the monitoring and other science activities in the FKNMS that were conducted between 1995 and 2000. The Comprehensive Science Plan was drafted following the 2000 Science Advisory Panel and serves to complement the Research and Monitoring Action Plan of the

Sanctuary's Management Plan by assessing the science needs at a more detailed level. The review of both the Year 2000 Science Advisory Panel recommendations and the Sanctuary Comprehensive Science Plan was to ensure that the Battelle review of the long-term monitoring projects and special studies would incorporate past recommendations made to WQPP management as well as the current management objectives detailed in the Comprehensive Science Plan.

This document provides an independent review of the long-term monitoring projects and special studies that have been finalized since the Year 2000 Science Advisory Panel review. The document focuses on determining whether the long-term monitoring and special studies conducted to date meet the goals and objectives detailed in the Comprehensive Science Plan. A matrix table presenting the documents reviewed and how well they met the specific management objectives presented in the Comprehensive Science Plan is included as Attachment 1. This document also provides Battelle's recommendations and the Year 2007 Science Advisory Panel recommendations and future considerations to the WQPP/FKNMS science program as it moves forward with future monitoring and special studies funding.

To orient the reader, Section 2.0 provides an overview of the major ecological elements of the FKNMS system. Section 3.0 summarizes the Year 2000 Science Advisory Panel recommendations and presents the management, monitoring and research goals and objectives discussed in the Sanctuary Comprehensive Science Plan. Whether the long-term monitoring projects for coral, seagrass and water quality are addressing the management goals/objectives of the Science Plan is discussed in Section 4.0. A similar review is conducted in Section 5.0 for the special studies projects. Because many agencies are responsible for various aspects of Sanctuary management, communication is critical for the Sanctuary's continued success. Hence Section 6.0 addresses current communication issues within the FKNMS Program and provides ideas on how to ensure effective communication in the future. Section 7.0 summarizes the recommendations developed by Battelle while Section 8 summarizes the recommendations developed by the Year 2007 Science Advisory Panel. Section 9.0 includes comments on the WQPP from elected officials and managers that attended the Year 2007 Science Advisory Panel workshop, along with specific comments received by other workshop attendees.

2.0 ECOSYSTEM ATTRIBUTES AND ECOLOGICAL MEASURES

Unique and nationally significant resources, including the only living coral barrier reefs in North America, emphasize the importance of the Keys and Sanctuary as part of a complex ecosystem. Nearshore and marine waters provide ~~a~~ unique habitats for a variety of plants and animals in the Keys, including seagrasses, fish, and shellfish. Nearshore waters throughout the country provide habitat for 80 percent of the fish species in the U.S., and most commercially valuable fish species depend on nearshore waters at some point during their development. Florida's coral reef tract is also one of the largest bank-barrier reef systems in the world. All but the northernmost reefs lie within the boundaries of the FKNMS. The 9950-km^2 Sanctuary was designated in 1990 to protect and conserve nationally significant biological and cultural marine resources of the area, including critical coral reef habitats, seagrass beds, hardbottom communities, and mangrove shorelines.

The ecologically important marine resources of the Florida Keys are being impacted by a variety of stressors, both natural and human-caused. Boat groundings, propeller scarring of seagrass, accumulation of debris, and improper anchoring practices have been responsible for thousands of hectares of resource damage (FKNMS 1996). Overfishing (both commercial and recreational) has dramatically altered reef fish and other targeted populations, contributing to an imbalance in ecological interactions that are critical to ecosystem structure and function. Evidence has emerged linking nutrients and inadequate wastewater and storm water treatment to degraded nearshore waters with possible ecosystem effects (USACE/SFWMD 2004). Long-term alterations in freshwater management regimes have apparently resulted in water quality concerns in the regional estuaries including Florida Bay and Barnes Sound.

Unique "black-water" and other diatom and phytoplankton events have purportedly caused sponge and seagrass die-offs and fish kills in Florida Bay, which adjoins the Sanctuary (FKNMS 2003). The recent region-wide decreases in coral cover and species diversity, as well as increases in coral diseases and bleaching in recent years, have been alarming and are a cause for great concern.

The Sanctuary addresses these threats using a variety of management programs and by applying regulations that address direct and indirect impacts to coral reef resources. In addition, a network of 24 fully protected ("no-take") zones, which cover approximately 6% of the Sanctuary but protect 65% of shallow bank reef habitats and 10% of coral resources overall, were implemented in 1997 (23 zones) and 2001 (Tortugas Ecological Reserve) to preserve specific areas more completely (see Figure 1).

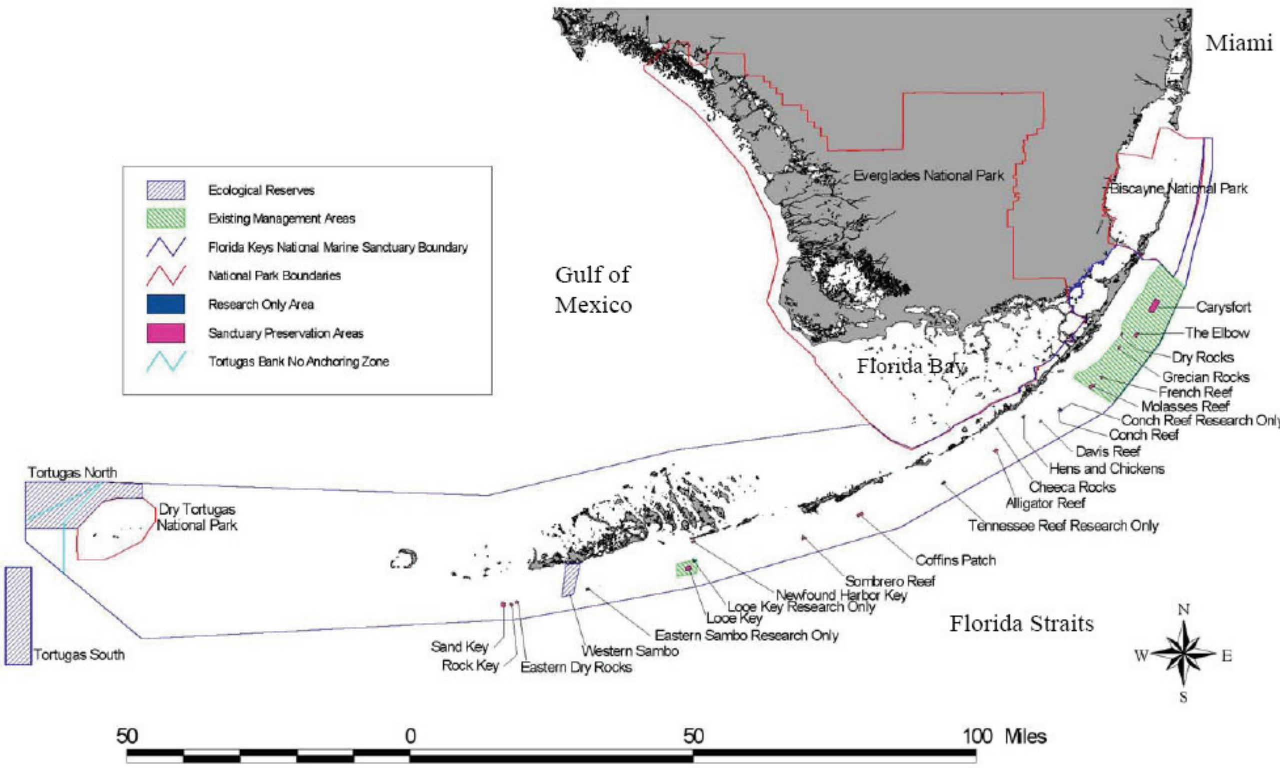

Figure 1. Map of the Florida Keys National Marine Sanctuary with locations of named reefs, ecological reserves and special management areas.

The recent, dramatic declines in reef resources highlight the importance of monitoring both status and trends of habitats Sanctuary-wide and changes within the fully protected zones. In addition, empirical cause-and-effect studies are critical to shed light on additional management tactics that could alleviate and improve overall ecosystem health.

The Florida Keys ecosystem contains one of North America's most diverse assemblages of flora and fauna. The Florida peninsula and Florida Keys serve as a partial barrier between the temperate waters of the Gulf of Mexico and the tropical to subtropical waters of the Atlantic Ocean, resulting in a unique distribution of marine organisms. The coral reef tract, arching in a southwesterly direction for 220 miles, comprises one of the largest communities of its type in the world. It is the only emergent coral reef system off the continental U.S. One of its most noticeable features is its seaward-facing spur-and-groove formation. Over 6,000 patch reefs, circular to oval in shape, lie in nearshore to offshore areas. In addition to corals, algae of various species dominate hard-bottom reef habitats at all sites throughout the Sanctuary. Sponges and soft corals cover a smaller percentage of the sea floor (from about 10 percent to 20 percent).

The ecosystem also supports one of the world's largest seagrass habitats which is among the richest and most productive submerged coastal communities. Seagrass provides food and habitat for commercially and recreationally important species of fish and invertebrates. Without the adjacent seagrass community, the ecological diversity of the coral reef community would likely collapse. Approximately 12,800 km^2 of seagrass beds lie within and adjacent to the Sanctuary. Some variability in seagrass cover and abundance has been identified, although populations seem relatively stable. Mangroves form an important component of this integrated ecosystem, fringing much of the more than 1,600 islands and 1,800 miles of shoreline. Mangroves provide important ecological functions, such as habitat for juvenile fishes and mobile invertebrates, shoreline protection, trapping and baffling of sediment, nutrient uptake and removal, and the surface area of the vast root systems provide habitat for attached organisms such as oysters, sponges, and algae.

Monitoring fish populations occurred for many years before the Sanctuary's designation and continues to the present (Keller and Donahue, 2006). From 1979 through 1998, a total of 263 fish species representing 54 families were observed. Over half of all fish observed were from just ten species. Relatively few fish of legal size have been seen, which is consistent with several studies that indicate reef fish in the Florida Keys are highly targeted. Despite population declines throughout much of the Sanctuary, fish numbers in fully protected zones (Sanctuary Preservation Areas, Ecological Reserves, and Special-use and Research-only areas) are increasing to some degree. Years of data from one monitoring program show that the numbers of individuals of three exploited species are higher in protected zones than in fished sites. Researchers have also seen an overall increase in the average abundance of three snapper species at several sites after the sites were protected (Keller and Donahue, 2006).

Spiny lobsters are more abundant in the larger Sanctuary Preservation Areas and Ecological Reserves that contain diverse lobster habitat than outside these areas. Researchers have found their average size is larger and catch rates (number of lobsters per trap) are often higher than in reference areas during both the open and closed fishing seasons. Queen conch populations have remained low for the last two decades despite a prohibition on their collection since 1985 (Bob Glazer, FWCC, personal communication). Attempts to supplement wild populations with laboratory reared stock and experiments aimed at improving their reproduction are designed to ameliorate the long-term decline in queen conch populations in the region. Sea urchins are low in abundance, especially the long-spined urchin, suggesting poor recovery of this species since its massive Caribbean-wide die-off in 1983 (Keller and Donahue, 2006).

The Florida Keys coral reef ecosystem is highly biologically diverse. The 1996 site characterization of the FKNMS (Chiappone *et al.*, 1996) identified resources which include:

- 520 species of fish, including over 260 species of reef fish
- 367 species of algae
- 5 species of seagrasses
- 117 species of sponges
- 89 species of polychaete worms
- 128 species of echinoderms
- 2 species of fire coral
- 55 species of soft corals
- 63 species of stony corals (45 species which are frequently encountered)

3.0 YEAR 2000 SCIENCE REVIEW PANEL AND 2002 FKNMS COMPREHENSIVE SCIENCE PLAN

In 2000, the WQPP Management Committee convened a Science Advisory Panel to review progress and make observations and recommendations of the long-term monitoring projects and special studies projects that had been conducted to date. The Comprehensive Science Plan was drafted following the 2000 Science Advisory Panel and serves to complement the Research and Monitoring Action Plan of the Sanctuary's Management Plan by assessing the science needs at a more detailed level. Section 3.1 provides a summary of the Year 2000 Science Review Panel recommendations and Section 3.2 presents an overview of the Comprehensive Science Program including the specific management and research goals and objectives.

3.1 Science Review Panel

The Year 2000 Science Advisory Panel was an independent group of scientists convened to provide input and guidance on future special studies and monitoring to the FKNMS managers. Six scientists, including one with local knowledge, were selected as panel members. Presentations on all WQPP-funded monitoring and special studies were presented to the panel members. This included an overview of the coral, seagrass and water quality monitoring projects, the special studies projects and the zone monitoring program. Following discussions to clarify the information presented, panel members made the following recommendations.

- Clear trends are evident from the monitoring projects and special studies data. Therefore, the FKNMS should not wait to start designing and implementing corrective actions.
- The strategic direction of the Program needs to shift the focus from simply status and trends monitoring to identifying and quantifying the causes of degradation and decline and the effectiveness of corrective actions. For example,
    - water quality and benthic communities in canals and nearshore areas are sufficiently degraded to warrant immediate corrective actions; and,
    - the rate of coral reef loss requires immediate attention to determine causes and identify and evaluate potential corrective actions.
- The program needs to identify management triggers which are decisions or action criteria based on chemical or biological measures that act as action levels or thresholds for immediate management action.
- The program needs to focus on quantifying land-based, human induced stressors and the effects/impacts of those human-induced stresses on the nearshore and offshore systems, as well as human health.
- The program may need to introduce a pollution component that focuses on human health and potential endocrine disruption issues in marine animals.
- The program needs to explore the ecological significance of hardbottom communities.
- The program needs to explore the effects of boats and people on the various types of marine habitats.
- The program needs to continue volunteer monitoring, and training in appropriate scientific techniques should be encouraged.

3.2 FKNMS Comprehensive Science Plan

The recommendations of the Year 2000 Science Advisory Panel were instrumental in the drafting of the Sanctuary's 2002 Comprehensive Science Plan. The purpose of the Comprehensive Science Plan is to identify and prioritize the science needs of the FKNMS. It serves to complement the Monitoring Action Plan of the Sanctuary's Management Plan by allowing for assessment of science needs at a much more detailed level. The science framework is established by the Monitoring Action Plan whereas the Science Plan identifies the specific management objectives and the associated monitoring and research needs to address those objectives.

The Science Plan is divided into categories representing the physical and ecological components of the FKNMS. These include: physical oceanography, water quality, coral reef communities, hardbottom communities, seagrass communities, algal communities, mangrove communities, fish communities, queen conch, spiny lobster and benthic invertebrates. The sections below summarize the science plan categories and corresponding management objectives, monitoring and research needs.

It was not the intent of this review to address the entire body of scientific information that may pertain to each of the management objectives and monitoring and research needs included in the Comprehensive Science Plan. Rather this review was limited to the monitoring and special studies projects funded by EPA and its partners implementing the WQPP and a small number of relevant scientific projects prepared external to the WQPP. Moreover, none of the WQPP-funded projects focused on management objectives associated with mangrove communities and other benthic invertebrates. Furthermore, only a small number of WQPP-funded studies have evaluated hardbottom communities, algal communities, queen conch, spiny lobster and fish. Hence, a separate task should be initiated to summarize and evaluate the efforts of other federal, state and local agencies, and individual researchers that are studying these important components of the FKNMS ecosystem.

Physical Oceanography

1. *Management Objective:* Improve our understanding of how regional and local water circulation patterns influence water quality in the Florida Keys.
   a) *Monitoring Need (High Priority):* Maintain or expand the existing SEAKEYS network of monitoring buoys to provide a long-term data set of physical oceanographic parameters.
   b) *Research Need (High Priority):* Develop an internal circulation model for the FKNMS that will interface with other models and will tie together local, regional, and larger-scale patterns.
   c) *Research Need:* Correlate existing water circulation monitoring projects with remote sensing.
2. *Management Objective:* Determine the influence of local and regional currents on recruitment, growth, and survival of Florida Keys marine species.
   a) *Research Need (High Priority):* Develop predictive larval recruitment, dispersal, and connectivity models that include sources, sinks, larval concentrations, and larval behaviors.
3. *Management Objective:* Apply knowledge of physical oceanographic processes to gain insight into biological processes, such as coral bleaching.

Water Quality

1. *Management Objective:* Quantify the relative importance of natural and anthropogenic nutrient and other pollutant loadings to Sanctuary waters from local, subregional (south Florida), and regional (Gulf of Mexico) sources.
   a) *Monitoring Need:* Design a more frequent sampling program.
   b) *Monitoring Need (High Priority):* Regularly scheduled samples should be supplemented with samples timed to include episodic events, such as rainfall, major storms, and upwelling to quantify the impacts of those events on water quality parameters in the Sanctuary.

c) *Monitoring Need:* Add additional stations outside the Sanctuary boundary to the north.

d) *Monitoring Need:* There is a continuing need to eliminate redundancy among existing water quality sampling stations.

e) *Monitoring Need:* Add groundwater monitoring at select locations to continually assess the impact of injected wastewater and storm water on ground water quality.

f) *Monitoring Need (High Priority):* Inter-laboratory comparisons of split samples and standards are essential to assure the comparability of data from samples taken in the FKNMS and analyzed at different laboratories.

g) *Monitoring Need:* Quantify nutrient loading from rain.

h) *Research Need (High Priority):* Develop a nutrient-loading model for the FKNMS ecosystem.

i) *Research Need:* Quantify the organic and nutrient loading from seagrass and algae wrack that accumulates along shorelines and in canals and other confined water bodies.

j) *Research Need:* Quantify loadings from Florida Bay and the Gulf of Mexico into waters surrounding the Florida Keys.

k) *Research Need (High Priority):* Investigate methods of improving water quality in Keys canals.

2. Management Objective: Eliminate or reduce the impact of anthropogenic nutrients, human pathogens, and other pollutants on biological communities and public health.

a) *Research Need (High Priority):* Quantify the geochemical changes in wastewater injected into disposal wells as it passes through limestone.

b) *Research Need:* Investigate how far from a pollutant source changes in biological community structure can be detected.

c) *Research Need:* Develop thresholds and target levels for nutrients and other pollutants that may be harmful to various components of the FKNMS ecosystem.

d) *Research Need (High Priority):* Assess the effects of mosquito spray and other toxicants on non-target living resources.

e) *Research Need:* Determine the role of turbidity and other non-nutrient factors in limiting Sanctuary biological resources.

f) *Research Need:* Assess the risk of poorly functional wastewater collection and treatment systems on public health.

3. Management Objective: Develop methods for rapidly and accurately determining if the ecosystem is responding to changes in water quality conditions. Identify sentinel species or conditions so problems can be identified and corrected before they become chronic.

Coral Reefs

1. Management Objective: Determine the causes of coral reef decline.

a) *Research Need (High Priority):* Determine direct and indirect causes of coral decline with emphasis on cause and effect.

b) *Research Need:* Quantify the effects of coral bleaching on coral survival.

c) *Research Need:* Conduct studies on coral pathology and epizoology with an emphasis on cause and effect.

d) *Research Need:* Identify sentinel species indicative of coral reef decline.

e) *Research Need:* Integrate current coral monitoring techniques with water quality monitoring data to develop water quality thresholds for corals.

2. Management Objective: Identify corrective actions that are required to enhance coral recruitment and growth and prevent future causes of degradation.

a) *Research Need:* Study the relationship between *Diadema antillarum* and corals with an emphasis on the possible enhancement of coral recruitment and growth as a result of *Diadema* transplantation.
b) *Research Need:* Investigate the negative effects of contaminants in the ocean surface layer on coral spawn and larvae.

3. *Management Objective:* Restore and speed up the recovery of coral reef areas that have been degraded.
   a) *Research Need:* Continue the development of reef restoration techniques with an emphasis on transplantation of hardy specimens, genetic variability, cultured corals, and coral plugs to damaged areas.
4. *Management Objective:* Assess and eliminate redundancy in the current coral reef monitoring programs.
   a) *Monitoring Need (High Priority):* Develop a refined coral monitoring program using existing data and assessment techniques.
   b) *Monitoring Need:* Conduct broad surveys of coral cover. In addition to monitoring long-term stations, there is a strong need for periodic, synoptic "snap shots" of coral reefs throughout FKNMS.

Hardbottom Communities

1. *Management Objective:* Determine functional significance of hardbottom communities in FKNMS, including a characterization of sponge communities.
   a) *Monitoring Need:* Develop a refined hardbottom community monitoring program based upon existing data and assessment techniques.
   b) *Research Need:* Determine the functional significance of hardbottom communities in the FKNMS ecosystem.
   c) *Research Need:* Assess the role of hardbottom communities in the life cycles of reef fishes.
   d) *Research Need:* Assess the effects of water quality on hardbottom communities.
2. *Management Objective:* Understand the history and ecological dynamics of hardbottom communities in the FKNMS environment and determine the role of hardbottom communities in predicting changes in reef communities.
   a) *Research Need:* Investigate the history and ecological dynamics of hardbottom communities on a geologic time scale.
3. *Management Objective:* Reduce anthropogenic impacts on hardbottom communities through the continued marking of hardbottom locations and boundaries.
4. *Management Objective:* Examine the effects of commercial sponging on hardbottom communities in the FKNMS.
   a) *Research Need:* Quantify the habitat value of commercial sponges and assess the impact of harvesting on habitat and water quality.
5. *Management Objective:* Ameliorate existing damage to hardbottom communities. Studies are required to determine the most effective approaches toward restoring damaged hardbottom communities.

Seagrass Communities

1. *Management Objective:* Identify the status and trends of local seagrass populations.
   a) *Monitoring Need (High Priority):* Maintain status and trends monitoring of seagrasses to track seagrass loss and recruitment Sanctuary-wide.
2. *Management Objective:* Determine the influence of seagrasses on the homeostasis of local communities. This objective includes identifying the extent that seagrasses serve as indicators of local and regional water quality changes.
3. *Management Objective:* Reduce anthropogenic impacts to seagrass beds and ameliorate existing damage that continues to occur.

a) *Monitoring Need:* Continue to assess impacts to seagrasses in the Sanctuary.
b) *Research Need (High Priority):* Develop and evaluate new restoration techniques.

4. Management Objective: Assess the linkage between seagrass diversity, distribution, and abundance and water quality parameters.

a) *Research Need (High Priority):* Assess the correlation between water quality and seagrass distribution.

Algal Communities

1. Management Objective: Understand the dynamics of algal communities in response to natural and anthropogenic environmental changes

a) *Monitoring Need:* Include measurement of species composition and productivity of benthic algae in seagrass and coral reef/hard bottom monitoring programs.
b) *Research Need:* Investigate the dynamics of algal communities in response to environmental changes.
c) *Research Need:* Develop a model to predict biological community responses to natural and anthropogenic stresses.

Mangrove Communities

1. Management Objective: Continue to protect mangrove resources with an emphasis on the removal and elimination of invasive exotics.

2. Management Objective: Restore mangrove shorelines in appropriate locations. In consultation with the FDEP, the identification of key areas for mangrove restoration projects should be determined.

a) *Monitoring Need:* Assess historic shoreline conditions using aerial photography.
b) *Monitoring Need:* Evaluate these data and develop priority restoration plans for mangroves in the Sanctuary.

Fish Communities

1. Management Objective: Maintain a healthy and diverse fish community.

a) *Monitoring Need (High Priority):* Continually evaluate and optimize existing status and trends monitoring.
b) *Research Need:* Examine the effects of habitat degradation and loss of coral on local fish community structure and stability.

2. Management Objective: Give more attention to and gain a better understanding of the role, diversity, and ecological significance of non-food fish species in the community; include biogeographic distribution in order to be more predictive of responses to protection.

a) *Monitoring Need:* Examine bycatch and incidental catch in alternative fisheries.

3. Management Objective: Assess the effectiveness of SPAs and other management tools used in the preservation of both target and non-target species.

a) *Monitoring Need (High Priority):* Monitor the effects of new artificial reefs, including the Spiegel Grove, on local fish communities.
b) *Research Need (High Priority):* Create an ecosystem model for reef fish communities in the FKNMS to predict cascading effects of zoning on reef fishes.

Queen Conch

1. Management Objective: Assess the effectiveness of current management actions and restore queen conch populations to historic levels.

a) *Monitoring Need (High Priority):* Continue current status and trends monitoring of queen conch.

b) *Research Need (High Priority):* Determine limiting factors to conch reproduction and survival including environmental factor(s), settlement of larvae and survival of juvenile queen conch.

2. Management Objective: Ascertain the role of queen conch in predicting changes in the coral reef community and determine the role of the larger ecosystem in their recovery.

Spiny Lobster

1. Management Objective: Continue to assist current fisheries managers where appropriate.

a) *Monitoring Need (High Priority):* Continue current spiny lobster status and trends monitoring, including zone monitoring.

b) *Research Need:* Investigate the impact of lobster fishing gear on the FKNMS environment.

2. Management Objective: Understand the role of spiny lobster in the ecosystem and determine their ecological significance.

a) *Research Need:* Assess and evaluate current knowledge concerning the ecological significance of lobster populations in the FKNMS.

Other Benthic Invertebrates

1. Management Objective: Determine the functional significance of benthic invertebrates, including bioeroders, in the FKNMS ecosystem.

a) *Research Need:* Investigate the functional significance of abundant macro-invertebrates such as sea biscuits *(Clypeaster rosaceus)*, cushion stars *(Oreaster reticulatus)*, sea cucumbers, and sand dollars.

b) *Research Need (High Priority):* Investigate the lack of recruitment of *Diadema* to adult populations.

2. Management Objective: Assess the importance of benthic invertebrates for purposes of bioassessment.

a) *Research Need (High Priority):* Identify appropriate bioindicators of overall reef health and environmental change with an emphasis on echinoderms, smaller benthic invertebrates, such as amphipods and isopods, and other benthic species that respond quickly to environmental change using an approach similar to that taken in the analysis of freshwater lakes and streams (Index of Biological Integrity).

Overarching Objectives and Needs

1. Management Objective: Complete the benthic habitat inventory for the FKNMS

a) *Research Need:* Use available technologies to fill gaps in the current benthic inventory for the Sanctuary

2. Management Objective: Identify Performance Indicators and thresholds with regard to resource management.

a) *Research Need:* Conduct studies necessary for the identification of valid performance indicators and thresholds with regard to resource management

3. Management Objective: Ascertain current use patterns, including diving boating and fishing in the FKNMS

a) *Research Need:* Conduct additional user surveys in the FKNMS to ascertain current use patterns including diving, boating and fishing in the FKNMS

4.0 LONG-TERM MONITORING PROGRAMS

The primary purpose of each of the long-term monitoring projects is to evaluate the status and trends of coral, seagrass and water quality. Long-term datasets can help manage marine ecosystems effectively. When designed and implemented effectively, these long-term data can capture many natural phenomena that occur over extended time periods such as population explosions and declines, diseases, periodic oceanographic events, global warming trends or sea level rise. The following section considers whether the WQPP-funded long-term monitoring programs for coral, seagrass and water quality are meeting the Year 2000 Science Advisory Panel recommendations and the Comprehensive Science Plan management objectives, monitoring and research needs. Also discussed is where these programs may be lacking.

4.1 Coral

The Coral Reef Evaluation and Monitoring Project (CREMP) conducted by the Florida Fish and Wildlife Conservation Commission's Fish and Wildlife Research Institute is part of the WQPP for the FKNMS. The ultimate goal of this project is to repeatedly sample fixed stations with broad spatial coverage and to statistically document status and trends of coral communities within the Sanctuary. The results are intended to assist managers in understanding, protecting, and restoring the living marine resources of the FKNMS. The ongoing plan is for the results of the coral reef monitoring to be integrated with the WQPP long-term seagrass and water quality monitoring projects. Results can be used to focus research on determining the cause and effect of recent coral reef decline (or stability) and to direct and implement future science-based management decisions. To address this review's objectives, the sampling program and key findings are first summarized. Specific progress towards each management goal under the CREMP is then addressed.

Sampling site locations were initially chosen in 1994 using a stratified random sampling procedure (US EPA EMAP). Forty reef sites were selected within the FKNMS and permanent station markers (4 stations per site) were installed in 1995 (Figure 2). Annual sampling began in 1996 and has continued through 2006. Statistical analyses of CREMP data provided for a reduction in sampling effort in the spring of 2001 with no reduction in spatial scale. This action resulted in significant cost savings. Three additional sites were installed and sampled in the Dry Tortugas beginning in 1999. In 2000, three hardbottom sites were dropped and one additional site was dropped in 2006. The project's existing 39 sites include three hard-bottom, 11 patch, and 12 offshore shallow and 13 offshore deep reef sites. It is important to note that the FY 2008 work plan for the CREMP calls for the addition of 6 patch reef sites within Hawk Channel; 2 each in the Upper, Middle and Lower Keys. In addition to modification in sampling locations, starting in 2001, additional sampling methods were incorporated to help researchers better understand the causes of coral decline and the effects of multiple stressors on coral reefs. These techniques included bio-eroding clionid sponge surveys, a more definitive evaluation of stony coral diseases, and stony coral population surveys. Small *in situ* temperature loggers were installed at all value-added sites during 2002 and early 2003. These data-loggers recorded water temperature hourly and are recovered, downloaded, and re-deployed quarterly. The temperature data are being collected to document possible trends within FKNMS sampling sites.

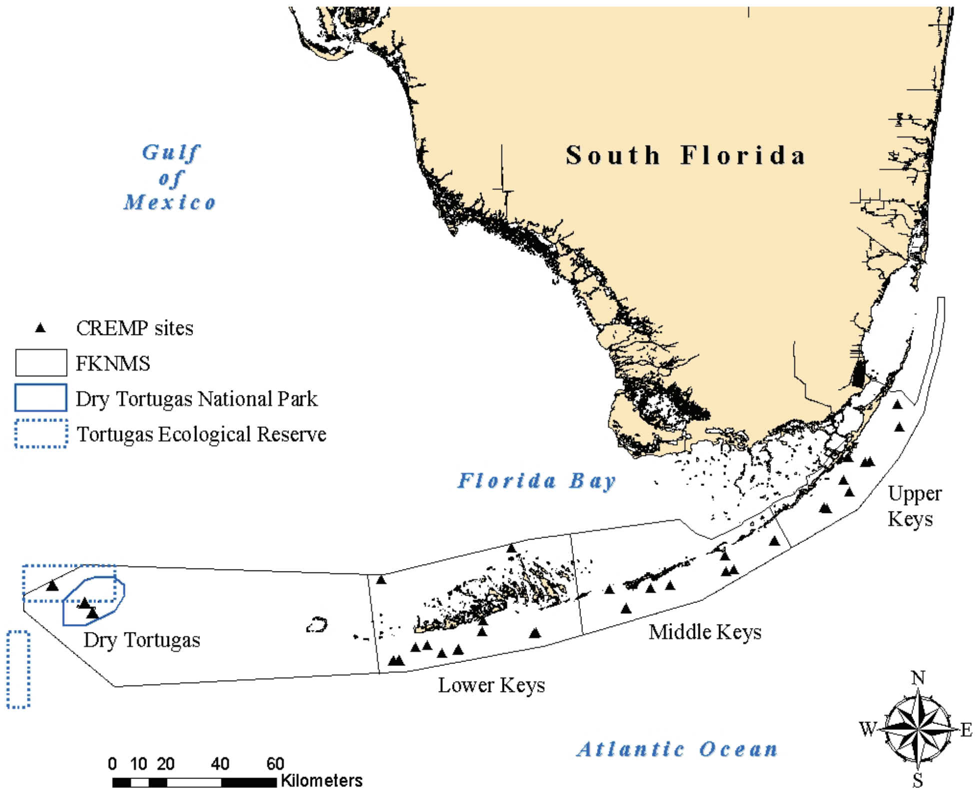

Figure 2. Map showing CREMP monitoring site locations and region boundaries as of January 2006

Annual report summaries of the CREMP have shown that Sanctuary-wide the number of stony coral species declined at 81 of 105 (77%) stations, increased at 19 (18%) stations, and remained unchanged at 5 (5%) stations from 1996-2005. Since 1996, a decline in the mean number of stony coral species was recorded in all habitat types except hardbottoms. However, between 2004 and 2005, the mean number of species increased at all habitat types except hardbottoms. During 2005, the offshore deep and patch reef stations had the greatest numbers of stony coral taxa with a mean of 17 and 16 species, respectively. Hardbottom stations had the fewest number of stony coral species, averaging 11 species per station. Between 1996 and 2005, the CREMP documented a decrease in the mean number of species per station at Upper, Middle and Lower Keys stations. However, between 2004 and 2005, the mean number of species per station increased at Upper, Middle and Lower Keys sites. By region, the Upper Keys has experienced the greatest decline with significant loss in coral cover, followed by the Lower Keys, and the Middle Keys. The greatest declines in coral cover occurred between 1996 and 1999. Coral cover declined from 11.9% in 1996 to 7.4% in 1999. The changes observed from 1996 to 1997, and 1999 to 2003 were determined to be not significant. A significant decrease was observed between 2003 and 2004 when stony coral cover decreased from 7.2% to 6.6%. No statistically significant change was detected in coral cover between 2004 and 2005. In 2005 stony coral cover Sanctuary-wide was 6.7%. Patch reef stations had the highest mean percent stony coral cover. Hardbottom stations had the lowest mean percent stony coral cover; however, those stations have been the most stable between 1996 and 2004.

From its inception, the CREMP has documented long-term changes in the status and trends of coral reefs throughout the 2,800-square-nautical-mile FKNMS. The outcome of these results, especially a precipitous drop in coral cover around 1998 led to the establishment of specific management objectives with regard to the CREMP. The cessation of rapid decline documented in the early stages of the project is encouraging.

However, there is a general consensus that multiple stressors acting at local, regional, and global scales are continuing to have negative affects on coral reefs in the Florida Keys and elsewhere.

As mentioned above, the overarching objective of the CREMP is to statistically document status and trends of coral communities within the Sanctuary. The specific objectives include:

1. providing data needed to make unbiased, statistically rigorous statements about the status and temporal trends of coral communities in the Sanctuary;
2. defining reference conditions in order to develop resource-based water quality standards; and
3. providing a framework for testing hypothesized pollutant fate/effect relationships through process-oriented research and monitoring.

The specific management objectives identified in the Comprehensive Science Plan for addressing corals include:

1. Determining the causes of coral reef decline;
2. Identifying corrective actions that are required to enhance coral recruitment and growth and prevent future causes of degradation;
3. Restoring and speeding up the recovery of coral reef areas that have been degraded; and
4. Assessing and eliminating redundancy in the current coral reef monitoring programs.

These specific objectives and whether the CREMP support them are addressed in the sections below.

4.1.1 Management Objective 1 - Causes of Coral Reef Decline.

The CREMP is directly relevant to the Coral *Management Objective 1*. In the initial years of the CREMP, there was a significant loss in coral cover throughout the Sanctuary. Understanding the causality of the decline became problematic, however, because of the numerous, essentially synchronous, disturbances that ravaged the system. These included coral disease outbreaks, coral bleaching events, predation by mobile corallivores, storms and hurricanes, and a “black water” event. It is presently thought that multiple stressors acting at local, regional, and global scales were the cause of the mortality (Porter *et al.*, 2002). However, because the CREMP sites are only monitored once per year, assigning specific causality to these events could only be made by inference because many of the causes of decline probably occur on time scales of less than one year. As a result, specific additions to the CREMP were made for evaluating coral disease, bleaching, and clionid sponge infestation. However, these are still limited by the current once per year monitoring protocol. Another area that has been especially problematic has been identifying the causative pathogen of the numerous reported diseases, therefore diseases have been described by their symptoms, such as ‘white pox’, ‘yellow blotch’ etc. limiting the usefulness of these data.

Another issue that plagues many recently established monitoring programs is that developing cause-effect information for much of the loss of coral cover is not possible because many of the sentinel species indicative of coral reef decline have already been reduced to the point were they can no longer serve as an indicator of reef health. These include the *Acropora* species and the *Montastraea annularis* species complex (Precht and Miller 2006). This is because the program began after substantial coral loss had already occurred, particularly the demise of the branching corals *A. palmata* and *A. cervicornis* (Porter and Meier, 1992). Of the original 40 sites in the study, only seven contained *A. palmata* in 1996. At these seven sites, the average loss of *A. palmata* was 85% between 1996 and 1999 (Patterson *et al.* 2002). However, given the rapid growth rates, these species may serve as the bellwether for reef recovery (Precht and Aronson 2006).

Only recently has there been an attempt to integrate water quality parameters and the reef community dynamics in the CREMP. This has limited the ability for researchers to develop basic hypotheses with which to address local water quality issues that could ultimately lead to developing water quality thresholds for corals. The CREMP co-principal investigator has prepared the first draft of a paper and the statistical comparison of data from both projects should be finalized in FY 2008.

4.1.2 Management Objective 2 - Identify Corrective Actions.

Although the CREMP does not specifically address the issue of "corrective actions;" long-term monitoring is necessary to assess current trends and future impacts that could lead to the development of species-specific studies established to support this objective. The CREMP, as it is currently designed, is investigating the dynamics between *Diadema* and the benthic community and the role this keystone species plays with regards to facilitation of reef recovery. At present, there is no experimental work nor transplantation studies being performed with *Diadema* within the CREMP. It should be noted, however, that the CREMP never proposed to undertake significant *Diadema* experiments. There are a few research programs outside the purview of this review that have experimentally re-seeded *Diadema* within small areas in the Sanctuary with mixed results (see Moe 2003; Miller and Szmant 2006).

4.1.3 Management Objective 3 - Restore and Speed up Recovery.

The CREMP does not specifically address this objective. However, long-term monitoring is necessary to assess current and future impacts. A research need identified for this objective in the Comprehensive Science Plan calls for development and evaluation of new coral restoration techniques. This is not included in current long-term coral reef monitoring project. For areas within the FKNMS in need of restoration, a demonstration project using new or existing techniques could be implemented and the current CREMP could play a role in the continued monitoring of the restoration area to provide information on project efficacy.

4.1.4 Management Objective 4 - Assess and Eliminate Redundancy

The CREMP continues to be refined through adaptive monitoring as trends in existing data reveal the need for additional information. This includes adding new assessment tools and techniques through time. At present the CREMP appears to fulfill the need to conduct broad surveys of coral cover over large areas through long-term monitoring of fixed stations. The EPA program and two other Keys-wide sampling programs (Murdoch and Aronson 1999; Miller, Swanson, and Chiappone 2002) are important because they documented patterns of community structure, and underlying processes that drive community structure can sometimes be inferred from patterns that emerge across multiple spatial scales. The CREMP results focused on change over time, but understanding change across spatial scales is also important. For example, across deeper reef sites (13–19 m) in the Keys, spatial variability was found to be greater between adjacent reefs than across geographic regions (Murdoch and Aronson 1999). Assessments of marine protected areas across the Florida Keys, which were originally selected to capture much of the shallow spur-and-groove habitat in the FKNMS, revealed that these reefs are as likely to be different from each other as they are from surrounding reference sites or those subjected to fishing (Miller, Swanson, and Chiappone 2002). Both studies suggest that processes operating at multiple spatial scales determine coral community structure. Furthermore, these results are important from a management perspective because it is easier and more cost-effective to manage a system if the constraints on overall system variability and history is known rather than trying to achieve results that are outside the bounds of the system (Precht and Miller 2006).

4.1.5 Hardbottom Communities Management Objectives

At present, only the CREMP addresses any of the research needs established for hardbottom communities in the Comprehensive Science Plan. However, only three of the 39 sites being monitored include hardbottom locations. Hardbottom stations in the CREMP had the fewest number of stony coral species, averaging only 11 species per station. While hardbottom stations had the lowest mean percent stony coral cover, those stations have been the most stable between 1996 and 2006. While coral cover has been relatively stable, these hardbottom stations exhibit high variability of other benthic components including sponges, octocorals, and algae. There are presently non-EPA funded studies that are addressing the variability of these hardbottom communities in more detail.

4.2 Seagrass

The overarching objective of the Seagrass Monitoring Project in the FKNMS is to evaluate the status and trends of seagrass communities to better assess the progress made toward protecting and restoring this critical resource. This project is conducted by Florida International University's Southeast Environmental Research Center. The specific objectives include:

1. providing data needed to make unbiased, statistically rigorous statements about the status and temporal trends of seagrass communities in the Sanctuary as a whole and within defined strata;
2. defining reference conditions in order to develop resource-based water quality standards; and
3. providing a framework for testing hypothesized pollutant fate/effect relationships through process-oriented research and monitoring.

Several goals have been identified to support the objectives and include:

- Defining the present distribution of seagrasses
- Providing high-quality, quantitative data on the status/condition
- Quantifying the importance of seagrass primary production
- Define the baseline conditions for the seagrass communities
- Determine relationships between water quality and seagrass status/condition
- Detecting trends in the distribution and status of the seagrass communities

Seagrasses in the FKNMS have been monitored since 1996 under this long-term monitoring project. The monitoring design consists of sampling at Level 1, Level 2 and Level 3 sites. This strategy is intended to monitor trends at several "permanent" sites (Level 1) and to characterize the broader seagrass population through less intensive sampling at additional sites (Level 2 & 3). Seagrasses are sampled quarterly at 30 Level 1 sites. These sites are co-located with the water quality monitoring sites (Figure 3) and are sampled for abundance, productivity and nutrient availability (for FY2000 – FY2003 also sampled for demographics – i.e., # shoots, # blades, blade length, etc.). The Level 2 and Level 3 sites are sampled annually and were randomly selected. Level 2 sites are sampled for abundance and nutrient availability (for FY2000 – FY2003 also sampled for demographics) and Level 3 sites sampled for abundance. During 2001 and 2002 sampling was not conducted at the Level 2 and 3 sites. In 2003 re-sampling of the same level 2 and level 3 sites that were sampled in 1996 was conducted. Likewise, in 2004, Level 2 and 3 sites that were originally sampled in 1997 were re-sampled and in 2005, Level 2 and 3 sites that were sampled in 1998 were re-sampled. By using this strategy, pairwise comparisons of the status of benthic communities over a 7-year interval can be conducted.

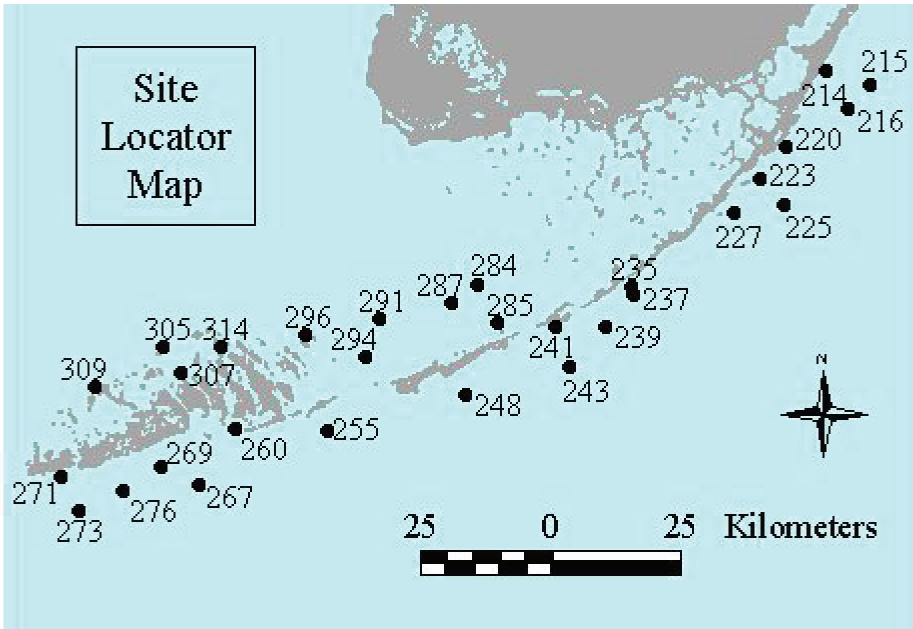

Figure 3. Location of Level 1 seagrass monitoring sites in the FKNMS. Site numbers correspond to water quality monitoring locations (Fourqurean *et al.*, 2000).

4.2.1 Management Objective 1 – Identify Status and Trends

The long-term Seagrass Monitoring Project is directly relevant to Seagrass *Management Objective 1* to identify the status and trends of local seagrass populations. The monitoring design using the Level 1, 2 and 3 sampling sites lends itself to this type of status and trends analysis. The latest Seagrass Monitoring Project annual report states that significant changes in seagrass communities are being observed at the Level 1 sites, and that the preliminary review of data from Level 2 and 3 sites are showing trends in abundance of several seagrass species (Fourqurean and Escorcia, 2005).

In addition to maintaining the status and trends monitoring, the Comprehensive Science Plan also recommends that remote sensing techniques be explored to monitor seagrasses. Remote sensing is not included in the annual reports for the seagrass monitoring project. It is unclear whether the Principal Investigators on the project have attempted to identify any techniques or acquire existing remotely sensed seagrass data for comparison to field data collected to determine if using this type of information would be scientifically beneficial and cost effective. It may be advantageous for the WQPP to provide additional funding, either through the existing long-term Seagrass Monitoring Project or a new special studies project, to address the remote sensing issues. Additionally, use of new aircraft mounted sensors could be tested through a demonstration project to evaluate remotely sensed output with the existing seagrass coverage information that has been generated over the 12 year seagrass monitoring project. By looking into use of remote sensing data, the long-term seagrass monitoring study could be streamlined if appropriate algorithms and models can be developed. The number of physical sampling stations monitored annually could potentially be reduced or at minimum, sampled less frequently.

Statistical optimization techniques may also be employed to determine if the number of sampling stations for Level 2 and Level 3 sites could be reduced either spatially or temporally. This analysis needs to be followed by a cost-benefit analysis of the reduced sampling. In many cases, given the preparation and mobilization time for these types of field activities, reducing a small number of sampling stations may not provide substantial cost savings.

4.2.2 Management Objective 2 – Seagrass Influence on Local Communities

In terms of *Management Objective 2* which includes identifying the extent that seagrasses serve as indicators of local and regional water quality changes, the data generated from the long-term seagrass monitoring project can be used to evaluate water quality conditions. The changes in the seagrass communities appear to be consistent with model predictions of nutrient-induced changes. The PIs state that "There may be reasons for these observations that are unrelated to man's activities in the region, but the spatial pattern of the changes and the agreement of the changes with models of the system suggest that there is a regional-scale change in nutrient availability that is causing changes in seagrass beds over a wide portion of the FKNMS" (Fourqurean and Escorcia, 2005). By evaluating the seagrass leaf tissue concentrations of nitrogen and phosphorus and the manner in which they change, the Project is also evaluating nutrient availability in the FKNMS.

4.2.3 Management Objective 3 – Anthropogenic Impacts Reduction

Management Objective 3 pertains to the reduction of anthropogenic impacts to seagrass beds and amelioration of existing damage that continues to occur. Currently, the long-term Seagrass Monitoring Project does not specifically address this issue; however, long-term monitoring is necessary to assess current and future impacts. A research need identified for this objective calls for development and evaluation of new seagrass restoration techniques. The current long-term seagrass monitoring project does not address this issue. However, separate from the long-term monitoring and special studies projects, EPA has funded an experimental seagrass restoration project at Lignum Vitae State Preserve (Kenworthy *et al.* 2000). That study evaluated the effect of injecting nutrients and plant growth hormones into seagrass scars. Additionally, the FKNMS has a Seagrass Restoration Team that evaluated other innovative restoration techniques such as bird stakes, sediment tubes, and automated planting devices. For areas within the FKNMS in need of restoration, a demonstration project using a new or existing technique could be implemented and the current seagrass monitoring project could play a role in the continued monitoring of restoration area to provide information on whether the project is successful.

4.2.4 Management Objective 4 – Seagrass and Water Quality Linkages

Along with *Management Objective 2*, *Management Objective 4* pertains to linkages between seagrass diversity, distribution, abundance and water quality parameters. The design of the Seagrass Monitoring Project and the Water Quality Monitoring Project allow for these linkages to be evaluated. The Level 1 sites are located in conjunction with the water quality monitoring sites, and the Principal Investigators have been sharing information. The research need for this management objective calls for an assessment of the correlation between various water quality parameters and seagrass distribution. In addition to this correlation, it may be beneficial to begin development of simple models to predict the impacts of various concentrations of particular water quality parameters on specific seagrass parameters to better set nutrient loading targets. Analyses of the data associated with the Seagrass Monitoring Project has led to twenty-two peer-reviewed publications in the scientific literature. One paper addressed the distribution and trends in macroalgal components of tropical seagrass communities in relation to water quality (Collado-Vides *et al.* 2007). Another paper forecasted the response of seagrass distribution to changes in water quality using statistical models (Fourqurean *et al.* 2003).

4.2.5 Algal Community Management Objective

In addition to monitoring the seagrasses within the FKNMS, the Long-term Seagrass Monitoring Project does record macroalgal abundance and distribution at the same seagrass monitoring sites (Level 1, 2 and 3). The macroalgal species are also recorded. The presence of macroalgae is critical to monitor along with seagrasses because as nutrients are added to aquatic systems, the competitive balance shifts from seagrasses to faster growing primary producers such as macroalgae. Additional studies and models are needed to evaluate and predict the dynamics of algal communities in response to environmental change.

These studies should attempt to identify threshold levels for a variety of parameters at which changes in the algal community are observed. It is not apparent whether the data collected for the Long-term Seagrass Monitoring Project are sufficient to address these specific algal community issues. One special study project evaluated chlorophyll concentrations via phytoplankton in response to eutrophication. Although the study confirmed that higher chlorophyll concentrations were often associated with areas with potential nutrient sources (i.e., cesspools, marinas, sewage outfalls etc.) the data do not appear to support the development of threshold concentrations for the algal community.

4.3 Water Quality

The general goal of the Water Quality Monitoring Project (WQMP) is to measure the status and trends of water quality parameters to evaluate progress toward achieving and maintaining water quality standards and protecting and restoring the living marine resources of the Sanctuary. The specific objectives include:

1. providing data needed to make unbiased, statistically rigorous statements about the status and temporal trends of water quality parameters in the Sanctuary as a whole and within defined strata;
2. defining reference conditions in order to develop resource-based water quality standards (biocriteria); and
3. providing a framework for testing hypothesized pollutant fate/effect relationships through process oriented research and monitoring.

Since it began in 1995, the WQMP has sampled standard water quality parameters quarterly at 154 stations throughout the Sanctuary (Figure 4). The parameters measured include salinity, temperature, dissolved oxygen, turbidity, relative fluorescence, light attenuation, chlorophyll a, alkaline phosphatase activity, nitrate, nitrite, ammonia, dissolved inorganic nitrogen, soluble reactive phosphate, total nitrogen, total organic nitrogen, total phosphorus, silicate and total organic carbon. For each annual report, rather than merely summarizing that year's findings, the Principal Investigators compile the results from every year of activity to provide a comprehensive view of the project's progress.

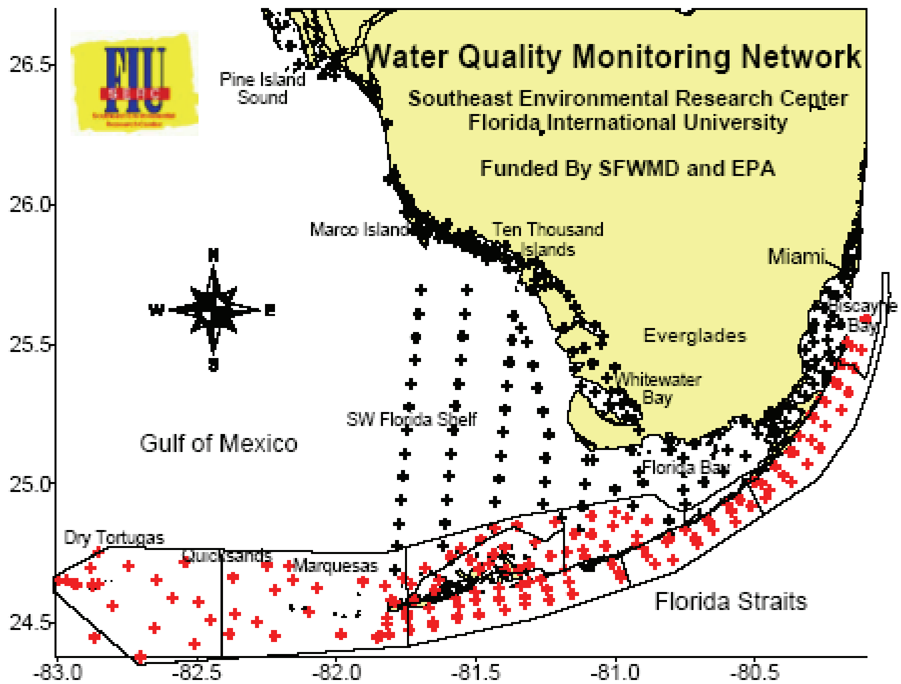

Figure 4. Water Quality Monitoring Project Sampling Locations – note red crosses are FKNMS based stations while black crosses represent sampling conducted in Florida Bay and the Southwest Florida Shelf in support of other projects conducted by the PIs

4.3.1 Management Objective 1 – Quantify Nutrient/Pollutant Loadings

The WQMP, conducted by Florida International University's Southeast Environmental Research Center, has sampled for the same suite of parameters since 1995. Substantial water quality data have been collected from 154 stations in the FKNMS, allowing for a good characterization of the area's water quality, supporting Management Objective 1 to quantify the relative importance of natural and anthropogenic nutrient and other pollutant loadings to Sanctuary waters from local, sub-regional (south Florida), and regional (Gulf of Mexico) sources. In an effort to fulfill part of the Science Plan's objective, the FIU Principal Investigators have evaluated the FKNMS data alongside water quality data collected from elsewhere in their monitoring network (*e.g.*, Florida Bay, Biscayne Bay, Southwest Florida Shelf, etc.). By plotting the FKNMS data with the non-FKNMS data, the regional distribution of the various water quality parameters can be elucidated and general observations can be made about some of the parameter's sources.

While the annual reports do a good job of determining which results may be influenced by anthropogenic and natural sources in the general sense, an attempt at the *quantification of the relative importance* of these broad sources is lacking at this point. As suggested in the Comprehensive Science Plan, one way to address relative source quantification may be to supplement regularly scheduled sampling efforts with episodic data collections (*e.g.*, coincident with rainfall events or upwelling occurrences). In addition, the Comprehensive Science Plan also suggests complementing the surface water quality network with groundwater monitoring, which can reveal wastewater and storm water contributions and, when combined with surface water data, may help elucidate areas with malfunctioning injection wells. The contribution of nutrients directly from rainfall could also be quantified. One of the advantages of source quantification is the potential development of an FKNMS nutrient loading model, which can help in the evaluation of monitoring efforts and management options.

While the WQMP has characterized the local and South Florida sub-regional water quality over the past twelve years, expansion of the network north to capture pollutant inputs coming from the Gulf of Mexico should be considered to more accurately meet the Science Plan objectives. Although the scale is considerably larger and more complex, an examination of the types and amounts of pollutants entering the FKNMS system from the Gulf of Mexico is critical to understanding its role in the regional ecosystem. While adding more stations may be cost prohibitive, it need not be if the existing water quality monitoring network could be optimized and streamlined. A statistical analysis may be conducted to determine if the number of stations sampled could be reduced. This should be followed by a cost benefit analysis of whether the reduction would provide any real cost savings.

4.3.2 Management Objective 2 – Reduce Nutrients, Pathogens & Pollutants.

Currently, the WQMP focuses only on the status and trends of water quality in the FKNMS and has not addressed pollutant management issues despite the emphasis on this objective in the Science Plan. For *Management Objective 2*, which pertains to eliminating or reducing the impact of anthropogenic nutrients, human pathogens and other pollutants on biological communities and public health, some of the specific research needs outlined in the Science Plan are unattainable solely by the WQMP, given the current suite of water quality parameters and sampling locations. With the exception of turbidity and other field parameters, the WQMP currently samples only for nutrient or nutrient-related water quality parameters. Consideration should be given to adding other pollutants to the monitoring suite, such as metals, pesticides, organic compounds, and bacteria, especially considering that understanding the local and regional characteristics of these types of non-nutrient parameters is one of the other major water quality objectives of the FKNMS Science Plan. Although separate from the WQMP, the same WQMP principal investigators are also conducting the Little Venice Water Quality Monitoring Project. Fecal coliform and enterococci bacteria are sampled weekly by the Little Venice Water Quality Monitoring Project to evaluate the effects of improved sewage treatment practices on water quality in residential canals and adjacent waters.

Additionally, two high-priority research needs are assessment of the effects of pesticides on non-target organisms and evaluation of human health risks from sewage-related bacteria. Another high priority need involves examining nutrient characteristics in ground water and the impact on surface waters. The WQMP does not presently sample for pesticide or bacterial parameters. However, several special studies projects have been implemented to address these issues (see Section 5.0).

Other research needs identified in the Science Plan, however, may be accessible given the current scope of the WQMP, albeit through collaboration with the other long-term monitoring projects operating in FKNMS. For example, the Science Plan highlights the importance of understanding the biological impacts of pollutant sources and suggests evaluating the distance from a pollutant source at which the biological community begins to be altered due to that source. The long-term coral and seagrass monitoring programs in the FKNMS may be able to work together with the WQMP to research this topic. Similarly, the development of nutrient and pollutant bioindicators is stressed by the Science Plan as an important goal; collaborating with other monitoring projects can help determine which components of the FKNMS biological community responds first and most reliably to changes in water quality.

4.3.3 Management Objective 3 – Methods & Indicators

From the materials reviewed for this effort, it does not appear that the WQMP has begun to address water quality indicator assessment methods in support of Management Objective 3: to develop methods for rapidly and accurately determining if the ecosystem is responding to changes in water quality conditions and identifying sentinel species or conditions so problems can be identified and corrected before they become chronic. However, by collaborating with the WQPP long-term coral and seagrass monitoring projects, initial steps towards addressing this objective may be met.

5.0 SPECIAL STUDIES AND "OTHER STUDIES"

The themes of the special studies projects as well as the other studies reviewed for this effort can essentially be narrowed into a few distinct groups. These include: physical oceanography, corals, other biota (lobsters, fish and conch), bacteria/pathogens and pollutant (including nutrients) sources and movement into surrounding areas.

5.1 Physical Oceanography

Several special studies relate to the Physical Oceanography Management Objectives in the Comprehensive Science Plan. These include Smith and Pitts, 1998; the SEAKEYS program; Szmant, 2004; and Szmant *et al.*, 2006. In addition to these studies, many of the special studies that pertain to nutrient fate and transport also relate to the physical oceanography management objectives. These include Chanton *et al.*, 1998, 2001; Lapointe and Matzie, 1997; Shinn *et al.* 1994, Kump, 1998a, 1998b.

5.1.1 Management Objective 1 – Regional & Local Circulation Patterns

The Florida Keys are characterized as a hydrologically open system, receiving waters from Florida Bay, the Gulf of Mexico and the Florida current. To improve understanding of how regional and local circulation patterns influence water quality in the Keys (*Management Objective 1*) knowledge of circulation patterns as well as nutrient concentrations are needed to determine loadings. One long-term monitoring network that provides some of the necessary parameters to evaluate circulation patterns is the SEAKEYS monitoring network. This program was instituted in 1989 through the Florida Institute of Oceanography and has continued to present. In cooperation with NOAA's National Data Buoy Center, the SEAKEYS program established six enhanced Costal Marine Automated Network (C-MAN) monitoring stations along the FL Keys reef tract from Fowey Rocks off of Key Biscayne to the Dry Tortugas. An additional station is located in Northwest Florida Bay. These stations record meteorological parameters such as hourly wind speed, wind direction, air temperature, barometric pressure and oceanographic parameters such as sea temperature, salinity, fluorometry and turbidity. Although some of the data from the SEAKEYS program may be used to enhance circulation models for the South Florida region, several parameters that need to be measured at these stations include current speed and direction. This would greatly enhance the ability of scientists and modelers to develop circulation models for the FKNMS.

None of the studies evaluated for this project appear to access remote sensing data to evaluate circulation patterns and support model development and/or validation. The WQPP program may want to consider funding a special studies project to begin acquiring the remotely sensed images and using the SEAKEYS data to see if correlations exist that would enhance the understanding of FKNMS circulation.

Many of the special studies reviewed for this effort do provide some preliminary information in support of *Management Objective 1*. The special study by Smith and Pitts (1998) evaluated the dissolved and suspended material transport from Florida Bay, through the tidal channels and Hawk Channel, and to the offshore reef tract in the FKNMS. A series of special studies evaluating nutrients in ground water (Chanton, 1998; 2001, Kump, 1998;, Lapointe and Matzie, 1997; Shinn *et al.*, 1994; and Swart 2000) also provide the groundwork for future studies to actually quantify nutrient loading into the FKNMS system; however, the lack of detailed current data and circulation models prohibits these studies from drawing exact conclusions about fate and transport to surrounding systems within the FKNMS.

5.1.2 Management Objective 2 – Influence of Currents on Marine Organisms

Several WQPP-funded special studies evaluated larval recruitment (Szmant 2004 and Szmant et al, 2006). However, because of the lack of physical oceanography data (i.e., current direction, speed, and an internal circulation model), these studies were limited in their ability to directly address *Management Objective 2* which is to determine the influence of local and regional currents on recruitment, growth and survival of Keys marine species. Szmant, 2004 studied settlement patterns of two species of coral and the factors that influence post-settlement survival. Szmant *et al.*, 2006 attempted to develop and test a new suite of approaches to monitor and follow dispersal patterns of coral spawn. This latter experiment shows great promise for directly addressing this management objective, particularly if the study could be expanded to include a more physical oceanographic component. However, factors beyond the control of the investigators, curtailed the experiment.

The research need stated for this management objective in the Comprehensive Science Plan involves developing predictive larval recruitment, dispersal, and connectivity models which include sources, sinks, larval concentrations and behaviors. The need for this research remains high. The Szmant studies do begin looking at recruitment behaviors and developing the methods to address larval concentrations and tracking. More detailed experimental designs under both field and laboratory conditions, for a number of marine organisms (not just coral larvae) need to be considered. The results of such studies, combined with circulation models, will be necessary to develop the appropriate species-specific larval recruitment models in the FKNMS.

5.1.3 Management Objective 3 – Physical and Biological Processes

The SEAKEYS program also provides some of the necessary information to support *Management Objective 3*: "To apply knowledge of physical oceanographic processes to gain insight into biological processes such as coral bleaching." Sea surface temperature data needs to be evaluated along with the long-term coral monitoring data. Additionally, remote sensing sea surface temperature maps could be acquired and evaluated along with both the SEAKEYS and coral data. Only through collaboratory efforts by the investigators looking into physical oceanographic processes and those evaluating the biological processes can this management objective, as well as many of the other management objectives, be fully met. Future WQPP funding may want to consider the interdisciplinary nature and collaboration of investigators in each proposal.

5.2 Corals

5.2.1 Coral Management Objective 1 – Causes of Coral Reef Decline

Several special studies funded by EPA are related to this Management Objective and associated research needs. Cook (1997; 1995 Funding) addressed nutrient stress as a potential cause for coral decline in the Sanctuary. The main result found no differences in nutrient exposure that would explain the differences in coral growth rates; corals at both sites seemed to be exposed to high nutrient levels, particularly nitrogen. This study partially addressed the emerging evidence that "bottom-up" ecological processes are not responsible for forcing coral community structure and dynamics in the FKNMS. In another project, Mueller, *et al.* (2001; 1997 Funding) looked at the distribution of coral diseases within the FKNMS and the use of these data as a tool for understanding the etiology of the coral diseases. This project should assist in evaluating the causality for disease associated coral decline in the Sanctuary and accordingly, fulfills at least in-part, one of the research needs developed for this management objective.

Richardson, (2001; 1997 Funding) directly addressed the etiology of two specific coral diseases known to be responsible for coral decline in the Sanctuary. Specifically, Black band disease is a complex, cyanobacterial-dominated microbial mat community similar to those found in sulfide-rich hot-spring outflows. In addition, during 1995, a severe coral disease outbreak occurred on reefs of the middle Florida Keys. This study was one of the first that was able to specifically document the epizootic as well as isolate the pathogen responsible for coral mortality, which turned out to be a new genus and species of bacteria, *Aurantimonas coralicida*. The special study fulfills one of the research needs developed for this management objective in determining direct and indirect causes of coral decline with emphasis on cause and effect.

Hallock Muller (2006; 2003 Funding) developed three proxy indicators to assess reef condition on time scales suitable for resource or risk assessment. These indices support, in-part, the research needs for this management objective by providing resource managers with simple procedures for determining the suitability of benthic environments for communities dominated by algal symbiotic organisms. While it does not specifically answer questions regarding the causality of coral decline, these data when combined with other studies and the long-term monitoring in the CREMP are useful in determining which factors may be responsible for coral mortality (i.e. coral bleaching related to increased SST's). This special study fulfills at least in-part one of the research needs developed for this management objective by assessing snapshots of reef condition and that compliment the CREMP data.

Lastly, Smith and Aronson (2006; 2003 Funding) identified patterns of change in the reef building species of the *Montastraea annularis* species complex and *M. cavernosa*. These species were evaluated at four sites in the FKNMS. Recruitment, mortality, growth and shrinkage of coral colonies located in permanent quadrats at two depths at each site were used to formulate models used on transition probability matrices. The special study fulfills this important management objective by predicting the trajectory of coral populations into the future. However, while causality is inferred in this study, no direct measures of the causality of the colonies monitored were made.

5.2.2 Coral Management Objectives 2 & 3 – Identify Corrective Actions and Restore & Speed up Recovery

The only two studies funded by EPA that relate to Management Objectives 2 and 3 include Szmant *et al.* (2003) and Szmant (2003). The first project investigated the larval behavior, dispersal abilities and settlement and post-settlement survivorship of the Caribbean reef-building coral *Montastraea faveolata*, a foundation species found throughout the Florida Keys and Caribbean. The specific objectives of this project included: (1) developing and testing a suite of new approaches to monitor and follow the dispersal patterns of coral spawn; and (2) conducting field and laboratory experiments investigating the factors that affect settlement patterns and post-settlement survivorship of *M. faveolata*. The next (Szmant 2003) continued experimental studies with cultured *M. faveolata* larvae to investigate factors that contribute to or reduce post-settlement mortality. The main results found that larvae of two species of *Montastraea* preferentially settle on the undersides of field-conditioned settlement plates and the preference is not due to orientation of the substrate. As well, the methods used to determine what components of community structure are responsible for attracting/inducing larvae were successful in discriminating between the community structure of the tops and undersides of the settlement plates. The results are encouraging for eventually fulfilling, at least in-part, the goals and management objectives by defining requirements for the potential seeding of reefs as a restoration tool.

5.2.3 Coral Management Objective – Assess and Eliminate Redundancy

Two special studies funded by EPA that function as a compliment to the CREMP protocol but do not duplicate the effort include Hallock Muller (2006; 2003 Funding) and Smith and Aronson (2006; 2003 Funding). Additionally, there are a number of Keys-wide coral monitoring programs that have been, and are still being, performed within the Sanctuary that are not part of the EPA funded WQPP. These include the projects described above (see Murdoch and Aronson 1999; Miller, Swanson, and Chiappone 2002;

Miller, Aronson and Murdoch 2003). The statistical design of these studies does not duplicate effort with the others and serve to compliment the CREMP study.

5.3 Other Biota

This section includes those studies reviewed for this effort that pertained to the Fish Communities category and Spiny Lobster category in the Comprehensive Science Plan. Queen conch are also identified in the Comprehensive Science Plan and although the WQPP funded several queen conch studies, no final reports were available for review. No other benthic invertebrate studies have been funded by the WQPP and therefore, no review of the management objectives for the "other benthic invertebrates category" in the Comprehensive Science Plan were reviewed.

5.3.1 Fish Communities Management Objectives

Ault *et al.* (2006) investigated coral reef fish populations before and after the establishment of the "no take" marine reserve (NTMR) network around the Dry Tortugas region of the Florida Keys. As an important source for coral reef fish, the Tortugas area is critical to the regional population.
As described in Section 3.2, the FKNMS Science Plan identified three separate management objectives for fish communities. The research conducted by Ault *et al.* (2006) serves these objectives well. *Management Objective 2* of the FKNMS Science Plan focuses on better understanding the role of non-food fish species in the broader community, including their biogeographic distribution. By studying all fish present during surveys (and not solely commercially- or recreationally-important species), Ault *et al.* (2006) has contributed to the understanding of the health of coral reef fish as a whole, with the ultimate goal of evaluating the successes and failures of the NTMR form of management, which also serves *Management Objectives 1 and 3*. With the apparent successes of the Dry Tortugas NTMR toward becoming a protected source of coral reef fish for the rest of Keys, future monitoring and research efforts should perhaps concentrate on evaluating other types of management actions, including (as suggested in the Science Plan) artificial reefs and the shifting of management zone boundaries in response to the modeled requirements of fish communities.

The information reviewed for this report suggest that any FKNMS-sponsored fish monitoring or research program should carefully examine and potentially incorporate the study design by Ault *et al.* (2006) due to the design's ability to holistically address the Science Plan recommendations.

5.3.2 Spiny Lobster Management Objectives

For this report, three studies on the Caribbean spiny lobster were reviewed, two of which were sponsored by FKNMS. Cox and Hunt (2005) conducted non-FKNMS funded research on the efficacy of the Western Sambo Ecological Reserve (WSER), a fully-protected marine management area, in improving the management of spiny lobsters. They concluded that, since the establishment of the WSER, the number of legal-sized spiny lobsters has increased significantly. Bertelsen *et al.* (2004) and Bertelsen and Maxwell (2005) also examined the implications of protected management areas on spiny lobsters, with the former research being conducted in WSER and the latter in the Dry Tortugas region. Both of these studies looked at the two management areas as effective sources of spiny lobsters to the exploitable population.

The FKNMS Science Plan identified two management objectives for spiny lobsters, one of which is more closely met by the three aforementioned studies. *Management Objective 1*, which is to continue to assist fisheries managers, is partially met. By evaluating the effects of protected management areas on commercial and recreational fisheries, Cox and Hunt (2005), Bertelsen *et al.* (2004), and Bertelsen and Maxwell (2005) have provided important data towards assessing whether these areas are of the appropriate location, size, arrangement, etc. for maintaining fishery and ecological health. Additional studies are needed to address the impact of lobster fishing practices on habitat features. *Management*

Objective 2, focused on further understanding of spiny lobster life history characteristics, is less clearly met by the three studies. More research should be conducted into feeding habits, habitat needs, and how the spiny lobster fits into the greater ecosystem. The first step in improving this body of knowledge should be to gather all existing knowledge and identify gaps to be filled. Protecting spiny lobster populations is critical not only for recreational and commercial purposes, but for the health of the FKNMS ecosystem as a whole.

5.4 Bacteria/Pathogens

Several WQPP-funded special studies and one "other study" examined bacteria or pathogens in the Sanctuary. Lipp *et al.* (2006) evaluated the extent of human sewage contamination along a nearshore to offshore transect in the Upper Keys using human enteric viruses as sewage markers and to assess risks to human health. They found evidence of human pathogenic viruses in ground water up to 11 km offshore and theorized that their presence was the result of rapid movement of ground water contaminated by inadequate sewage treatment practices in the Florida Keys. Rose *et al.* (1997) conducted a similar study, only concentrating on specific Florida Keys canals. Finally, the Little Venice Water Quality Monitoring Project (Boyer *et al.*, 2004; Boyer and Briceño, 2006) looked at the human fecal indicators present in the waters surrounding one community both before and after the implementation of a wastewater treatment system.

5.4.1 Water Quality Management Objective 2 - Reduce Nutrients, Pathogens & Pollutants.

This management objective, which includes eliminating or reducing the impact of human pathogens on biological communities and public health, is not entirely met by the three studies described above. All three of the research studies evaluated the existing state of pathogen contamination in nearshore environments, with Lipp *et al.* also examining pathogens at offshore reefs. Characterizing the existing state of pathogenic or bacterial contamination is important, but taking the next step toward researching ways to ameliorate water quality for the sake of human and ecological health would be beneficial. It is important to note, however, that many of the special studies funded by the WQPP provided the technical information necessary for the State of Florida to take action and pass State Law 99.395 and for the U.S. Congress to approve the Florida Keys Water Quality Improvements Act of 2001.

5.5 Pollutants and Nutrients

Many of the special studies and "other studies" reviewed for this effort pertain to nutrients and to a lesser extent pollutants. Chanton *et al.*, 2001; Kump, 1998 a, 1998b; Lapointe and Matzie, 1997; and Shinn *et al.* 1994, have all examined the chemistry and/or fate of wastewater-derived nutrients in ground water while Boyer *et al.*, 2004; Boyer and Briceno, 2006 and MACTEC, 2003 have evaluated the nutrients in canals in various residential areas in the Keys. Ayers Associates (1998) have addressed management techniques for reducing the introduction of wastewater nutrients into surrounding waters. The only pollutant study, not directly relating to nutrients was Pierce, 1998 who studied the impacts of pesticides on non-target organisms in the FKNMS.

5.5.1 Water Quality Management Objective 1 – Quantify Nutrient/Pollutant Loadings.

These studies provide support to several of the Comprehensive Science Plan goals and objectives, particularly those related to water quality. Although *Management Objective 1* is primarily addressed through the long-term Water Quality Monitoring Project, many of these studies provide a snapshot of nutrient sources from ground water and insight into how quickly nutrients from waterwater can move into surrounding surface waters. For example, using tracers, Chanton *et al.*, 2001 demonstrated that ground water is a source of nutrients in coastal waters near the Keys. However, rate of transport, direction of flow, amount of dilution and timing can vary throughout the region due to local geology, rainfall and tides. Several of the other studies also address how the geology and tidal pumping can impact the fate of and pathways through which nutrients move from ground water into surface waters. Shinn *et al.* (1994) installed 24 wells in the limestone beneath the Keys, Hawk Channel and the outer reef tract to determine whether sewage effluents injected into wells onshore are reaching the reef areas via underground flow. All of these studies are directly relevant to a high priority research need stated in the Comprehensive Science Plan, that of developing a nutrient loading model for the FKNMS ecosystem.

A second high priority research need stated in the Science Plan under Management Objective 1 is to investigate methods of improving water quality in Keys canals. Boyer *et al.*, 2004; Boyer and Briceno, 2006 and MACTEC, 2003 as well as the demonstration project conducted by Ayers and Associates (1998) are directly related to this research need. The Little Venice Water Quality Monitoring Project (Boyer *et al.*, 2003 and Boyer and Briceno, 2006) evaluated water quality pre- and post implementation of a centralized waterwater treatment plant on Vaca Key. Although the pre- and post- monitoring activities to date have not provided conclusive results, this type of information is necessary to further understand how to improve water quality in these residential canals throughout the Keys.

5.5.2 Water Quality Management Objective 2 – Reduce Nutrients, Pathogens & Pollutants.

Several of the studies cited above in Section 5.5 are directly relevant to *Management Objective 2*, to eliminate or reduce the impact of anthropogenic nutrients, human pathogens, and other pollutants on biological communities and public health. The impacts of human pathogens on public health are addressed above in Section 5.4. In contrast, the WQPP-funded and "other studies" that are evaluating the nutrients in ground water and their fate and transport are each directly relevant to many of the research needs corresponding to this management objective, including quantifying the geochemical changes that occur in wastewater as it passes through limestone and evaluating the biological community structure changes with distance from pollutant sources.

The objectives of the initial Kump study (1998a) were to characterize the chemistry of the ground water system surrounding a shallow wastewater injection facility, and determine the reactivity of the wastewater nutrients with the surrounding ground water. Kump (1998b) also evaluated whether wastewater phosphate is immobilized in the saline carbonate ground water through precipitation induced by the interaction with the limestone. Both these studies are directly relevant to a high priority research need to quantify the geochemical changes in wastewater injected into disposal wells as it passes through limestone.

The Lapointe and Matzie study (1997) also addressed a research need under Management Objective 2. The Comprehensive Science Plan states that studies are needed that investigate how far from a pollutant source changes in the biological community structure can be detected. The objective of the Lapointe and Matzie study (1997) was to assess the degree to which land-based wastewater dissolved inorganic nitrogen contributes to macroalgal blooms in nearshore and offshore waters of the FKNMS. The study results suggest that land-based wastewater nutrient discharges from the Keys do enhance blooms of phytoplankton, macroalgae and seagrass epiphytes as far offshore as Looe Key reef. To further address this research need, similar studies and statistically robust designs need to be conducted throughout the Keys. This will help determine if any additional nutrient sources are affecting the biological community structure as well as the extent of any changes and enable better monitoring for trends in the system.

The only special study that addresses the research need for impacts of pollutants that are not nutrients is Pierce (1998). That study evaluated potential impacts of mosquito control applications on the ecology of the FKNMS by assessing the transport and persistence of these chemicals in the environment. Although this study addresses a high priority research need under *Management Objective 2*, additional studies are needed that quantify the impacts on a variety of organisms, including various life stages of different marine fish and invertebrates.

Several of the research needs have not been met by the studies discussed in this section or through the long-term water quality monitoring project. These include the development of thresholds and target levels for nutrients and other pollutants that may be harmful to various components of the FKNMS ecosystem and the role of turbidity and other non-nutrient factors in limiting FKNMS biological resources.

5.5.3 Water Management Objective 3 – Methods & Indicators.

As discussed in Section 4.3, none of the special studies, or the long-term Water Quality Monitoring Project appear to meet the water quality objective to develop methods for rapidly and accurately determining if the ecosystem is responding to changes in water quality conditions. Although some of the studies may provide basic information from which to draw upon, addressing this management objective and many of the research needs for the other water quality management objectives will require principal investigators to collaborate, share information and design the appropriate studies that yield quantifiable results that are understood and can be utilized by resource managers to make informed decisions. The Seagrass Monitoring Project, however, has begun to look at indicators and has developed two innovative indicators linked to water quality to annually assess the status and trends in seagrass communities of the Sanctuary. A decrease in either the elemental indicator (EI) or species composition indicator (SCI) developed for seagrass data will be interpreted as a decrease in overall water quality.

6.0 FKNMS COMMUNICATION ISSUES

In any program where multiple federal and state agencies are involved in the planning and management of a system as vast as the FKNMS, both internal, as well as external, communication is critical to the success of the program. The following sections addresses some communication issues that the FKNMS funding partners need to consider in the future management of their respective programs.

6.1 Project Communication/Structure

Since the early beginnings of the WQPP, the EPA has been committed to providing sound science-based information to help foster an understanding of the unique ecological linkages within the FKNMS (Kruczynski and McManus 2002). With that said, there has been minimal coordination between the various funded components of the WQPP, except between the Water Quality Monitoring Project and Seagrass Monitoring Project. Accordingly, each funded member (or project) of the WQPP should work cooperatively to share information and strategies to benefit the coral reef and adjacent environments within the FKNMS and the overarching goals and objectives of the WQPP. It should be noted that the CREMP has failed to integrate the long-term water quality monitoring data into their annual reports, yet many of the projects interpretations are built on the foundation that water quality is a main forcing function of coral community dynamics within the Sanctuary. It should be noted, however, that a statistical evaluation of data from the CREMP and Water Quality Monitoring Project is scheduled to be finalized in FY 2008. Additionally, the PIs for the all of the monitoring projects (coral, seagrass and water quality) have scheduled a meeting in Miami for December 2007 to continue work on integration of data among the three projects.

While much of the raw data and subsequent technical reports and summaries are presented during scheduled meetings and made available to all parties, including the general public, via the internet, it is imperative that all parties working on funded projects share and transfer information and ideas on a regular, continuing basis. One key to success of any long-term program is to be able to make changes mid-stream to improve the overall quality of the project deliverables. This includes examining current and emerging coastal and ocean management tools, monitoring techniques, and strategies, as well as to consider mechanisms for enhancing our ability to protect, manage and restore the coastal ecosystems within the FKNMS in the face of new challenges whether local, regional, or global. This adaptive approach to ecosystem studies is currently being performed within individual projects, but not within the overall WQPP. Thus, for adaptive management to succeed there should be a commitment by all funded parties to work collaboratively.

6.2 Centralized Website/Data Repository

To facilitate communication among the key agencies involved with the FKNMS Science Program, including the WQPP, it is recommended that the existing data and information management system be updated and improved. This will enable investigators to easily access the most current data. Currently, there are two managing websites, the FKNMS and the Florida Fish and Wildlife Research Institute, with links to the Water Quality Monitoring Project and Seagrass Monitoring Project websites which present their respective projects along with project data.

The benefit of designing one uniform website is that all overarching information about the program can be explained once by the joint collaboration between the agencies and not multiple times from each individual agency's perspective. All projects supported by the agencies can be included in one location, not on individual sites based on the project's funding. The metadata for individual projects, as well as the data could also be made readily available from one location. Duplication of data on different websites can be problematic. If a principal investigator updates a dataset, it may not get updated on all sites making it questionable of where the most up-to-date and accurate information exists. The maintenance of one site will also help reduce costs and will demonstrate success to senior management within all agencies involved as well as the science community.

7.0 BATTELLE RECOMMENDATIONS

During the preparation of this document, it became apparent that an important improvement to the FKNMS Science Plan, including the WQPP, is improved collaboration between all stakeholders. Many of the objectives in the Comprehensive Science Plan will require joint efforts between the principal investigators evaluating water quality issues, physical oceanography issues and all forms of biota in the FKNMS. The studies conducted thus far have been instrumental in laying the groundwork for future multidisciplinary approaches that will result in quantifiable thresholds and targets from which managers can make decisions.

Next steps are also apparent from review of the current long-term monitoring projects and special studies projects. The WQPP now has over 10 years of monitoring data for corals, seagrasses and water quality and monitoring optimization efforts have been conducted. However, it may be beneficial to conduct additional rigorous statistical reviews of the data sets to determine if and how the monitoring projects can be streamlined spatially and temporally. The result of this statistical optimization effort should be followed by a comprehensive cost-benefit analysis to see if there are any real cost savings associated with reducing sites and/or frequency of sampling.

In addition to evaluating the existing long-term monitoring projects to see if they can be further streamlined or enhanced, each project should also evaluate whether the use of remotely sensed information can be incorporated into the projects and if so, would that result in cost savings. Using remote sensing data was referenced in several categories within the Comprehensive Science Plan. In the long-term, this type of information may be particularly useful for the continued monitoring of status and trends. However, it may be more useful with some projects than others due to the spectral resolution issues.

Similar to utilizing technologies like remote sensing to support long-term monitoring, the use of new technologies to evaluate and improve wastewater practices and storm water run-off in the Keys should also be considered. Currently, the Florida Keys Water Quality Improvements Program: Final Program Management Plan calls for implementation of several wastewater and storm water master plans that have been prepared for Monroe County and local municipalities in Monroe County. Within the Plan, several wastewater management alternatives were evaluated to identify the most environmentally favorable and cost effective plan. Additionally, structural Best Management Practices and a number of nonstructural source controls were identified as potential alternatives for storm water issues. Future WQPP funding may want to consider demonstration projects involving some of the newer wastewater technologies and Best Management Practices and/or nonstructural source control storm water designs and/or technologies. Vendors of these technologies should work with multidisciplinary teams of scientists and engineers familiar with the physical environment in the Keys to develop a statistically robust experimental design testing the adequacy of these technologies in the unique island setting of the Florida Keys.

Another immediate next step would be to conduct an effort similar to this current one with all of the other science programs and research ongoing throughout the Florida Keys, including Florida Bay and not just those funded through EPA. There are a number of funded projects being performed within the FKNMS that support the goals of the WQPP. However, the Comprehensive Science Plan also includes management objectives and monitoring and research needs for several biological components that have not been addressed by the studies funded through the WQPP. Additionally, there are a host of other researchers conducing basic and applied research on many systems in the Keys that should be evaluated against the current Comprehensive Science Plan goals and objectives. Many of these studies may fill the gaps where WQPP-funded studies are presently lacking.

A comprehensive review of the WQPP and non-WQPP studies being conducted throughout the Keys should include reevaluation of the current goals and objectives in the Comprehensive Science Plan. It is time to put the practice of "Adaptive Management" to the test. Some of the existing goals and objectives of the Science Plan may need to be refined or completely altered based on new information. Many of the current objectives are not directly measurable. These should be revised to clearly state quantifiable targets or actions that can be addressed. Managers need the ability to make decisions based on these "management objectives." The current wording of many of these objectives does not facilitate decision making.

One way to accomplish many of Battelle's recommendations is for EPA and the FKNMS to host a WQPP Information and Technology Transfer Workshop/Conference organized around five broad themes: (1) goal setting, (2) assessment, (3) adaptive management, (4) restoration, and (5) measuring results. This would include scientific presentations that are required to address the management goals and actions as part of the presentation.

EPA should serve as the primary agency for relaying information from the WQPP studies. The proposed WQPP Information and Technology Transfer Workshop/Conference should be conducted to encourage the sharing of environmental information to a large audience, including all stakeholders of the FKNMS. WQPP-funded scientists from diverse areas of interest need to share their findings in support of the overall goals and objectives of the FKNMS Comprehensive Science Plan. The main purpose of these meetings and workshops should be designed to foster sharing of information among participants about current monitoring, research, accomplishments, or issues of concern to the FKNMS. The presentations will thus serve as a critical component to ecosystem-based conservation, management, communications, and ultimately proactive stewardship of the resource. The WQPP Information and Technology Transfer Workshop/Conference should be held about every 3-5 years, with the meeting dates set to accommodate the schedules of as many members as possible as well as the availability of potential guest speakers.

As such, the WQPP Workshops should include “lessons learned” to determine what aspects of the program are working well, what aspects need improvement, and to generate alternative methods to conduct activities in the future. These should result in the following process driven outcomes:

Information-sharing: overview of all stakeholder activities in the areas of special studies, monitoring, modeling and management with discussion of opportunities for collaboration and identification of knowledge gaps.

Management toolkit: compilation of all available strategies, techniques, and programs for adaptive management of coastal resources within the FKNMS available in an information toolkit that can be shared with all stakeholders.

Program planning: strengthen and reinvigorate the existing framework for an integrated monitoring/special studies program to improve the understanding of local and system-wide responses and “establish partnerships” that enhance our ability to develop management responses.

8.0 SCIENCE ADVISORY PANEL WORKSHOP AND RECOMMENDATIONS

A workshop convening a Science Advisory Panel was held on September 20, 2007 in the Florida Keys to discuss the results and recommendations of the information contained within this report and to solicit additional recommendations from panel members. Similar to the Year 2000 Science Advisory Panel, the Year 2007 Panel consisted of an independent group of scientists including one with local knowledge of the FKNMS and FL Keys issues. Panel members and their affiliations are shown in Table 1. In addition to the Science Advisory Panel members, several local elected officials, Sanctuary Resource Managers and other resource agency professionals were in attendance. These individuals also offered comments/input into the future direction of the WQPP. Their input is summarized below in Section 9.0.

Table 1. Year 2007 Science Advisory Panel Members

Panel Member	Affiliation
Dr. Jane Caffrey	University of West Florida
Mr. John Hunt	Florida Fish and Wildlife Conservation Commission
Dr. Ronald Kneib	University of Georgia, Sapelo Island Marine Laboratory
Dr. Marguerite Koch	Florida Atlantic University
Dr. Esther Peters	Tetra Tech, Inc.
Dr. Rob van Woesik	Florida Institute of Technology

Following presentations on the WQPP, the FKNMS Science Program and the overview of the Battelle Report, the Science Advisory Panel met separately to discuss and develop recommendations for the WQPP. These include general recommendations, recommendations specific to the long-term monitoring projects and special studies projects, additional recommendations for communication issues and additional comments on Battelle's recommendations.

General Recommendations

- The program has focused on monitoring and the panel is of the opinion that these baseline data are important to understand spatial and temporal changes and should be continued (i.e., seagrass, corals, water quality).
- Special studies are also important to reach a better understanding of the key processes that drive spatial and temporal changes in the ecosystem and assist in the interpretation of monitoring data.

Recommendations on Communication

- Improving communication of scientific information to the general public and managers is critical. This could be done with simple pamphlets and a fact page book on the Keys and Florida Bay that is currently in preparation. The WQPP should consider consulting with The Nature Conservancy and Sea Grant for other approaches that have been successful.
- The panel recommends using conceptual models as communication tools to relate findings at various scales both spatially and temporally, particularly when trying to relate the time that may be required for ecosystem response to management actions, (e.g., the Little Venice Wastewater Management System). This can be done in pictorial or schematic form.

Monitoring Recommendations

- Focus on integrating the information across the monitoring programs.
- Event-driven water quality monitoring: *In situ* stations that capture random events are needed. Use long-term data to determine where to optimize the location of recorders and/or current moorings.
- Monitoring should be conceptual model based, particularly needed in the coral monitoring program.
- Coral monitoring program should consider quantifying corals beyond percent cover. For example: species composition, size frequency distribution, functional forms (stress tolerators).
- The monitoring program should use the 10+ years of data to develop hypotheses to further define mechanisms which are causing declines in the resources.
- There is a need to monitor mangroves in the system, perhaps related to potential for stormwater runoff mitigation.

Special Studies Recommendations

- Link water quality with remote sensing data (e.g. temperature, chlorophyll) to associate processes with state water quality standards.
- Future special studies should be focused in two general areas: (a) process-oriented and (b) syntheses.
- Hydrodynamic models should be integrated into interpretation of water quality data and should be explored in special studies.
- An interdisciplinary "systems" integrating project should be attempted to synthesize long-term data monitoring and mechanistic results to date.
- Investigate the sediment nutrient profiles from shore toward the reef, comparing historic data where possible.
- Continue research effort on patch reef and hard bottom communities and why they are responding differently than offshore reefs.
- Continue investigating various approaches to source tracking pathogenic microorganisms in the system.

Evaluation of Battelle Recommendations

- Agree with updating a web-based data repository available to managers, scientists and public, and agree that collaboration among the studies in the water quality program is critical. In particular, the special studies project PIs should collaborate/communicate/coordinate with the water quality/seagrass/coral monitoring projects.
- Panel does not feel that the vessel-based seagrass monitoring program should be replaced with remote sensing; however, integrating remote sensing data into interpretation of water quality data should be explored in special studies (see above).
- Based on discussions with Seagrass and Water Quality Monitoring Project PIs, statistical optimization has already been conducted; instead a synthesis of the results to date by the PIs may be used to optimize the program and then acquire additional temporal data.
- Demonstration projects for wastewater are unnecessary. Wastewater treatment systems are mandated to be implemented.
- Demonstration projects for storm water are unnecessary. Implementation of well-established techniques, such as BMPs and wetland buffers (e.g., reestablishment of mangrove/wetland buffer zones to mitigate/ameliorate storm-water runoff) should be conducted.
- Comprehensive review of non-WQPP studies throughout the FKNMS would be useful. Implementation of a Florida Keys WQPP Information and Technology Transfer Conference or Workshop might be useful for this effort.
- The Panel agrees that focusing the goals of the Science Plan toward management is useful and that the program has made strides in that direction.

9.0 ADDITIONAL WORKSHOP INPUT (INCLUDING DECISION MAKERS AND ELECTED OFFICIALS)

During this workshop, Battelle and EPA inquired from Sanctuary managers, agency decision makers and elected officials as to whether the information collected by the WQPP has been useful to them in making decisions. Of the elected officials and managers present, the overall concensus was that the long-term monitoring and special studies being conducted through the WQPP has been very useful to date. Some feel that compared to 10 years ago, there is a great deal of acceptance for the Sanctuary and that is due, in part, to the scientific information being produced. All agreed that communication of the science to the public, as well as managers and decision makers, can be difficult and that mechanisms to get the right information to the right people need to be developed. Decision makers and elected officials often get requests from the public for more information. Thus, it is important for these decision makers and elected officials to develop relationships with key agency personnel so they know who to talk with to better understand the science and what it means.

In terms of the future of the WQPP, the decision makers and elected officials at the workshop emphasized the importance of continuing the long-term monitoring projects, particularly given the changes that are being seen due to global climate issues. The special studies should also continue, particularly if they can be designed to answer specific questions. Most also expressed opposition to demonstrations projects and preferred that money not be wasted on smaller scale "demo" projects. Several decision makers suggested that it is time to put the shovels in the ground and get the large-scale projects mandated in wastewater master plans initiated and completed.

EPA and Battelle received comments from others who attended the workshop, but were not Panel members or Decision Makers/Elected Officials. Several comments pertained to the long-term monitoring projects both in terms of design and interpretation of results. It was suggested that when communicating the reduction in live coral coverage from 11% to 7% during the 1997 – 1998 period, emphasis needs to be placed on the bleaching and diseases being global events and not limited to the Caribbean area.

Otherwise, the public will assume that the impacts to coral were locally induced by poor water quality combined with elevated sea temperatures. It was also suggested that the FKNMS consider proposing to NSF, a coral long-term ecological research (LTER) program which could support spatial and temporal scale issues, process research and intensive site sampling. A question was posed pertaining to the long-term seagrass monitoring project and whether monitoring of the soft bottom benthos was ever considered. Many of these benthic organisms are excellent indicators of pollution and it could be beneficial to establish a baseline for evaluating trends.

Another comment suggested that the development of a framework for integrated monitoring and assessment would be beneficial. This framework would document the need for various types of monitoring and research programs and demonstrate how these various programs would "fit together." The framework would also help to define the questions that managers and stakeholders find important and identify how the special studies fit into the overall technical program and address specific the specific management questions. In addition to the framework, it was suggested that a valuation of ecosystem services, landscape models and alternative futures analysis be conducted.

Along with the decision makers, elected officials and the Science Advisory Panel members, comments on communication issues were also received. It was suggested that the WQPP program consider focus group workshops to identify what types of communication and outreach products would be useful to different stakeholders as well as managers, decision makers and policy makers. It was also suggested that creating a position for an individual with the skills of facilitating communication between highly technical scientists and other stakeholders might be useful.

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