WATER-QUALITY PROTECTION PROGRAM FOR THE FLORIDA KEYS NATIONAL MARINE SANCTUARY PHASE I REPORT

U.S. Environmental Protection Agency
Oceans and Coastal Protection Division

July 21, 1992

Contract No. 68-C8-0105
Work Assignment 3-225

Prepared by

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GENERAL INTRODUCTION

1.0 PURPOSE AND SCOPE

The Florida Keys National Marine Sanctuary (FKNMS) was created with the signing of HR5909 (Public Law 101-605) on 16 November 1990. Included in the sanctuary are 2600 nmi^2 of nearshore waters extending from just south of Miami to the Dry Tortugas (Figure 1-1). The Environmental Protection Agency (EPA) and the State of Florida have been directed to develop a Water-Quality Protection Program for the Sanctuary. This Program will be considered by the National Oceanic and Atmospheric Administration (NOAA) for inclusion into the comprehensive management plan that will be prepared to guide the use of the Sanctuary. The purpose of the Water-Quality Protection Program is to recommend priority corrective action and compliance schedules addressing point and nonpoint sources of pollution. The Program will be developed in two phases.

The first phase of the Program, which is the subject of this report, involves a compilation and synthesis of information on the environment within the FKNMS. The second phase of the Program will involve an evaluation of the necessity and type of corrective action to be taken to restore and maintain the biological integrity of the Sanctuary. Additional field data may need to be collected in Phase II to make an accurate evaluation.

The scope of this report follows from the Work/Quality Assurance Project Plan for this work assignment. Five tasks (Tasks 2 through 6) were identified in the work assignment that form this report. They are as follows.

- Task 2 Water-Quality Assessment
- Task 3 Coral Community Assessment
- Task 4 Submerged and Emergent Aquatic Vegetation Assessment
- Task 5 Nearshore and Confined Waters Assessment
- Task 6 Spill and Hazardous-Material Assessment

The Water-Quality Assessment includes information on point, nonpoint, and external sources potentially affecting water quality. The existing information on physical oceanography and water quality of the region is summarized. The potential for water-quality degradation in the future (Year 2010) is also discussed.

The Coral Community Assessment involves a compilation and summary of information on coral communities within the FKNMS. Known and potential causes of adverse impacts to Caribbean and Florida Keys coral communities are also discussed.

The Submerged and Emergent Aquatic Vegetation Assessment includes information on seagrasses and mangroves within the FKNMS. The known effects of water quality on these types of communities are discussed. Community trends in the FKNMS are discussed relative to existing and potential water quality.

The Nearshore and Confined Waters Assessment encompasses an evaluation of waters within the FKNMS. Water-quality studies conducted in nearshore and confined waters are presented and discussed.

The Spill and Hazardous-Material Assessment includes information on historic spills and hazardous-material contamination. Total numbers of previous spills, causes, and potential preventative measures are discussed.

Recommendations regarding data adequacy and the direction for the Phase II effort are provided.

Section 2.0 provides general background information on the environment of the FKNMS. This information is provided to acquaint the reader with the general environment.

A list of acronyms used throughout this report is presented in Appendix A. Appendix B contains the Florida Keys National Marine Sanctuary Water-Quality Protection Program Workshops Summary report.

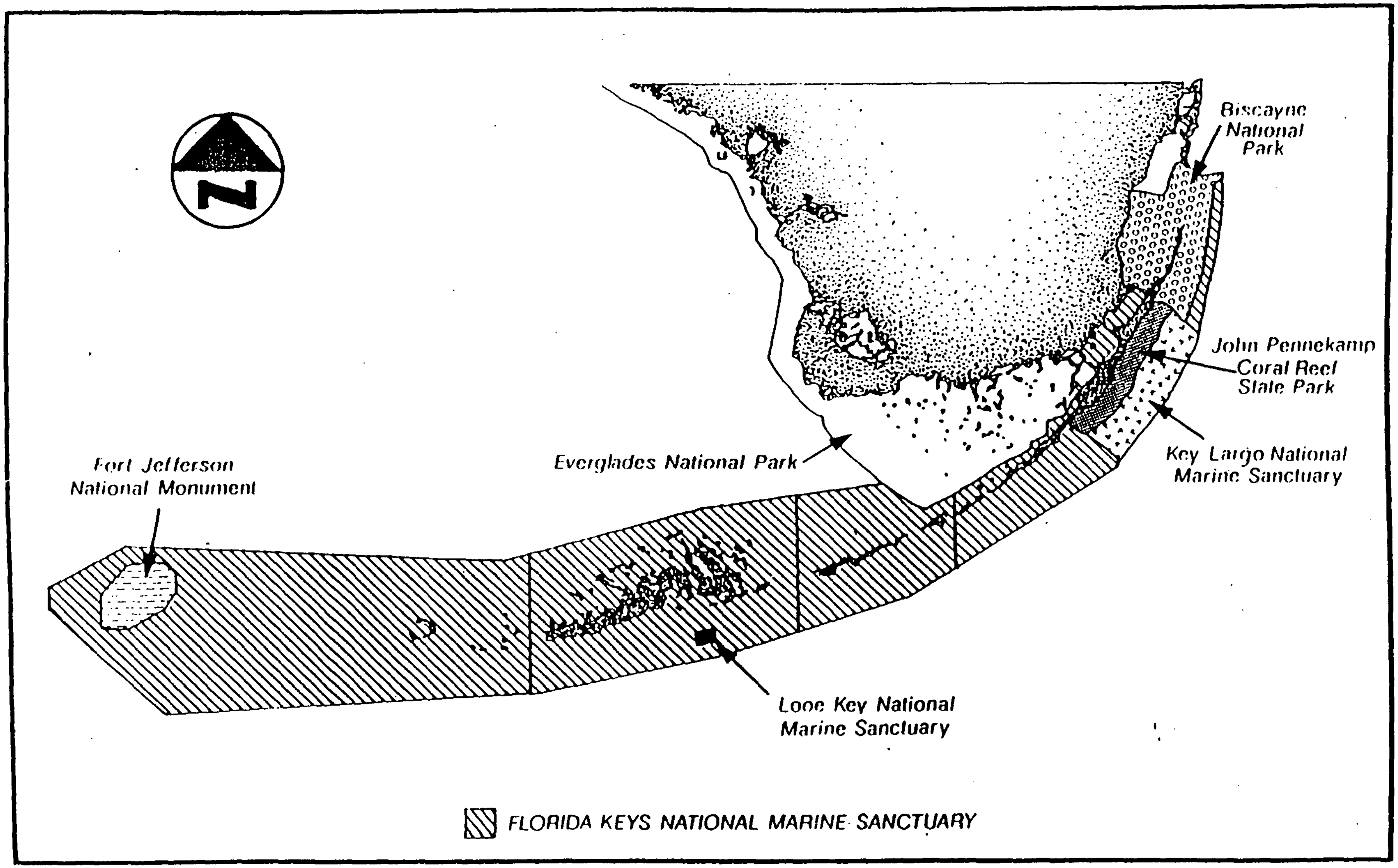

Figure 1-1. The Florida Keys National Marine Sanctuary.

2.0 DESCRIPTION OF THE FLORIDA KEYS NATIONAL MARINE SANCTUARY

2.1 SETTING

The FKNMS includes the waters off all of the Keys between Key Largo and Key West. The Sanctuary extends from the southern tip of Key Biscayne westward through the Tortugas Bank located on the western side of the Fort Jefferson National Monument (Dry Tortugas island group). North of Key Largo, the Sanctuary encompasses that portion of the Florida Reef Tract seaward of the boundary of Biscayne National Park down to the 92-m (300-ft) isobath. West of Key Largo, the Sanctuary includes Barnes and Card Sounds (**Figure 1-1**). These boundaries effectively cover the entire Florida Reef Tract from Key Biscayne through the Tortugas Bank, protecting all of the inshore bays and sounds along this same stretch of coastline.

The Key Largo National Marine Sanctuary and Looe Key National Marine Sanctuary, as existing Federally designated sanctuaries, will eventually be incorporated into the FKNMS. Until this incorporation is completed, they will continue to operate as independent entities awaiting emplacement of the new, comprehensive management plan. Everglades National Park, Biscayne National Park, and Fort Jefferson National Monument are excluded from the new Sanctuary. John Pennekamp Coral Reef State Park will continue under the jurisdiction of the State of Florida (NOAA 1991).

Exposed and sheltered mangrove shorelines dominate the fringing vegetation of the Florida Keys. Because the shoreward boundary on the Sanctuary is the mean highwater mark (NOAA 1991), most of these mangrove stands will lie within Sanctuary jurisdiction. Generally, the islands of the Florida Keys lie only 0.6 to 1.0 m (2 to 3 ft) above the mean high-tide mark. Maximum elevations, seen in the Key Largo area, reach only 5 m (18 ft) above sea level (Hoffmeister and Multer 1968).

Beyond the shoreline, extensive tidal flats and seagrass beds are seen on both sides of the Keys. Southward toward the Straits of Florida, the Florida Reef Tract parallels the islands. The major living reefs seen along the reef tract are concentrated on the reef tract's seaward edge. There, they form a discontinuous band showing good development in the upper (northern) Keys, poor to marginal development in the middle Keys (i.e., in the Seven Mile Bridge area), and better development again in the lower Keys and west from Key West.

The Sanctuary can be divided into three physiographic provinces distinguished by the shape, orientation, and lithology of the banks and islands in each (Schomer and Drew 1982). The northernmost province (Key Biscayne through Marathon), is characterized by long, narrow islands oriented northeast to southwest. These narrow islands restrict water exchange between the Atlantic, Florida Bay, and the various sounds in this area. It is here that the Florida Reef Tract is best developed. The central province (Bahia Honda through Key West) is characterized by roughly triangular islands oriented in a northwest to southeast direction, or at right angles to the Florida Reef Tract. These islands are built on an extension of the Miami Oolite Formation and their northwest-southeast orientation results from the directional movement of tidal currents over differing sea-level stands in the Gulf of Mexico and the Straits of Florida (Hoffmeister and Multer 1968). The western extension of the Sanctuary (Key West through Tortugas Bank) is composed of scattered islands, described as distal atolls by White (1970), and various shallow banks and shoals. The islands seen here are not actually atolls at all, but a scattering of approximately 30 roughly circular sand keys lying west of Key West. Moving westward from Key West, major features within this western extension of the Sanctuary are the Boca Grande island group, the islands forming the Marquesas, the Quicksands Banks through Rebecca Shoals, and the islands of Dry Tortugas, which are separated from Rebecca Shoals by a trough of relatively deeper water.

2.2 CLIMATOLOGY

The FKNMS has a mild, semitropical maritime climate, with a small daily range in temperatures. Water temperatures and salinities vary seasonally and are affected by individual storms and seasonal events. The winds that affect the Sanctuary are generally southeast to easterly, and they bring in moist tropical air over the area. Major storms, usually hurricanes, historically have affected the area on an average of once every 7 years.

During winter, cold fronts occasionally push rapidly through the area, and may cause rapid drops in temperature and high winds from the northwest. These types of winter conditions generally last 4 to 5 days (Zieman 1982).

The Sanctuary is characterized by a relatively long, and sometimes severe, dry season (November through April) and a wet season. Approximately 50% to 80% of the annual rainfall is received during the May through October wet season (Schomer and Drew 1982). These wet/dry seasonal precipitation levels, coupled with the winter increases in population seen in the Florida Keys, have numerous ramifications in terms of freshwater resource allocation and potential nearshore pollution problems within the Sanctuary (Lapointe *et al.* 1990).

2.3 HYDROLOGY AND PHYSICAL OCEANOGRAPHY

In the South Florida coastal region, physical oceanographic processes (including tides, currents, and surface waves) force local and regional circulation and, as a result, drive water-mass transport and exchange, embayment flushing, and bottom-sediment transport. Working separately or in combination, these processes affect the local water quality by transporting potential pollutants (polluted waters or sediments) in to or out of the region, or by maintaining them in place.

The physical oceanography of the South Florida coastal region is distinguished by the fact that a major world ocean current, the Florida Current, flows within the narrow boundaries of Straits of Florida, within a few tens of kilometers of shore. The Florida Current connects the Loop Current of the Gulf of Mexico to the Gulf Stream and flows through the straits bounded on the west by the Keys and the continental United States and on the east by the Bahamian-Caribbean archipelago (Figure 1-2). The Florida Current is a surface current restricted to the waters beyond the shelf break (i.e., beyond the edge of the continental shelf). Its influences, however, are felt by the nearcoastal waters of the Keys and mainland Florida and has a measurable effect on nearshore circulation.

2.3.1 Regional Circulation

The westward flowing North Equatorial Current splits at the Lesser Antilles and flows into the Caribbean as the Caribbean Current and north of the Bahamas Bank as the Antilles Current. The Caribbean Current is persistent and well defined, flowing westward throughout the year, with mean speeds at the core of about 50 cm/s (DOD 1983). Countercurrents have been observed along the shores of the Caribbean. The Caribbean Current flows into the Yucatan Current (at around 18° N Lat.) and passes through the Yucatan Strait with strong northward flows. Surface speeds at the core range between 50 and 150 cm/s, and eddies frequently occur north and south of the western tip of Cuba. On exiting the Yucatan Channel, the Yucatan Current widens and looses speed as it branches out into the Gulf of Mexico to form the Loop Current.

The Loop Current is so named because of the meandering loop it forms as it swings north then east then south again as it passes through the Gulf of Mexico before exiting via the Straits of Florida as the Florida Current (Figure 1-2). The extent of the intrusion of the Loop Current into the Gulf (its northern edge) fluctuates considerably. There may be a seasonal pattern to these meanders (Leipper 1970) but some controversy remains on this point (Vukovich 1986). Today, observations of the Loop Current are made using satellite thermal images. Acceptable imagery can be collected 6 to 9 months of the year, typically during the late fall, winter, and spring when thermal contrast and relatively clear skies allow. Satellite and other observations indicate that the Loop Current does not normally intrude landward of the 100-m isobath. However, phenomena associated with the Loop Current frequently intrude quite near the coast. These include perturbations that affect the circulation of the eastern Gulf of Mexico, taking the form of alternating cold and warm filamentlike structures, cold intrusions, and cold meanders. These perturbations are most pronounced in the north and east boundaries of the Loop Current. They average 100 to 200 km in size, have translation speeds of 6 to 24 km/day, and

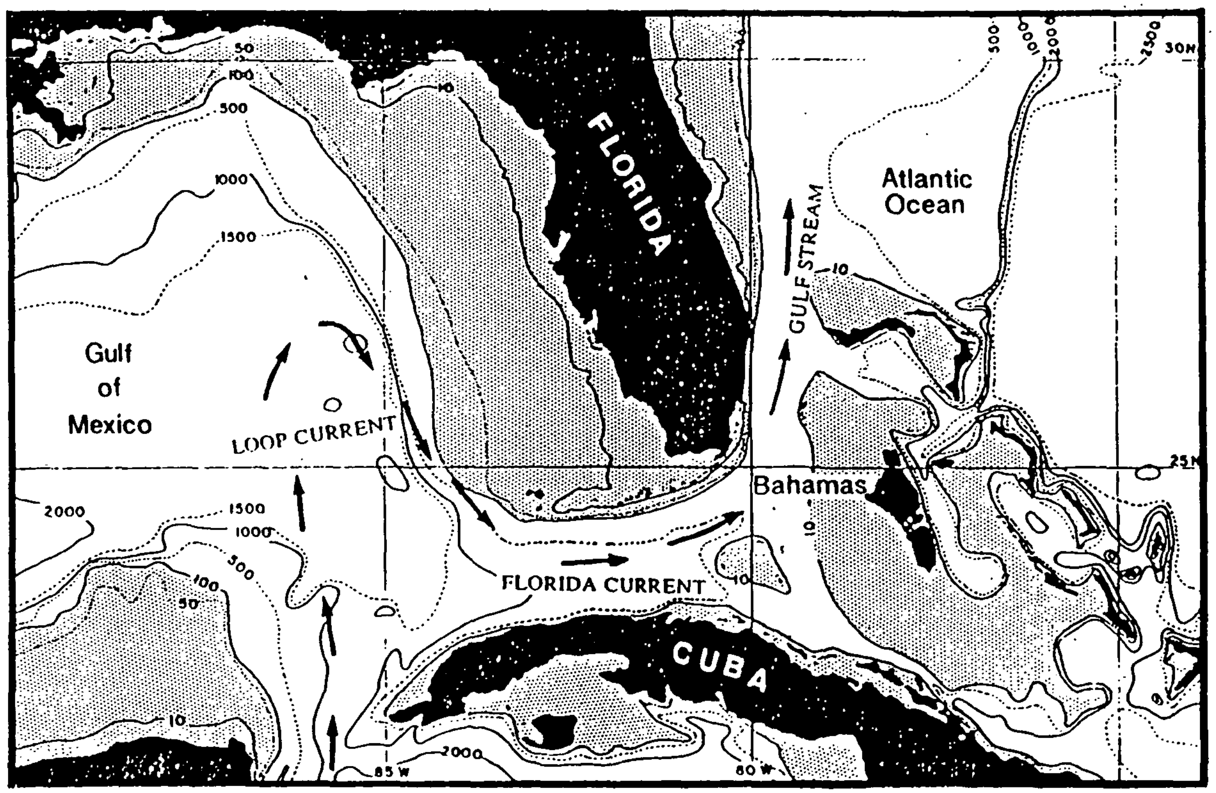

Figure 1-2. General bathymetry (fathoms) of the eastern Gulf of Mexico, Straits of Florida, and the Bahamas [From Wennekens 1959] and general configuration of the Loop Current, Florida Current, and the Gulf Stream.

exhibit life cycles of 16 to 120 days (Vukovich and Maul 1985). Upwelling, an important mechanism for transporting nutrients from deeper waters of the Gulf up onto the Florida shelf, is often associated with these perturbations.

The Florida Current sweeps through the Straits of Florida, past the Florida Keys and the southeastern Florida mainland, and moves into the Gulf Stream. Because of the very narrow continental shelf off southeast Florida, the Florida Current is within a few tens of kilometers of the shore. The Florida Current dominates the offshore transport of the region. Mean current velocity at the core is 100 cm/s, with maximums recorded as high as 300 cm/s (DOD 1983; Richardson *et al.* 1969). The total transport of the Florida Current has been estimated from current-meter measurements as 3.2×10^7 m^3/s (Schmitz and Richardson 1968). The Florida Current is limited by the Channel of the Straits of Florida and does not meander like the Loop Current or the Gulf Stream. Nearshore, a countercurrent has been observed with surface mean flows of 20 cm/s east to west off of Key West (Brooks and Niiler 1975). This seems to be a persistent feature in the western Keys, and is probably a cyclonic recirculation of the Florida Current. No such nearshore countercurrent has been observed in the northern Keys. Surface measurements off Marathon Key and Miami recorded mean flows to the east and north at 20 cm/s at 5 km offshore (Richardson *et al.* 1969). A deep countercurrent (below 400 m) has been observed in the northern Keys and off the eastern Florida mainland (DOI 1990). However, this does not affect the shallow coastal waters. Cyclonic eddies that spin off the western edge of the Florida Current have been observed east of Miami (Lee 1975) and are probably common throughout the northern Keys. These eddies are 20 to 30 km long (north-south) and 10 km across (east-west), and they move northward through the coastal waters with translation speeds of 25 cm/s (Lee 1975).

2.3.2 Regional Hydrography

The hydrographic properties of the water masses of the Straits of Florida and Florida continental shelf have been well studied (see, for instance, Wennekens 1959). The hydrography of the offshore waters of the Florida Keys region is greatly influenced by the flow of water originating in the Caribbean Sea and the Gulf of Mexico and to a lesser extent by the waters of the western Atlantic Ocean. The Caribbean and Yucatan waters are identified by their well-defined salinity maximum and are found all along the length of the Florida Current. A new water mass is formed in the western Gulf of Mexico as original Yucatan water is modified by evaporation and seasonal cooling. On the southwestern Florida continental shelf, a water mass that is intermediated between the Yucatan and Western Gulf Waters becomes differentiated. This water is found along the entire nearcoastal margin of the Straits of Florida, including the Keys, indicating the west to east transport of this water along the southern coast of the Keys. An influx of western Atlantic water, detected by its higher oxygen content, is frequently observed in the northern Straits of Florida off the northern Keys, but this is restricted to a narrow band along eastern margin of the Straits.

2.4 GEOLOGY

The FKNMS lies atop the Floridian Plateau. The Floridian Plateau, characterized by nonclastic, chemically or biologically produced sediments, underlies the Everglades, Florida Bay, the Florida Keys, and a large portion of the west Florida continental shelf to a depth of 92 m (300 ft). The Florida Keys represent elevated remnants of a Pleistocene coral reef tract that extends from Soldier Key through Key West (Hoffmeister and Multer 1964). In the northeastern part of the Sanctuary, Key Largo through Big Pine Key, the surficial sediments are part of an aerially weathered and recrystallized limestone formation known as Key Largo Limestone. At Big Pine Key, this feature dips beneath another sedimentary layer known as the Miami Oolite, which continues through Key West (Hoffmeister and Multer 1964). West of Key West, the oolitic facies submerge under a layer of recent biogenic sediments, but they continue to form the bed rock underlying the Holocene features of the

Marquesas Keys and Quicksands Banks. The Tortugas Bank and islands of the Fort Jefferson National Monument are Holocene features again built on Pleistocene limestone, presumably the Key Largo Formation (Shinn *et al.* 1989).

2.5 MARINE BIOLOGICAL COMMUNITIES

Broadly speaking, the FKNMS contains three unique and critically important marine biological communities:

(1) The mangrove forest lining its shorelines

(2) The extensive seagrass meadows, estimated to be some of the largest in the world, which lie on both sides of the island chain and extent offshore to the reef tract itself

(3) The Florida Reef Tract, which contains the only shallow-water coral reef ecosystem within the continental United States.

All these communities are tremendously complex within themselves, and each is made up of a vast number of interacting organisms. As is the case with the redwood forests of California, a few key plant and animal species define each community. These species, the mangroves, seagrasses, and hard corals, actually build and define the habitat, providing the structure that supports each community's countless individual inhabitants. Most of the fish and invertebrate species that contribute so heavily to Florida's sports and commercial fishing economy, as well as the majority of other mobile reef species, utilize all these different habitats at varying stages of their development.

The biological communities of the FKNMS form an integrated and unique ecosystem. It is the recognition of this fact that prompted creation of the Sanctuary. These marine biological resources are unique within the United States, and it is the objective of the National Marine Sanctuary Program to preserve and enhance them for future generations.

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WATER QUALITY ASSESSMENT
Task 2

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Task 2 - WATER QUALITY ASSESSMENT

1.0 INTRODUCTION

This task report assesses the water quality in the Florida Keys National Marine Sanctuary (FKNMS). The information presented in this report was obtained by review of the literature, Florida State agency reports, and examination of Florida and Federal agency records.

Point and nonpoint sources of pollutants are identified and discussed. External sources that could potentially affect water quality in the Sanctuary are also discussed. Information concerning the physical oceanography and status of water quality in the Florida Keys is presented. Future pollutant loadings and their potential effect on Sanctuary water quality are presented to the level possible through consideration of the available data.

2.0 HYDROLOGY/PHYSICAL OCEANOGRAPHY

2.1 CURRENTS OF THE WATERS OF THE FLORIDA KEYS

2.1.1 Mean Currents

Current-meter measurements made on the southwest Florida shelf (DOI 1987b) have observed long-term (multiyear) mean currents flowing southward down Florida Bay along local isobaths (**Figure 2-1**). Currents then turn westward along the north coast of the Keys, consistent with earlier hydrographic observations (Wennekens 1959), before flowing south through the passages between Key West and the Dry Tortugas, and then toward the east along the south coast of the keys. The mean velocities of near-surface and near-bottom currents were observed between 1 and 3 cm/s nearshore and between 3 and 10 cm/s offshore. Along the south coast of the Keys, a mean westward current has been observed associated with a countercurrent in the nearshore waters of the western Keys (Brooks and Niiler 1975). For the northern Keys, no observations of long-term patterns in current flow (e.g., mean flows) could be found in the literature. However, short-term observations of northward-moving eddies spun off shoreward by the Florida Current (Lee 1975) suggest mean nearshore currents flowing northward along the northern Keys.

Although mean currents give an indication of the continuous net transport of water masses, the transport of bottom sediments is more complex. To initiate motion of bottom sediments, the near-bottom fluid velocity must exceed a certain threshold that is dependent upon the sediment size, cohesiveness, and the presence of bedforms. Under normal conditions, near-bottom mean currents may not exceed this threshold. However, currents associated with episodic events such as large storms, powerful eddies shed by the Florida or Loop Currents, or orbital velocities under large waves, may be strong enough to initiate sediment motion. An indication of the likelihood of sediment resuspension by mean currents is available (e.g., by statistics of velocity exceedence levels from near-bottom current meters). Measurements reported by the Department of the Interior (DOI 1987b) indicate that mean near-bottom currents measured in shallow waters (13 m depth) of Florida Bay exceeded 20 cm/s only 14% of the time for the period December 1983 through October 1985. Near-bottom velocities of 20 cm/s are generally considered sufficient to initiate the suspension of fine sediments. It should also be noted that these values are hourly average velocities and do not represent wave velocities. Similar statistics are not available for the south coast of the Keys.

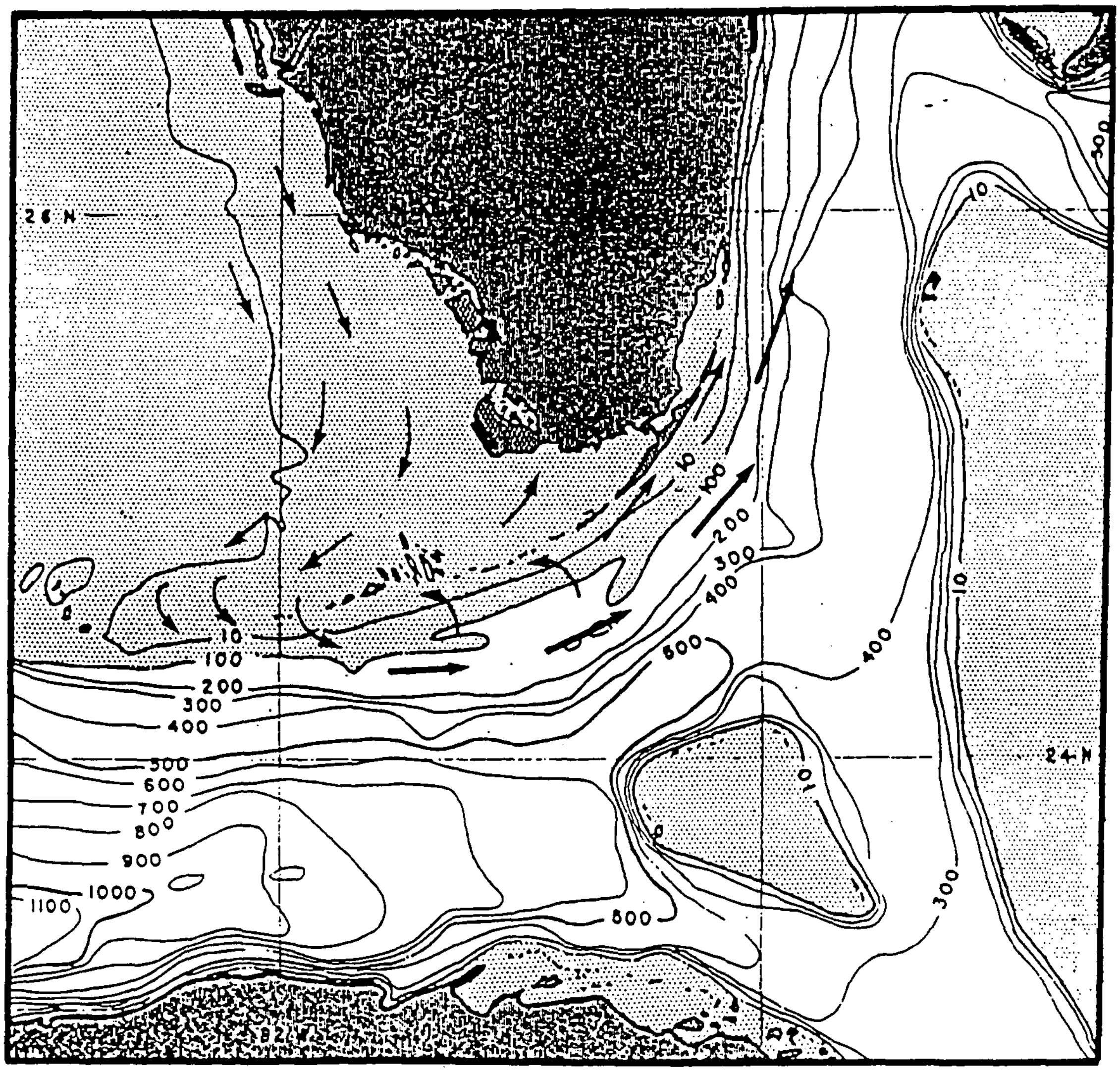


Figure 2-1. Bathymetry (fathoms) of the Straits of Florida [From Wennekens 1959] and the general pattern of mean currents measured on the U.S. continental shelf.

2.1.2 Tides

Tides of the south Florida shelf are driven by mixed diurnal (daily) and semidiurnal (twice daily) constituents, exhibiting two high tides of unequal heights per day. Tidal exchange between Florida Bay and the Atlantic Ocean is limited by the Florida Keys. The shallow inner shelf waters (<10 m depth) adjacent to shore are dominated by the tidal currents (DOI 1987a). Tidal velocities range between 5 and 15 cm/s on the shallow shelf, but where tidal flows are channeled by the Keys, velocities are much greater and may reach 130 cm/s (Enos 1977). Such velocities are great enough to cause substantial tidal flushing and sediment transport. Tidal ranges and average maximum flood and ebb tides for selected locations are given in **Table 2-1.**

Although tidal currents are oscillatory, residual currents and net transport result from energy dissipation due to bottom friction amplified by coastal bathymetry. On the shallow shelf south of the Keys, a net westward residual has been measured (Enos 1977), although this may be associated with the countercurrent rather than being tidally induced.

2.1.3 Wind-Driven Currents

The persistent trade winds of the Caribbean contribute a significant amount of energy to the water column in the form of surface shear, resulting in large surface waves and wind-induced currents. The prevailing direction of the tradewinds is from the northeast in the fall and winter and from the east in spring and summer, the latter of which occurs as the Bermuda high shifts to a more northeasterly position (DOD 1983; Weber and Blanton 1980). Direct evidence of wind-forced currents in Florida Bay is seen in current-meter measurements reported by the DOI (1987b). These showed significant statistical coherence between wind and current measurements in the 3- to 6-day band. The highest coherence was observed in the shallow waters of the midshelf (10 to 50 m). On the east coast of the U.S. South Atlantic, the DOI (1984) reports that the midshelf of the South Atlantic Bight is dominated by wind forcing. High correlations were observed between measured wind events and currents in the 2- to 14-day period band.

In addition to an along-shore current, along-shore winds may set up a weaker cross-shore circulation. An easterly wind blowing to the west along an east—west coast such as the south coast of the Florida Keys causes an onshore movement of water in the near-surface layer. This onshore movement of near-surface water is due to the earth's rotation; a comparable offshore movement of water occurs in the near-bottom layer, resulting in downwelling of coastal water. Westerly winds (directed toward the east) will result in offshore movement of the near-surface layer and upwelling of nutrient-rich deeper water. The strong east-to-west tradewinds of the Florida Keys region result in the downwelling of near coastal water along the coast bordering the Straits of Florida and an exchange of water with the Florida Current, which may have a significant effect on coastal water quality. A schematic diagram of this response is shown in **Figure 2-2**. This effect is most pronounced during periods of strong winds.

Hurricanes and tropical storms visit this region occasionally, and the associated high winds can result in large increases in current speed throughout the water column. During Tropical Storm Bob, in November 1985, the average near-bottom current speeds measured in Florida Bay showed over a fivefold increase for a period of 2 to 3 days (DOI 1987a). Bob was a moderate tropical storm with sustained winds of only 40 kn. The temperature record from the same current meter showed a 3 °C change over the same period, indicating a large water mass exchange, significant movement of shelf water, and possible upwelling.

Table 2-1. Tidal ranges and average maximum flood and ebb tidal currents for selected locations.

Location	Mean Tidal Range (cm)	Average Maximum Flood (cm/s)	Flood Direction	Average Maximum Ebb (cm/s)	Ebb Direction
Key Largo (Garden Cove)	85				
Pumpkin Key	25				
Long Key Viaduct	77	50	349°	60	170°
Duck Key	87				
Grassy Key (north side)	65				
Flamingo Key	78				
Fat Deer Key	45				
Vaca Key	59				
Sombrero Key	61				
Knight Key Channel	28				
Pigeon Key (south side)	43				
Molasses Key	40				
Bahia Honda Key (bridge)	49	70	004°	110	182°
No Name Key	28	40	312°	50	142°
Big Spanish Key	105				
Cudjoe Key	40				
Bird Key	30				
Sand Key	47				
Key West (Northwest Channel)	53	60	353°	70	162°
Gordon Key, Dry Tortugas	45				
Channel Key	35				

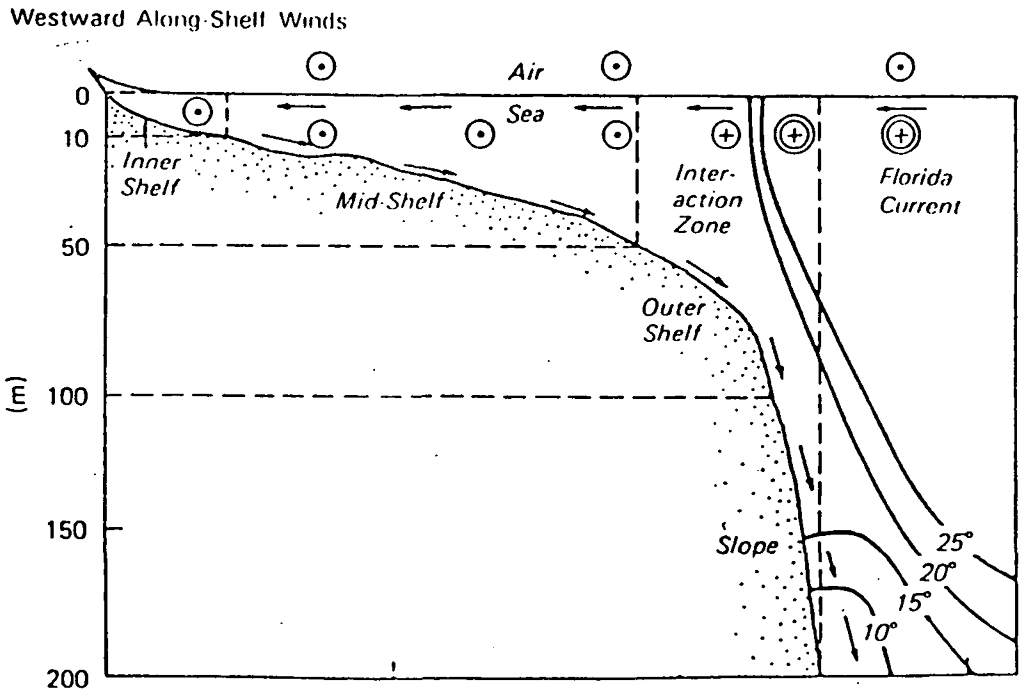


Figure 2-2. Schematic representation of shelf-water response to along-shore wind on the south coast of the Florida Keys. [Adapted from DOI 1984]

2.2 SURFACE WAVES

As suggested previously, oscillatory currents due to surface waves can penetrate to the bottom in shallow water, and sediments (e.g., contaminated sediments) can be resuspended into the water column. This will affect water quality by the simple process of mixing. Contaminated sediments, mobilized into the water column by wave action, can be transported as resuspended particulates to other locales by mean currents. Typically, these mean currents are otherwise too weak to initiate sediment resuspension alone. It is important to note that the transport of sediments is most efficiently achieved, and most common, when waves as well as currents are present. Orbital, to-and-fro wave motions are present under all surface waves. These motions vary with wave height. They are strongest near the surface and weaker with increasing depth. Such wave motions result in little or no *net* motion since the orbits are nearly closed. In the shallow waters near the coast, these orbital motions affect the bottom and can provide enough energy to resuspend bottom sediments, but do not transport the sediments. However, once suspended off the bottom, these sediments are free to be transported by any mean current.

The persistent trade winds of the Caribbean induce large waves. The prevailing direction of waves in the region follows the prevailing wind directions, from the northeast in fall and winter and from east in spring and summer (Jones *et al.* 1973). Data from offshore buoys maintained by the National Data Buoy Center, National Weather Service, report mean monthly wave heights from 0.6 to 1.5 m for Florida Bay (DOI 1986). The highest waves were recorded during the winter months when waves exceeded 1.5 m 51% of the time and 2.5 m 13% of the time. As offshore waves move landward, they lose energy as a result to their interaction with the bottom. An offshore wave with a wave height of 0.6 m (mean monthly value) and a period of 7 s will result in orbital bottom velocities of 10 cm/s at 20-m water depths and 21 cm/s at 10-m depths. When the mean wave height increases to 1.5 m and the period increases to 10 s, orbital bottom velocities reach 38 cm/s at 20-m and 64 cm/s at 10-m water depths. These are monthly mean values and contrast notably with the 14% exceedence of 20 cm/s for the *mean* current velocities presented earlier. Inshore stations in the lee of land masses report reduced wave heights (DOI 1987b). Despite this, the wave climate of the region will commonly penetrate to the bottom and resuspend bottom sediments in shallow waters.

2.3 PROCESS CHARACTERIZATION

Available data from studies in the Florida Bay and the Straits of Florida show that the circulation of the Florida Keys region is affected by several factors, including tidal currents, wind forcing, and the effects of the nearby Florida and Loop Currents. These processes, which are addressed individually in **Sections 2.1** and **2.2**, may, at times, act alone, but more typically they act in concert in a complex interrelationship that makes it difficult to predict circulation patterns. However, it is possible to characterize these processes by considering separately the regions of the continental shelf where different processes tend to dominate. A schematic characterization of the shelf is presented in **Figure 2-3**.

On the inner shelf (<10 m water depth), the effects of the Florida Current (including related eddies or countercurrents) are not present. Nearshore circulation and the exchange and transport of water masses are dominated by tidal currents and atmospheric forcing (Lee 1985). In a study of the Key Largo Coral Reef Marine Sanctuary, Lee (1985) found that approximately 80% of the cross-shelf variance and 50% of the along-shelf variance on the inner shelf was due to tidal forcing, and that the remaining variance was due largely to wind forcing. Although present everywhere across the shelf, tidal currents of the inner shelf are amplified by shallow water and narrow channels around and between the Keys. Although the tidal currents can be quite strong, the net transport is small because tidal currents are oscillatory and net transport depends on weak tidal residual currents. At the same time, sediment transport is most significant owing to the shallow nature of the region. Wave velocities penetrate to the bottom, where they can suspend bottom sediments. The midshelf (20- to 50-m water depths) is generally dominated by the effects of wind forcing, although in the western Keys, an east-to-west countercurrent is also present. Currents on the midshelf show variability over a 2- to 10-day band,

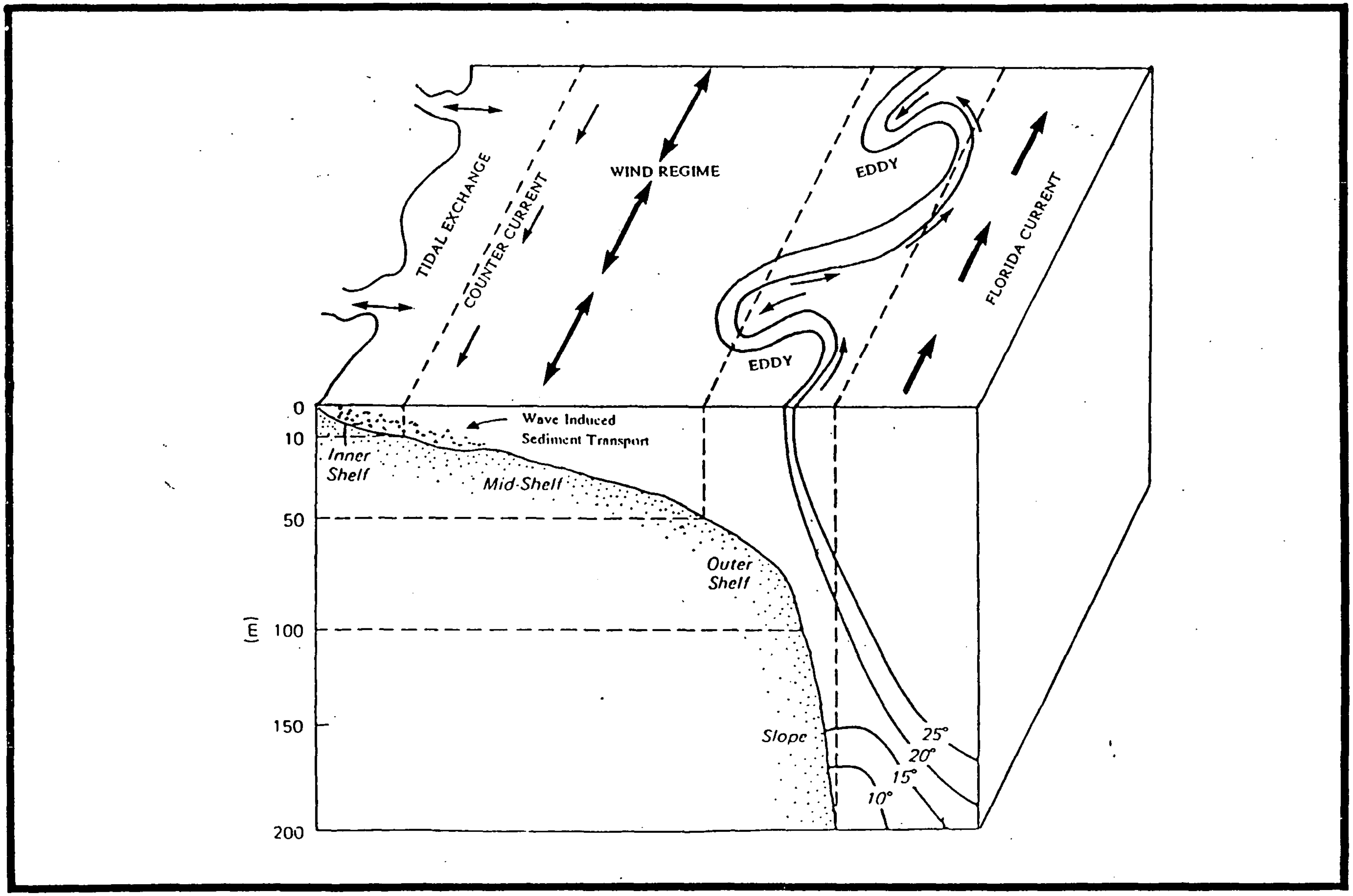


Figure 2-3. Schematic representation of continental shelf processes and the Florida Current. [Adapted from DOI 1984]

roughly equivalent to the major periods of meteorological variability. In the midshelf, sediment transport is still common because the moderate depths still allow considerable wave-induced currents near the bottom. In Florida Bay, the midshelf is as much as 100 km wide; weak westward mean currents flowing along the north side of the Keys are driven by regional circulation. The outer shelf (50- to 100-m water depths) is typically the interface between either the midshelf waters and the energetic Florida Current to the south or the Loop Current to the west and north. Within this region, eddies and filaments shed by the major currents can episodically increase transport processes. Beyond the 100-m isobath lies the continental slope, with overlying waters under the direct influence of the Florida or Loop Currents.

The most important physical processes for the region from the viewpoint of water quality may be episodic events such as hurricanes, tropical storms, and the shoreward incursion of energetic eddies and filaments associated with the Florida or Loop Currents. Although infrequent, these processes may have a significant effect, as they may produce large increases in current velocities throughout the water column, and result in large-scale water-mass exchange and sediment transport. Unfortunately, few measurements of currents (and measurements of sediment transport) have been made during severe storms. The anecdotal evidence suggests their importance, but the available data are too sparse to quantify their climatological effect. A numerical modeling study of the Keys using storm surge models including wave-current interaction may provide good estimates of the importance of storms in water mass exchange, but that is beyond the scope of this study.

3.0 SOURCES AFFECTING WATER QUALITY IN THE SANCTUARY

3.1 POINT SOURCES

3.1.1 Definition

For the purposes of this study, point-source dischargers are defined as those facilities that discharge effluent directly to surface waters. Important types of potential point-source dischargers include wastewater treatment plants, water supply treatment plants, industrial facilities, and power plants.

3.1.2 Background

The Federal Water Pollution Control Act, also known as the Clean Water Act (CWA), requires that a Federal permit be issued whenever pollutants are discharged into navigable waters from a point source (Basta *et al.* 1985). Therefore, all point-source dischargers must receive National Pollutant Discharge Elimination System (NPDES) permits from the Environmental Protection Agency (EPA) in order to operate their facilities. Most also receive permits from the Florida Department of Environmental Regulation (FDER). The FDER's responsibility has been defined in Section 403.011, Florida Statutes, the "Florida Air and Water Pollution Control Act."

The number of facilities discharging into surface waters has steadily decreased over the years. According to EPA data (1991a), 71 NPDES permits have been issued in Monroe County since 1974. At the start of 1991, there were 36 facilities operating with NPDES permits. As of January 1992, there were only 17 facilities with permits. This attrition is attributable partially to the more stringent FDER water quality standards recently adopted by the State (G. Rios, FDER, personal communication, 1991). The dischargers that have discontinued releasing effluent into a receiving water body have either received permits from FDER to discharge their effluent into injection wells (i.e., boreholes) or into on-site septic systems (G. Rios, FDER, personal communication, 1991). Others were deactivated because the permittees closed their businesses (G. Rios, FDER, personal communication, 1991). Several entities maintain NPDES permits for emergency purposes only (e.g., Fleming Key Animal Import Center). As of January 1992, only 13 of 17 facilities were still actively discharging their effluent into one of the many receiving water bodies in the Florida Keys. Of those remaining, several are planning to eliminate surface-water discharge by connecting to an existing treatment facility [Sigsbee Park to Key West Sewage Treatment Plant (STP) (Solin 1991)] or discharge via injection wells or on-site septic systems (G. Rios, FDER, personal communication, 1991). There is a single facility in Dade County (Florida Power and Light) with an NPDES permit for discharging into surface waters of the FKNMS.

3.1.3 Types of Facilities

Domestic wastewater treatment facilities account for the largest number of active dischargers in the region (i.e., 10). These include a campground, Florida Keys Community College, and municipal waste treatment plants (i.e., Key West, Key Colony Beach). Five facilities are Federal installations and they discharge wastewater daily. The remaining actively discharging facilities include two industrial dischargers. They are the Key West Steam Power Plant and the Ocean Reef Club, a large residential development in North Key Largo that operates a desalination plant. There is also a single permit for stormwater runoff from a Federal facility.

Figure 2-4 graphically locates all 17 facilities. **Tables 2-2** and **2-3** list each facility and provide detailed information pertaining to daily flow rates and the characteristics of individual discharges.

3.1.4 Size of Facilities

Table 2-4 summarizes the wastewater facility discharges. All but one of the wastewater facilities are considered to be minor dischargers with volumes of less than five million gallons per day (MGD). The only major discharger is the Key West STP. It has a design capacity of 10 MGD and discharges into the Atlantic Ocean (Solin 1991). According to the City of Key West's contract engineering firm, CH_2M Hill, average annual discharge flow between March 1988 and February 1989 was 5.82 MGD. The maximum daily flow was 7.22 MGD, which occurred during peak season. The Key West facility is subject to a considerable amount of infiltration/inflow, both from the city's collection system as well as the Navy's collection system. The sewage that flows to the Key West facility is composed of infiltration/inflow (36%), residential (32%), and commercial (32%) (Solin 1991). The largest of the remaining wastewater facilities is the City of Key Colony Beach, with a 0.2-MGD design capacity and average daily flow of 0.17 MGD. The plant discharges to Bonefish Bay (EPA 1991b). The remaining have a total combined flow of 1.02 MGD. Two facilities are industrial dischargers. Key West Utility (Stock Island Steam) uses seawater for cooling. The average daily discharge from this facility was 21.4 MGD for the first 8 months of 1991 (EPA 1991b). The second facility is a desalinization unit at Ocean Reef Club. The average daily discharge from this facility was 0.39 MGD for the first 6 months of 1991 (EPA 1991b).

3.1.5 Location of Facilities

In general, most point-source discharge facilities are scattered throughout the Keys. The Key West area represents the lone exception to this general tendency. Nearly half of the active point sources in the region are located in Key West. A number of these facilities are military-related. The one major wastewater plant in the Keys, the Key West STP, is located on Fleming Key, adjacent to Key West.

Table 2-2. Inventory of NPDES point-source permits, January 1992.

Fig. 2-4 ID #	Facility Name	NPDES # (EPA)	GMS # (FDER)	Latitude	Longitude	Type of Facility	Receiving Water
215	FL Keys Aqueduct — Long Key	FL0035467	—	Not available		I	Atlantic Ocean
216	FL Keys Aqueduct — Ramrod Key	FL0035459	—	Not available		I	Atlantic Ocean
201	FL Keys Community College	FL0033928	5244S03349	24°34′50″N	81°44′40″W	D	Gulf of Mexico
165	Key Colony Beach STP	FL0021253	5244M03028	24°43′30″N	81°01′18″W	D	Bonefish Bay
177	Key West STP	FL0025976	5244M06172	24°32′47″N	81°47′54″W	D	Atlantic Ocean
211	Key West Util-Stock Isl Steam	FL0002089	5244M02019	24°33′49″N	81°44′03″W	I	Atlantic Ocean
199	Monroe Cnty Pub Ser Bldg	FL0030562	5244C02855	24°34′20″N	81°44′59″W	D	Cow Key Channel
210	Ocean Reef Club	FL0025607	5244P02472	24°54′51″N	80°38′00″W	I	Atlantic Ocean
113	USCG Islamorada Station	FL0025763	5244F00025	24°57′12″N	80°35′10″W	F	Florida Bay
66	USCG Marathon Station	FL0021709	5244F00026	24°42′38″N	81°06′24″W	F	Unknown
212	USDA Animal Import Center	FL0033359	5244F02036	24°35′05″N	81°47′47″W	I	Gulf of Mexico
176	USDA FWS Key Deer NWR	FL0029688	—	24°40′00″N	81°20′00″W	F	Gulf of Mexico
7	USN Boca Chica STP	FL0020982	5244F00020	24°35′14″N	81°41′46″W	F	Gulf of Mexico
205	USN Sigsbee Park STP	FL0020991	5244F00021	24°35′56″N	81°46′35″W	F	Gulf of Mexico
213	USN NAS Key West	FL0001716	—	Not available		F	Gulf of Mexico
15	Venture Out in Am-Cudjoe Key	FL0034924	5244P03339	24°39′27″N	81°28′22″W	D	Kemp Channel
214	FP&L Turkey Crk Pt Power Plant	FL0001562	—	Not available		I	Biscayne Bay

Sources: EPA 1991a,b; FDER 1991b; CH_2M Hill 1979; G. Rios, FDER, personal communication, 1991; M. Robertson, M. Donahue, and R. Phelps, EPA, personal communication, 1991.

D: Domestic.
I: Industrial.
F: Federal.

Table 2-3. NPDES point-source flow and constituent data, January 1992.

Fig. 2-4 ID #	Facility Name	Range of Max. Daily Flow (MGD)	Range of Daily Flow (MGD)	Range of BOD (mg/L)	Range of pH	Range of TSS (mg/L)
215	FL Keys Aqueduct — Long Key	Discharge Monitoring Report indicates not in operation				
216	FL Keys Aqueduct — Ramrod Key	Discharge Monitoring Report indicates not in operation				
201	FL Keys Community College	0.003-0.007	0.002-0.007	0.0-15.0	6.8-6.9	0-15
165	Key Colony Beach STP	0.2247-0.4990	0.135-0.195	2.0-11.0	6.8-7.2	3-6
177	Key West STP	9.06-9.41	5.585-7.546	5.0-13.0	6.9-7.0	4-8
211	Key West Util-Stock Isl Steam	14.83-36.00	14.83-36.00	No data reported		
199	Monroe Cnty Pub Ser Bldg	0.003-0.008	0.002-0.003	2.0-12.0	6.9-7.2	1-12
210	Ocean Reef Club	0.666-0.752	0.287-0.411	0.1-1.05[a]	7.3-7.7	1-12
113	USCG Islamorada Station	0.003-0.0035	0.001-0.002	1.0-3.0	7.0	2-4
66	USCG Marathon Station	0.0027-0.0067	0.001-0.005	4.0-13.0	6.9-7.2	3-12
212	USDA Animal Import Center	Only an emergency discharge point; has never been used				
176	USDA FWS Key Deer NWR	EPA discharge monitoring report not available; discharge minor				
7	USN Boca Chica STP	0.127-0.516	0.0115-0.99	3.3-8.1	6.7-7.3	2-6
205	USN Sigsbee Park STP	0.787-1.040	0.713-0.793	7.4-12.7	7.2-7.3	8-41
213	USN NAS Key West	Stormwater runoff permit for a fuel tank farm				
15	Venture Out in Am-Cudjoe Key	0.029-0.062	0.020-0.054	6.0-7.5	6.0-7.5	3-24
214	FP&L Turkey Crk Pt Power Plant	Only for emergency discharge				

[a]Total phosphorus

Sources: EPA 1991a,b; FDER 1991b; CH_2M Hill 1979; R.J. Helbling, FDER, personal communication, 1992; G. Rios, FDER, personal communication, 1991; M. Robertson, M. Donahue and R. Phelps, personal communication, 1991.

MGD: Million gallons per day

BOD: Biological oxygen demand

TSS: Total suspended solids

Table 2-4. Sanitary wastewater facility discharges.

Facility Name	Average Daily Flow (MGD)
Florida Keys Community College[c]	0.00600
Key Colony Beach STP[a]	0.17475
Key West STP[c]	5.82000
Monroe Cnty Pub Ser Bldg[c]	0.00200
USCG — Islamorada[b]	0.00186
USCG — Marathon[b]	0.00229
USDA FWS Key Deer NWR	No data available
USN Boca Chica STP[b]	0.13090
USN Sigsbee Park STP[a]	0.75383
Venture Out in Am-Cudjoe Key[b]	0.03271
TOTAL:	6.92434

MGD: Million gallons per day
[a]FDER 1991c.
[b]Keith and Schnars, unpublished data 1991.
[c]Solin 1991.

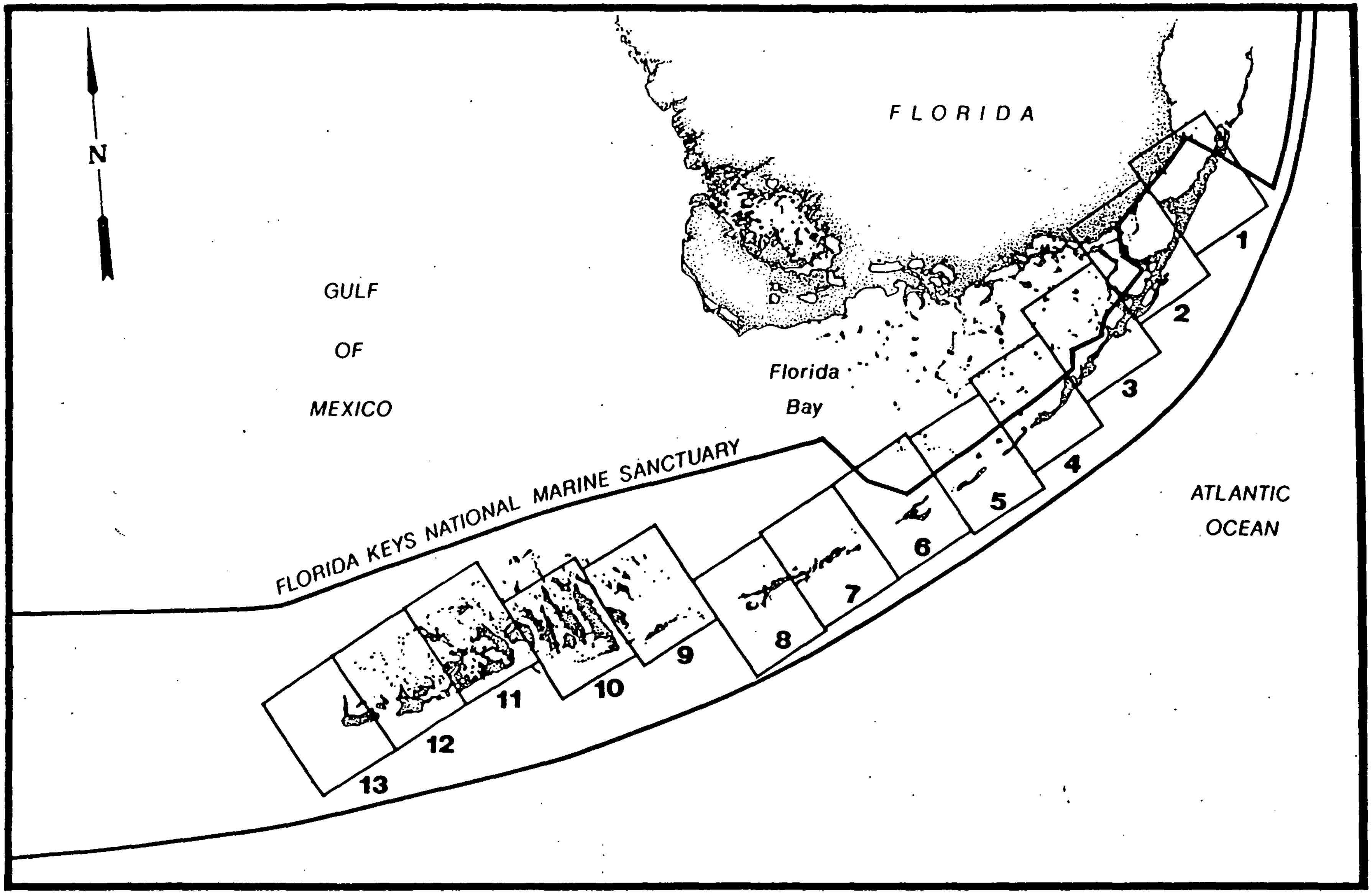


Figure 2-4. Wastewater treatment facilities and discharge canals.

This Figure and its 13 components, which follow, indicate the geographic locations of the discharge canals (Turkey Point Cooling Canal, Model Land Canal, and C-111 Canal), the sanitary wastewater facilities that discharge via injection wells (indicated on the maps by O) or surface waters (NPDES; indicated on the maps by □), and other surface-water (NPDES) dischargers (indicated on the maps by Δ). Numbers associated with NPDES facilities and sanitary wastewater correspond to the numbers in Tables 2-2 and 2-5, respectively. Locations of sanitary wastewater facilities compiled for the unincorporated Monroe County and City of Key West by Keith and Schnars (unpublished data 1991) and Solin (1991). Base maps redrawn from maps provided by Wallace Roberts & Todd.

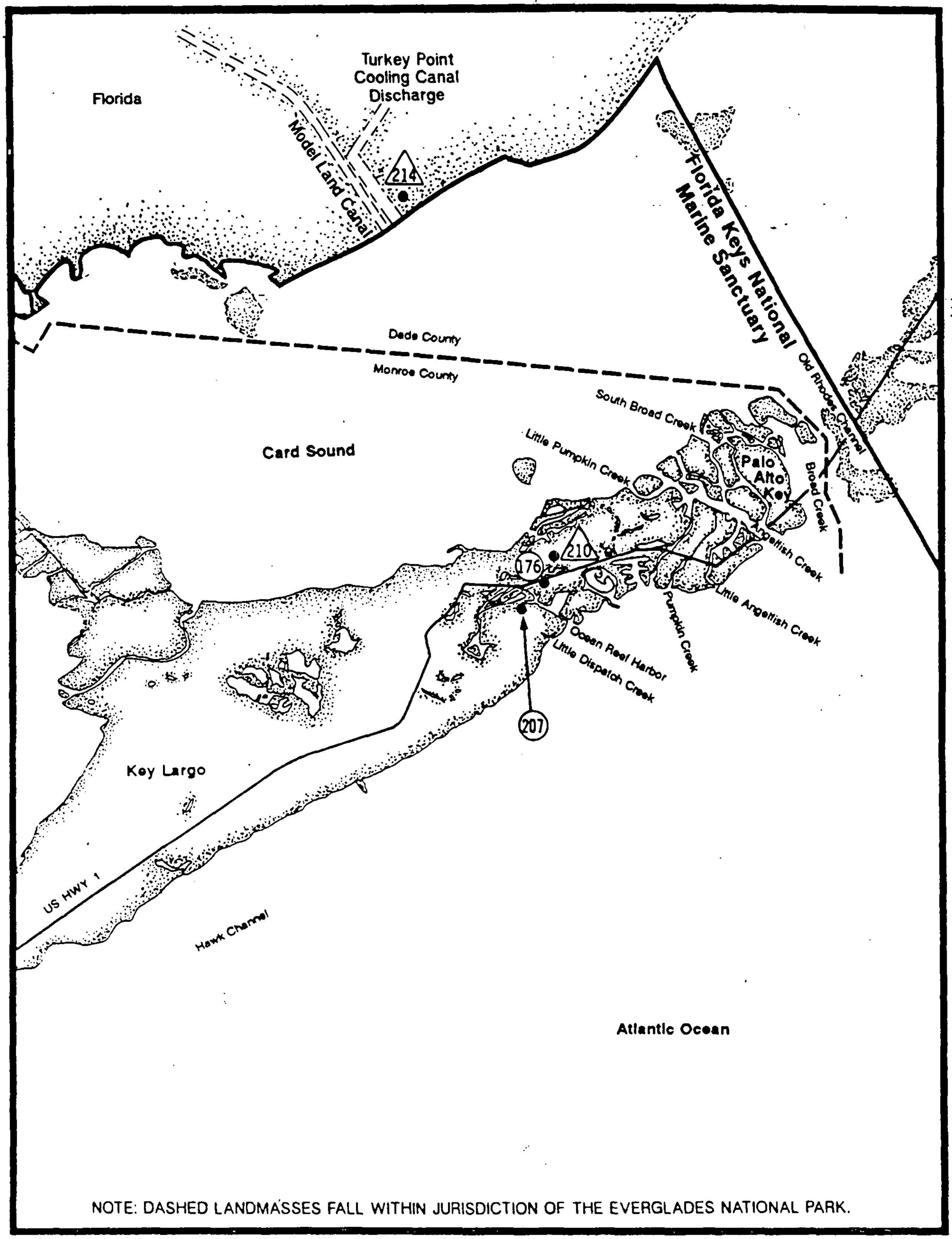


Figure 2-4-1. Wastewater treatment facilities and discharge canals. (continued)

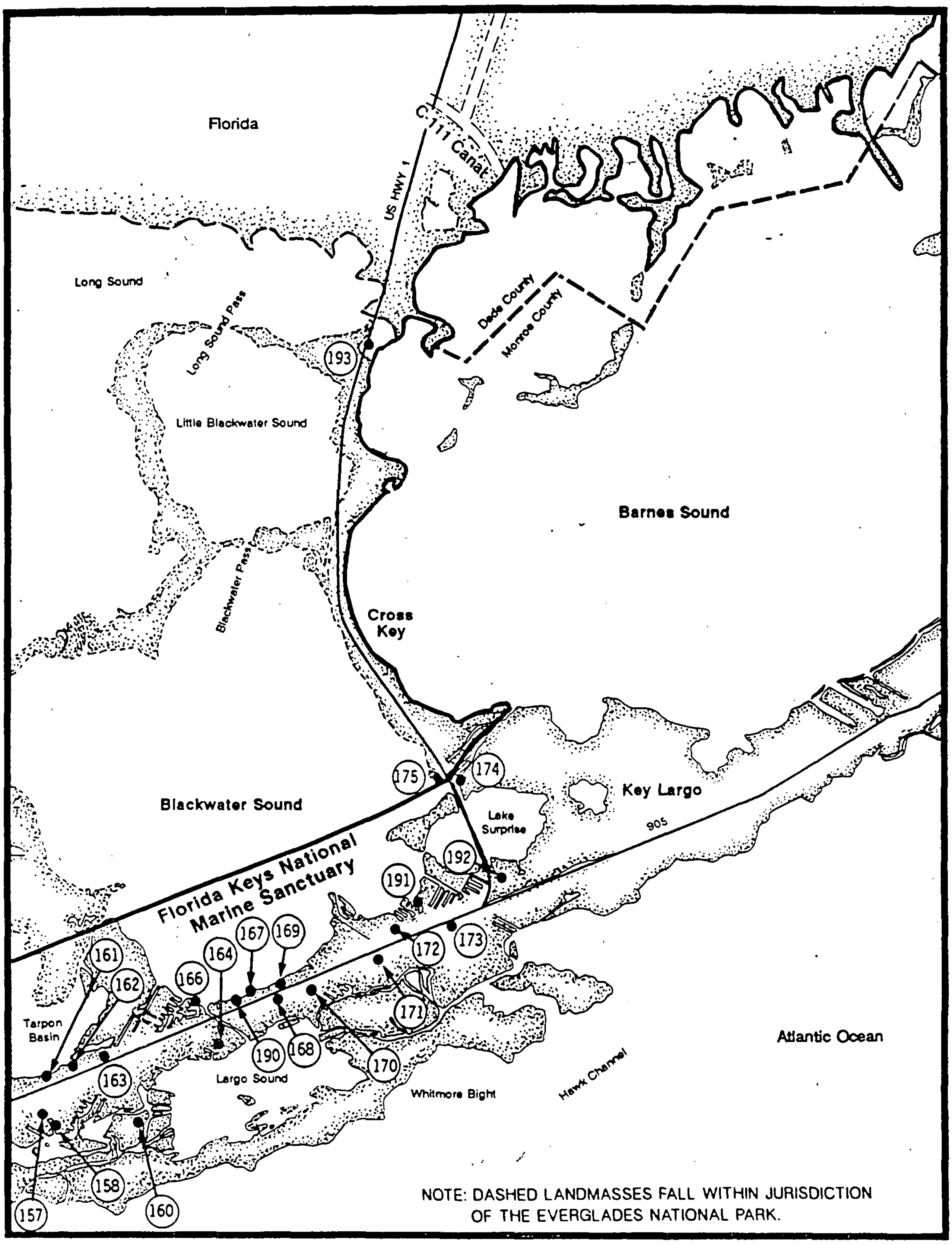


Figure 2-4-2. Wastewater treatment facilities and discharge canals. (continued)

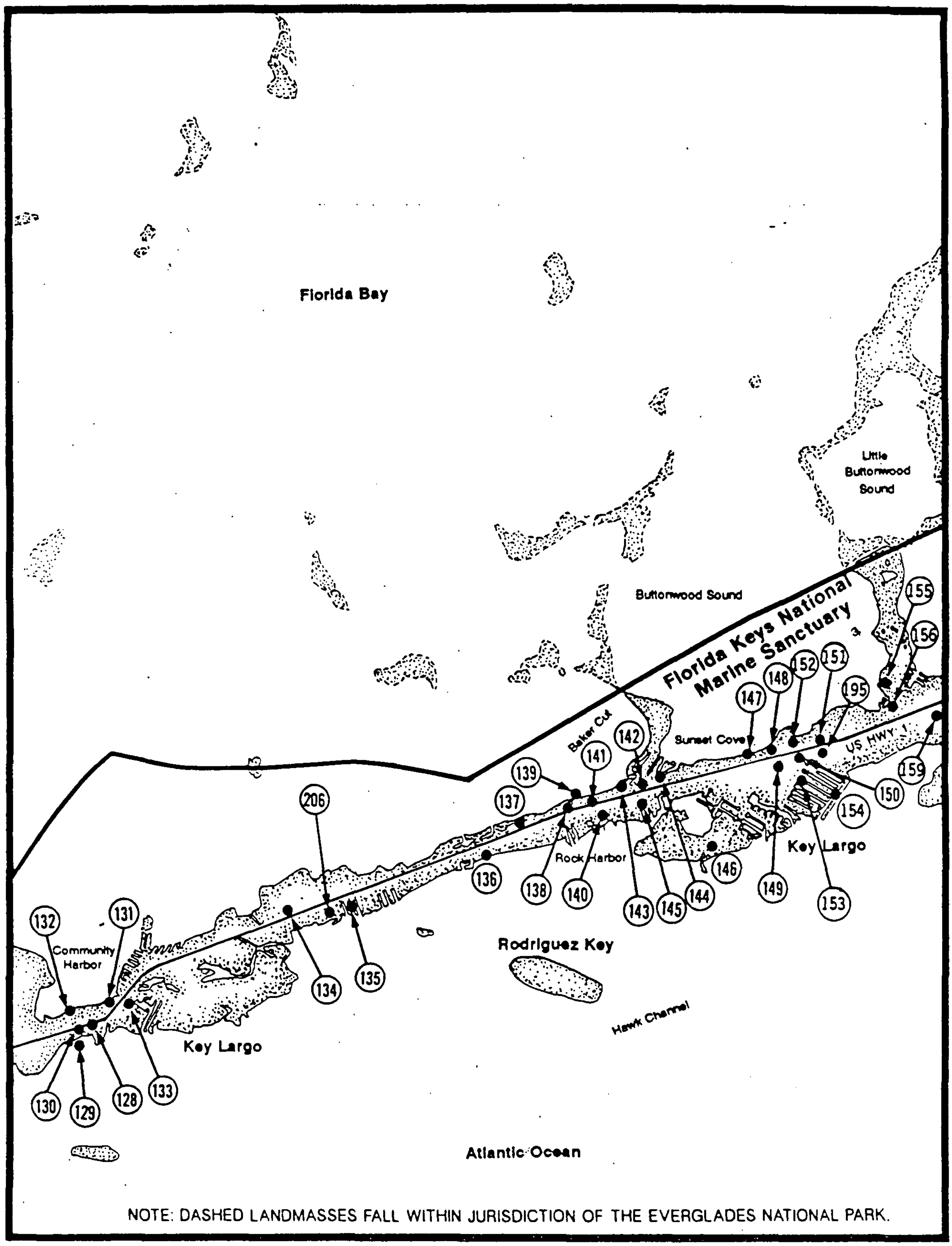


Figure 2-4-3. Wastewater treatment facilities and discharge canals. (continued)

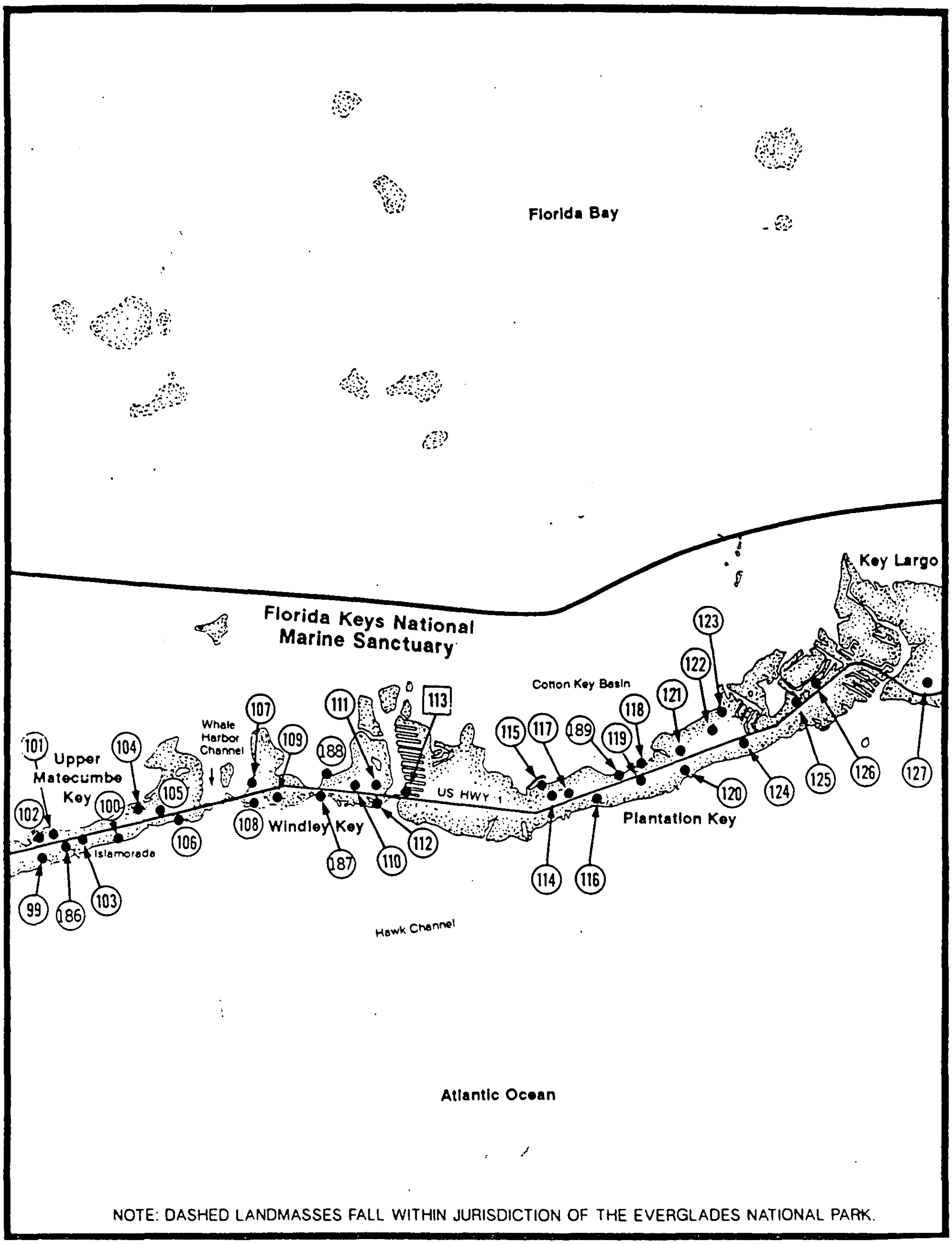


Figure 2-4-4. Wastewater treatment facilities and discharge canals. (continued)

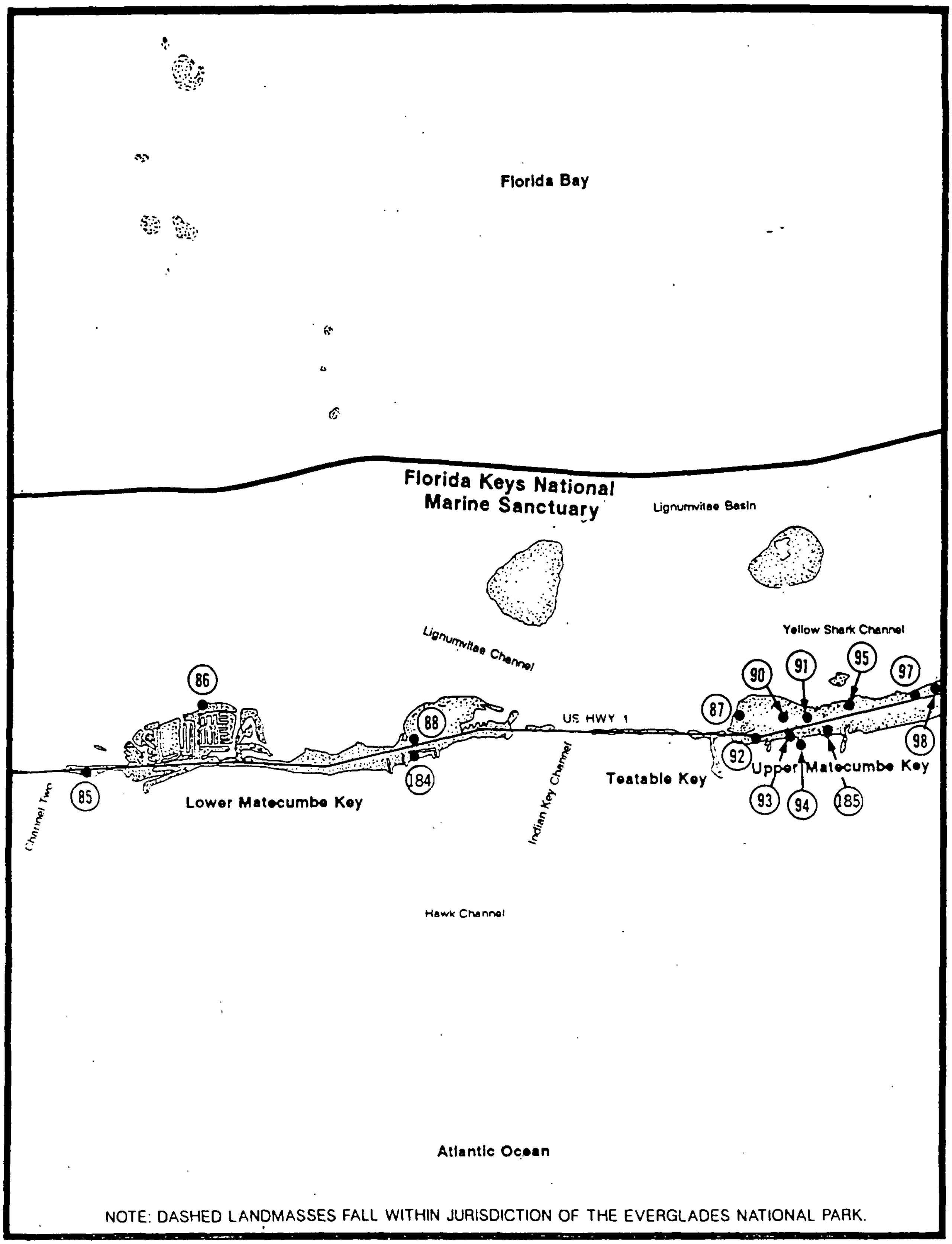


Figure 2-4-5. Wastewater treatment facilities and discharge canals. (continued)

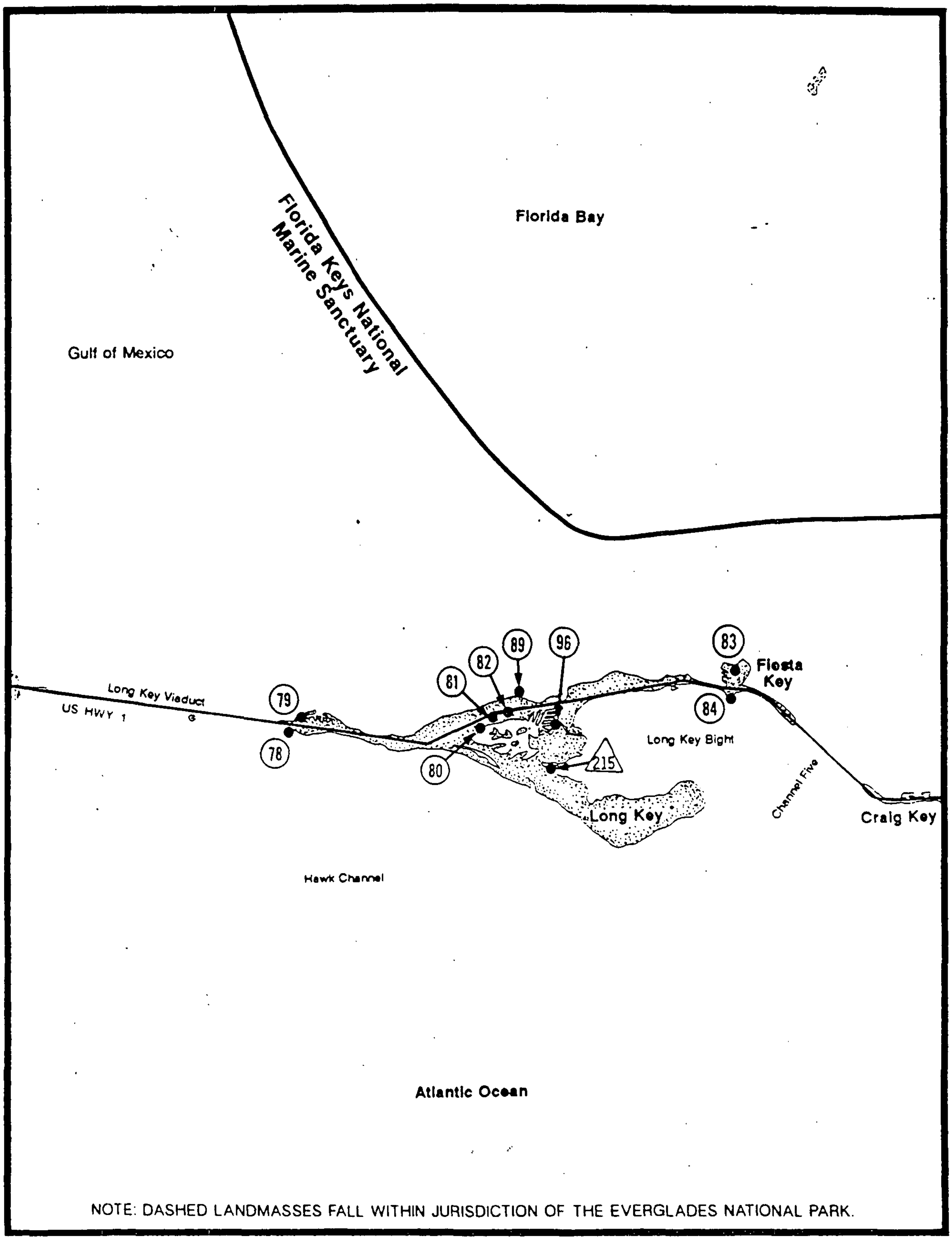


Figure 2-4-6. Wastewater treatment facilities and discharge canals. (continued)

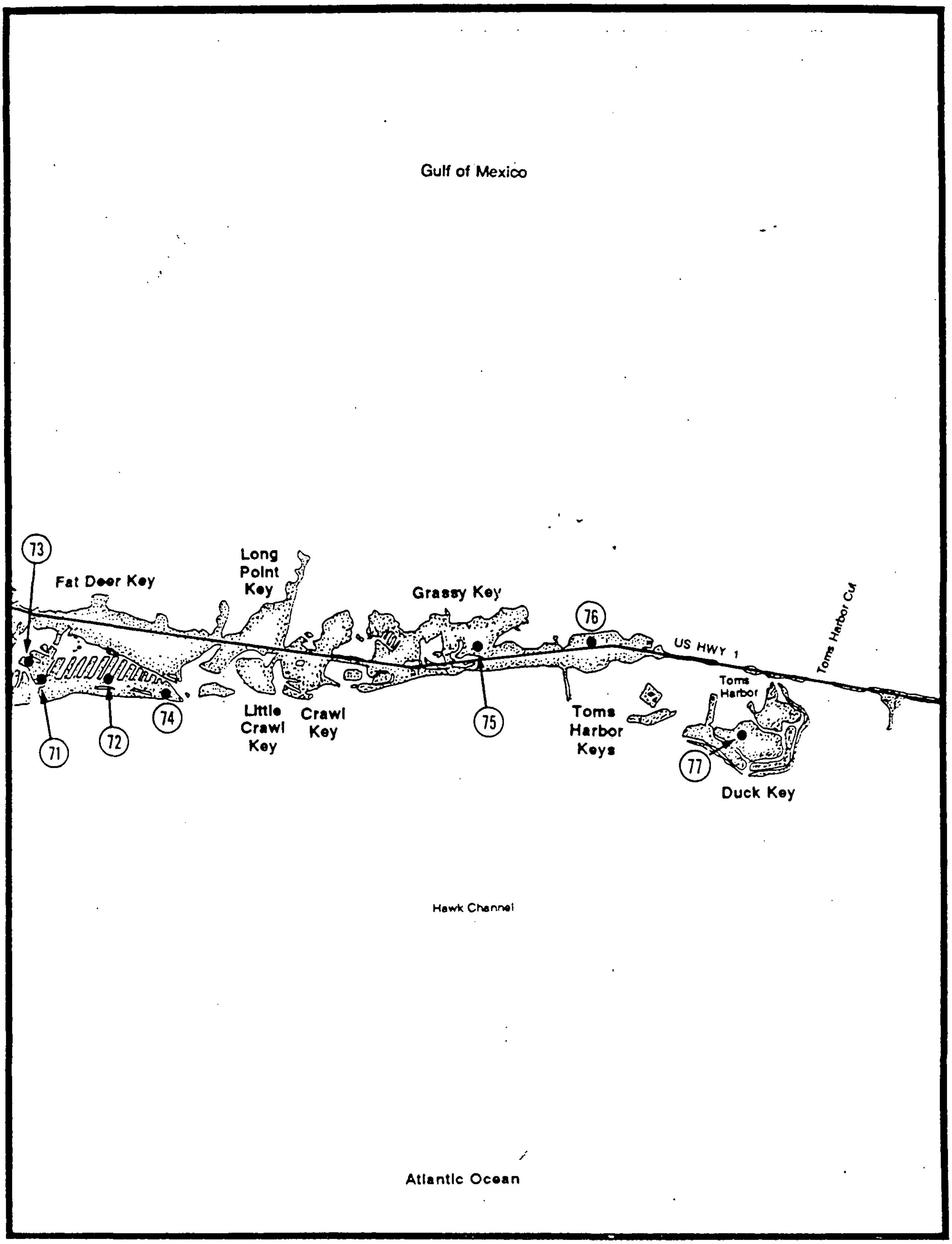


Figure 2-4-7. Wastewater treatment facilities and discharge canals. (continued)

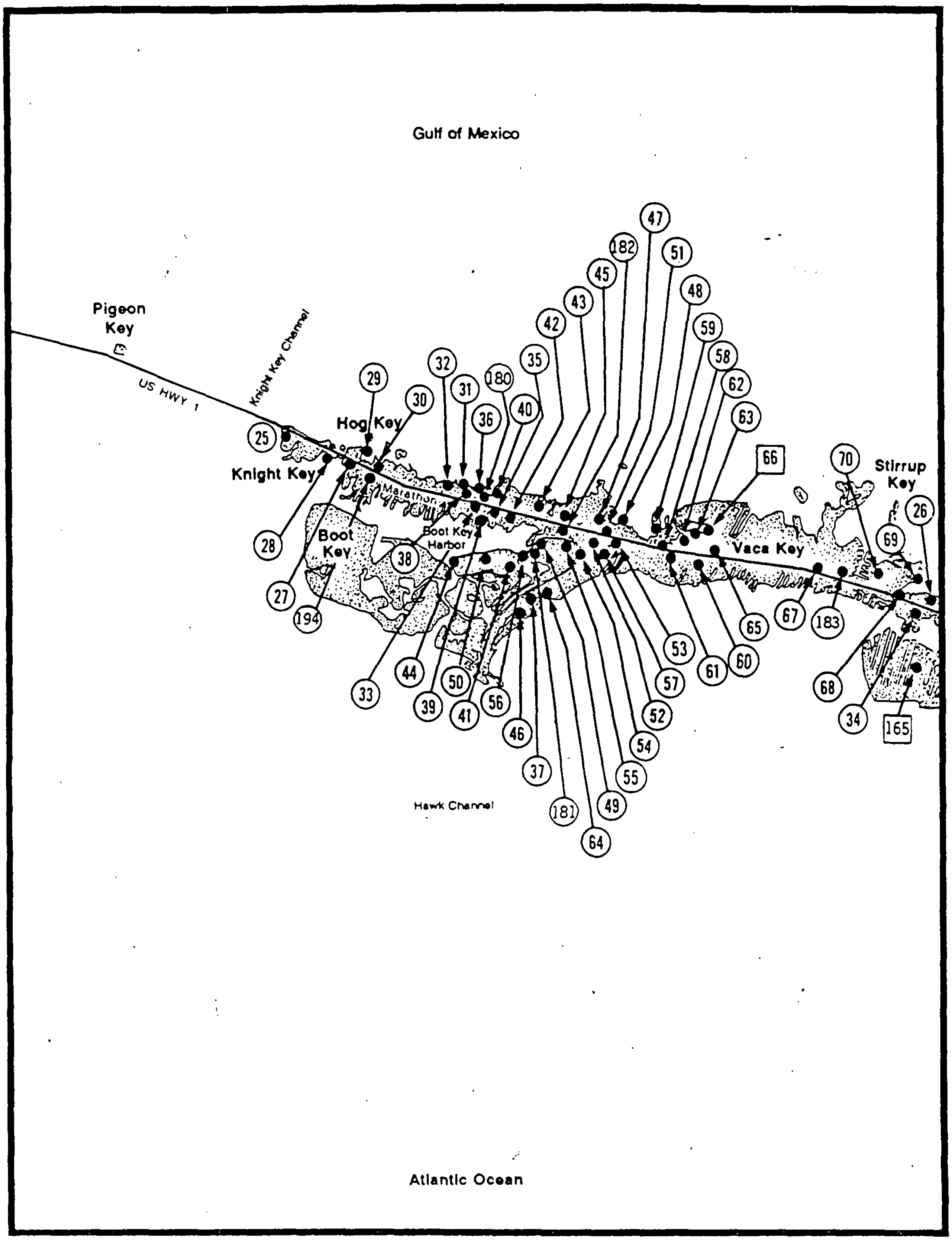


Figure 2-4-8. Wastewater treatment facilities and discharge canals. (continued)

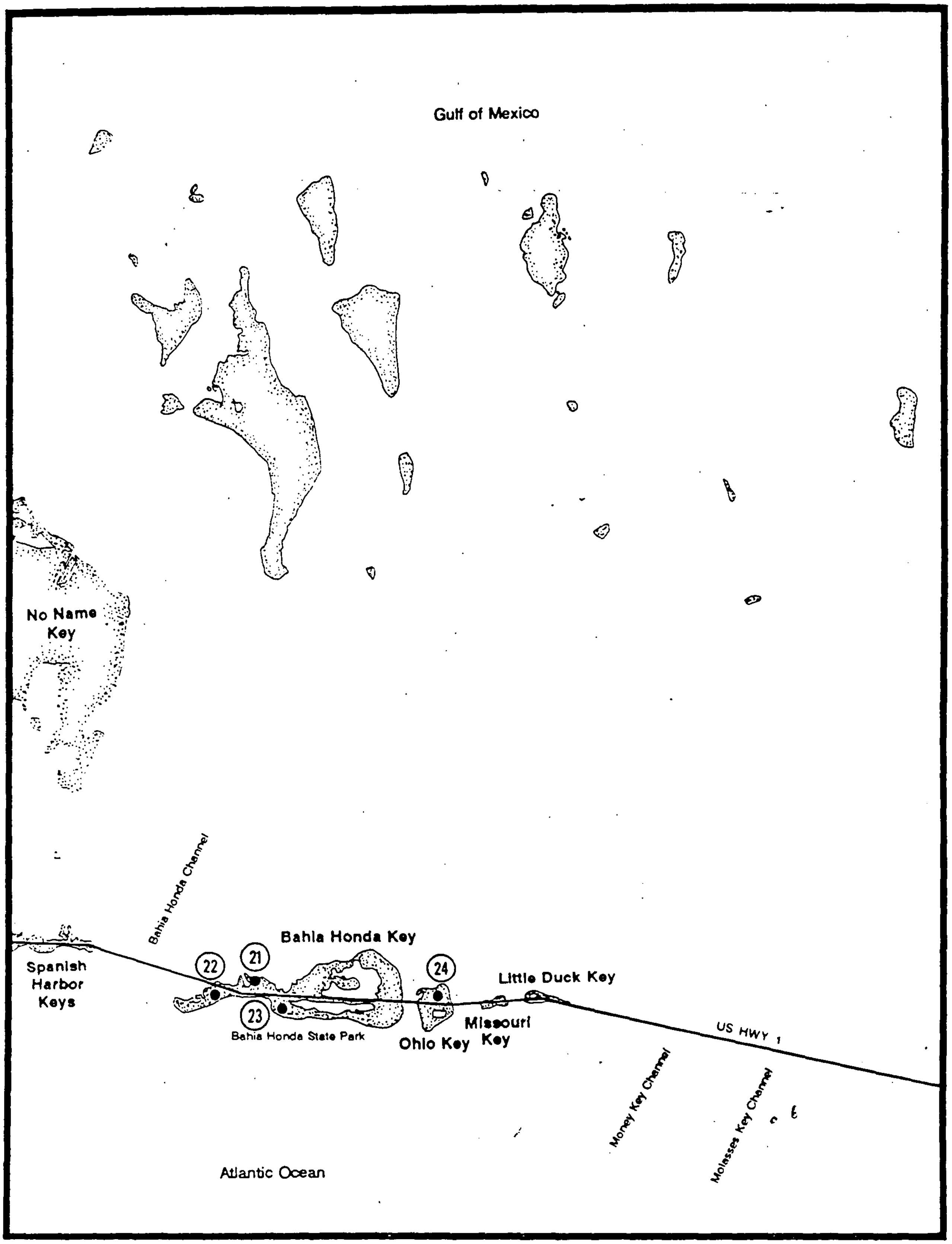


Figure 2-4-9. Wastewater treatment facilities and discharge canals. (continued)

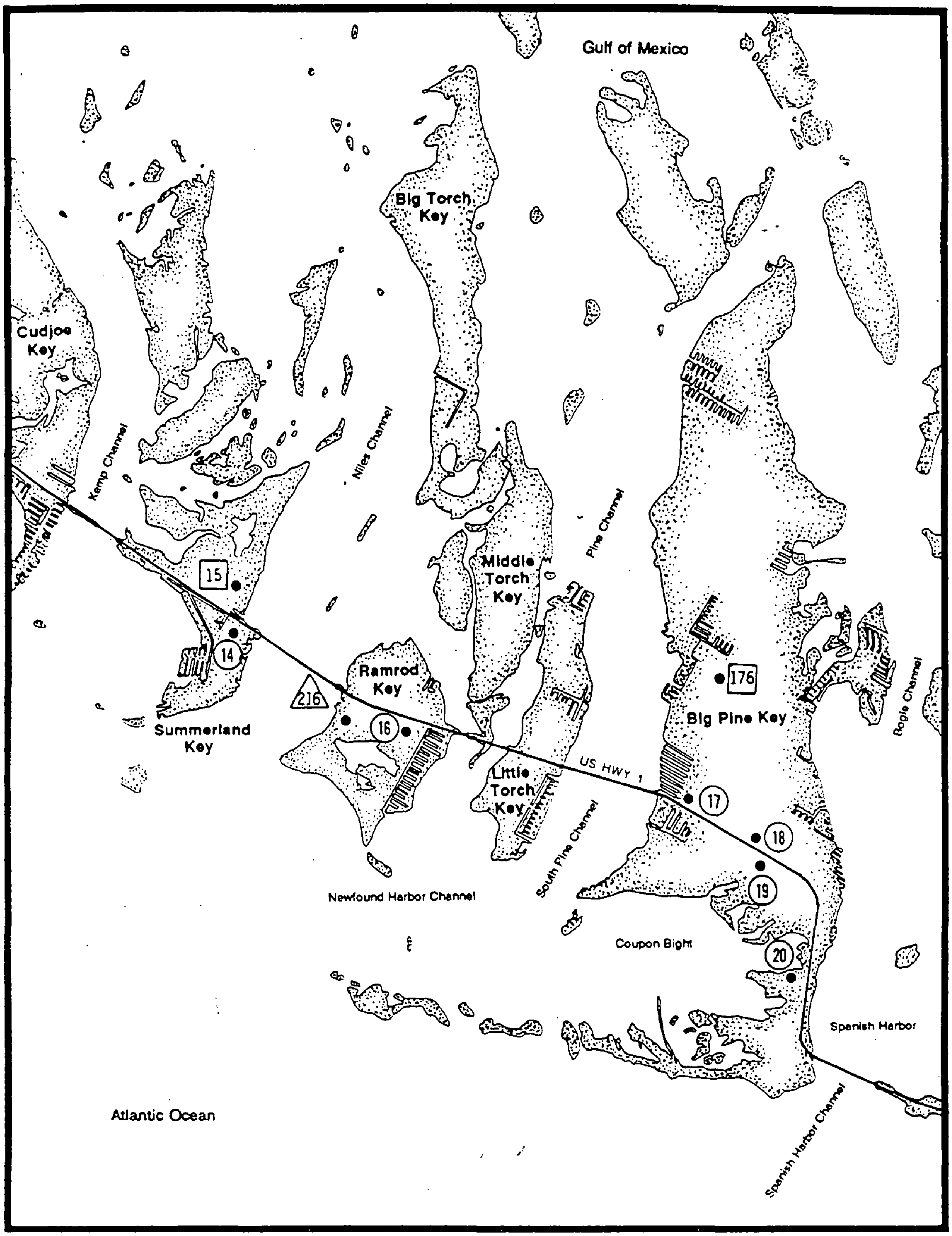


Figure 2-4-10. Wastewater treatment facilities and discharge canals. (continued)

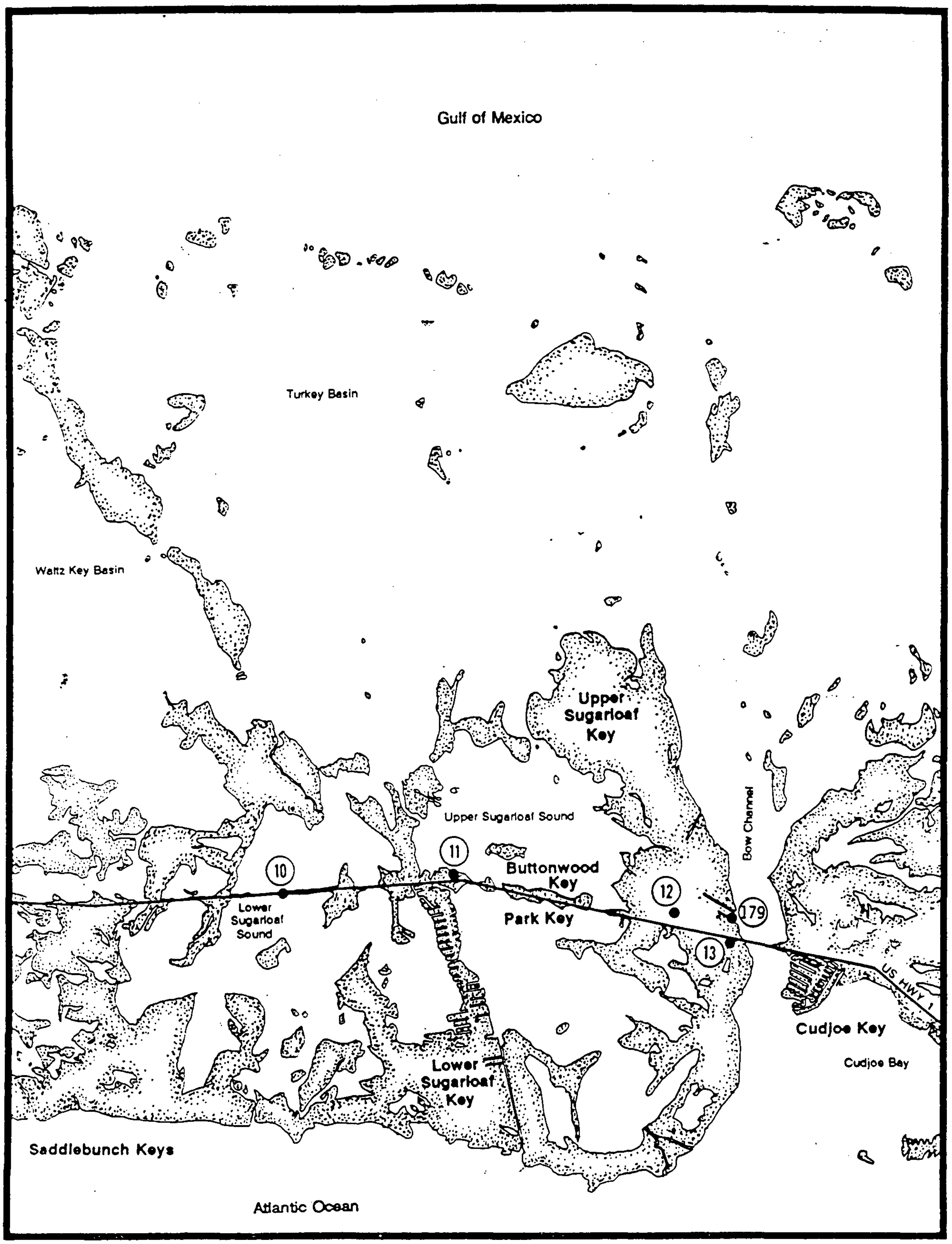


Figure 2-4-11. Wastewater treatment facilities and discharge canals. (continued)

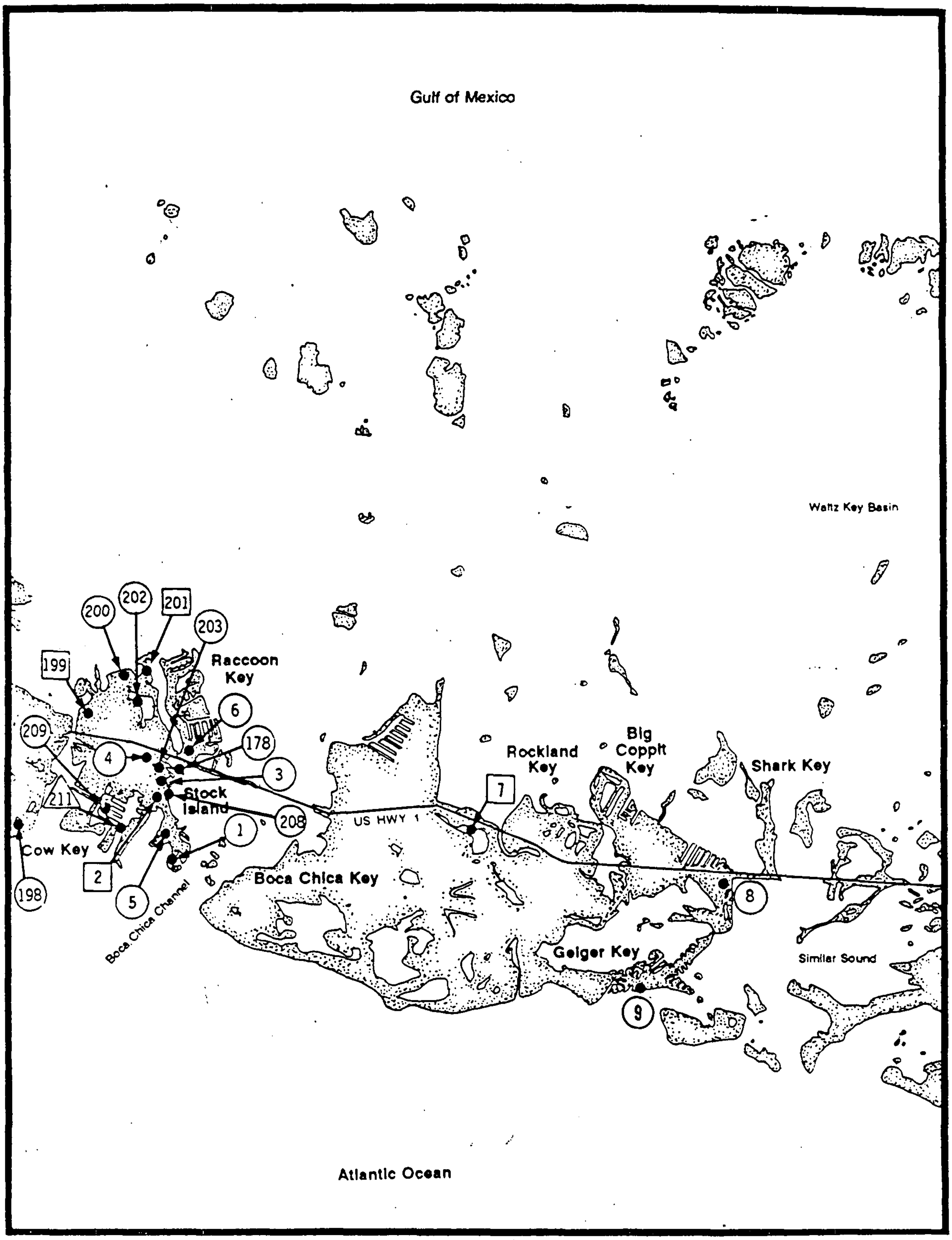


Figure 2-4-12. Wastewater treatment facilities and discharge canals. (continued)

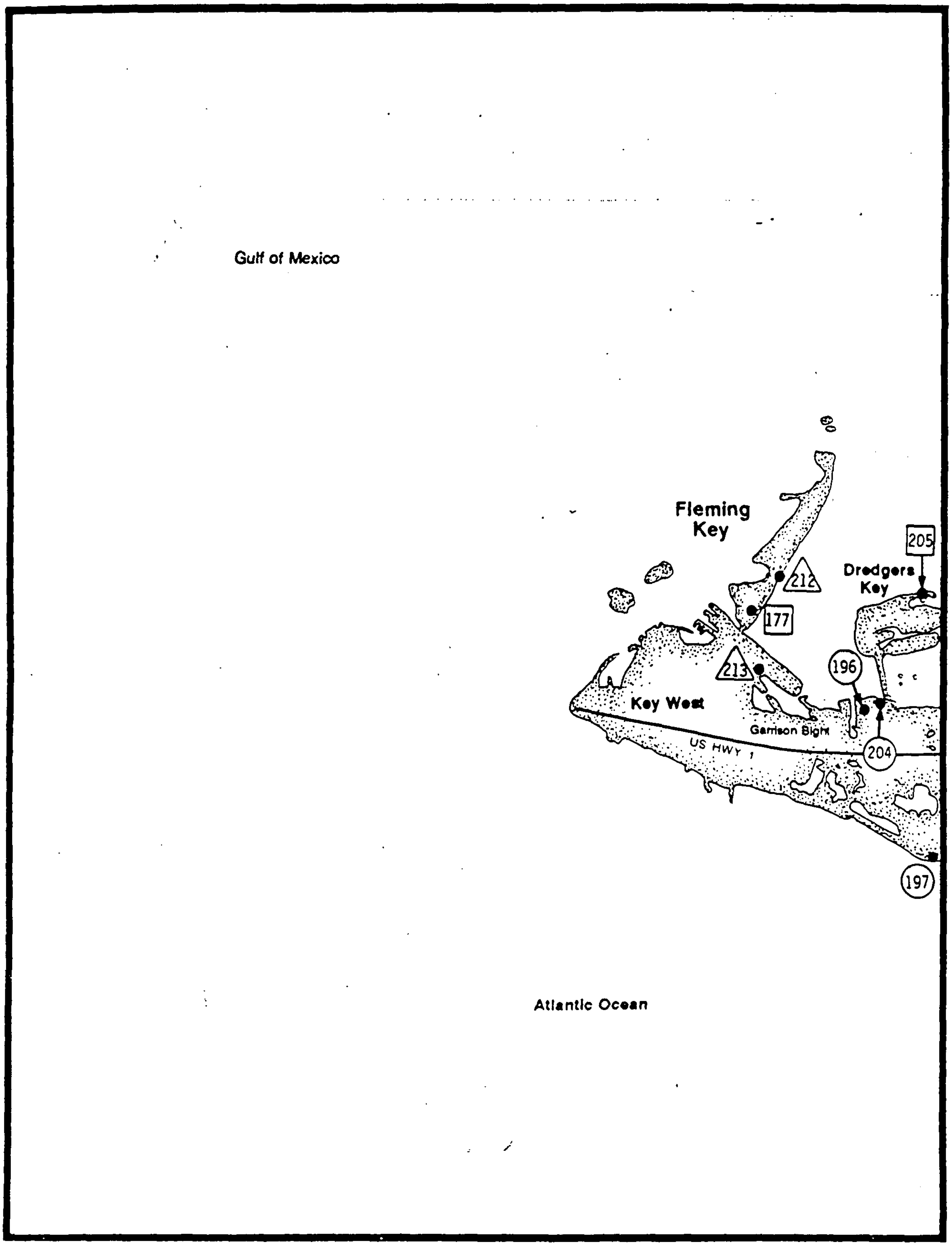


Figure 2-4-13. Wastewater treatment facilities and discharge canals. (continued)

3.1.6 Water Quality Monitoring

All point-source discharge facilities that receive operating permits from EPA or FDER are required to submit monthly discharge monitoring reports. These reports monitor various water quality parameters such as biochemical oxygen demand (BOD_5), pH, and total suspended solids (TSS). Based on a review of the available permit information from both agencies, these three parameters are reported most frequently; however, others include dissolved oxygen (DO), chlorine (total residual), and fecal coliform. No permittee is required to monitor for nutrients.

While the Key West STP presently operates under a discharge permit that does not require the monitoring of nutrients, the City's engineering consultant has been recording nutrient measurements of the influent and effluent. The average effluent concentrations for NH_3-N, NO_3-N, and PO_4-P for 1990 were 2.0, 1.8, and 2.49 mg/L, respectively (Solin 1991).

3.1.7 Canals

The South Florida Water Management District (SFWMD) operates two canals that discharge into Sanctuary waters, and are considered point sources to the Sanctuary. Both canals, C-111 and the Model Land Canal, discharge into the northern area of the Sanctuary (Figure 2-4-1 and 2-4-2). The C-111 canal discharges into Manatee Bay (Barnes Sound) west of Key Largo (SFWMD 1990). In August 1988, an earthen plug was removed that allowed discharge of freshwater into Manatee Bay. For 8 days, approximately 2500 ft^3/s of freshwater was discharged (Haunert 1988). Flow after this initial period was reduced to 600 ft^3/s.

The SFWMD (1990) reported phosphorus and nitrogen levels within the C-111 canal for August 1985 to August 1987. Total phosphorus concentrations during this period ranged from 0.004 to 0.015 mg/L. Inorganic nitrogen (nitrate plus nitrite plus ammonium) concentrations ranged from 0 to 0.45 mg/L.

The Model Land Canal has a connection to Card Sound (R. Alleman, SFWMD, personal communication, 1991). This connection consists of a length of canal that terminates at a culvert. Alleman (R. Alleman, SFWMD, personal communication, 1991) stated that there are no extant water quality data for this canal.

3.2 NONPOINT SOURCES

3.2.1 Definition

For the purposes of this study, nonpoint sources are defined as those discharges that are not made directly to surface waters. Such discharges would include all those made into the groundwater and stormwater runoff flow.

3.2.2 Groundwater Inputs

3.2.2.1 GEOLOGY, HYDROGEOLOGY, AND AQUIFERS

It is important to describe the geology, hydrogeology, and aquifers of the Florida Keys prior to describing the inputs to the groundwater. A general discussion of these topics is provided in the following sections.

3.2.2.1.1 Geology and Hydrogeology

The principal geologic formations of interest in the region include the undifferentiated sand deposits of Pleistocene to Recent Age, including the Pleistocene Age Miami Oolite Limestone and Key Largo Limestone; Ft. Thompson Formation; and the Anastasia Formation (**Figure 2-5**).

The undifferentiated sands found in the Florida Keys can be classified as one of two types. The first and most abundant type is the Pamlico Sand Formation, which has been described as very fine- to coarse-grained permeable quartz sands, typically either black to white or red in color. These sands were deposited during Pleistocene sea-level changes that occurred in response to global glacial activity. The second type of undifferentiated sand, deposited in more recent times (postglacially), is described as calcareous beach sands with lesser amounts of coral and shell fragments, white to cream in color. The areal distribution and thickness of these undifferentiated sands varies widely throughout the Florida Keys. The most common terrestrial occurrence of these sands in the Florida Keys is as sand dunes and old beach ridges. These same calcareous beach sands form extensive offshore deposits along the Keys and in the Marquesas Quicksands area (Shinn *et al.* 1990).

Formed as a shoal deposit in warm shallow seas, the Miami Oolite Limestone is a soft, yellow to white, stratified to massive, cross-bedded limestone formation. The term *oolite* or "ooid" refers to spherical and concentric ovules of calcite. These minute concretionary bodies, which average about 1 mm in diameter, are distributed randomly throughout the Miami Oolite Limestone matrix. Miami Limestone is currently divided into three distinct facies: the bryozoan facies; the bedded facies; and the mottled facies (Evans 1982). The bedded and mottled facies are confined to the topographic high of the Atlantic Coastal Ridge, but the bryozoan facies does not, as previously reported, underlie the Atlantic Coastal Ridge (Evans 1983). The bryozoan facies is confined to the low lying area to the west of this ridge. This is an important point because it means that the portion of the Miami Limestone that was an active ooid system (the Atlantic Coastal Ridge) originated and grew in place; it did not migrate backward over the platform interior of bryozoan deposits. The bryozoan facies were deposited as a direct result of the growth of the ooid system forming a bathymetric high to shelter them from the open ocean (Halley and Evans 1983).

Recent shallow-water marine carbonate sediments are composed largely of metastable carbonate materials such as aragonite and a variety of calcite containing more than 4% $MgCO_3$ (high-magnesium calcite). Such sediments have a very high porosity, typically 45 to 50% for carbonate sands and 70 to 80% for carbonate muds. Ancient carbonate rocks are composed of calcite and dolomite and show very low porosity. Miami Limestone represents a geologic unit in transition; it is moving from modern sedimentary rock formations to ancient limestone. Evans (1982) generated an average porosity of 45% for Miami Limestone. The average porosity volume within the Miami Limestone has not changed much from that of unconsolidated ooid sand. The mineralogy has stabilized, but the rock has not begun to acquire the low porosity typical of ancient carbonate rocks. As evidenced at several locations in south Dade County, karst development and internal dissolution are actually increasing pore size within exposed sections of this formation. Although the mineralogical trends of the Miami Limestone are leading toward a composition typical of ancient carbonate rock, the porosity trends are

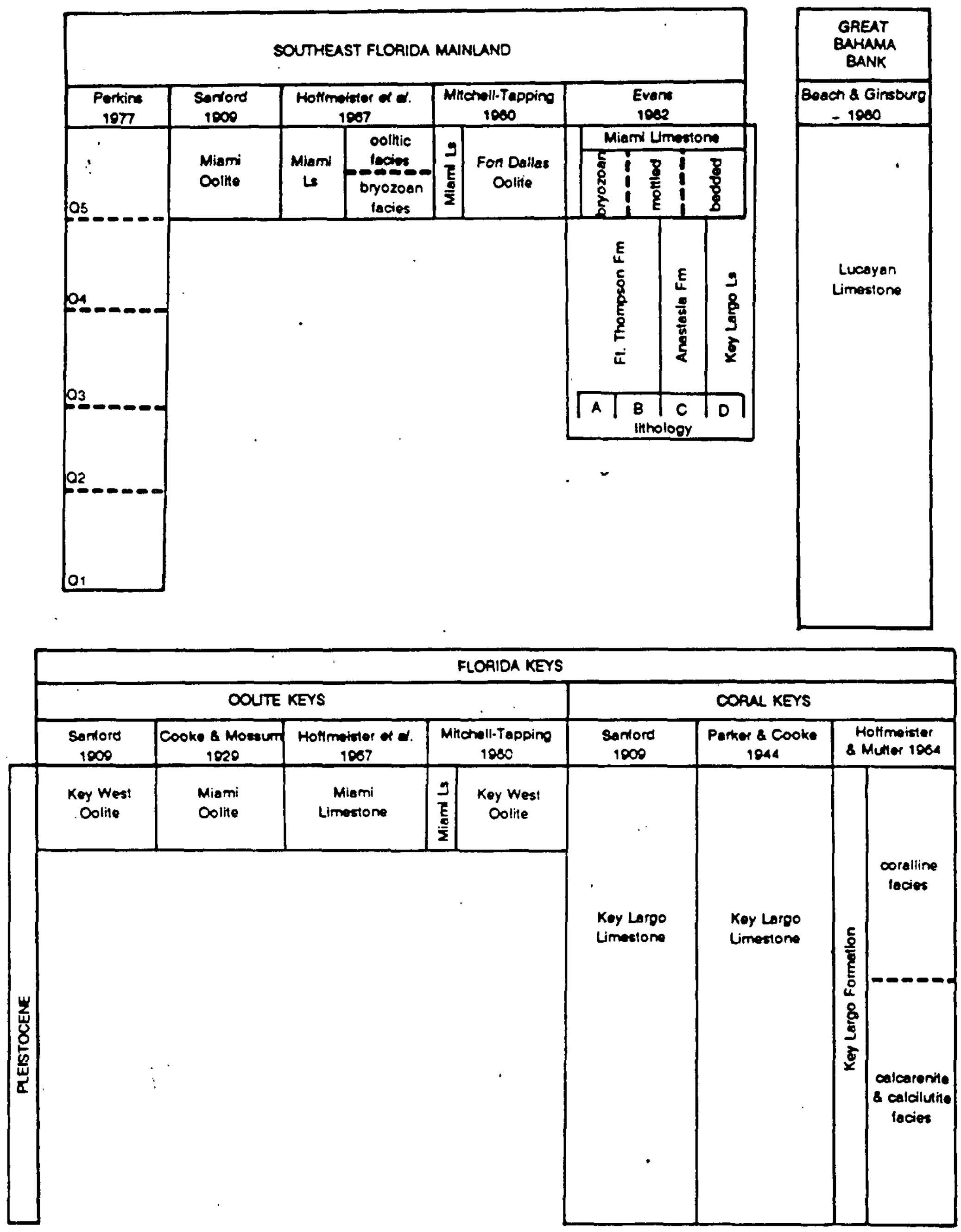


Figure 2-5. Stratigraphic nomenclature for the late Pleistocene of peninsular Florida [Evans 1982]. [Adapted from Halley and Evans 1983].

not. This indicates that significant loss in the porosity of South Florida carbonates does not occur until carbonate rocks are carried into the subsurface by continued subsidence and sedimentation (Halley and Evans 1983).

Preferential weathering of the ooids within the Miami Limestone creates voids or pore spaces that are commonly replaced (filled) with deposits of very fine to medium quartz sands. The majority of these "secondary" deposits have been described as sands from the Pamlico Group.

The Miami Limestone is a very cohesive formation. Consequently, the Miami Limestone does not possess excessively high values with regard to transmissivity and hydraulic conductivity. Two factors that influence the hydraulic characteristics of the Miami Limestone are (1) a large degree of porosity that is due to the preferential weathering of the ooids characterizing this formation and (2) the lack of interconnection between solutional or structural "pipelines" and the resulting restrictions on the horizontal intrinsic permeability (hydraulic conductivity) that inhibits the lateral (horizontal) flow of fluids.

The Miami Limestone formation, which ranges between 6 and 12 m in thickness, can be found at land surface from Big Pine Key to Key West, Florida, and is regarded as an offshore extension of the same formation found in southeast Florida (i.e., within Collier, Broward, Dade, and Monroe Counties). It overlies the Key Largo Limestone in this area.

The Key Largo Limestone is a complex carbonate unit that characterizes the depositional environment of an ancient coral "back reef" area. It is described as a white to cream, compact to soft, cavernous coralline reef rock. It is composed of reef building corals, amorphous limestones, shell fragments, and detritus from wastage of the reef. A high degree of porosity and permeability characterize this formation, attributed to the depositional environment from which it was formed. An abundance of solution cavities, which typically are located between relict coral heads, allows the water to move freely in and out of this formation. It is a very dispersive medium, conducive to the vertical and horizontal movement of water. Areas consisting of relict coral heads have lower transmissivity and hydraulic conductivity values than do those areas immediately adjacent to the coral heads. As described previously, adjacent areas consist of reef wastage such as clastic sediments and shell fragments. These porous "zones" have, through the course of time, been exposed or subjected to preferential chemical and physical weathering because of their poor structural integrity and lack of internal cohesiveness (lithification). These areas have consequently become cavernous zones or pathways susceptible to the transport of fluids, because they provide a route of least resistance by their higher transmissivity and hydraulic conductivity values.

The Key Largo Limestone is found at land surface in the Florida Keys from Soldier Key (off Miami) to Bahia Honda. Averaging approximately 18 m in thickness in the Florida Keys, it is recognized as an offshore extension of the same formation that underlies southeast Florida.

The Key Largo Limestone possesses a higher degree of transmissivity and hydraulic conductivity than the Miami Limestone. While the Miami Limestone is a fairly permeable and porous limestone, the absence of interconnecting pore spaces reduces its effective transmissivity and hydraulic conductivity by several orders of magnitude. However, the Miami Limestone's vertical hydraulic conductivity component is comparable to that of the Key Largo Limestone.

Although the Miami Oolite and Key Largo Limestones can be differentiated based solely on their lithologic structure, basic morphology, and fossil assemblages, Hoffmeister (1974) and others have demonstrated through extensive field work that the Miami Oolite and Key Largo Limestones formed contemporaneously. Geologic cross sections developed from drilling cores display zones where the Miami Oolite and Key Largo Limestones "interfinger" or overlap numerous times. The transitions are not abrupt, which suggests that the transformation from one formation to another was gradational in its response to a changing marine environment. The coral reef environment in which these sediments were deposited may have shifted in response to any number of reasons or causes.

The Pleistocene limestone (Miami Oolite and Key Largo) of the Florida Keys ranges from 30 m thick in the upper Keys to more than 60 m thick in the lower Keys (Perkins 1977). The porosity of the limestone ranges from 35 to 50% and the permeability is very high (E. Shinn, United States Geological Survey Center for Coastal Geology, personal communication, 1992). There are five distinct subaerial unconformaties or exposure surfaces within the formation, with each unconformity representing a period when sea level dropped and vegetative material accumulated on top of exposed reef platform (Perkins 1977). When this has occurred, the pores in the upper 0.6 to 1 m of exposed limestone have largely been filled with a calcite material, reducing their permeability. In addition to this, a calcrete crust (between 1 and 10 cm thick) of very low permeability has been formed along the surface of these unconformities (Harrison *et al.* 1984; Shinn and Corcoran 1988). This indicates that the formation consists of large, highly porous layers of limestone sandwiched between narrow "aquatards" which prevent the vertical movement of fluids. This complex layering of permeability has great ramifications in terms of pollutant transport and water quality monitoring. Of the five unconformities, the thickest and most widespread is the Q3 (Q = Quarternary). It lies approximately 8 to 10 m below the surface in the Keys (Harrison *et al.* 1984). Shinn and Corcoran (1988) found leachates from the Dade County landfill concentrated in the highly permeable zone immediately above this unconformity (approximately 5 m below the surface), and above the depth to which Dade County's monitoring wells had been drilled.

The Tamiami Formation, which consists of numerous lithologies that are primarily Miocene to Pliocene in age, underlies the Key Largo Limestone at varying depths along the Florida Keys tract. The Tamiami Formation grades downward from a poorly hardened limestone and calcareous sand of low permeability into a more highly permeable sandy, fossiliferous limestone intermixed with coarse Miocene-age clastic sediments.

The Hawthorn Group, which underlies both the Miami Limestone, Key Largo Limestone, and Tamiami Formation acts as a confining unit that serves to inhibit or reduce the downward migration of fluids. It forms a boundary between the Surficial and Floridan Aquifer Systems. It is described as highly impermeable, green to gray in color, consisting of silts, clayey sands, silty sands, and sand. This formation, which extends throughout all of Florida, averages approximately 60 to 90 m in thickness throughout the Florida Keys area.

3.2.2.1.2 Aquifers

Two principal aquifers underlie Monroe County in the Florida Keys area. They are the Biscayne Aquifer, more commonly referred to as the Surficial Aquifer System, and the Floridan Aquifer, which is a confined or artesian aquifer system.

The primary system of importance in this region is the Biscayne Aquifer, which is an unconfined aquifer system because it is under water-table conditions. Aquifers under water-table conditions are free to rise and fall in direct relation to regional and local recharge mechanisms, such as precipitation, diurnal and seasonal tidal fluctuations, or discharges to the canal systems, the latter of which constitute groundwater loss. The Biscayne Aquifer System is regarded as the primary or "sole source aquifer" of potable water throughout most of southeastern Florida, with the exception of the Florida Keys. It is one of the most productive and permeable aquifer systems in the world (Parker *et al.* 1955). Unfortunately, because of its excessive chloride content within the Florida Keys region, it is designated as a nonpotable water source. Water sources that contain chloride concentrations greater than 250 mg/L are regarded as unpotable waters and unfit for human consumption. These guidelines are discussed in Florida Chapter 17-3, Florida Administrative Code (FAC). Consequently, most of the water pumped from the Florida Keys Aquifer System is utilized primarily for irrigation, cleansing, toilet flushing, and numerous other nonpotable water uses.

The Biscayne Aquifer in the Florida Keys comprises the Miami Limestone, Key Largo Limestone, and Tamiami formations. The elevation, or mean distance to the surface, of the Biscayne Aquifer closely mimics surface elevation contours and averages approximately 1 m below surface grade. These elevations vary seasonally in response to periods of increased and/or declining rainfall amounts, and vary on a daily basis from tidal fluctuations, as well as with the seasonal variances that occur. Consequently, the residents of the Florida Keys, despite their abundant supply of nonpotable water, must receive the bulk of their potable water from the Florida Keys Aqueduct Authority. The Authority pumps this water from a wellfield located in Dade County at a rate of 18 MGD. It is pumped through 36- to 48-in. culvert pipes to transfer stations were the water is allocated proportionately to residential, commercial, and industrial facilities.

While the primary water-bearing hydrologic units are presently unsuitable for drinking use by the residents of the Florida Keys, it should be noted that on some of the larger Keys, with areas of high topographical relief (i.e., Big Pine Key, Key West, Sugarloaf Key, and Cudjoe Key), there are thin lenses of potable freshwater that typically average 6 m in thickness. Net volumes of this available freshwater are not sufficient to support the current consumptive use of residents of the Keys. These lenses of fresh water essentially float or lie atop the denser, more saline waters. The dimensions of these lenses vary seasonally and depend on pumpage rates and volumetric discharge for irrigation usages and other related (nonpotable) use activities, natural freshwater losses (discharge) to the sea across hydraulic gradients, annual recharge rates from rainfall, and evapotranspiration from indigenous flora. Uses of these freshwater lenses for potable use would quickly deplete the supply and enhance the encroachment of saltwater into the aquifers.

3.2.2.2 DOMESTIC WASTEWATER FACILITIES

3.2.2.2.1 Overview

Section 403.021(2) of the Florida Statutes, as amended, establishes that no wastes are to be discharged to any waters of the State without first being given a degree of treatment necessary to protect the beneficial uses of such water. Responsibility for enforcement was assigned to the FDER. In implementing this section of the statute, FDER developed and adopted a set of minimum standards for the design of domestic wastewater facilities and established minimum treatment and disinfection requirements for the operation of domestic wastewater facilities. Domestic wastewater is defined as "wastewater derived from dwellings, business buildings, institutions, and the like; . . ." (Rule 17-600, Florida Administrative Code [FAC], January 1, 1991).

3.2.2.2.2 Background

There are 209 wastewater treatment facilities operating in close proximity to the Sanctuary. Of this total, 197 facilities are located in unincorporated Monroe County (Wallace Roberts & Todd *et al.* 1991a) and 10 others are located in the City of Key West (Solin 1991). In addition, the City of Key Colony Beach operates a municipal sewage treatment plant. A package treatment plant serving the Goshen College, Marine Biology Facility, is also located in the City of Layton. **Table 2-5** provides a listing of the facilities. The facilities are also located on **Figure 2-4**.

Of the 209 wastewater treatment facilities in the region, 10 discharge their effluent to surface waters. These point-source discharges are discussed in **Section 3.1.3 Types of Facilities**. The remaining 199 facilities discharge into boreholes (injection wells) (Wallace Roberts & Todd *et al.* 1991a; Solin 1991; FDER 1991b).

Table 2-5. Wastewater Treatment Facilities.
[From Keith and Schnars, unpublished data, 1991; Solin 1991; FDER 1991a]

Figure Reference #	Name of Facility	Key
1	Oceanside Marina	Stock Island
2	Boyd's Campgrounds	Stock Island
3	Roy's Mobile Home Park	Stock Island
4	Coconut Grove Mobile Home Park	Stock Island
5	Harbor Shores Mobile Home Park	Stock Island
6	Key Haven Utilities	Raccoon
7	USNAS (Boca Chica Field)	Boca Chica
8	Seaside Resorts, Inc.	Big Coppitt
9	Geiger Key Marina	Geiger
10	Lazy Lakes Campground	Sugar Loaf
11	Sugar Loaf Lodge	Sugar Loaf
12	Sugar Loaf Elementary School	Sugar Loaf
13	Sugar Loaf K.O.A.	Sugar Loaf
14	The Galley Restaurant	Summerland
15	Venture Out @ Cudjoe Key	Summerland
16	Looe Key Reef Resort	Ramrod
17	Breezy Pine Trailer Park	Big Pine
18	Big Pine Plaza Shopping Center	Big Pine
19	Big Pine Motel	Big Pine
20	Big Pine Key Road Prison	Big Pine
21	Bahia Honda #3	Bahia Honda
22	Bahia Honda #4	Bahia Honda
23	Bahia Honda #2	Bahia Honda
24	Sunshine Key Travel Park	Ohio
25	Hawk's Nest Condo	Knight
26	The Quay Restaurant	Fat Deer
27	Galway Bay Mobile Home Park	Marathon
28	Boot Key Marina	Hog
29	Pelican Restaurant	Vaca
30	Faro Blanco Resort	Vaca
31	Stanley Switlik Elementary School	Vaca
32	Hurricane Motor Lodge	Vaca
33	Casa Cayo Condo	Vaca
34	Coral Lagoon Resort	Fat Deer
35	Fisherman's Hospital	Vaca
36	Lady Alexander Condo	Vaca
37	Marathon High School	Vaca
38	Mid-Town Trailer Park	Vaca
39	Monroe County Housing Authority	Vaca
40	Schooner Condo's	Vaca
41	Spanish Galleon Condo	Vaca
42	Tradewind West Condo	Vaca
43	Buccaneer Lodge	Vaca
44	Cobia Point Condo	Vaca
45	Marathon Key Beach Club	Vaca

Table 2-5. Wastewater Treatment Facilities.
[From Keith and Schnars, unpublished data, 1991; Solin 1991; FDER 1991a] (continued)

Figure Reference #	Name of Facility	Key
46	Sombrero Beach Village	Vaca
47	Days Inn	Vaca
48	Gulfside Village Shopping Center	Vaca
49	Harbor Club South Condo Association	Vaca
50	Harbor House Condo	Vaca
51	International House of Pancakes	Vaca
52	Island Club Condo	Vaca
53	Key Lime Condo (Resort)	Vaca
54	Marathon Country Club Condo	Vaca
55	Sombrero Resort	Vaca
56	Sombrero Ridge Condo	Vaca
57	K-Mart Shopping Center	Vaca
58	Lucy Apartments	Vaca
59	The Reef at Marathon	Vaca
60	Captain's Quarters Condo	Vaca
61	Coral Club Condo	Vaca
62	Howard Johnson's	Vaca
63	Key RV Park	Vaca
64	Marathon Manor Nursing Home	Vaca
65	Perry's Restaurant	Vaca
66	USCG Station - Marathon	Vaca
67	Pizza Hut	Vaca
68	Sea Watch Condo	Vaca
69	Wendy's Restaurant	Vaca
70	Winn-Dixie Plaza	Vaca
71	Bonefish Tower	Fat Deer
72	Treasure Cay Condo	Fat Deer
73	Coco Plum Beach Apartments	Fat Deer
74	Royal Plum Condo	Fat Deer
75	Pelican Motel & TP	Grassy
76	Jolly Roger Trailer Park	Grassy
77	Hawk's Cay Resort	Duck
78	Long Key Ocean Bay Condo	Long
79	Outdoor Resort's @ Long Key	Long
80	Long Key State Park #1	Long
81	Long Key State Park #2	Long
82	Long Key State Park #3	Long
83	Fiesta Key KOA	Fiesta
84	Kingsail Resort	Fiesta
85	Caloosa Cove Marina	L. Matecumbe
86	Sandy Point Condo	L. Matecumbe
87	Papa Joe's Restaurant	U. Matecumbe
88	Matecumbe Resort (Indian Key)	L. Matecumbe
89	Aultman Construction Company	Long
90	Ocean 80	Islamorada

Table 2-5. Wastewater Treatment Facilities.
[From Keith and Schnars, unpublished data, 1991; Solin 1991; FDER 1991a] (continued)

Figure Reference #	Name of Facility	Key
91	The Palms of Islamorada	Islamorada
92	Sea Gulls Condo	Islamorada
93	Breezy Palm Resort Motel	Islamorada
94	La Siesta Resort	Islamorada
95	Fisherman's Kettle Restaurant	Islamorada
96	Goshen College (FIO)	Long
97	Bay Colony Villas	U. Matecumbe
98	Woody's Lounge	U. Matecumbe
99	Cheeca Lodge	U. Matecumbe
100	Pelican Palm Trailer Park	U. Matecumbe
101	Caribbean Sunset Inn	U. Matecumbe
102	Lore Lei Restaurant	U. Matecumbe
103	Perry's Inn	U. Matecumbe
104	Beacon Reef Condo	U. Matecumbe
105	Coral Grill Restaurant	U. Matecumbe
106	Chesapeake Motel of Whale Harbor	U. Matecumbe
107	Howard Johnson's	Windley
108	Holiday Isle Resort	Windley
109	Pelican Cove Resort	Windley
110	B.C.'s Sand Bar	Windley
111	Erick's Floating Restaurant	Windley
112	Windley Key Trailer Park	Windley
113	USCG Station - Islamorada	Plantation
114	Plantation by the Sea	Plantation
115	Plantation Yacht Harbor Resort	Plantation
116	Sea Breeze Trailer Park	Plantation
117	Executive Bay Club	Plantation
118	Consi Harbor Club	Plantation
119	Futura Yacht Club	Plantation
120	Mariner's Hospital	Plantation
121	Summer Sea Condo	Plantation
122	Plantation Key Governmental Company	Plantation
123	Coral Shores High School	Plantation
124	Sunset Acres Mobile Home Park	Plantation
125	Plantation Key Elementary School	Plantation
126	Turek Enterprise Inc.	Plantation
127	Tavernier Towne Shopping Center	Key Largo
128	Harbor 92 Condo	Key Largo
129	Silver Shore M.H.P.	Key Largo
130	Driftwood Travel Trailer Park	Key Largo
131	Anchor Condo	Key Largo
132	Blue Water Trailer Park	Key Largo
133	Chico Commercial Building	Key Largo
134	Sunset Hammock Condo	Key Largo
135	Key Largo Ocean Resort	Key Largo

Table 2-5. Wastewater Treatment Facilities.
[From Keith and Schnars, unpublished data, 1991; Solin 1991; FDER 1991a] (continued)

Figure Reference #	Name of Facility	Key
136	Buttonwood Bay Condo	Key Largo
137	The Sheraton	Key Largo
138	Key Largo Yacht & Tennis Club	Key Largo
139	Harborage Condo Corporation	Key Largo
140	Rock Harbor Club	Key Largo
141	American Outdoors Key Largo	Key Largo
142	KOA Keys Restaurant	Key Largo
143	Holiday by the Sea Condo	Key Largo
144	Paradise Point M.H.P.	Key Largo
145	The Landings of Largo	Key Largo
146	Kawama Yacht Club	Key Largo
147	Pizza Hut	Key Largo
148	Ocean Divers, Inc.	Key Largo
149	Waldorf Plaza Shopping Center	Key Largo
150	Florida Bay Resort STP	Key Largo
151	Best Wester Suites	Key Largo
152	Holiday Inn	Key Largo
153	Leeside Professional Building	Key Largo
154	Port Largo Villas	Key Largo
155	Coastal Waterway Trailer Park	Key Largo
156	Calusa Camp Resort	Key Largo
157	Glenn's Trailer Park & Campground	Key Largo
158	Key Largo Campground & Marina	Key Largo
159	Tradewinds/K-Mart Shopping Center	Key Largo
160	Coral Reef State Park	Key Largo
161	Howard Johnson's	Key Largo
162	Paradise Pub	Key Largo
163	The Quay Restaurant	Key Largo
164	Koblick Marine Center	Key Largo
165	Key Colony Beach STP	Fat Deer
166	Florida Bay Club	Key Largo
167	Senior Frijoles Restaurant	Key Largo
168	Italian Fisherman Restaurant	Key Largo
169	Moonbay Condo	Key Largo
170	Tamarino Bay Club, Inc.	Key Largo
171	Key Largo Elementary School	Key Largo
172	Winn Dixie	Key Largo
173	Barefoot Key R.V. Resort	Key Largo
174	Gilbert's Motel & Marina	Key Largo
175	The Anchorage Resort	Key Largo
176	USDA FWS Key Deer NWR	Big Pine
177	Key West STP	Flamingo
178	Waters Edge Colony Park	Stock Island
179	Mangrove Maria's	Sugarloaf
180	Casa De Los Tres	Vaca

Table 2-5. Wastewater Treatment Facilities.
[From Keith and Schnars, unpublished data, 1991; Solin 1991; FDER 1991a] (continued)

Figure Reference #	Name of Facility	Key
181	Sombrero Marina & Dockside Lounge	Vaca
182	Susan's "Wobbly-Crab" Restaurant	Vaca
183	Jim Green Marathon Veterinarian Clinic	Vaca
184	Fantasy Harbor Condo	L. Matecumbe
185	Sand Pebbles	U. Matecumbe
186	Perry's Seafood Restaurant	U. Matecumbe
187	Harbor Lights Motel/Holiday Isle	U. Matecumbe
188	Tropical Reef Resort	Windley
189	Ocean Harbor Condo	Plantation
190	North Key Largo Plaza	Key Largo
191	Lake Surprise Conto II	Key Largo
192	L'Oasis	Key Largo
193	Cross Key Marina/Restaurant	Cross
194	Marathon Trailerama	Vaca
195	The Sanctuary	Key Largo
196	Hampton Inn	Key West
197	Martha's Restaurant and Benihana's Restaurant	Key West
198	Key Ambassador Resort	Key West
199	Monroe County Municipal Services Office Complex	Stock
200	Gerald Adams Elementary School	Stock
201	Florida Keys Community College	Stock
202	Florida Keys Memorial Hospital	Stock
203	Key West Resort Utilities	Stock
204	Scotty's	Key West
205	USN Sigsbee Park STP	Dredgers
206	Key Largo Marina	Key Largo
207	Key Largo Anglers Club	Key Largo
208	S & H Seafood	Stock
209	King Shrimp Company	Stock

3.2.2.2.3 Uses

Domestic wastewater facilities are utilized by many different domestic and industrial concerns. Large facilities such as those located in Key West serve entire communities. However, the smaller facilities, commonly called "package plants," tailor their services to individual uses, such as by schools, hospitals, restaurants, hotels/motels, trailer parks, campgrounds, condominiums, resort complexes, and shopping centers. The FDER maintains a large computerized data and information system known as the Groundwater Management System (GMS). GMS consists of a number of different databases that contain information on different facility permits (e.g., injection wells, dredge and fill, domestic wastewater plants, underground storage tanks, landfills). The FDER (1991b,c) provides detailed information pertaining to domestic wastewater treatment facilities. Approximately 25% of all package plants are utilized by condominiums and apartments. An additional 24% of the plants serve restaurants and motels. Nearly 20 trailer parks and mobile home parks, as well as most resorts in the Keys, depend upon package plants (FDER 1991b).

3.2.2.2.4 Injection Wells

Within the Florida Keys, there are many injection well facilities commonly termed "boreholes". They are used primarily for wastewater effluent disposal, either from one of the many package plants or from aerobic treatment units used by single family residences. Injection wells are also used as a means to dispose stormwater drainage, laundry wastewater, or air-conditioning heat pump return-flow, however, very few such facilities exist (FDER 1992).

Boreholes are permitted by both the FDER, and the Monroe County Health Department functioning under the auspices of the Florida Department of Health and Rehabilitative Services (FDHRS). According to the FDER GMS database, as of February 1992, there are 557 active FDER- permitted injection wells in the Keys. An additional 113 wells are classified as inactive. Of the 226 aerobic plants permitted by the Monroe County Health Department, 186 discharge their effluent via a borehole. The remaining aerobic plants utilize on-site absorption beds similar to the on-site sewage treatment (septic tank) systems (C. Williams, Monroe County Health Department, personal communication, 1992).

Boreholes in the Keys generally range in depth from 18 to 27 m with a casing depth ranging from 9 to 18 m (FDER 1992). The FDER now requires boreholes to be drilled and cased to a depth of 27 m and 18 m, respectively.

3.2.2.2.5 Facility Size

FDER Rule 17-600, FAC regulates domestic wastewater facilities. According to the Rule, wastewater facilities are classified as being one of three types.

- **Type I** — A wastewater facility having a permitted capacity of 500,000 gallons per day (GPD) or greater
- **Type II** — A wastewater facility having a permitted capacity of 100,000 GPD up to, but not including, 500,000 GPD
- **Type III** — A wastewater facility having a permitted capacity of over 2000 GPD up to, but not including, 100,000 GPD

The Rule sets forth requirements regarding facility design and discharge treatment, with differing requirements depending upon the classification of the facility (Rule 17-600, 1991).

There is no wastewater facility with a permitted capacity of 500,000 GPD (i.e., Type I) that discharges into a borehole. The City of Key West STP has a design capacity in excess of 500,000 GPD; however, it discharges its effluent into the Atlantic Ocean. According to EPA (1991a) and the FDER (1991b), six Type II facilities are in proximity to the FKNMS, including

Facility Name	Method of Discharge
• Key West Resort	Borehole
• Key Haven Utilities	Borehole
• United States Naval Air Station (Boca Chica)	Surface waters
• Landings of Largo	Borehole
• Key Colony Beach	Surface waters

It is evident that the largest number of dischargers are the small package plants (Type III), whose design capacities range from 2000 to 99,999 GPD. In the Florida Keys, the typical size of these plants are in the range of 10,000 to 20,000 GPD. The few larger facilities, those with an average daily flow of 40,000 to 75,000 GPD, primarily serve various resorts in the Keys.

3.2.2.2.6 Location of Facilities

While package plants are found throughout the Keys, the lower Keys have relatively fewer of these facilities than do the middle and upper Keys. This is attributed to the population size within the City of Key West and the handling of domestic wastewater treatment through a large, consolidated facility. Although several package plants handle wastes from individual developments, most of the City is served by the City municipal wastewater treatment facility.

Areas having significant concentrations of package plants include Marathon, Islamorada, and Key Largo. Marathon alone contains 49 package plants concentrated in an area approximately 6 mi long. Average daily flows range between 500 and 18,000 GPD. Most of the facilities are operating between 20% and 40% of design capacity (Wallace Roberts & Todd *et al.* 1991a). Key Largo has 48 package plants; however, unlike Marathon, they are not clustered but are distributed along the length of the Key, which is approximately 24 mi long. Islamorada and Plantation Key are two other areas where a number of package plants are located within close proximity to one another. Twenty such facilities are located along a 4-mi stretch of U.S. Highway 1 in Islamorada; another 15 plants are situated on Plantation Key, from Mile Marker 86 northward to Mile Marker 91.

3.2.2.2.7 Water Quality

Secondary treatment plants are required to report certain water quality parameters to the FDER (Rule 17-600, FAC). Permittees generally are required to submit monthly operating reports. FDER enters the water quality data into their GMS Monthly Operating Reports database, commonly labeled GMS36. Standard water quality parameters and other pertinent information regarding facilities operation typically are entered into GMS36. Archived information includes analytical data (e.g., BOD_5, pH, TSS, fecal coliform) and operational parameters (e.g., maximum daily flow, average daily flow, chlorine residual).

In 1988, the FDER conducted a chemical analysis of secondarily treated domestic sewage being disposed of via 20 boreholes to determine whether or not the "minimum criteria" for groundwater quality was being violated.

The study results indicated that the groundwater was of relative good quality for disposal into Class G-III groundwater. However, it was noted that the findings were not related to nutrients (Merchant and Haberfeld 1988).

There is no State administrative rule requiring permittees to monitor the effluent from their wastewater treatment plants for nutrients (e.g., nitrogen and phosphorus). Wastewater treatment plants designed to meet secondary treatment standards will not be efficient in nitrogen and phosphorus removal. Typical removal efficiencies reported for secondary treatment were 10% to 20% of effluent concentrations for both nutrients (Saarinen 1989).

FDER has undertaken two studies in an attempt to evaluate the impact of domestic sewage discharged via boreholes. Merchant and Haberfeld (1988) concluded that the secondarily treated domestic sewage being disposed of via Class V injection wells is of relatively good quality for disposal into Class G-III groundwater. However, it was also noted that nutrient enrichment of surface waters adjacent to the groundwater discharges studied was not addressed. In response to this concern, another monitoring study of a long-term nature was initiated by the FDER Marathon Office in April 1989 (G. Rios, FDER, personal communication, 1991). The purpose of the study was to assess water quality impacts from wastewater discharged into Class V wells on the groundwater and adjacent surface waters. These wells are associated with a relatively new recreational vehicle park that, to date, is less than 50% built. Preliminary results do not indicate significant nutrient enrichment, however, in 1991, the plant was operating at only 5% of its design capacity. Continued monitoring is planned along with a dye tracking survey (G. Rios, FDER, personal communication, 1991).

3.2.2.3 ON-SITE SEWAGE DISPOSAL SYSTEMS

3.2.2.3.1 Background

It is estimated that 65% of the wastewater flow generated in Monroe County is treated by individual on-site sewage disposal systems (OSDS) (Monroe County 1991; Wallace Roberts & Todd *et al.* 1991a). There are an estimated 24,000 permitted septic tanks and 5000 cesspits in the Florida Keys (S. Lysik, Keith and Schnars, P.A., personal communication, 1991). Although septic tank systems are regulated, cesspits are not. Cesspits represent an unregulated, on-site disposal system that discharges directly into local groundwater without waste treatment. Considerable concern has been raised over the impact of OSDSs and cesspits on water quality (Lapointe and O'Connell 1988; Saarinen 1989; Burnaman 1991).

The regulation of OSDS facilities is the responsibility of the FDHRS, and is administered through the Department's authorized agents, the individual county public health units. The Monroe County Health Department operates three branch offices where OSDS permits may be secured, including Key West, Marathon, and Tavernier.

In general, OSDS facilities are regulated in accordance with Rule 10D-6 (FAC), which applies Statewide. However, in the case of the Florida Keys, there are other requirements that must be met. Due to the unique soil conditions and water-table elevations, densities and setback requirements have also been enacted. The State has implemented additional regulations for those counties where more than 60% of the soils are Key Largo Limestone. These regulations apply also to those islands where more than 60% of the soils are Miami Limestone. These supplemental requirements were added by the State in 1986 in a special section titled Part II of Chapter 10D-6, FAC (Burnaman 1991). In a memorandum from the FDHRS Environmental Health Program Supervisor, the Department sought "increased purification of OSDS effluent" to protect surface water quality (Burnaman 1991). Since this rule change was enacted, no monitoring of the effectiveness of the Part II provisions has been undertaken as required by the Department's own rules (Burnaman 1991). Modifications to the Rule are presently being considered by FDHRS (K. Sherman, FDHRS, personal communication, 1991).

The Florida Department of Community Affairs (FDCA), in exercising its authority with regard to its local comprehensive plan review responsibilities (see Section 163.3161, Florida Statutes), indicated that it had concerns about how Monroe County had addressed OSDS standards. Therefore, in accordance with its statutory authority, FDCA and the County entered into a Stipulated Agreement that requires the County to adopt standards for OSDSs that are based on an environmental carrying-capacity approach. This approach addresses nutrient loading and attempts to maintain the quality of the nearshore waters. These OSDS requirements and specific levels of service will be established as a result of undertaking a Sanitary Wastewater Master Plan. It is expected that this study will be completed in 1995.

3.2.2.3.2 Soils

Due to their inherent physical properties, all soil types present in Monroe County are rated as having either severe (29.5%) or very severe (70.5%) limitations for use as septic tank absorption fields (Ayers Associates 1987). To overcome the soil's limitations, septic tanks would require special design, would potentially generate significant increases in construction costs, and could possibly realize higher maintenance costs. In general, most soil types exhibit similar restrictive soil features. The most common soil features are depth to rock, wetness, flooding characteristics and potential, and filter characteristics (DOA 1989).

OSDS can be a significant source of nutrient and bacterial groundwater contamination. The Monroe County Health Department indicated that bacterial contamination is not a problem (H. Rhode, Monroe County Health Department, personal communication, 1991); however, conventional OSDS do little in removing nutrients (Ayers Associates 1987).

A general discussion of the Florida Keys geology is presented in **Section 3.2.2.1 Geology, Hydrogeology, and Aquifers**.

3.2.2.3.3 Location

A majority of the OSDSs in the area of interest are located in the unincorporated portions of Monroe County. As noted previously, nearly all areas in the City of Key West are served by the Key West STP (Solin 1991). It is estimated that within the City there are fewer than 50 septic tank systems remaining. Further, it is anticipated that, by 1995, all remaining septic tank users will have connected to the Key West STP (K. Williams, CH_2M Hill, personal communication 1991). In addition, the residents of the City of Key Colony Beach have their own sewage treatment facility.

The firm of Wallace Roberts & Todd is presently completing an inventory of all permitted and unpermitted septic tanks and cesspools in unincorporated Monroe County. However, even though the specific number of OSDS units operating in the Keys cannot be determined, it is highly probable that the density of OSDS units will mirror the distribution of population. Using this approach, the highest concentrations of OSDS units are expected in areas such as Marathon and Key Largo.

3.2.2.3.4 Types of Facilities

Several OSDS designs are in use in the Florida Keys. They include conventional, mound, and aerobic systems.

The conventional system for on-site treatment and disposal of domestic wastes consists of a buried septic tank and a subsurface infiltration trench or bed (Bicki *et al.* 1984). Septic tanks with conventional soil absorption systems can provide an effective method of treatment and disposal when site conditions, construction methods, and maintenance requirements are considered. Based on existing soil conditions throughout the Keys, it is apparent that an alternative means of treatment and disposal must be used in areas where the soil is insufficient to provide adequate purification of the waste before it reaches the groundwater (CH_2M Hill 1979). Conventional and mound OSDS methods are not designed to remove nutrients. There is a minimal amount of nutrient reduction through phosphorus absorption and precipitation in the natural soil system (Monroe County 1991).

The mound system utilizes a septic tank; however, its drainfield is constructed at a prescribed elevation in a prepared bed of fill material (FDHRS 1991). As described in the Monroe County 201 Wastewater Facilities Plan (CH_2M Hill 1979), the effluent flows by gravity into a pumping chamber. A pressure distribution network is used to provide uniform application of the effluent in the seepage bed.

The aerobic system, unlike the traditional septic system, incorporates a means of introducing air into sewage so as to provide aerobic biochemical stabilization during a detention period (FDHRS 1991). There are 226 aerobic treatment units serving both residential and commercial uses in the Keys. While there are 40 located in the upper Keys, and 13 to 15 in the middle Keys, the vast majority are situated in the lower Keys. The aerobic systems can discharge effluent into either a drainfield system (similar to a septic tank) or through a gravel filter, then into a borehole. Of the units installed, 186 systems discharge effluent into a borehole and the remainder utilize drainfields (C. Williams, Monroe County Health Department, personal communication, 1992). The FDER monitored these systems from 1987 through 1989. Data indicate that many of these systems do not function in compliance with the National Science Foundation standards (Wallace Roberts & Todd *et al.* 1991a; Burnaman 1991; G. Rios, FDER, personal communication, 1991). In addition, these systems do not achieve nutrient reduction (Saarinen 1989).

The RUCK system is an alternative wastewater disposal system being considered as an alternative to conventional OSDS. It relies upon segregating toilet wastewater (blackwater) from other household wastewater (greywater). "Under field testing, the RUCK system was found to have an overall nitrogen removal efficiency of 70%. The final effluent before infiltration into the soil had a total nitrogen content of less than 10 mg/L and a nitrate concentration of 0.2 to 5 mg/L" (Monroe County 1991).

3.2.2.3.5 Wastewater Flow

Projected wastewater flows generally are described in terms of average daily flow (ADF), either per equivalent dwelling unit or by using a per capita method. This Section presents the various methods that have been used to project future wastewater flow.

The Monroe County Comprehensive Plan (Monroe County 1991) cites an average daily flow of 250 GPD per equivalent dwelling unit. All land uses are reflected in that figure. Before accepting the 250-GPD value, Monroe County conducted a review of wastewater generation rates developed by Bicki *et al.* (1984). A summary of sources and daily flow estimates developed by Bicki *et al.* (1984) is presented in **Table 2-6**.

The County evaluated whether or not the weighted per capita average of 44 GPD cited by Bicki *et al.* (1984) was appropriate for the Florida Keys. Based on their findings, the County adopted the value of 250 GPD per equivalent dwelling unit.

Camp Dresser and McKee, Inc. (1990) used per capita flow values of 100 GPD for residents and 60 GPD for tourists. These per capita values were derived from the 1979 Monroe County 201 Wastewater Facilities Plan (CH_2M Hill 1979).

Table 2-6. Summary of average daily residential wastewater flows. [From Bicki *et al.* 1984]

Study	# of Homes	Study Duration (months)	Wastewater Flow Study Average (GPCD)	Range of individual residence averages (GPCD)
Linaweaver *et al.* 1967	22	—	49	36-66
Anderson and Watson 1967	18	4	44	18-69
Watson *et al.* 1967	8	2-12	53	25-65
Cohen and Wallman 1974	8	6	52	37.8-101.6
Laak 1975	5	24	41.4	26.3-65.4
Bennett and Linstedt 1975	5	0.5	44.5	31.8-82.5
Siegrist *et al.* 1976	11	1	42.6	25.4-56.9
Otis 1978	21	12	36	8-71
Duffy *et al.* 1978	16	12	42.3	—
Weighted Average			44	

GPCD: Gallons per capita per day.

Another set of wastewater generation rates to be considered is the level of service standard adopted by the City of Key West in its Comprehensive Plan, Sanitary Sewer Facilities and Services Subelement. The levels of services, by facility, were

Residential Uses	100 GPCD (gallons per capita per day) for permanent residents based on 90 GPD for seasonal residents;
Nonresidential Uses	660 GPAD (gallons per acre per day).

3.2.2.3.6 Wastewater Characteristics

Septic tank effluent contains varied concentrations of nitrogen, phosphorus, chloride, sulfate, sodium, toxic organics, detergent surfactants, and pathogenic bacteria and viruses. Several studies have investigated sewage effluent constituents. **Table 2-7** compares constituents by package plants, boat live-aboard systems, and OSDSs. **Tables 2-8** and **2-9** characterizes typical residential wastewater from several sources.

An indication of typical septic tank effluent is provided in **Table 2-10**. For septic tank effluent as it is discharged into the drainfield, the soils provide additional treatment prior to contact with groundwater (Saarinen 1989). The degree of treatment depends upon the efficiency of constituent removal in the soil underlying the drain system and the thickness of the unsaturated zone between the bottom surface of the drainfield and the high water table. **Table 2-11** describes typical reduction in effluent parameter concentrations as the effluent passes from the septic tank to the drain system and finally to the groundwater.

3.2.2.3.7 Water Quality

If properly installed and maintained, OSDS units have functioned adequately in terms of their removal of fecal coliform and suspended solids (G. Rios, FDER, personal communication, 1991; H. Rhode, Monroe County Health Department, personal communication, 1991), as required under Rule 10D-6, FAC. However, as discussed earlier, conventional OSDS units do little to remove nutrients. The aerobic OSDS unit removes slightly more nitrogen than a conventional OSDS (J. Bottone, FDER, personal communication, 1992). There has been considerable energy put forth to establish a link between OSDSs and nearshore water quality (Bicki *et al.* 1984; Lapointe and O'Connell 1988). However, there have not been definitive conclusions concerning the exact relationship between septic tank effluent and nearshore water-quality degradation. There is, however, reasonable suspicion that a portion of nearshore water-quality degradation can be attributed to the nutrient-loading from regulated and unregulated OSDSs (Wallace Roberts & Todd *et al.* 1991a).

3.2.2.4 LANDFILLS

The Monroe County Municipal Service District (MSD) is responsible for providing solid waste services throughout unincorporated Monroe County, including Layton and Key Colony Beach. The City of Key West manages its own solid waste disposal operation (Monroe County 1991; Solin 1991).

In 1990, there were four active landfill operations in the FKNMS located on Stock Island (serves Key West), Cudjoe Key, Long Key, and Key Largo. As of February 1992, only the Key West facility still had an active landfill operation. This facility will also be closed by November 1993. Presently, the Key West facility is operating under a FDER Consent Order (W. Krumbholz, FDER, personal communication, 1992). The landfill

Table 2-7. Effluent characteristics by source. [From Applied Biology, Inc., and Camp Dresser and McKee, Inc. 1985; Canter and Knox 1985; Camp Dresser and McKee 1990]

Constituent	Effluent Concentration	
	Package Plant (mg/L)	OSDS (mg/L)
Suspended solids	20	75
Biological oxygen demand	20	140
PO_4-P	8	11
NH_3-N	5	30
NO_3-N	35	0

OSDS: On-site sewage disposal system.

Table 2-8. Characteristics of typical residential wastewater.[a] [From Bicki *et al.* 1984]

Parameter	Mass loading (GPCD)	Concentration (mg/L)
Total solids	115-170	680-1000
Volatile solids	65-85	380-500
Suspended solids	35-50	200-290
Volatile suspended solids	25-40	150-240
BOD_5	35-50	200-290
Chemical oxygen demand	115-125	680-730
Total nitrogen	6-17	35-100
Ammonia	1-3	6-18
Nitrates and nitrites	<1	<1
Total phosphorus	3-5	18-29
Phosphate	1-4	6-24
Total coliforms (organisms/liter)	—	10^{10}-10^{12}
Fecal coliforms (organisms/liter)	—	10^{8}-10^{10}

GPCD: Gallons per capita per day.
[a]For typical residential dwellings equipped with standard water-using fixtures and appliances (excluding garbage disposals) generating approximately 45 GPCD or 170 L per capita per day.

Table 2-9. Residential wastewater characteristics. [From Canter and Knox 1985]

Constituent	Concentration (mg/L)
BOD_5	300
Chemical oxygen demand	750
Total organic carbon	200
Total solids	781
Total volatile solids	438
Suspended solids	250
Volatile suspended solids	194
Total Kjeldahl nitrogen	38
NH_3-N	12
NO_3-N	0.6
NO_2-N	—
Total phosphorus	25
PO_4-P	8.8
Oil and grease	94
Methylene blue active substances	19

Table 2-10. Septic tank effluent quality. [From Laak 1975]

Constituent	Concentration (mg/L)
BOD_5	90-348
Chemical oxygen demand	150-720
Total organic carbon	129
Total solids	820
Suspended solids (98% 0.5-5.0 μm)	40-350
Volatile suspended solids	80% SS
Total nitrogen	25-36
Organic N	30% TN
Ammonia (NH_4-N)	70% TN
PO_4	35-100
Grease	50-150
E. coli (organisms/100 mL)	106-108

SS: Suspended solids.
TN: Total nitrogen.

Table 2-11. Typical effluent concentrations from septic tank systems. [From Canter and Knox 1985]

Parameters (mg/L)	Septic Tank Effluent	Drain System Effluent	Removal from Drain System (%)
Suspended solids	75	18-53	29-76
BOD_5	140	28-84	40-80
Chemical oxygen demand	300	57-142	53-81
Total nitrogen	40	10-78[a]	—
Total phosphorus	15	6-9	40-60

[a] Reported as ammonia nitrogen

operations at the Key Largo and Long Key facilities are now closed. The facility at Cudjoe Key no longer accepts solid waste; however, the seven acre, synthetically-lined [60 mil high-density polyethylene (HDPE)] expansion completed in December 1990, is being kept in reserve for emergency or future use (Monroe County 1991; W. Krumbholz, FDER, personal communication, 1992). In addition to these four facilities, the FDER files document that there are four "old" landfills that have been closed for some time (W. Krumbholz, FDER, personal communication, 1992). They include the old Key Largo, Saddleback Key, Fleming Key, and Boot Key landfills. All landfills are located near coastal waters.

As of December 1990, Monroe County contracted Waste Management, Inc. (WMI) to haul the county's solid waste out of the county. WMI hauls wet garbage, yard waste, and construction debris to a WMI landfill located in Pompano Beach, Florida (Monroe County 1991). Although the landfills at Key Largo, Long Key, and Cudjoe Key no longer function as active landfill operations, these facilities do serve as subdistrict transfer locations where WMI picks up the waste for hauling (Monroe County 1991).

Hazardous and biohazardous wastes are not handled by the MSD. Those generating such wastes must contract with a licensed hazardous-waste transporter, and have the wastes hauled to a Federally-permitted facility.

Ground water beneath the solid waste landfills is classified as G-III due to the influence of salt water (see Rule 17-3.403 Florida Administrative Code for definition of G-III). Based on available FDER monitoring data, the G-III standards have not been violated (W. Krumbholz, FDER, personal communication, 1992). In addition, bioassays have been conducted on the coastal waters adjacent to Stock Island and Long Key landfills. No toxic levels were detected (R.J. Helbling, FDER, personal communication, 1992).

Landfills within the Florida Keys have operated within legal limits and/or have met Federal and State water quality standards; however, like wastewater treatment systems the detectable limits may be set too high for the oligotrophic waters present in the FKNMS. Also, monitoring of the nearshore marine waters surrounding the existing and closed landfill facilities is vitally important in order to assess the long-term impact of these facilities.

3.2.3 Marinas/Boat Live-Aboard

3.2.3.1 BOATING OVERVIEW

With a setting such as the Florida Keys, it is not surprising that water-oriented activities are of primary interest and importance, not only to the resident population but to seasonal visitors as well. Certainly one indicator of the popularity of water activities is boating. Based on Florida Department of Natural Resources (FDNR) data summarized by the University of Miami Boating Research Center, in 1982 there were 462,765 boat registrations. By 1988, this number had increased by 37% to 635,342 (Snedaker 1990). A sizeable number of seasonal residents also bring their boats to the Keys during their stay. These boats are not reflected in the Boating Research Center data.

3.2.3.2 MARINAS

Within the Florida Keys are 186 marinas. Marinas vary in size from those with only several wet slips to those with multiple docking facilities having in excess of 100 wet slips. Based on the best available data, there are estimated to be 1285 slips in the lower Keys, 589 wet and 696 dry. In the middle and upper Keys, there are a total of 2053 and 1664 slips, respectively. The middle Keys has 1284 wet slips and 769 dry slips; in the upper Keys, there are 830 dry and 834 wet slips (Monroe County 1986). The geographic distribution of marinas is graphically depicted in **Figure 2-6** and listed in **Table 2-12**. The services provided by each marina vary widely.

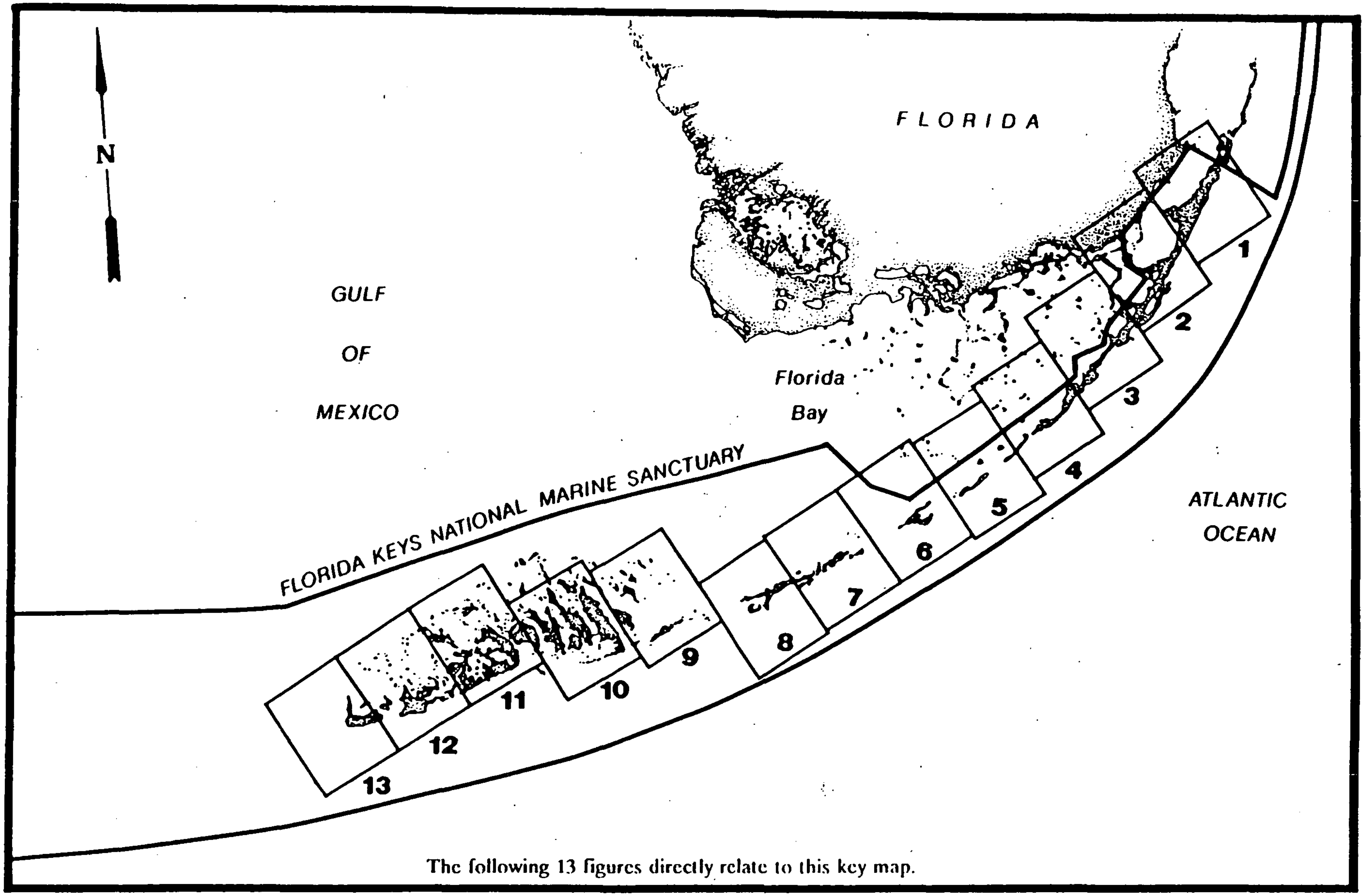


Figure 2-6. Marina facilities.

This Figure and its 13 components, which follow, indicate the geographic locations of marina facilities (indicated on the maps by O). Numbers correspond to those in Table 2-12. Locations of marina facilities in unincorporated Monroe County and the City of Key West provided by Wallace Robert & Todd (unpublished data 1991) and Solin (1991), respectively. Base maps redrawn from maps provided by Wallace Roberts & Todd.

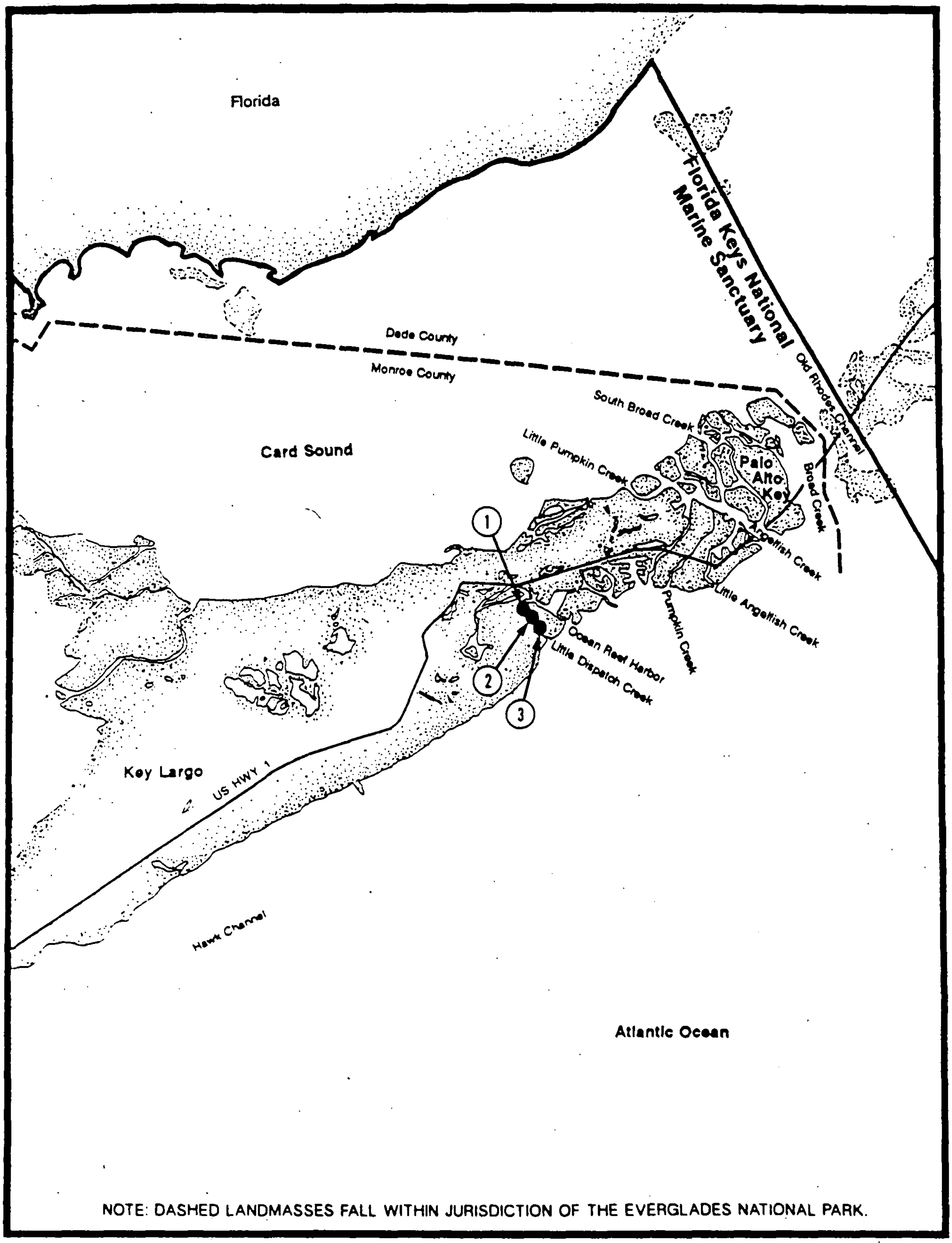


Figure 2-6-1. Marina facilities. (continued)

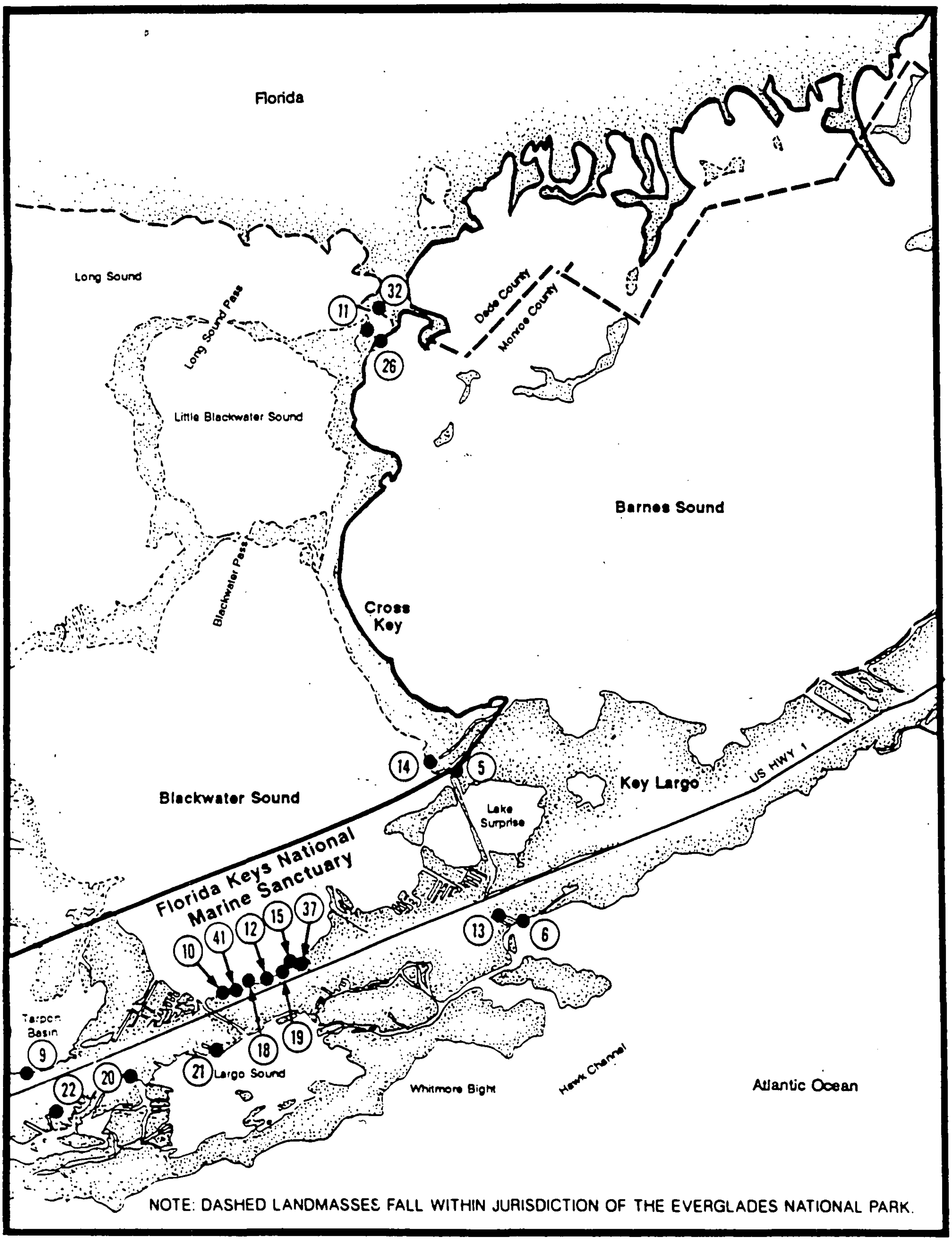


Figure 2-6-2. Marina facilities. (continued)

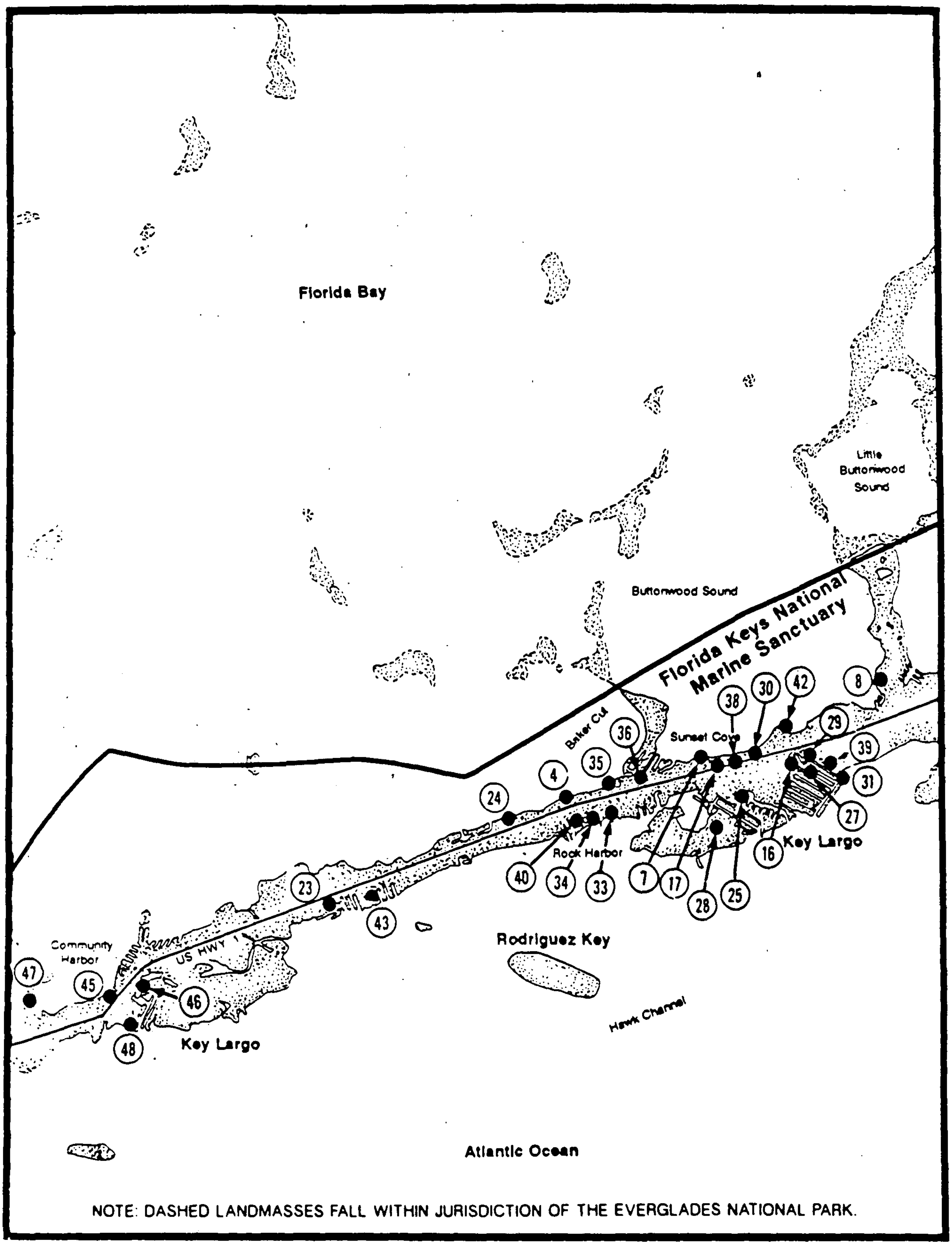


Figure 2-6-3. Marina facilities. (continued)

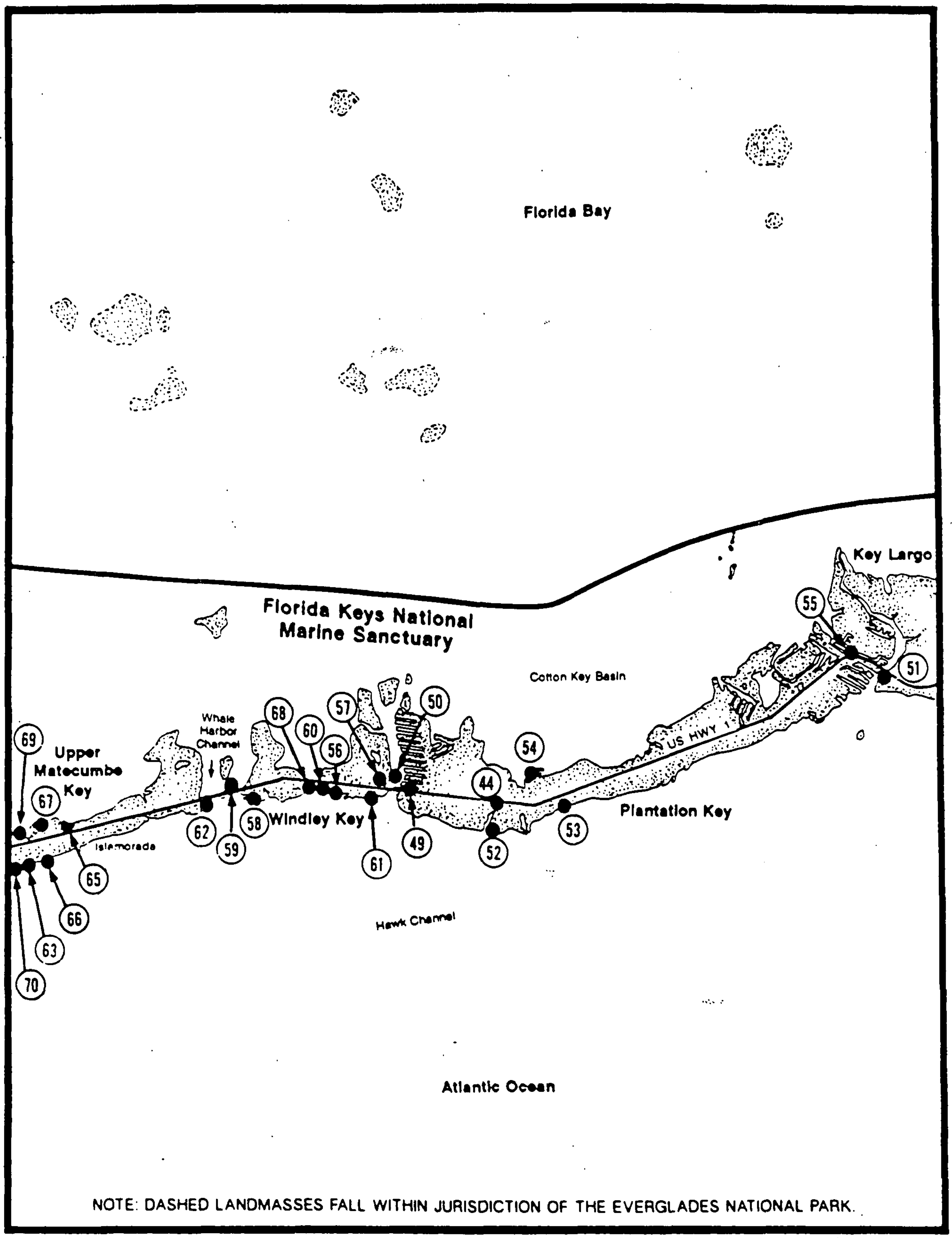


Figure 2-6-4. Marina facilities. (continued)

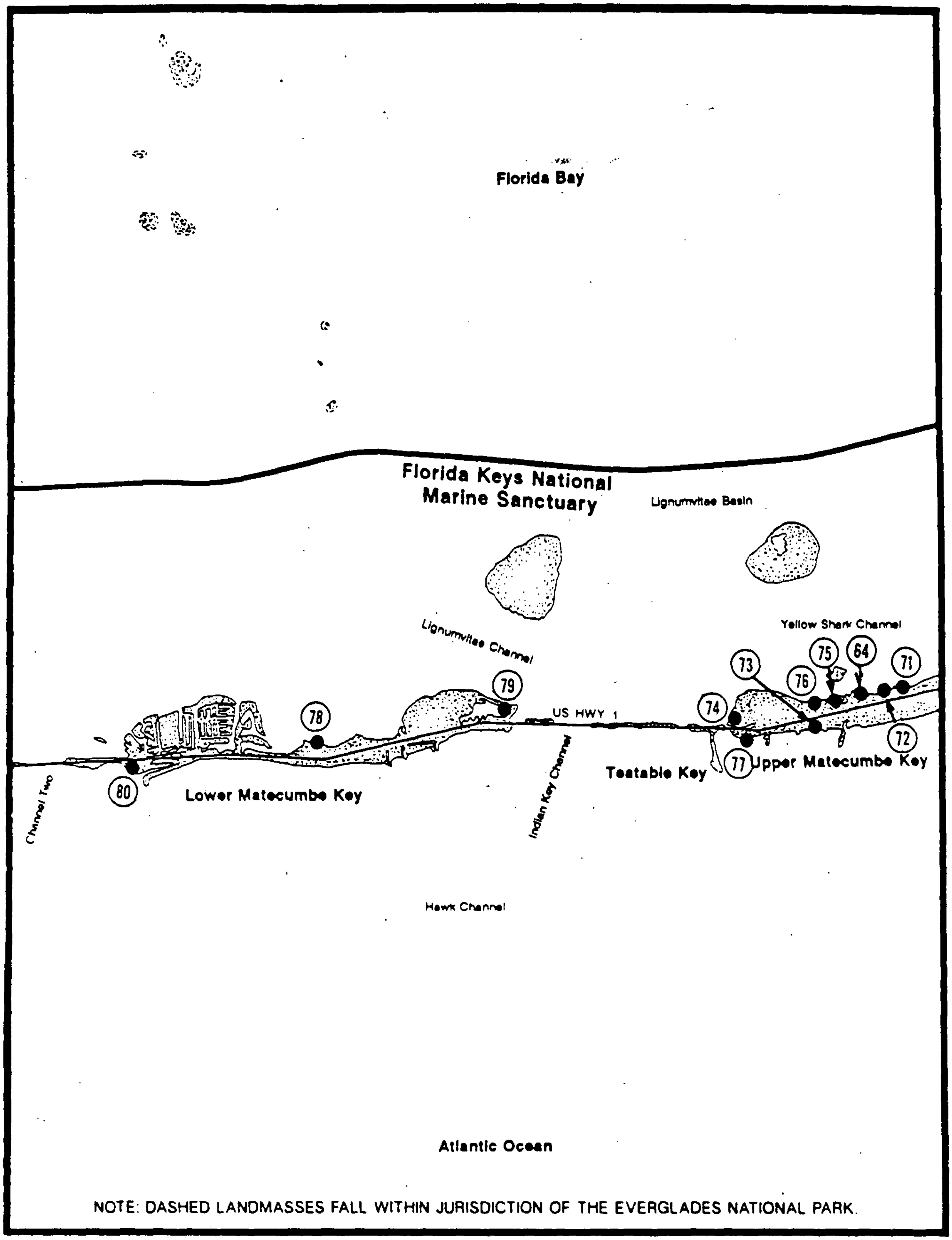


Figure 2-6-5. Marina facilities. (continued)

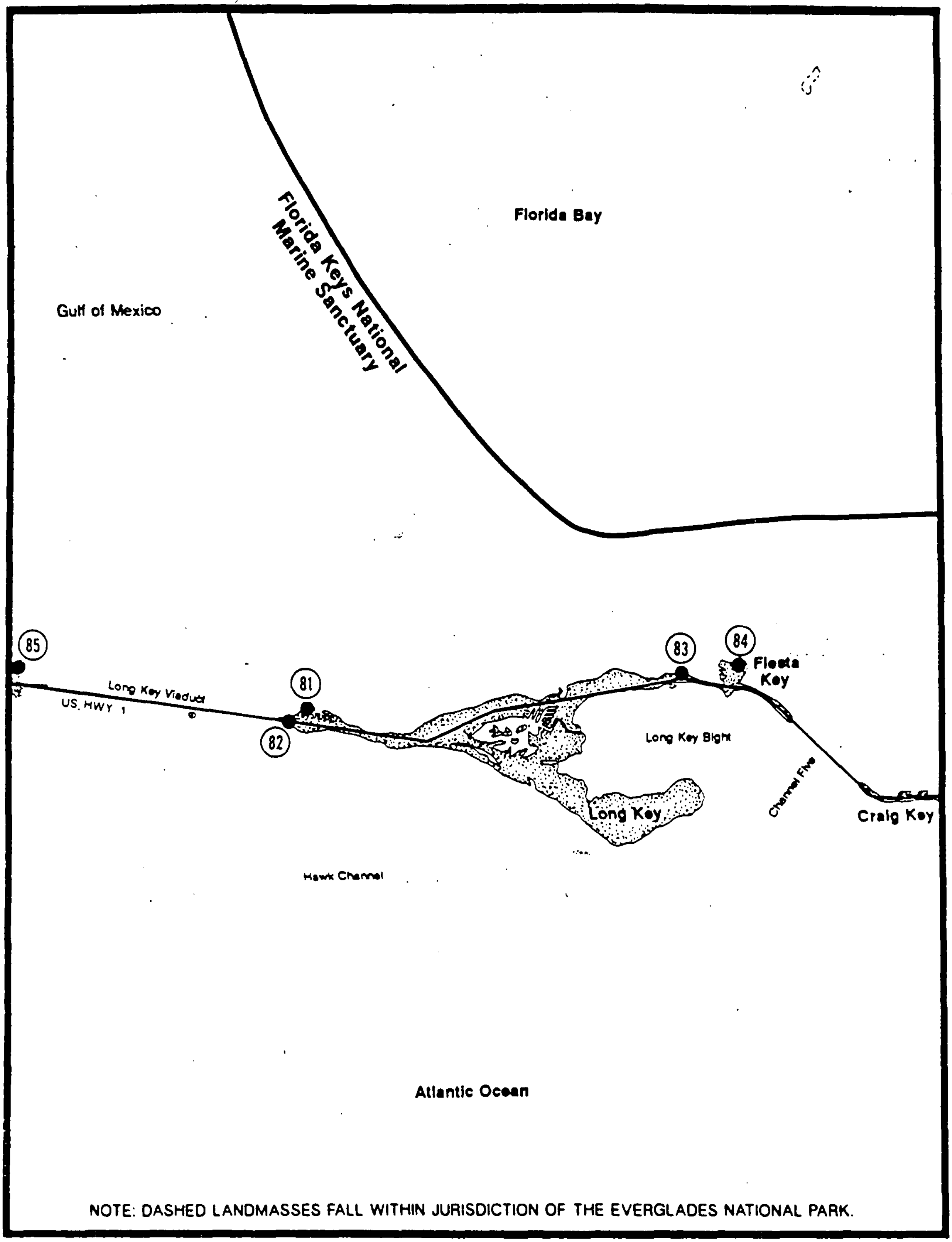


Figure 2-6-6. Marina facilities. (continued)

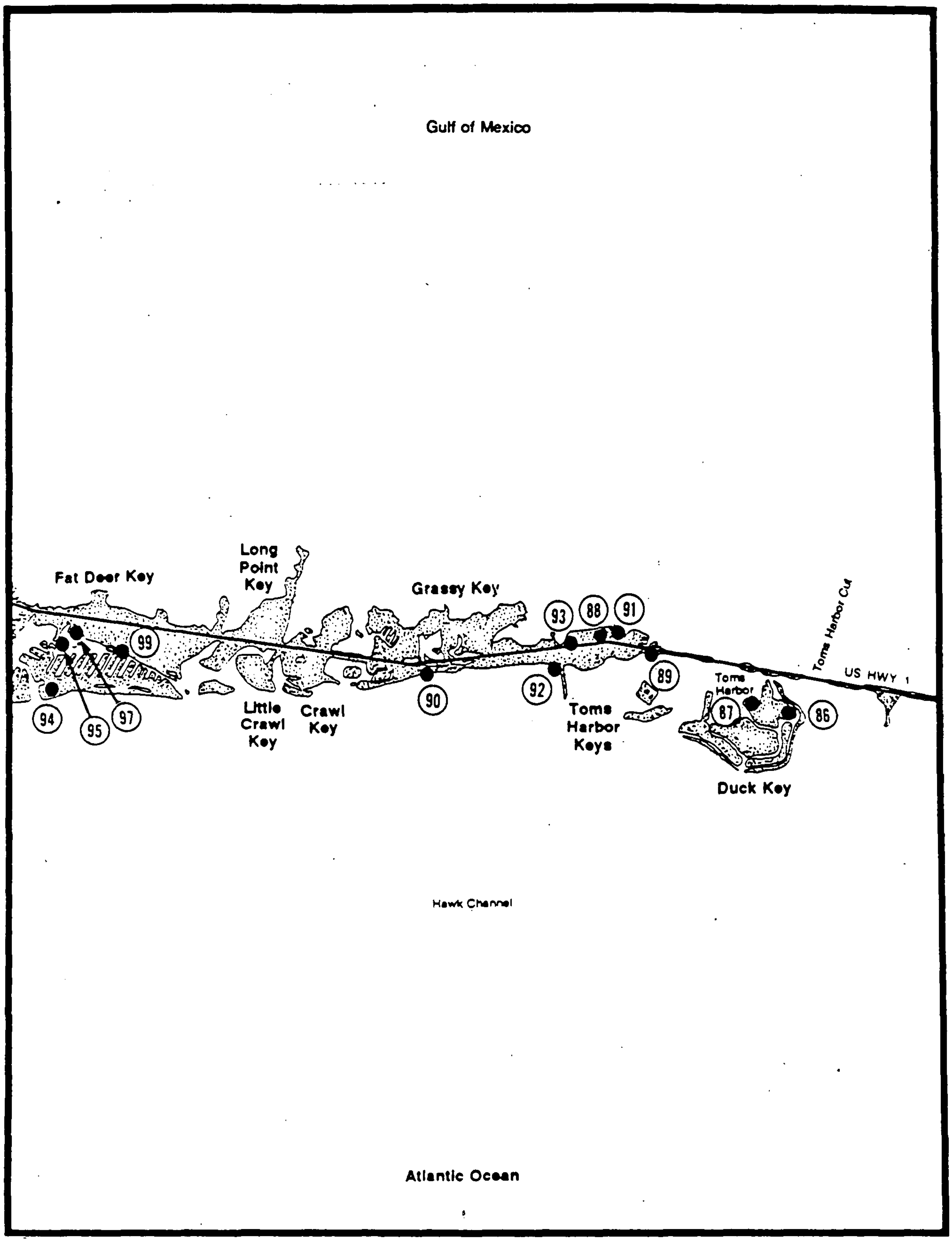


Figure 2-6-7. Marina facilities. (continued)

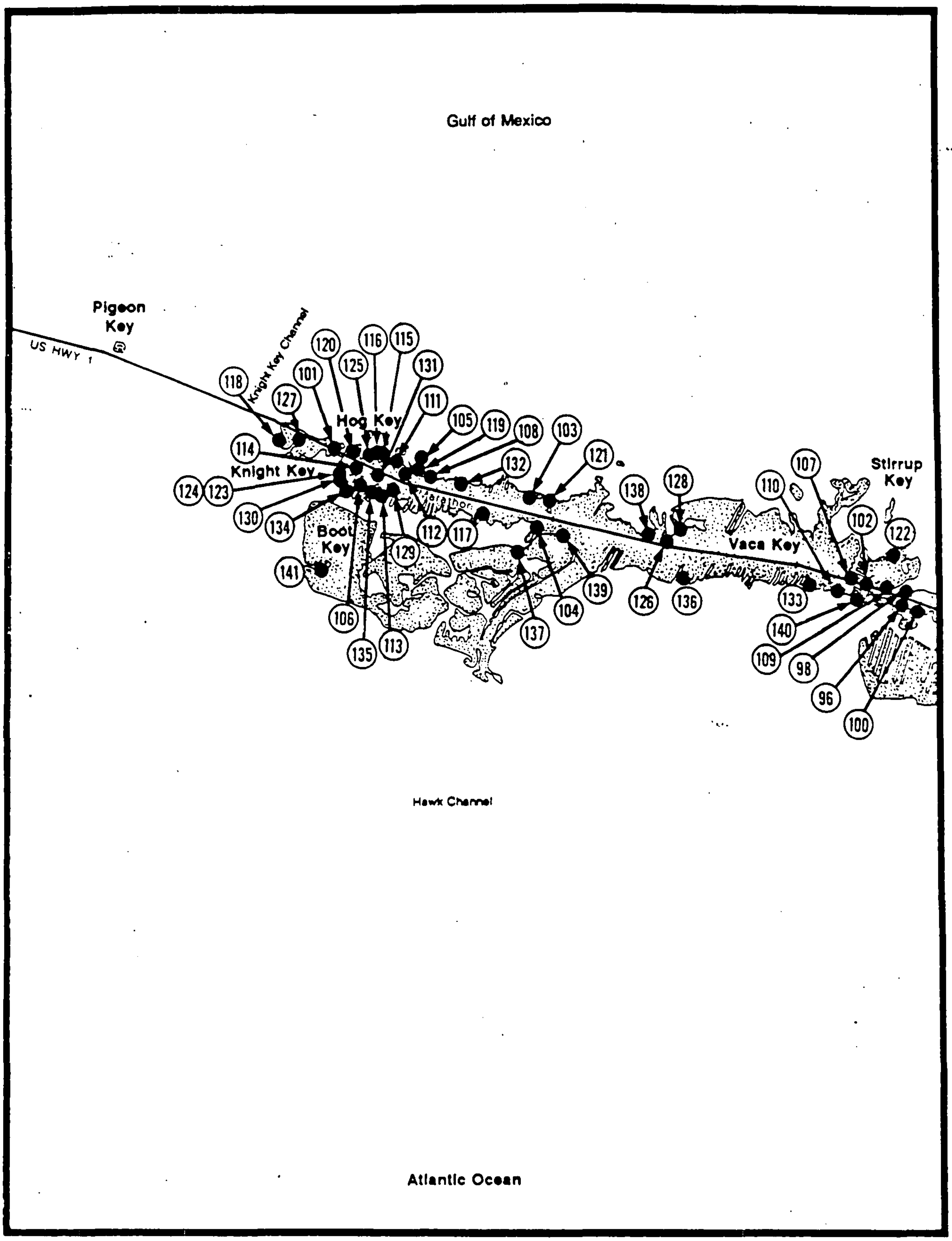


Figure 2-6-8. Marina facilities. (continued)

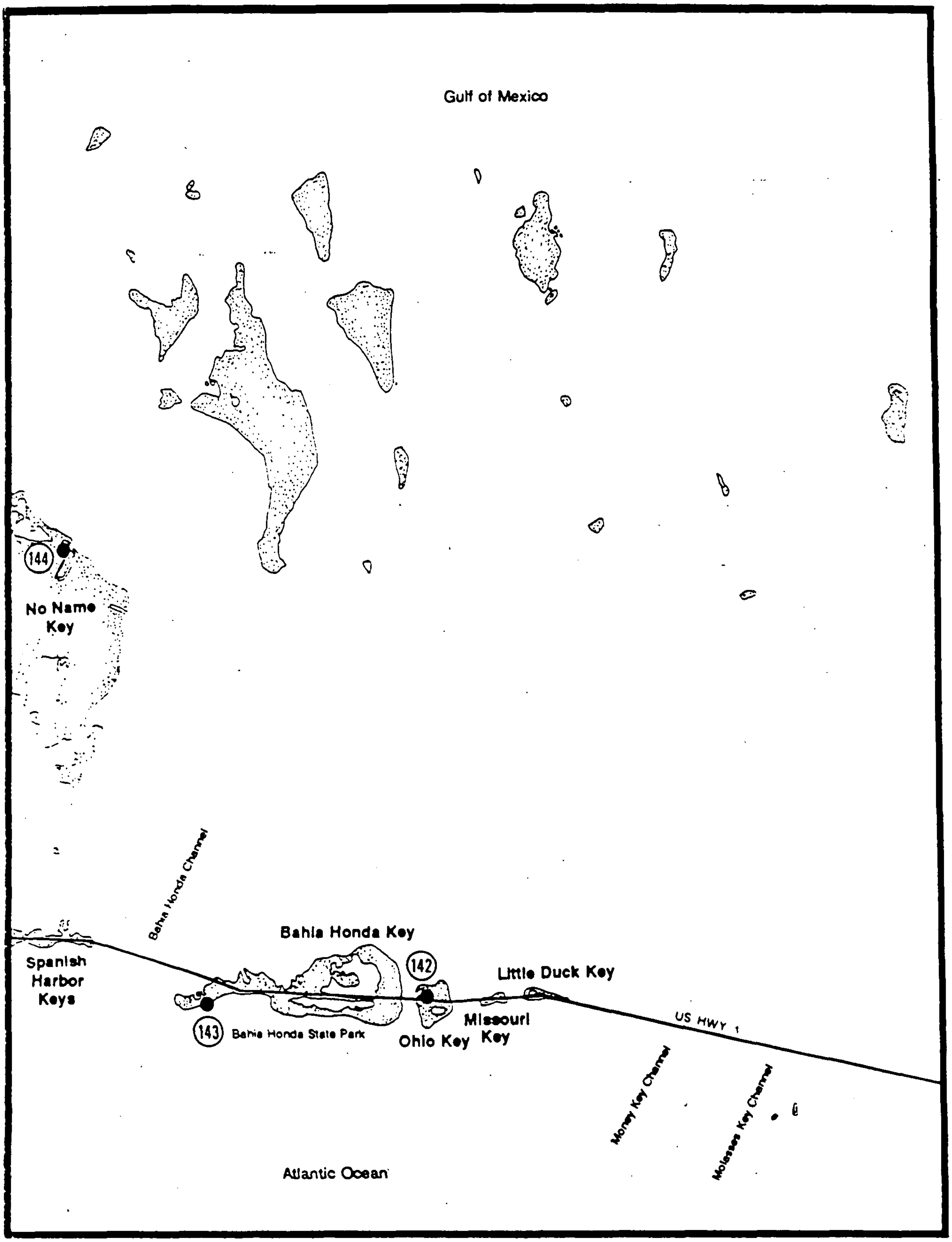


Figure 2-6-9. Marina facilities. (continued)

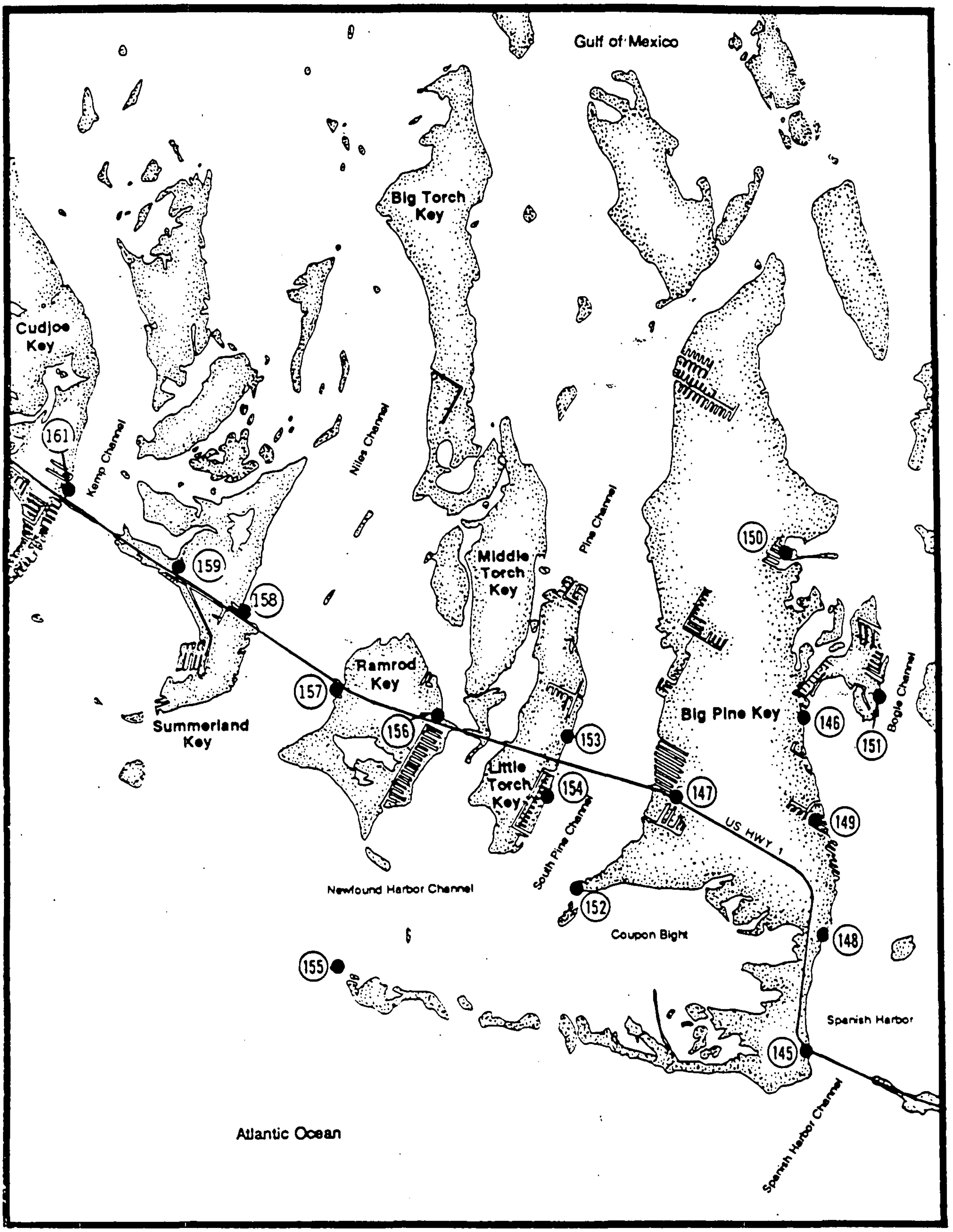


Figure 2-6-10. Marina facilities. (continued)

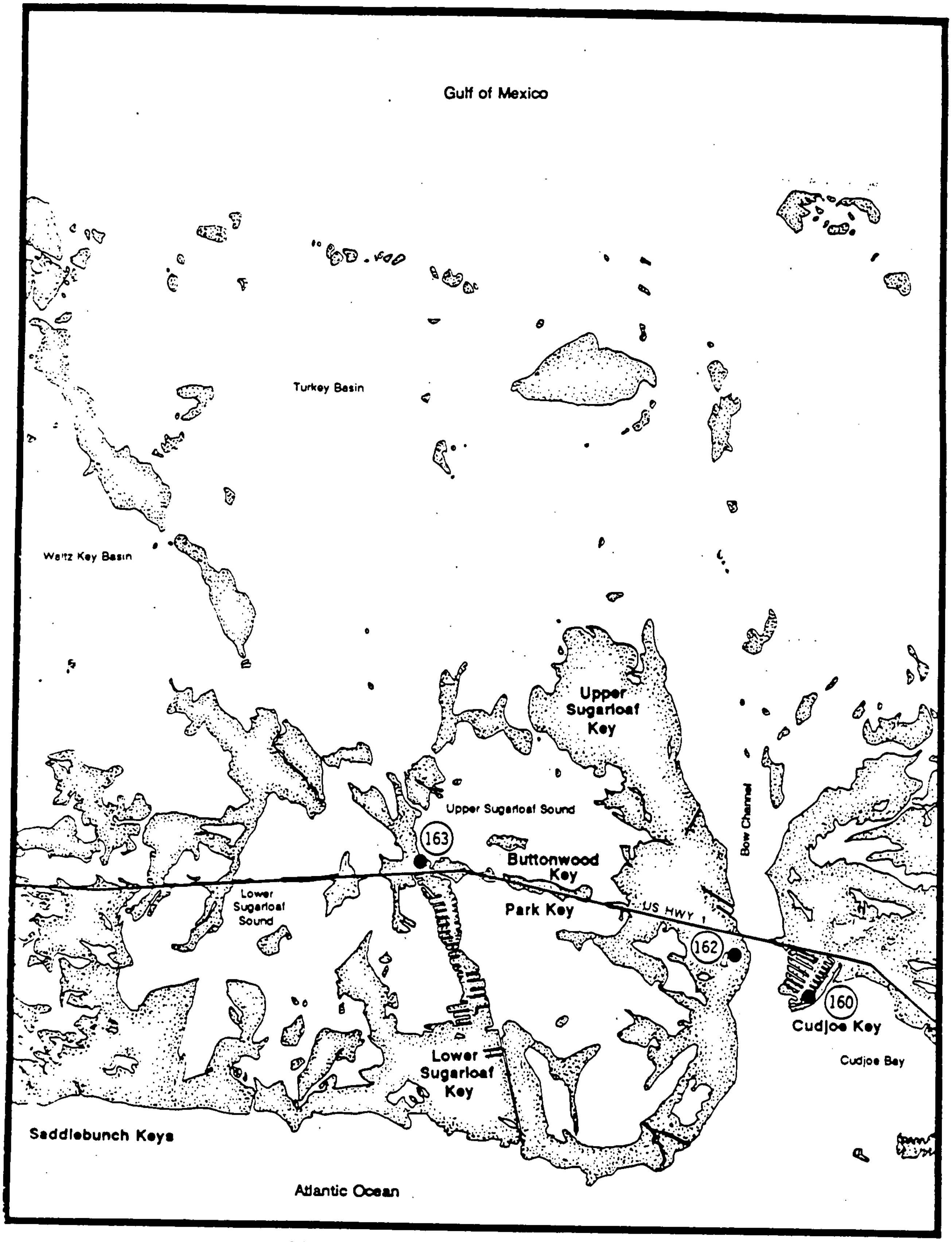


Figure 2-6-11. Marina facilities. (continued)

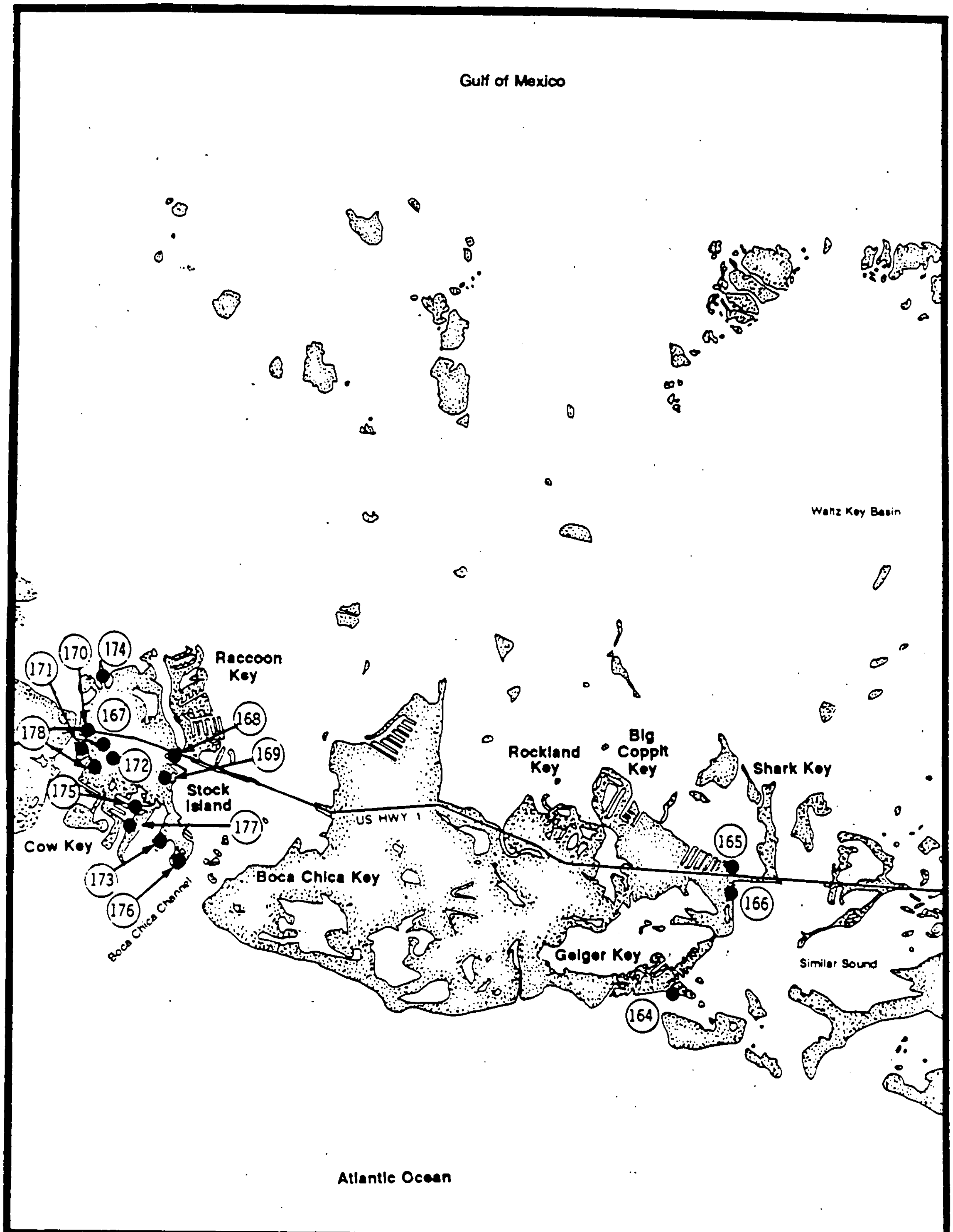


Figure 2-6-12. Marina facilities. (continued)

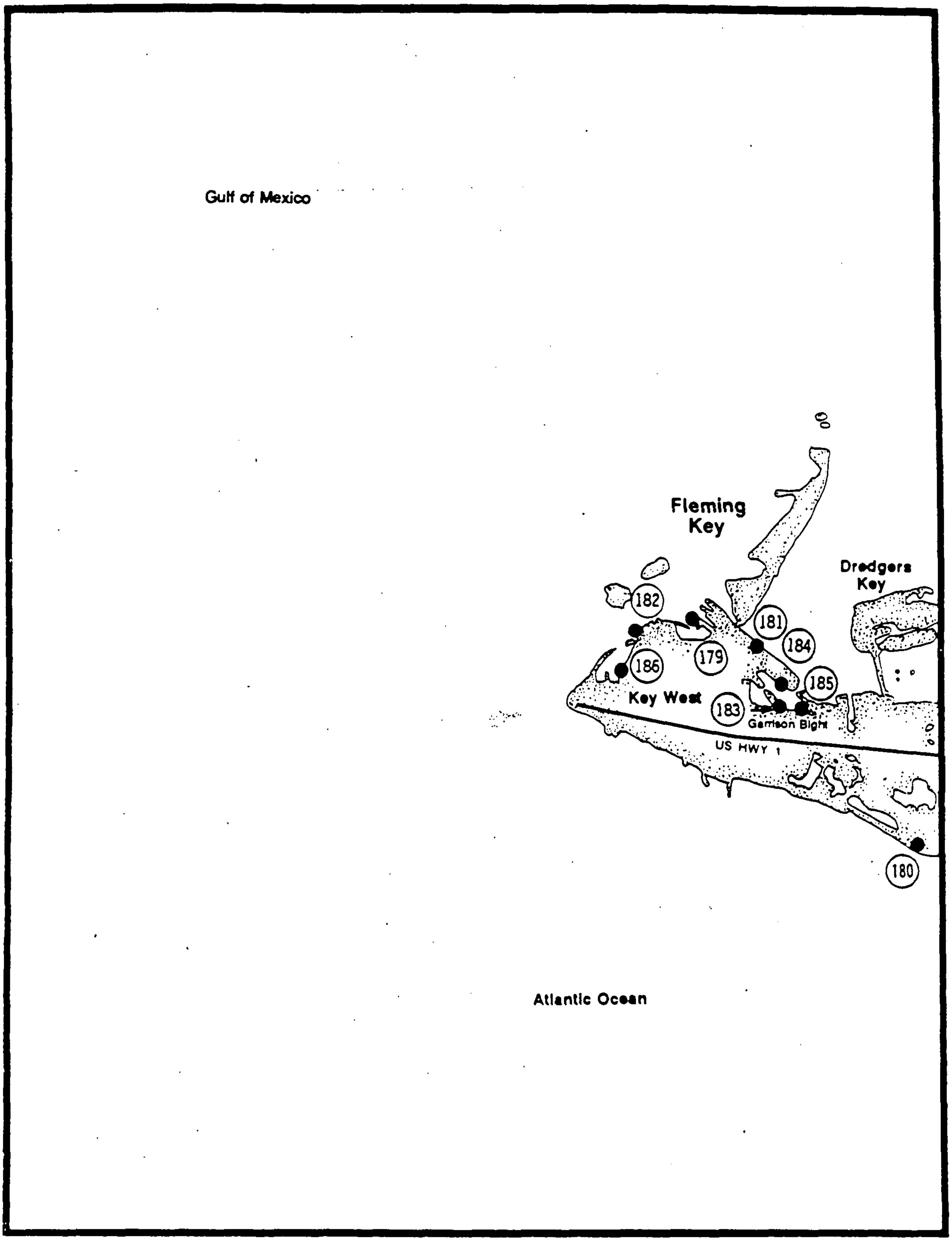


Figure 2-6-13. Marina facilities. (continued)

Table 2-12. Marinas of the Florida Keys. [From Solin 1991; Wallace Roberts & Todd, unpublished data 1991]

ID #	Key	Marina Name	ID #	Key	Marina Name
	North Key Largo		54		Plantation Yacht Harbor
1		Angler's Club	55		Plantation Key Marina
2		Carysfort Yacht Club		Windley	
3		Ocean Reef Club	56		Tropical Reef Resort
	Key Largo		57		Richmond's Landing, Inc.
4		American Outdoors Marina	58		Holiday Isle Resort
5		Anchorage Resort & Yacht	59		Este's Fishing Camp
6		Atlantis Marina	60		Drop Anchor Motel
7		Blue Lagoon Motel	61		Sandbar Restaurant/Marina
8		Calusa Campgrounds		Islamorada	
9		Camper's Cove Trailer Park	62		Whale Harbor Resort
10		Captain Jax	63		Sea Isles Resort
11		Cross Key Marina	64		Kon-Tiki Resort
12		Deep Six Marina	65		Sunset Inn
13		Garden Cove Marina	66		Islander Resort
14		Gilbert's Marina	67		Islamorada Yacht Basin
15		Hideaway Motel	68		Harbor Lights
16		Holiday Inn Marina	69		Coral Bay Marina
17		Island Houseboat Motel	70		Cheeca Lodge/Marina
18		Italian Fisherman Marina	71		Caribee Outboard Marina
19		J. Ron's Marina	72		Bayside Marine, Inc.
20		John Pennekamp Coral Reef Marina State Park	73		Pines/Palms Marina
			74		Papa Joe's Marina
21		Jules (Koblick) Marine	75		Max's Marina
22		Key Largo Kampground Marina	76		Matecumbe Marina
23		Key Largo Ocean Marina	77		Bud 'N Mary's Marina
24		Key Largo Sheraton		Lower Matecumbe	
25		Lake Largo	78		Topsider Resort
26		Manatee Bay Marina	79		Robbie's Boat Rentals
27		Marina del mar Resort	80		Caloosa Cove Resort
28		Marina del Rey		Long	
29		Ocean Divers Marina	81		Outdoor Resorts
30		Palm Bay Yacht Club	82		Edgewater Marine
31		Pilot House Marina	83		Bird Marina
32		Point Laura Marina		Fiesta	
33		Riptide Trailer Park	84		KOA Kampground
34		Rock Harbor Marina		Conch	
35		Rock Reef Resort	85		Conch Key Marina
36		Roger's Marine		Duck	
37		Rowell's Marina	86		Hawk's Cay Marina
38		Tarpon Marina	87		Duck Key Marina
39		Tortola Marina		Grassy	
40		The Fishing Club	88		Pelican Motel
41		Twin Harbor Motel	89		Coco Palms's
42		Upper Keys Sailing Club	90		Rainbow Bend Resort
43		Weekender Camping	91		Jolly Roger Travel Park
	Tavernier		92		Lion's Lair
44		Treasure Harbor Charter Yachts	93		Bonefish Harbor/Gulfside 59
45		Island Bay Resorts		Fat Deer	
46		Curtis Marine	94		Bonefish Marina
47		Campbell's Marina	95		Coco Plum Marinas
48		Blue Waters Marina	96		Coral Lagoon Resort
	Plantation		97		Driftwood Harbor
49		Cobra Marine	98		Hawaiian Village Botel
50		Coast Guard Station	99		Marie's Yacht Harbor
51		Tavernier Creek Marina	100		The Boat House
52		Ragged Edge Resort		Knight	
53		Seabreeze Trailer Park	101		7 Mile Marina

Table 2-12. Marinas of the Florida Keys. [From Solin 1991; Wallace Roberts & Todd, unpublished data 1991] (continued)

ID #	Key	Marina Name
	Marathon	
102		Anchor Lite Botel
103		Banana Bay Resort
104		Becker Marine
105		Blue Waters Resort
106		Boot Key Marina
107		BP Surfside Gulf
108		Buccaneer Lodge
109		Captain Hook's Marina
110		Captain Pip's Marina
111		Coast Guard Station
112		Faro Blanco Marina
113		Fishermen's Pointe
114		Galway Bay Mobile Home
115		Gulf Stream Travel Park
116		Halls Resort
117		Harborside Marina
	Knight	
118		Hawk's Nest Condo
	Marathon	
119		Hidden Harbor Botel
	Hog	
120		Hog Key Marina
	Marathon	
121		Hurricane Resort
122		Key Lime Resort
123		Key Trailer Park
124		Keys Boat Works
125		Key Vaca Marina
126		Kingsail Motel
	Knight	
127		Knights Key Park
	Marathon	
128		Seahorse Lagoon Resort
129		Marathon Boat Yard
130		Marathon Seafood
131		Marathon Trailerama
132		Marathon Yacht Club
133		Ocean Isles Fishing Village
134		Oceanside Marine Services
135		Pinellas Marine Goods
136		Seascape Resort
137		Sombrero Marina
138		The Reef Resort
139		Winner Docks
140		Vaca Cut Botel
	Boot	
141		Boot Key
	Ohio	
142		Sunshine Key Marina
	Bahia Honda	
143		Bahia Honda State Park
	No Name	
144		Bahia Shores/Dolphin Harbor
	Big Pine	
145		Big Pine Fishing Lodge
146		Halcyon Beach Trailer Park
147		Keys Sea Center, Inc.
148		Outward Bound
149		Mariner Resort
150		Big Pine Shores
151		Old Wooden Bridge Fish Camp
152		Seacamp
	Little Torch	
153		Parmer's Place
154		Dolphin Marina
	Newfound Harbor	
155		Little Palm Island
	Ramrod	
156		Looe Key Reef Resort
157		(Near MM 26)
	Summerland	
158		Summerland Marina
159		Summerland Key Marina
	Cudjoe	
160		Cudjoe Gardens Marina
161		Bluefish Canal
	Sugarloaf	
162		KOA Kampground & Marina
163		Sugarloaf Lodge Marina
	Geiger	
164		Geiger Key Marina
	Big Coppitt	
165		Caribbean Village
166		Seaside Resort
	Stock	
167		US 1 Marina
168		First Key West Marina
169		Boyd's Campground
170		Captain Billy & Key West Diver
171		Cow Key Marina
172		Leo's Campground
173		Munro's Marine
174		Murray Marine
175		Oceanside Marine
176		Peninsular Marine
177		Safe Harbour
178		Sunset Harbor Trailer
	Key West	
179		Land's End Marina
180		Key West Oceanside Marina
181		Key West Yacht Marina
182		Key West Redevelopment Agency
183		Key West Municipal Marina
184		Steadman Boat Yard
185		Garrison Bight
186		Mallory Dock

The types of boating-related services that marinas offer may include food provisions, restaurants, boat maintenance (including the scraping and repainting of boat hulls), boating supplies, and marine fuel (diesel/gasoline).

3.2.3.3 LIVE-ABOARDS

The boating public is not limited to just the recreational boater. Another major segment are those individuals who live aboard their boats. A live-aboard is defined as one whose continuous residence is a boat, not necessarily at a fixed location, for a period of more than 2 months (Antonini *et al.* 1990). The largest number of live-aboards are found in marinas, but many also anchor offshore (Schroeder 1987; Antonini *et al.* 1990). Live-aboards comprise both permanent and seasonal residents. The types of vessel utilized by live-aboard boaters vary. Generally, live-aboard vessels are of three types: a sailboat, a powerboat, or a floating home. The Florida Keys is very attractive to those seeking to live aboard their boat for an extended period. Certainly, the year-round warm-weather climate makes the Keys a choice place to live on a boat either permanently or seasonally. In 1988, it was estimated that there were 1410 live-aboard boats in the Florida Keys (Antonini *et al.* 1990). The total live-aboard population was estimated at approximately 3000 individuals (Antonini *et al.* 1990).

3.2.3.4 LOCATION OF MARINAS/LIVE-ABOARDS

As indicated above, marinas are graphically depicted in Figure 2-6. Although marinas are found throughout the Florida Keys, certain areas have a higher concentration than others. In the lower Keys, most marinas are located in either Key West or Stock Island. In the middle Keys, most marinas are situated in Marathon and Key Colony Beach. In the Marathon area, there are approximately 40 marinas (Wallace Roberts & Todd *et al.* 1991a). In the upper Keys, over 40 marinas are located in Key Largo (Wallace Roberts & Todd *et al.* 1991a). A number of live-aboard vessels are present in Fat Deer Key and Grassy Key. Islamorada has nearly 20 marinas located within a 4-mi strip. One of the largest marinas, Campbell's Marina with 94 wet slips, is in Tavernier (FDER 1988).

According to a survey of live-aboard vessels conducted by Schroeder (1987), live-aboard boats could be found throughout the Keys; however, most were concentrated at a few locations. At the time of the survey, Campbell's Marina (Tavernier) had between 45 and 50 live-aboards docked at its facility. In Marathon, two marinas contained significant numbers of live-aboards: they were Boot Key Harbor (65 to 70 live-aboards, based on a ground count) and Faro Blanco Marina (70 live-aboards, based on ground count). On Stock Island, it appeared that 30 to 40 boats were used for commercial fishing and shrimping. Another clustering of waterborne vessels was present in the Garrison Bight area. Several marinas in the Key West area consist of a series of smaller marina operations (Schroeder 1987). In addition to the live-aboard boats that are tied up in marinas, a sizeable number are anchored offshore. When the Antonini *et al.* (1990) study was conducted, 274 live-aboard type vessels were anchored in the Keys. The number varied according to season (368 in February; 141 in October). According to Antonini *et al.* (1990), prominent locations where boats were anchored included

Lower Keys
- Christmas Tree Island
- Garrison Bight
- Houseboat Row
- Cow Key Channel
- Boca Chica Channel
- Pine Channel

Upper Keys
- Matecumbe Harbor
- Islamorada
- Mile Marker 84.5, Bayside
- Community Harbor
- Largo Sound
- Cross Key
- Card Sound Bridge

Middle Keys
- Boot Key Harbor
- Key Colony Beach

Schroeder (1987) substantiated the Antonini study; however, the Schroeder survey also documented that 60 boats were anchored in Sigsbee Park.

As authorized by Chapter 253, Florida Statutes, the State has had the right to regulate live-aboard vessels that anchor in State-owned submerged lands. With the growing number and popularity of live-aboard vessels, the FDNR has begun a rule-making process that will probably result in the development of a rule to assist it in managing live-aboard vessels on sovereign submerged lands. Issues regarding live-aboards differ around the State; therefore, FDNR is conducting a series of public workshops Statewide. Some of the issues that are expected to be raised in the Keys include problems of finding appropriate places for off-shore mooring, assessing the impacts of live-aboards on public services, and controlling the practice of discharging raw sewage from moored boats.

The City of Key West has applied for a permit from the FDER to establish a mooring field. It is anticipated that employing this technique would enable the City to effectively manage the large number of live-aboard boaters who visit the City annually (D. Fry, FDER, personal communication, 1991).

Live-aboards fluctuate in numbers during the year. The seasonality of the Keys is reflected in the live-aboard population as well. Almost twice as many vessels (1.78) were counted in November as were counted at the same locations in August (Schroeder 1987). In the Antonini *et al.* (1990) study, the researchers found that the number of year-around boats was substantial. An estimated 87.7% of floating homes were year-around, followed by sailboats (76.9%) and power vessels (48.2%). Both studies documented a seasonality in live-aboard presence in the Keys. The most recent winter-to-summer ratio for all boat types is 2:1 (Antonini *et al.* 1990).

According to Antonini *et al.* (1990), disposal of sanitary waste is accomplished by a variety of methods: overboard flushing, holding tank storage and subsequent shoreside pump-out, and/or on-board pretreatment and discharge. The mean sewage pretreatment capacity for live-aboard boats in the Florida Keys is about 30% reduction of the biochemical oxygen demand (BOD_5) of the sewage load, roughly equivalent to a primary sewage treatment plant. The remaining 70% of the BOD_5 load of sanitary waste is degraded in the receiving waters (Antonini *et al.* 1990).

There are over 180 marinas in the Keys. However, only nine of these are equipped with sewage pump-out facilities. Two of these marinas are located in the lower Keys: Key West (Galleon Resort) and Stock Island (Key West Resort-Oceanside Marina). Five marinas are in the middle Keys: Marathon (Faro Blanco, Boot Key Marina, Sombrero Resort), Key Colony (Marie's Yacht Harbor), and Duck Key (Hawk's Cay Marina). In the upper Keys (extending from Lower Matecumbe Key to North Key Largo), there are two marinas with pump-out facilities available, the Ocean Reef Club and the John Pennekamp Coral Reef State Park (Antonini *et al.* 1990; A. Nielson, FDNR, personal communication, 1992)). Of the nine facilities, three are private clubs (Marie's Yacht Harbor, Hawk's Cay Marina, Ocean Reef Club), making these locations unavailable to the general boating public. Although there are only a limited number of pump-out facilities, marinas commonly provide shoreside shower and toilet facilities.

3.2.3.5 WASTEWATER FLOWS

In the 1979 Monroe County 201 Wastewater Treatment Facilities Plan (CH_2M Hill 1979), wastewater flows were based on per capital rates of 100 GPD for residents and 60 GPD for tourists. In the Campbell's Marina study (FDER 1988) the projected volume of wastewater per capita was 100 GPD per boat.

3.2.3.6 WATER QUALITY

Water quality in marinas is affected by both general marina operations as well as live-aboard vessels docked in the marina slips. Live-aboard boaters anchored offshore also have an impact on water quality (Antonini *et al.* 1990).

Water-quality degradation related to general marina operations has been detected in terms of concentrations of heavy metals and the presence of copper and other metals such as zinc-chromate, titanium dioxide, yellow iron, lead oxide, and strontium (Heatwole 1987; Rios 1990; Snedaker 1990). As noted by Snedaker (1990):

> "The absence of rich organic sediments in the oligotrophic carbonate environment of [the] Keys suggests that marina pollutants are not as effectively sequestered in local sediments, but rather are dispersed into the nearshore marine environment."

Besides the heavy metals that have been documented, water-quality studies of several marinas (e.g., Campbell's, Boot Key and Faro Blanco) linked the presence of live-aboard boats to water degradation. Measurements of coprostanol, an indicator of mammalian excreta, was identified in sediments directly below and around boat slips (Heatwole 1987; Rios 1990).

3.2.4 Mosquito Control Program

The Mosquito Control Program in the Florida Keys area is directed by guidelines from the FDHRS. While the potential exists for mosquito control application from Dade County (where it is administered by the Department of Public Works) to affect the FKNMS, the southernmost point that is sprayed is 9 mi from the county line. The risk of spray drifting into FKNMS waters would be minimal, although water-borne transport from Dade County is possible. Due to the nature of this program, which involves the application of insecticides by aerial dispersion (i.e., by airplane or helicopter) and land application, it is regarded as a source of atmospheric and land-based nonpoint loading on the Florida Keys environment.

The Mosquito Control Program in the Florida Keys acts to limit the mosquito population in one of two ways.

- The eradication of adult mosquitos through the application of adulticides prior to their ability to develop a second generation mosquito population
- The eradication of mosquitos while they are in the larval or pupae stage, prior to development and proliferation.

The Mosquito Control Program is in operation throughout the year, although the summer months (April through September) are the most active months for the application of chemicals and insecticides. The most commonly used insecticides (by tradename), along with the most active ingredient, are listed below

Chemical/Insecticide	Active Ingredient
Baytex	Fenthion
Dibrom 14C	Naled
Malathion	Malathion
Biomist 4+12	Permethrin + Piperonyl Butoxide
Abate	Temephos
Altosid	Methoprene
Arosurf	POE isooctadecanol
Diesel Oil	Petroleum oil
Teknar	*Bacillus thuringiensis* var. *israeliensis*

Bactimos	*Bacillus thuringiensis* var. *israeliensis*
Vectobac	*Bacillus thuringiensis* var. *israeliensis*
Scourge	Resmethrin + Piperonyl Butoxide
Fog oil	Petroleum oil

The application of mosquito control dispersants is restricted on most, if not all, Federally owned properties within the Florida Keys area. Other areas where their use is precluded include State Fish and Wildlife Preserves and State and National Recreational Park locations. Most applications are limited to the areas surrounding residential communities, commercial and light industrial site locations, within the boundaries of local landfills (i.e., in areas of sewage and sludge burial), and within areas of standing water, all of which favor the proliferation of mosquito development.

The ecological effects of some of the most commonly used insecticides is briefly summarized below based on Material Safety Data Sheets (MSDS) from manufacturers and Pesticide Fact Sheets from EPA provided by the Pesticide Information Office/Florida Cooperative Extension Service and other sources.

- **Baytex (Fenthion)**
  Fenthion is an organophosphate insecticide that was widely used in aerial spraying programs because of its effectivity. Like other organophosphate insecticides, it is readily adsorbed by soil. Fenthion is phytotoxic and is highly toxic to birds and moderately toxic to fish. It should not be applied for mosquito control in areas containing fish, shrimp, crabs or crayfish. Care in preventing contamination of water bodies by Fenthion is recommended. Up to 50% of the original application can remain in the water after 2 weeks.

- **Dibrom 14 (Naled)**
  Dibrom is a non-persistent organophosphate insecticide that is toxic to fish and wildlife and should not be applied directly to water. Although it is practically insoluble in water, it has a half-life of 2 days. While no documentation is available, it is believed to be unlikely to bioaccumulate or biomagnify. Contaminated materials such as soils or other absorbent laden with Dibrom 14 may be regarded as hazardous.

- **Malathion (Cythion)**
  Malathion is a wide-spectrum organophosphate insecticide that is non-persistent, unlikely to bioaccumulate or biomagnify, and has a half-life of 1 week in river water. Malathion is toxic to most types of aquatic life, particularly fathead minnows, bluegills, and mosquitofish. Malathion may produce a pollution hazard if dilution water is improperly disposed of or runoff control from adjacent land surfaces is not controlled.

- **Biomist 4 + 12 (Permethrin)**
  Permethrin is a synthetic pyrethroid that is toxic to fish and should be kept out of all bodies of water, including lakes, streams, ponds, and canals, which are particularly sensitive. Synthetic pyrethroids tend to bioconcentrate in estuarine environments.

- **Abate (Temephos)**
  Temephos is insoluble in water and is a highly effective organophosphate larvicide with long residual action that causes death by respiratory failure in insects. Laboratory trials with rats and chickens show low toxicity with similar effects as malathion.

- **Altosid (Methoprene)**
  Methoprene is an insect growth regulator used as a larvicide. Altosid is non-persistent and is readily adsorbed into soil. Although it has a half-life of less than 2 days in water, it has been documented as harmful (and may cause death) to shrimp and crabs. Fish are not highly sensitive to Altosid.

- **Arosurf**
  Used as a larvicide, it acts as a surfactant, producing a surface film with lowered surface tension causing suffocation of larvae and pupae. It has low toxicity to humans, fish, and wildlife and is readily broken down by naturally-occurring microbial populations.

- **Diesel fuel**
  As a petroleum hydrocarbon product, diesel fuel is used in the aerial dispersal of insecticides. When ignited and combined with the appropriate insecticide, a "fumigant" material is released. Toxicity or contamination of ground and/or water surfaces has not shown diesel fuel to be detrimental to the ecosystem.

- ***Bacillus thuringiensis* var. *israeliensis***
  BTI is an insecticide which causes death through the production of toxins when ingested by larvae. It is considered to be relatively environmentally safe due to its specificity. It biodegrades and does not persist in the gut of birds and has not been shown to be toxic to fish. While it can cause death of other insects during mosquito control, experimental tests do not suggest that BTI adversely affects non-target insects and aquatic invertebrates. It is a naturally occurring pathogen that is classified as immobile and dissipates in water after 48 hours.

The use of Baytex has been discontinued as the product has been taken off the market. The manufacturer of Baytex has tentative plans of re-registering the product. Currently, Biomist is the main product used in the mosquito control program in Monroe County (L. Ryan, Monroe County Mosquito Control District, personal communication, 1992). Dade County is using Dibrom 14C as its main mosquito control spray (M. Latham, Dade County Public Works Department, personal communication, 1992).

The above listings present some, but not all, of the current insecticides that may be adversely affecting the nearshore marine environment. The quantification of loads being dispersed into the Florida Keys area to control mosquito populations during the period 1987 to 1990, including the type of chemical or insecticide being used, the mode or method of dispersal, and the areal distribution of points being treated are summarized in **Table 2-13**. However, to date there have been no direct, in-depth toxicological studies to correlate mosquito spraying with deteriorating ecological and/or environmental systems in the Florida Keys.

A few unpublished studies on the environmental effects of mosquito control agents are available. Studies have demonstrated the potential impact of the Baytex, Dibrom, and Malathion (adulticides) applications on estuarine organisms. Baytex and Dibrom may have a devastating effect on Schaus swallowtail butterfly populations. The applications rates for Dibrom in Monroe County are 400 to 4,000 × the lethal dose for third instar larvae of the endangered swallowtail butterfly. Baytex is applied at 500 × the concentration that causes 50% mortality in the third instar larva (Emmel 1986). While technical problems confounded the results of the bioassay tests, calculated application rates of Baytex and Malathion were found to be lethal to eggs and larvae of snook (EPA 1981). While field tests with Dibrom, Malathion, and Baytex did not cause mortality in juvenile common snook, tarpon snook, and sheepshead minnows, larval fish suffered increased mortality and decreased growth and activity. Dibrom and Baytex caused acute mortality in copepods (Tucker *et al.* 1986).

Studies suggest that larvicides may have lesser environmental impacts than the adulticides. Abate applications did not cause acute toxicity in mysid shrimp, brown shrimp, grass shrimp, sheepshead minnows, and pinfish (Pierce *et al.* 1988a,b). Adult fiddler crabs were not affected by Abate though some retention was observed (Pierce *et al.* 1989). Toxicity and bioaccumulation have not been observed in bivalves. Mussels did not suffer toxicity from or bioaccumulate Altosid and Abate (Pierce *et al.* 1989). Oysters exposed to Abate depurate after 72 hours (Pierce *et al.* 1988a).

Table 2-13. Quantities of insecticides used by the Mosquito Control Group in the Florida Keys.

Insecticide	Quantity	Area Treated
	1987	
Baytex	289,812 ounces	45,508 miles
Scourge (180)	46,980 ounces	2,281 miles
Malathion	43,614 ounces	2,042 miles
Teknar liquid (4:100)	4,434 ounces	277 acres
Teknar liquid (16:100)	4,018 ounces	251 acres
Vectobac 12	1,039 ounces	129 acres
Dibrom 14 — Diesel fuel (4:100)	105,050 gallons	840,416 acres
Altosid briquets	1,399,532 briquets	49,291 acres
Bactimos briquets	2,555 briquets	26 acres
Teknar granules	5,662 pellets	943 acres
Bactimos pellets (manual dispersement)	390 pellets	70 acres
Abate 5% pellets	223 pellets	41 acres
Vectobac granules	1,400 pounds	140 acres
Bactimos pellets (helicopter dispersement)	75 pounds	9 acres
Bactimos granules	50 pounds	5 acres
	1988	
Baytex	258,666 ounces	40,168 miles
Scourge (180)	150,390 ounces	7,032 miles
Malathion	1,692 ounces	84 miles
Teknar liquid	36,992.2 ounces	415 acres
Vectobac 12	168 ounces	21 acres
Dibrom 14 — Diesel fuel (4:100)	39,423 gallons	314,384 acres
Florida Larvacide	864 gallons	216 acres
Altosid briquets	1,082,644 briquets	40,466 acres
Bactimos briquets	95,740 briquets	1,244 acres
Bactimos pellets (manual dispersement)	675 pellets	130 acres
Abate 5% pellets	44 pounds	4 acres
Altosid pellets	22 pounds	11 acres

Table 2-13. Quantities of insecticides used by the Mosquito Control Group in the Florida Keys. (continued)

Insecticide	Quantity	Area Treated
	1989	
Baytex	204,315 ounces	29,604 miles
Scourge (180)	103,140 ounces	4,905 miles
Teknar liquid	24,656 ounces	734 acres
Abate 4E liquid	32 ounces	32 acres
Dibrom 14 — Diesel fuel (4:100)	22,635 gallons	181,080 acres
Abate 5G powder	900 gallons	450 acres
Altosid briquets	506,852 briquets	29,155 acres
Bactimos briquets	163,635 briquets	2,842 acres
Vectobac G	4,800 pounds	480 acres
Vectobac	3,520 pounds	110 acres
Vectobac 12	2,560 pounds	160 acres
Altosid pellets	22 pounds	10 acres
Abate 5% pellets	22 pounds	STP
Bactimos pellets (helicopter dispersement)	40 pounds	40 acres
	1990	
Baytex	290,460 ounces	39,209 miles
Scourge (180)	36,054 ounces	1,878 miles
Malathion	3,492 ounces	129 miles
Biomist	1,680 ounces	46 miles
Permanol	897 ounces	17 miles
Vectobac 12	655 ounces	41 acres
Dibrom 14 — Diesel fuel (4:100)	55,401 gallons	443,208 acres
Vectobac G	22,000 gallons	2,998 acres
Abate 5G	650 gallons	260 acres
Altosid briquets	608,874 briquets	33,811 miles
Bactimos briquets	19,183 briquets	165 acres
Teknar concentrate		
(2 ounces/gallon)	4 briquets	1 acre
(8 ounces/gallon)	88 briquets	11 acres
(16 ounces/gallon)	1,294 briquets	58 acres
(8.5 ounces/gallon)	128 briquets	15 acres
(10.6 ounces/gallon)	16 briquets	2 acres
Altosid pellets	472 briquets	229 acres

Larvicides are not persistent. Aerial spraying of Abate resulted in delivery to the mangrove forest floor of 15 to 78% of the amount deposited on the canopy. It did not persist in ambient water and sediment due to tidal flushing, although it was observed to persist in tide pools and mangrove leaves up to 72 hours after application (Pierce *et al.* 1988b, 1989).

No available information on the impact of BTI and Altosid on non-target insect populations in coastal areas has been located. The impact of these agents should be investigated in monitoring programs.

3.2.5 Stormwater

Stormwater is defined by Florida Chapter 17-25, Florida Administrative Code (FAC) as the "flow of water which results from, and which occurs immediately following, a rainfall event."

The SFWMD is responsible for issuing surface water management (including stormwater management) permits. The permitting of surface water management systems by the SFWMD is specified in Chapter 373, Part IV, Florida Statutes. Permits are issued pursuant to the guidelines set forth in Chapter 40E-4, FAC. The SFWMD regulates stormwater quality through the provisions contained in Chapter 17-25, FAC, which are the State stormwater discharge regulations. **Table 2-14** lists the current permits for unincorporated Monroe County. **Figure 2-7** shows the locations of the permits. The following activities are allowed under the permits: irrigation, construction and operation, potable water usage, surface drainage, hydrocarbon recovery systems, and road improvement.

The SFWMD evaluated Nationally collected data (EPA 1983) in an assessment of urban land use and stormwater runoff quality relationships. Treatment efficiencies for various stormwater management systems were also summarized (Whalen and Cullum 1988).

The EPA study determined that stormwater runoff characteristics can vary significantly from one land use location to another. As a consequence of this phenomenon, both water quantity as well as quality can be highly variable. Although different land use(s) produce similar pollutants, quantification of pollutant loads varies from one storm event to another (i.e., due to fluctuations in rainfall durations, pollutant accumulation rates between storm events, and ratio of impervious to pervious land surfaces).

The SFWMD in its assessment of land use and stormwater runoff quality established numerous treatment methods regarded as the current "Best Available Technologies" (BAT). These treatment technologies involve the detention (the delay of storm runoff prior to discharge into a receiving water body) or retention (the prevention of stormwater runoff from direct discharge into a receiving water body).

Unfortunately, there are very few available data from the Florida Keys regarding the chemical constituents of the contained stormwater runoff. Literature values for typical stormwater concentrations of nutrients and other constituents according to land-use category are generally applied to the Florida Keys.

A study of environmental and hydraulic conditions within the Riviera Canal and adjoining salt ponds in Key West, Florida, was conducted by CH_2M Hill (1988). A component of the study involved estimating stormwater loads. However, no site-specific field data of stormwater loading was performed. A preliminary evaluation of probable stormwater loads was performed with estimated drainage areas, average annual rainfall, land-use information for the appropriate area of Key West, and typical runoff coefficients associated with specific land uses. The calculations suggested that approximately 1.5 tons of both total nitrogen and phosphorus were discharged to the Riviera Canal each year. Stormwater inputs to the Salt Ponds were estimated as 0.5 ton of total nitrogen and 0.25 ton of total phosphorus each year. The preliminary evaluation of stormwater loads suggested that they could be a contributing factor to poor water quality.

Table 2-14. South Florida Water Management District surface water management permits, unincorporated Monroe County.
[From Keith and Schnars, unpublished data 1991]

Map Number	Permit Number	Receiving Body	Land Use	Acreage	Location — Section/ Township/Range
1	GP-83-186	NA	Highway	NA	34/67S/25E
2	GP-83-199	NA	Highway	NA	22/67S/26E
3	GP-44-00078	Gulf of Mexico	Commercial	2.90	29/67S/25E
4	44-00038	Gulf of Mexico	Residential	56.00	14,15,23/67S/26E
5	GP-44-00047	Lower Sugarloaf Sound	Recreational Vehicle	11.47	8/67S/27E
6	GP-44-00050	Florida Bay	Landfill 1	20.00	19/66S/29E
7	GP-86-119	NA	Highway	NA	32/66S/28E
8	GP-83-120	NA	Commercial	NA	26/66S/29E
9	GP-44-00004	Groundwater	Commercial	8.8	23/66S/29E
10	GP-87-12	NA	Highway	NA	4/66S/29E
11	GP-44-00102	Boot Key Harbor	Commercial	9.33	10/66S/32E
12	GP-44-00044	Gulf of Mexico	Commercial	10.00	10/66S/32E
13	GP-83-69	Retention Pond	Highway	NA	4,5/66S/33E
14	GP-44-00091	Atlantic Ocean	Residential	14.00	14/66S/33E
15	GP-85-101	Tidal	Commercial	NA	11/66S/33E
16	44-00113	On-site	Commercial	197.4	1/66S/32E
17	GP-84-75	NA	Highway	NA	6/66S/33E
18	44-00045	Gulf of Mexico	Residential	43.8	5,6/66S/33E
19	GP-44-00087	On-site	Residential	22.3	35/65S/33E
20	GP-83-5	NA	Highway	NA	25/65S/33E
21	GP-83-5	NA	Highway	NA	33-35/65S/33E
22	86-238	On-site	Commercial	60.8	21/65S/34E
23	GP-78-71	NA	Commercial	NA	5,6/65S/35E
24	GP-84-4	NA	Highway	NA	11,14,15,20-22/64S/34E
25	GP-44-00160	FL Bay/Atlantic Ocean	Highway	21.8	5,6,32/64,63S/37E
26	GP-44-00107	On-site	Residential	5.76	21/64S/34E
27	GP-86-66	On-site	Commercial	NA	32,33/63S/37E
28	GP-44-00156	NA	Highway	NA	22,27,28/63S/37E
29	GP-84-29	NA	Highway	NA	18/63S/38E
30	GP-44-00007	Atlantic Ocean	Residential	12.56	7,8,18/63S/38E
31	GP-87-82	Atlantic Ocean	Highway	30.32	18/63S/38E
32	GP-86-120	On-site	Commercial	NA	8/63S/38E
33	GP-44-00088	On-site	Commercial	0.69	33/62S/38E
34	44-00036	Atlantic Ocean	Residential	69.4	26,27/62S/38E
35	GP-44-00053	Florida Bay	Residential	13.7	6,7/32S/39E
36	GP-44-00092	On-site	Commercial	4.2	33/61S/39E
37	GP-44-00006	Atlantic Ocean	Residential	29.22	32,33/61S/39E
38	GP-83-114	NA	Commercial	0.75	28/61S/39E
39	GP-44-00040	Buttonwood Sound	Residential	24.0	28/61S/39E
40	GP-44-00041	On-site/Tidal	Commercial	25.18	22/61S/39E
41	GP-44-00104	NA	Highway	83.66	1,6,11-15/61S/39,40E
42	GP-44-00119	NA	NA	NA	11/61S/39E

Table 2-14. South Florida Water Management District surface water management permits, unincorporated Monroe County. [From Keith and Schnars, unpublished data 1991] (continued)

Map Number	Permit Number	Receiving Body	Land Use	Acreage	Location - Section/ Township/Range
43	GP-83-115	NA	Residential	8.15	12/61S/39E
44	GP-44-00122	NA	NA	NA	1/61S/39E
45	GP-44-00108	NA	NA	NA	47-50/60S/40E
46	44-00005	On-site Lakes	Residential/ Commercial	33.4	31,32/60S/40E
47	GP-78-190	NA	Highway	NA	20,21,29/60S/40E

NA: Not available.

Missing Documents from SFWMD Files:
Permit No. 85-0074
44-00039
44-00051
44-00054
44-00124
44-00136
44-00142
44-00003
44-00147
44-00148
77-84

Source: SFWMD 1991.

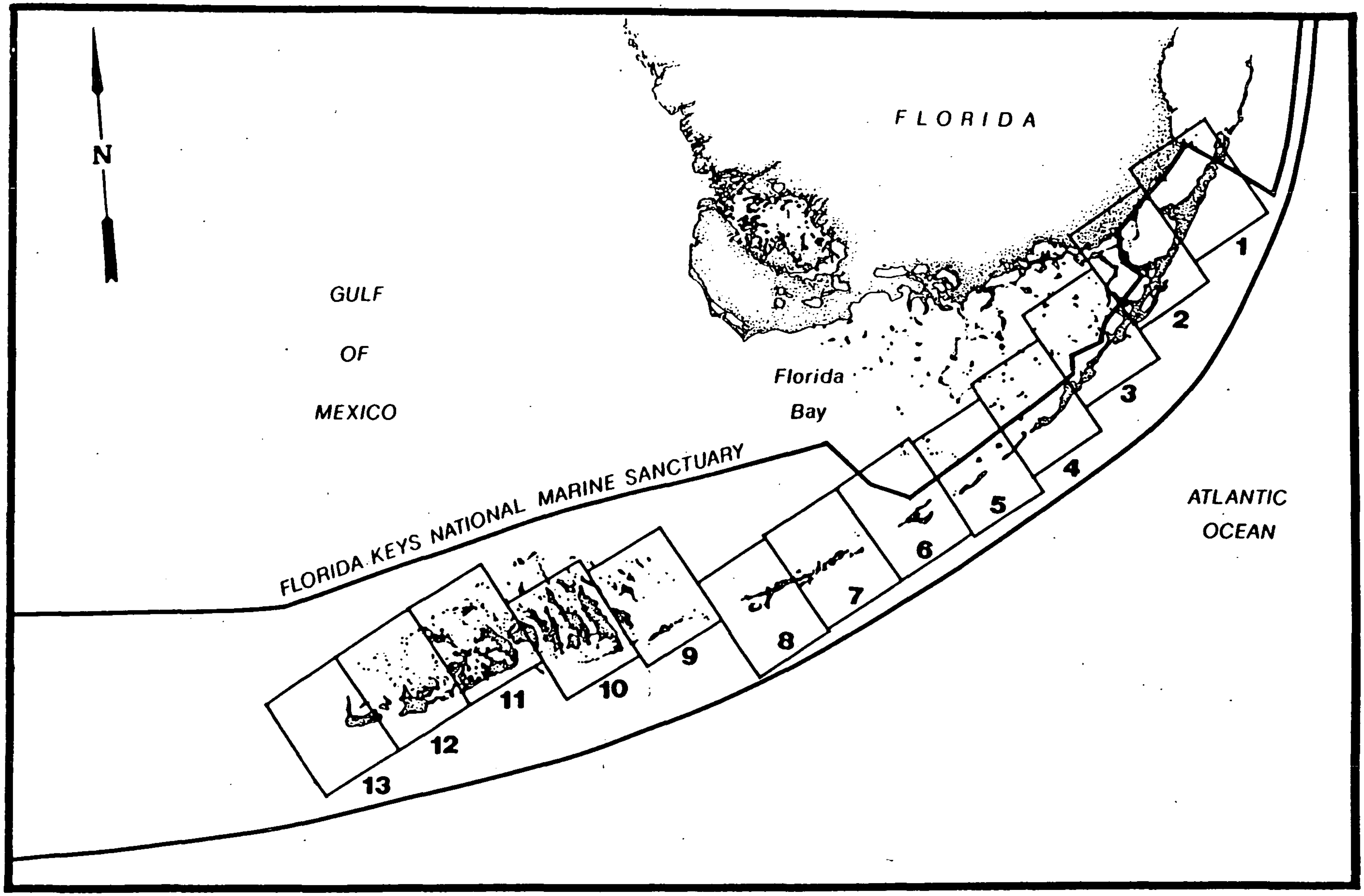


Figure 2-7. South Florida Water Management District (SFWMD) Surface Water Management Permits.

This Figure and its 13 components, which follow, indicate the geographic locations of the SFWMD Surface Water Management Permits (indicated on the maps by ●). Numbers correspond to those in Table 2-14. Locations provided by Keith and Schnars (unpublished data 1991). Base maps redrawn from maps provided by Wallace Roberts & Todd.

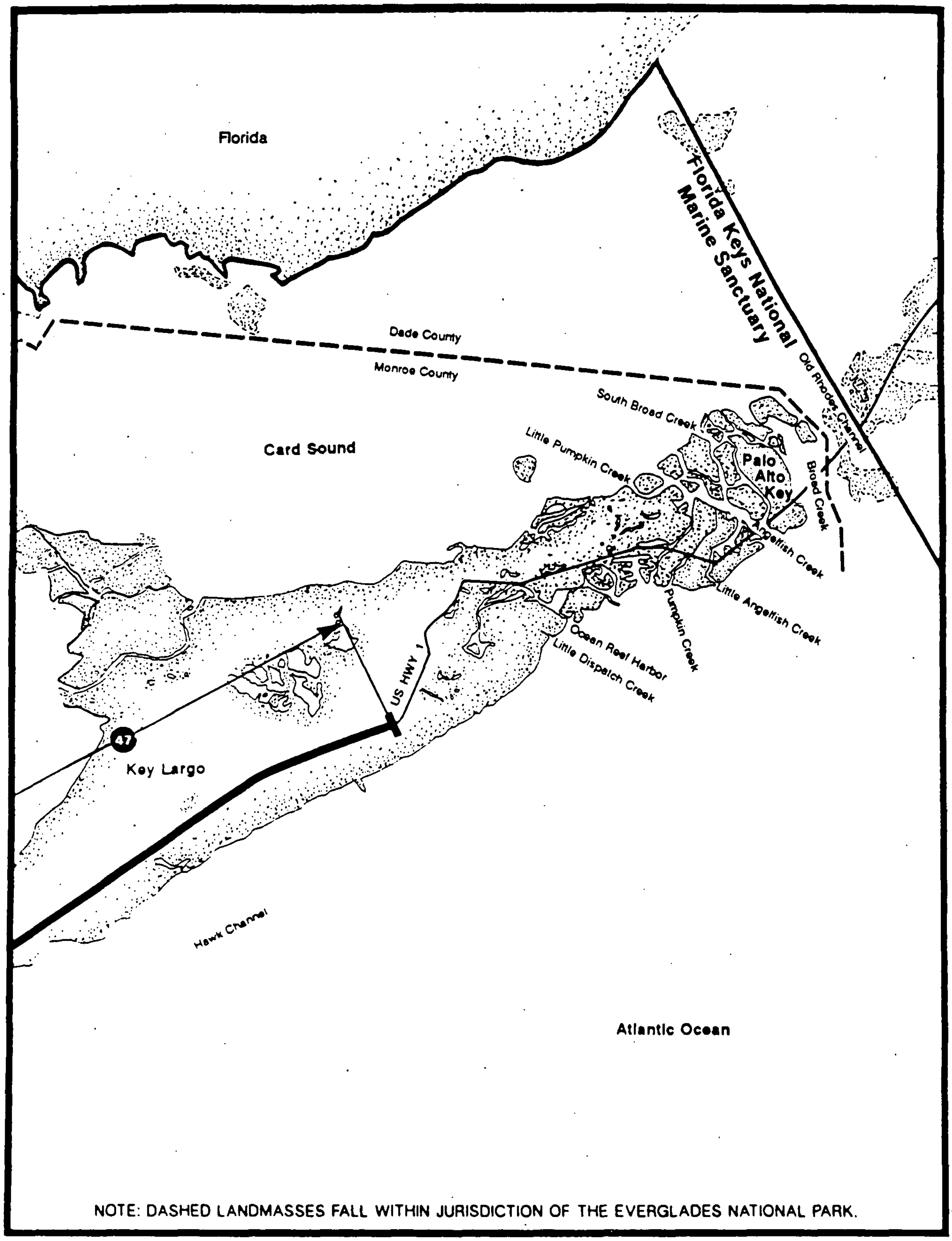


Figure 2-7-1. SFWMD Surface Water Management Permits. (continued)

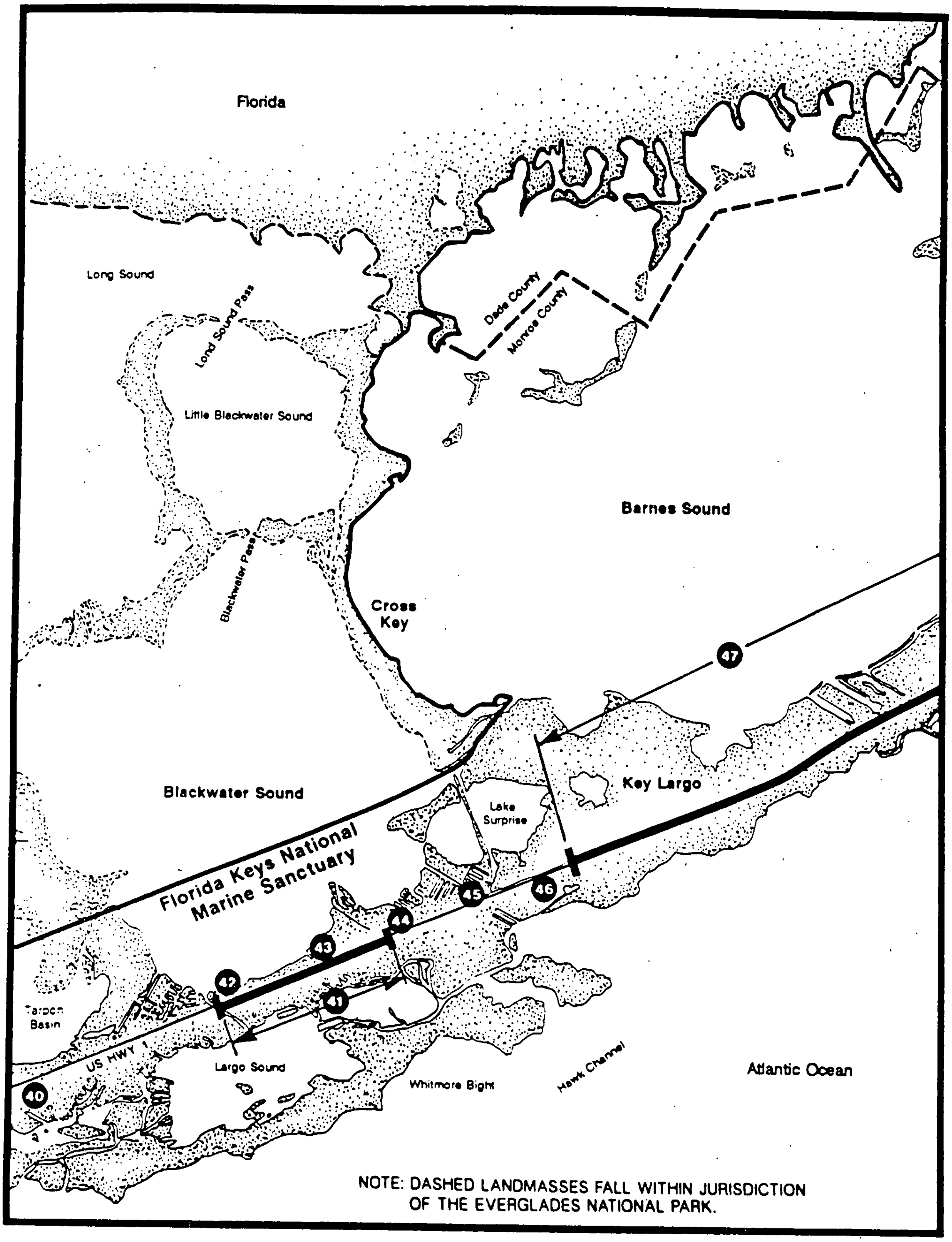


Figure 2-7-2. SFWMD Surface Water Management Permits. (continued)

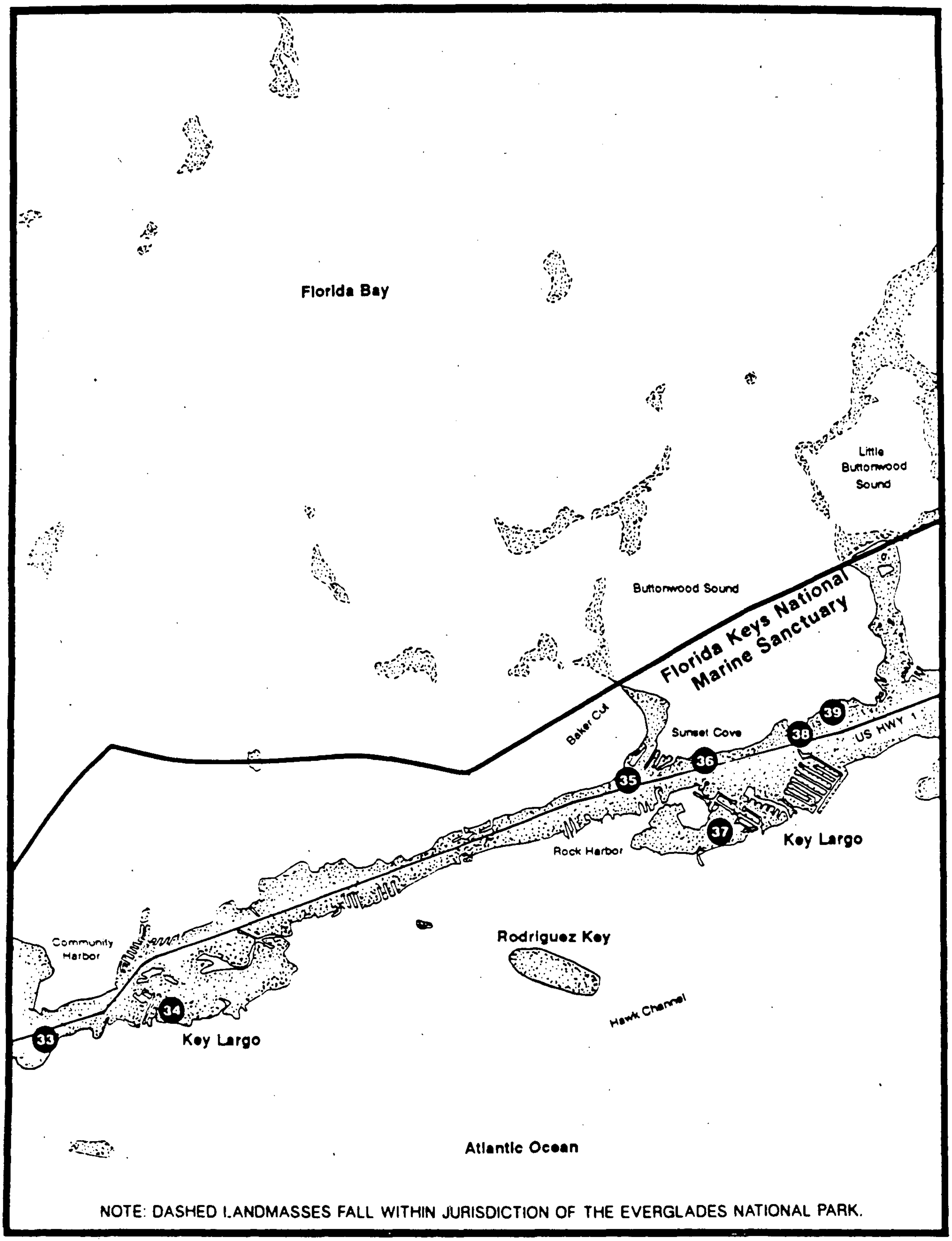


Figure 2-7-3. SFWMD Surface Water Management Permits. (continued)

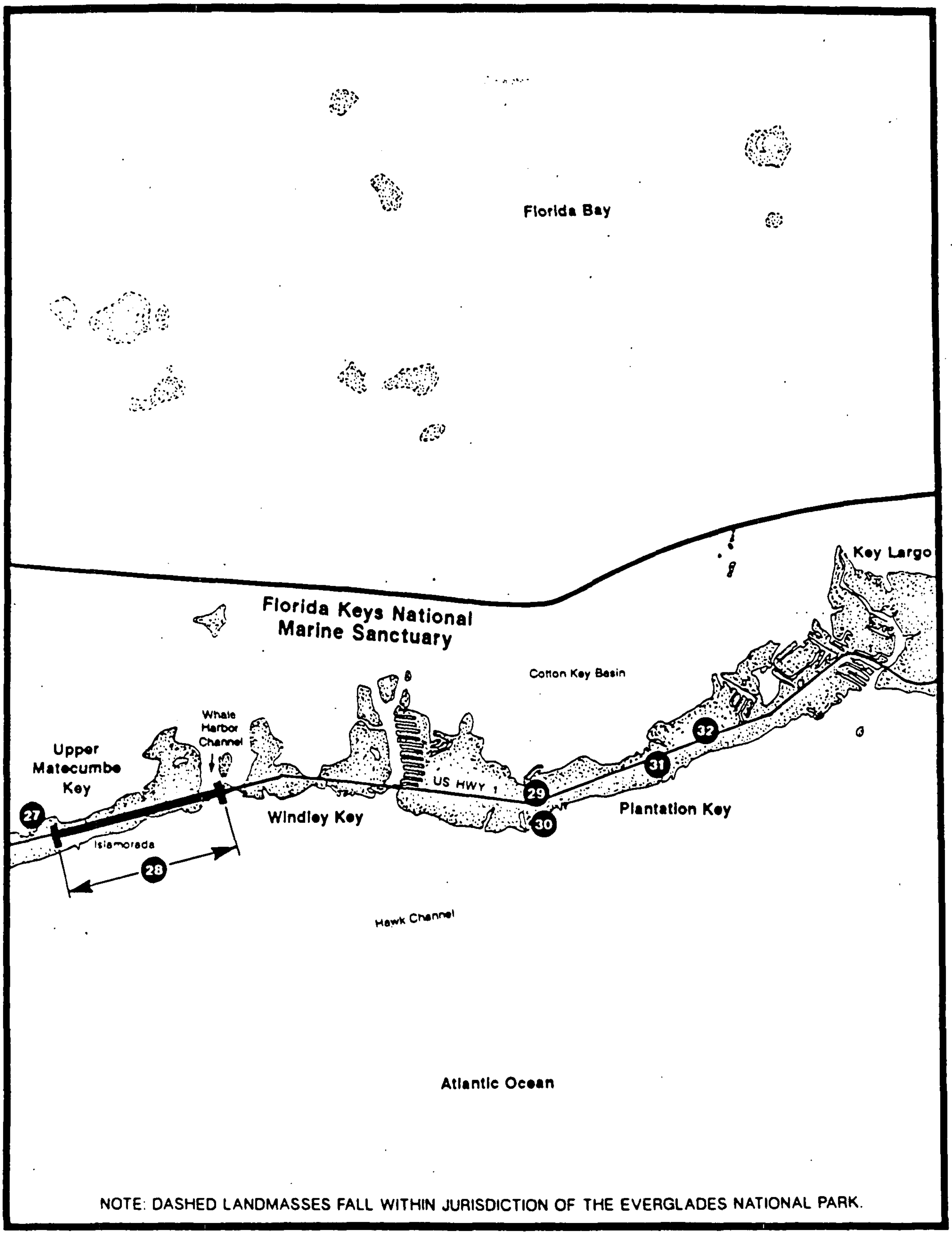


Figure 2-7-4. SFWMD Surface Water Management Permits. (continued)

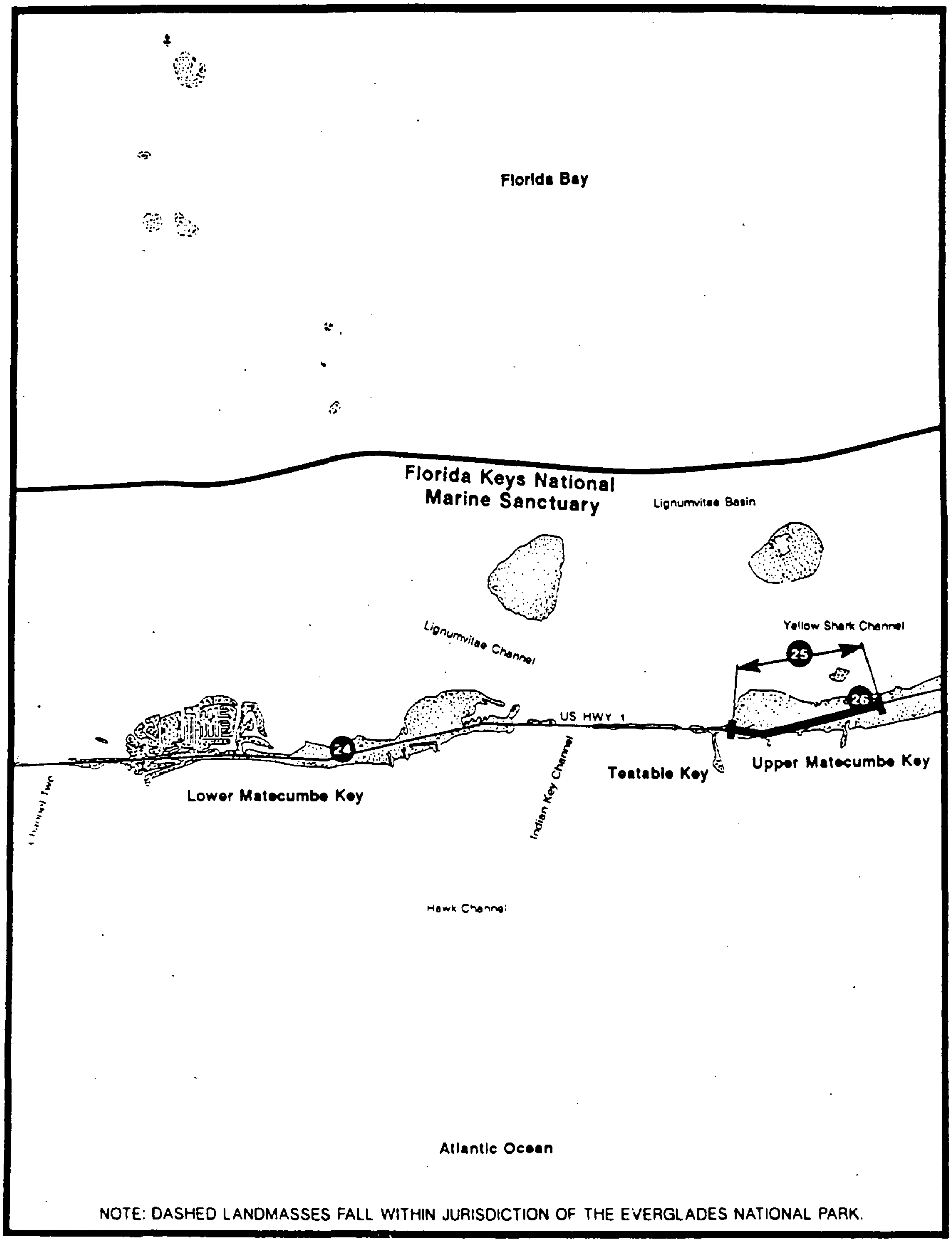


Figure 2-7-5. SFWMD Surface Water Management Permits. (continued)

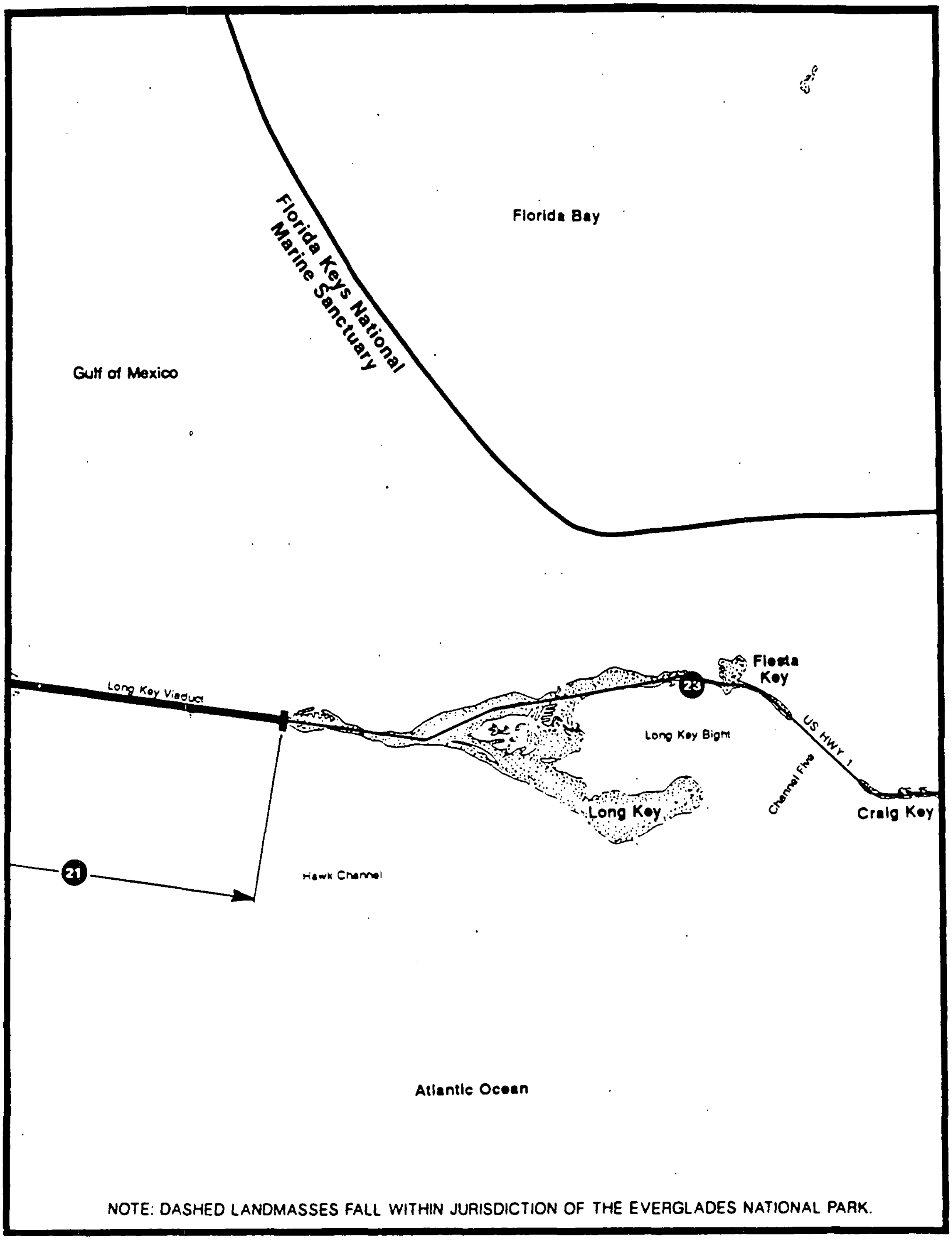


Figure 2-7-6. SFWMD Surface Water Management Permits. (continued)

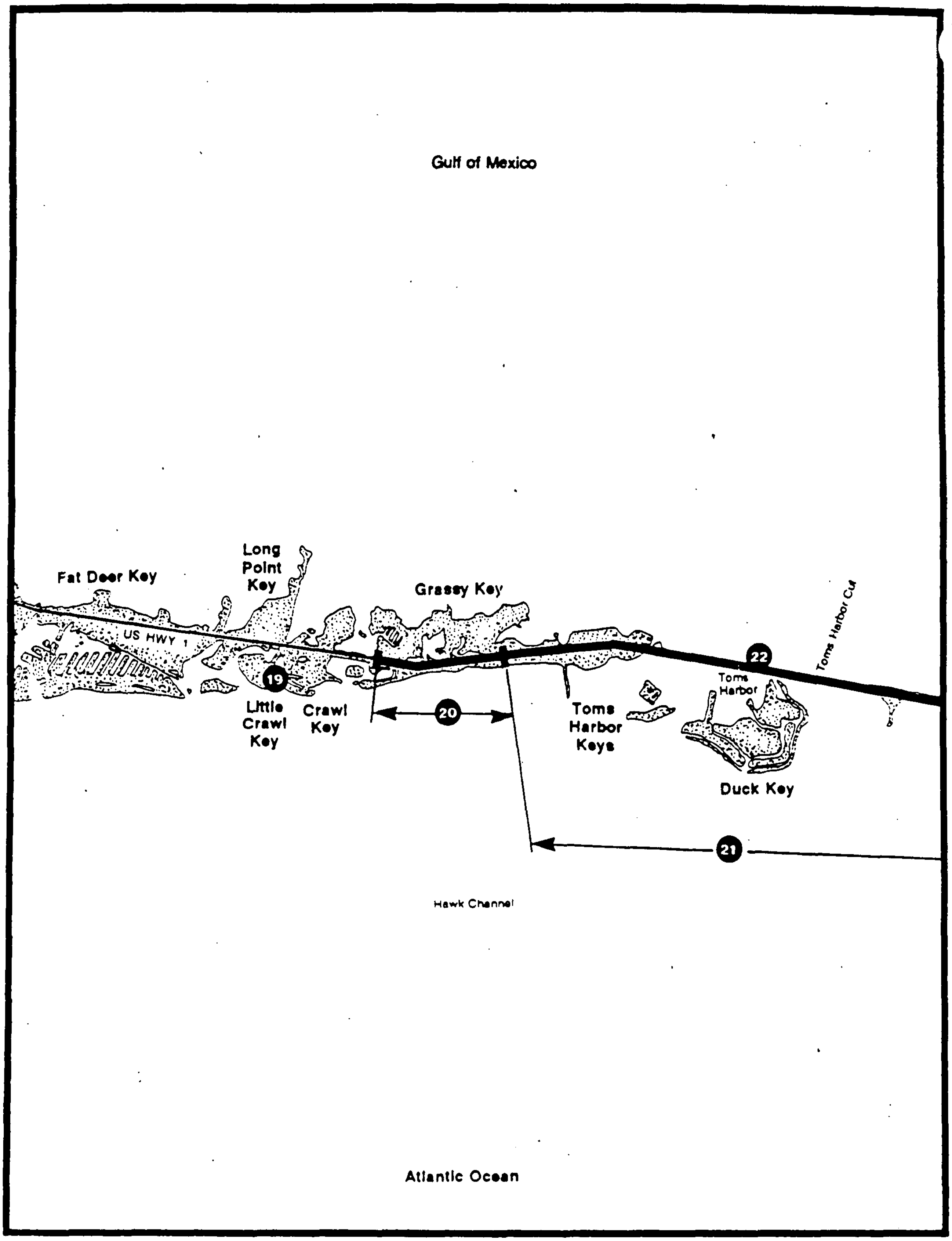


Figure 2-7-7. SFWMD Surface Water Management Permits. (continued)

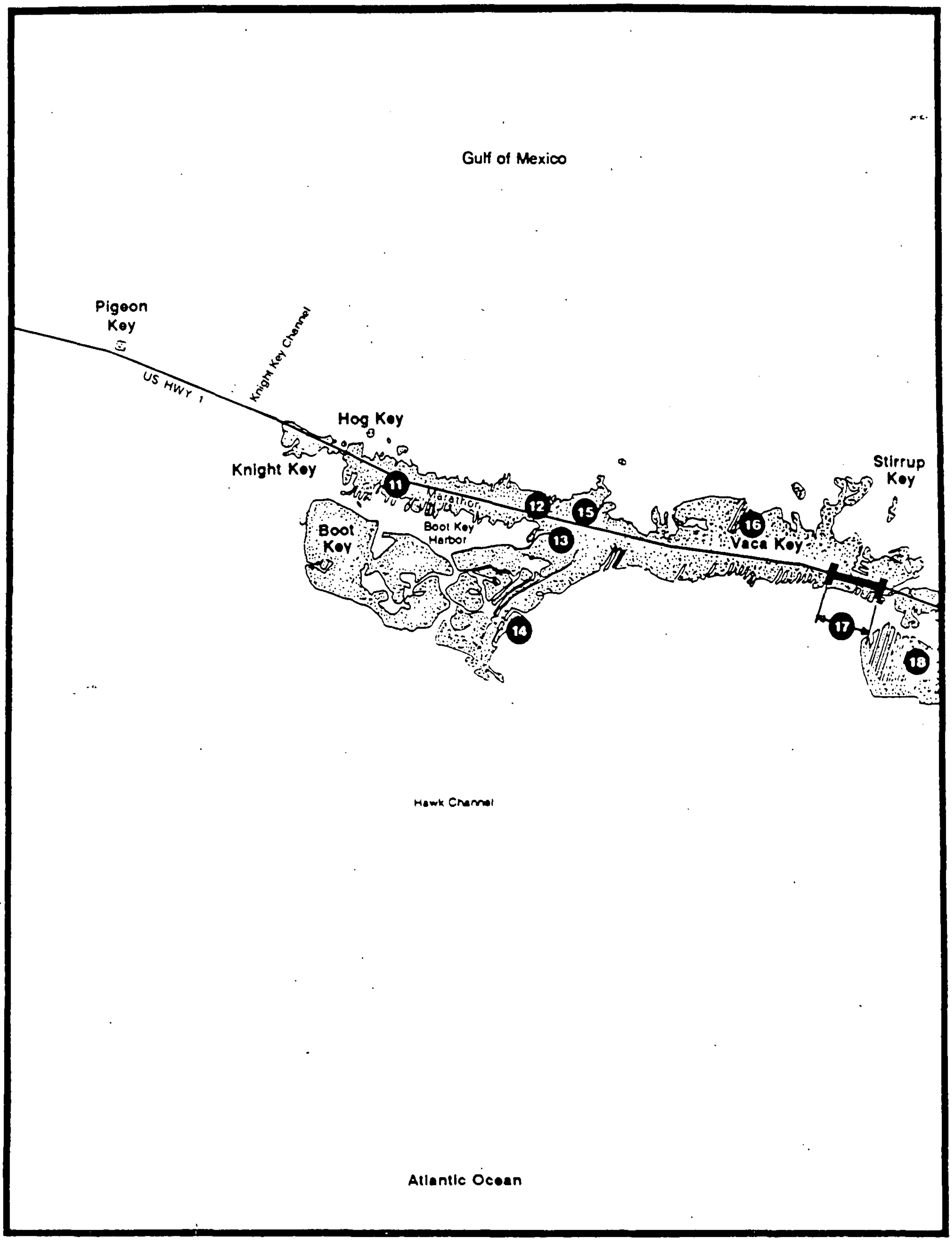


Figure 2-7-8. SFWMD Surface Water Management Permits. (continued)

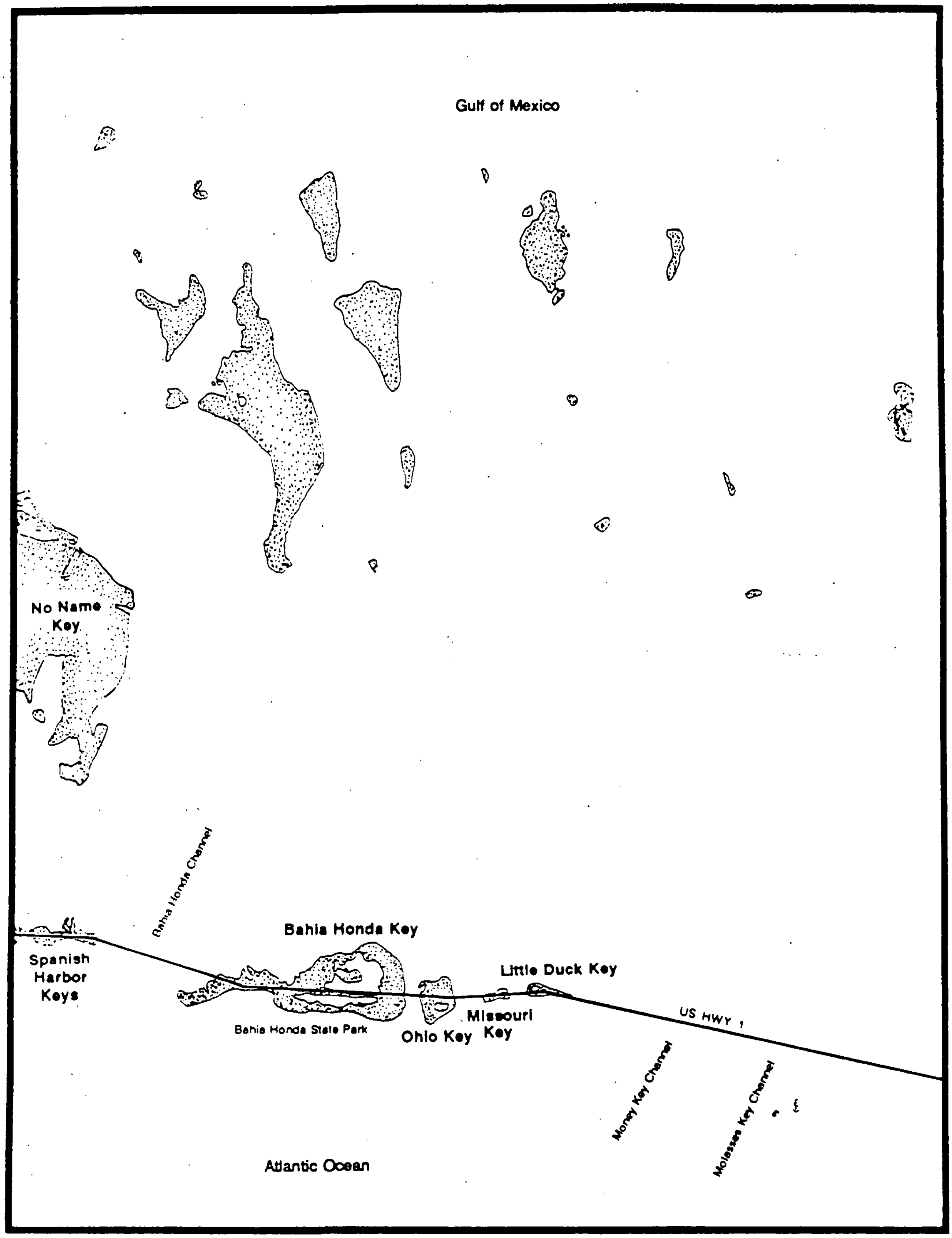


Figure 2-7-9. SFWMD Surface Water Management Permits. (continued)

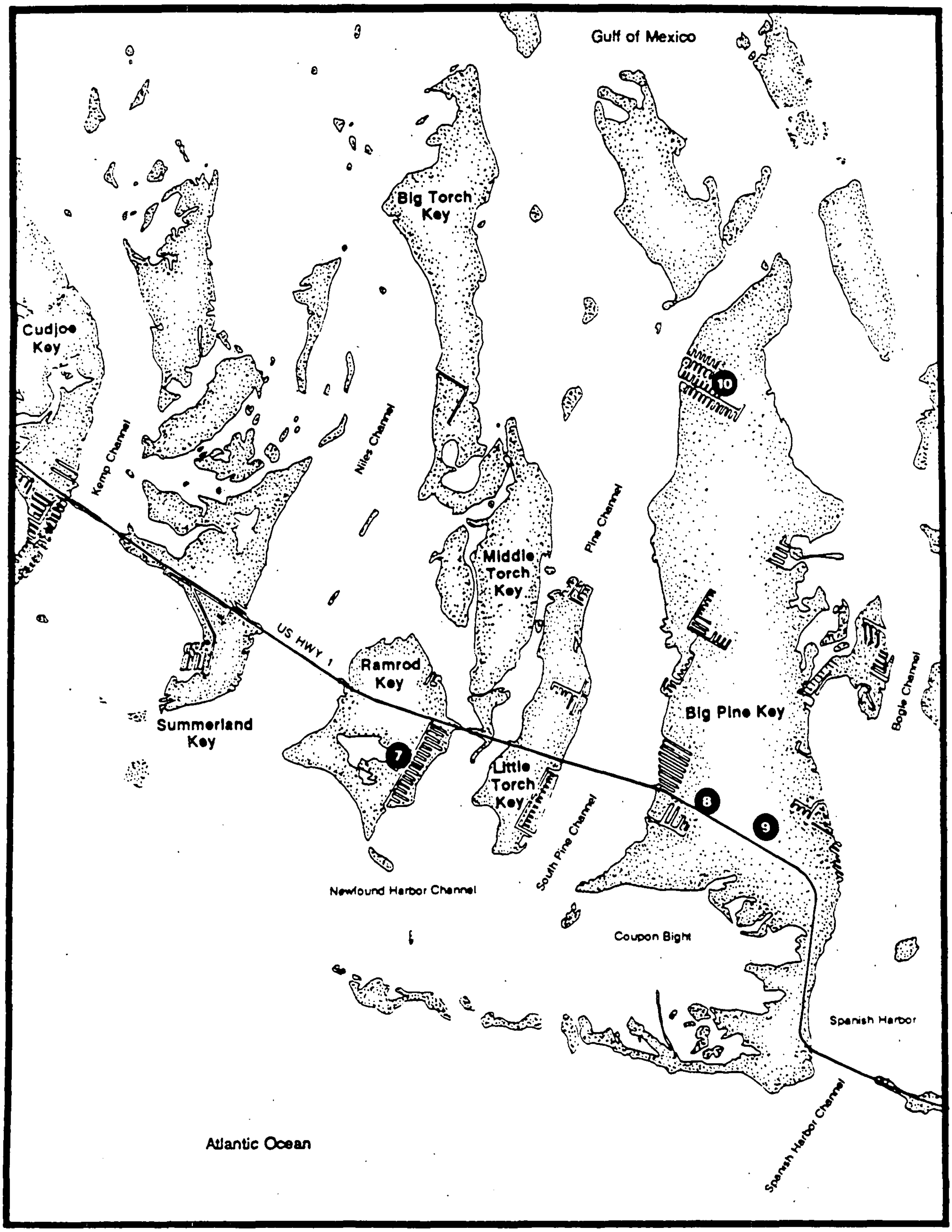


Figure 2-7-10. SFWMD Surface Water Management Permits. (continued)

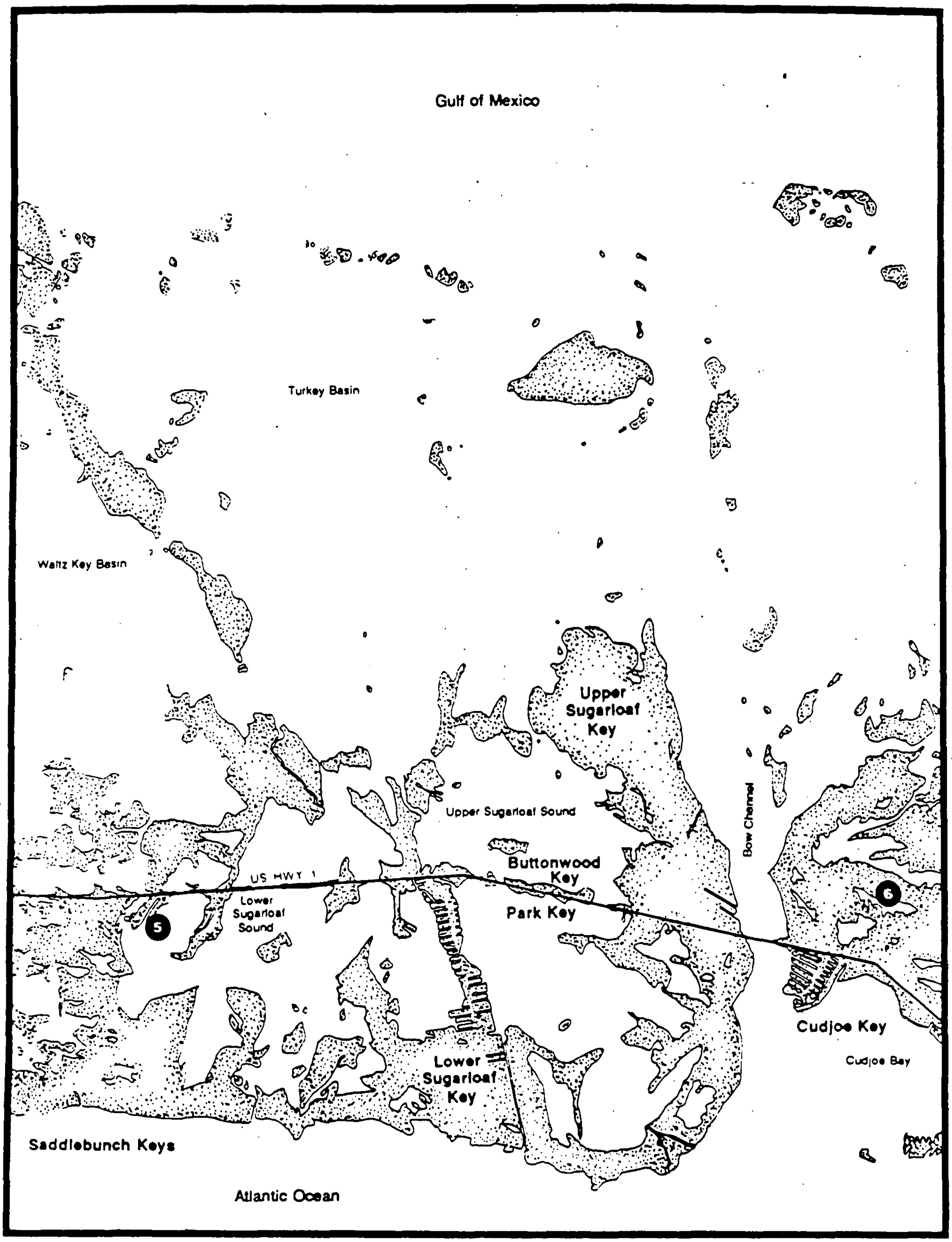


Figure 2-7-11. SFWMD Surface Water Management Permits. (continued)

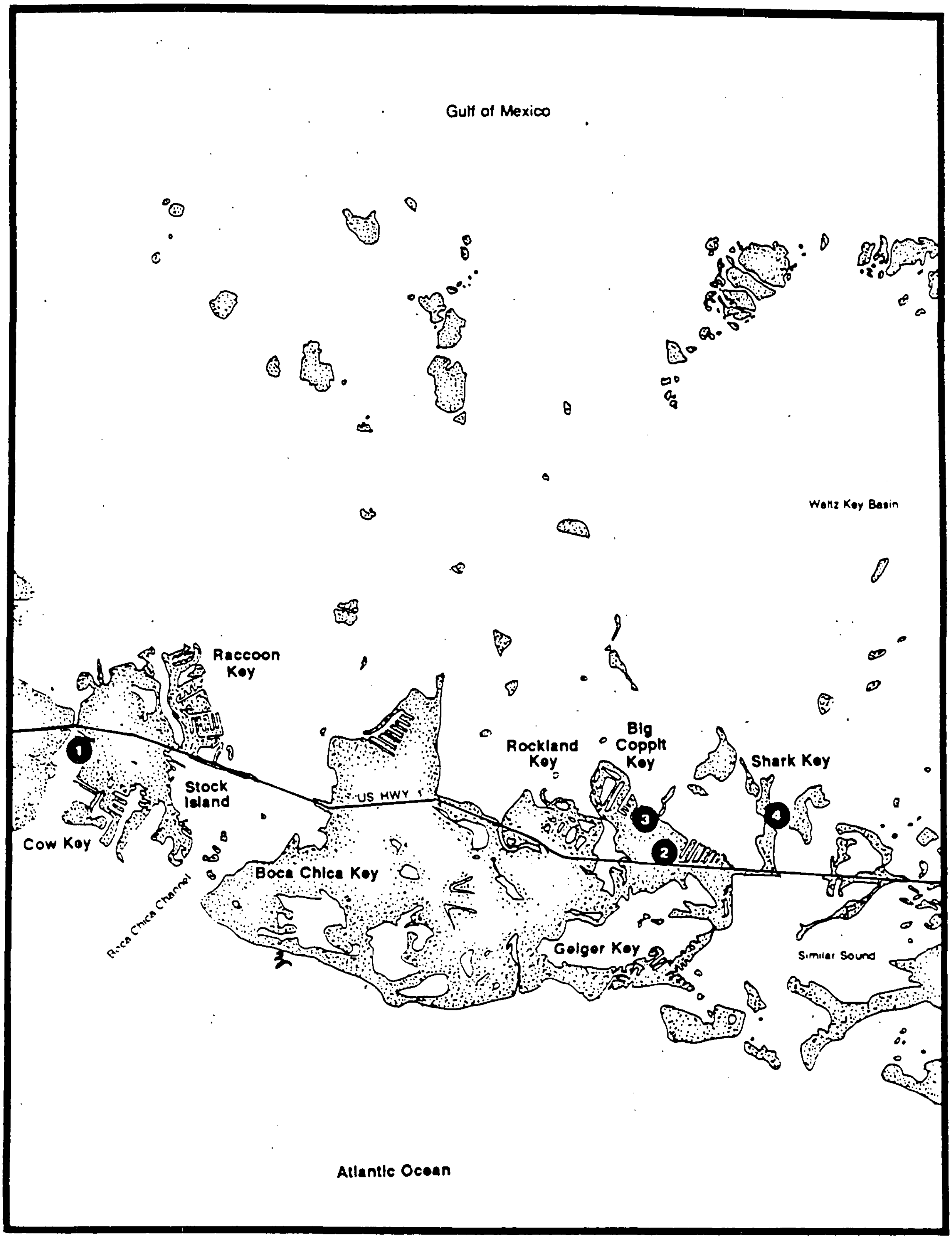


Figure 2-7-12. SFWMD Surface Water Management Permits. (continued)

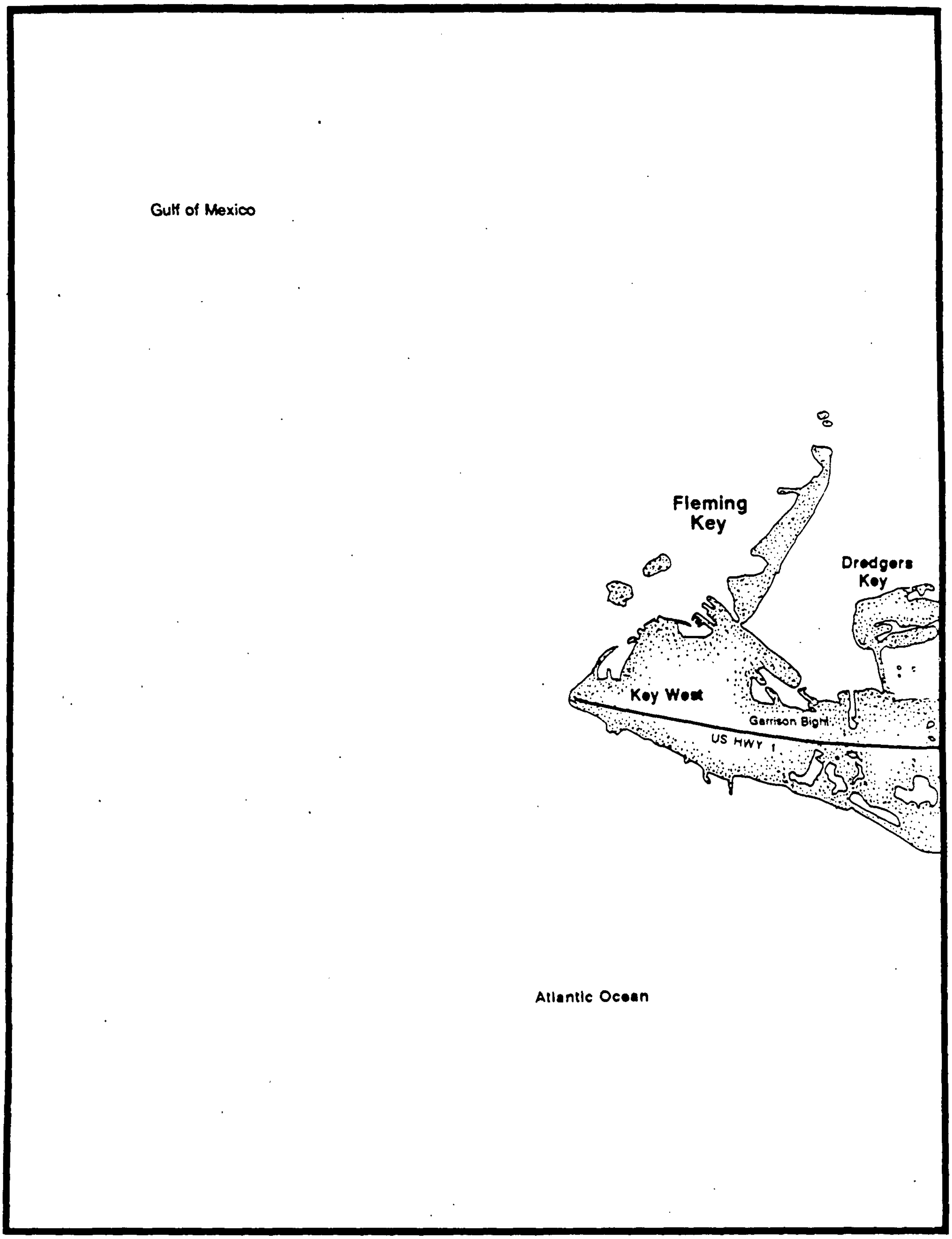


Figure 2-7-13. SFWMD Surface Water Management Permits. (continued)

Camp Dresser and McKee, Inc. (1990) performed a stormwater pollution loading analysis for the upper Keys (Sand Key to Windley Key) based upon data collected throughout the United States, with particular emphasis on Florida-based information. Loadings were calculated for different land-use categories based on annual runoff volumes and event mean concentrations for different pollutants. The impervious fraction of each land-use category was used as the basis for determining the rainfall/runoff relationships.

The City of Key West is considering a comprehensive master stormwater drainage plan. All methods of stormwater treatment will be considered and evaluated so that this plan can recommend the methods that are the most practical and cost-effective for the different conditions that prevail. This plan will establish a practical level of service standard for the City as a whole and will consider all factors to set forth a recommended schedule of upgrading the stormwater system to prevent the discharge of untreated runoff (Solin 1991). Monroe County is in the process of developing criteria for a stormwater management ordinance. Additionally, the County has identified issues related to stormwater management. New policy is currently being developed to address the issues as part of the County's Growth Management Plan (Wallace Roberts & Todd *et al.* 1991a). The policies include the development of a comprehensive Stormwater Master Plan by 1995. The Plan will consider both quality and quantity of stormwater runoff and will consider all current and proposed State and Federal stormwater runoff regulations.

3.3 EXTERNAL SOURCES OF POLLUTANT LOADS

Water quality in the FKNMS can be affected by sources of poor water quality located outside the Sanctuary bounds. These sources could potentially include Florida Bay, Biscayne Bay, and other nearby waters. Other sources of contamination include water entrained from distant sites and carried over or through the Sanctuary. Both categories would be considered as nonpoint sources that affect water quality within the Sanctuary, although they may represent individual point or nonpoint sources whose initial location lies beyond Sanctuary bounds. Sources of poor quality water may be either natural or manmade, or they may represent a situation where one of these two sources exacerbates conditions caused by the other. Water-quality degradation may come in the form of increased turbidity or suspended solids, temperature changes, increased nutrients, salinity changes, or increased levels of heavy metals, synthetic organic chemicals, and anthropogenic organic chemicals.

3.3.1 Areas Adjacent to the Sanctuary

3.3.1.1 FLORIDA BAY AND EVERGLADES NATIONAL PARK

Florida Bay has been postulated to be a source of poor water quality affecting the reef tract adjacent to the Florida Keys. Most causes of potentially poor water quality within Florida Bay might be considered to be natural in origin. However, Fourqurean (1992) pointed out that, historically, freshwater inputs from the Everglades have been an important influence on the salinity of Florida Bay; the tendency to hypersalinity may have increased in modern times due to human engineering and diversion of water from the Everglades as a result of water management in the watershed. Causes of poor water quality include wind-driven transport of suspended particulates; the presence of soluble nutrients; decomposition; transport of mangrove detritus; seagrass decomposition with associated biologic activity; and naturally occurring, low DO at night, attributed to plant respiration. Very little quantitative information is available on the movement of poor quality water from Florida Bay out onto the reef tract.

Florida Bay has shown no indications of a prevalent anthropogenic problem with contaminants other than freshwater (Schomer and Drew 1982; SFWMD 1991). The natural quality of Florida Bay water is highly variable, depending upon prevailing weather and climatic conditions. Periods of extreme cold or warm weather cause drastic heating or cooling of Bay water. The Bay water then moves out into coastal waters and potentially over the reef tract (Shinn *et al.* 1989). The current and circulatory patterns of Florida Bay and the other shallow estuaries of south Florida are primarily wind- and tide-driven. Extended windy periods cause highly turbid water conditions (Lee and Rooth 1972; Lee 1975). This highly turbid water is then available to move out of the Bay into oceanside coastal waters. Szmant (1991) documents the movement of turbid waters through several channels between Florida Bay and oceanside waters.

Nutrients have been shown to be elevated in Florida Bay, primarily due to a seagrass die-off whose origins have not been defined (Fourqurean *et al.* to be published). Fourqurean (1992) presented water quality data for 26 sample sites near the centers of relatively discrete basins defined by the mud banks in Florida Bay. Samples were collected eight times between Summer 1989 and Summer 1990. Ranges of nutrients observed by Fourqurean were as follows:

Nitrate	below detection - 6.13 μM
Nitrite	below detection - .94 μM
Ammonium	.02 - 11.03 μM
Soluble reactive phosphorus	below detection - .33 μM

The relative contribution of nutrients to Florida Bay from anthropogenic sources has not been defined (SFWMD 1991). Szmant (1991) reported levels of all nutrients measured to be higher in samples collected from Florida Bay (at Long Key) than for samples taken from comparable proximal ocean sites. Several water quality parameters in Florida Bay and the adjacent estuaries of the Everglades National Park have been defined and are listed in **Tables 2-15** and **2-16**.

Shinn *et al.* (1989) discussed the development of the Florida reef tract and the basis for the formation of the Florida Keys 6000-10,000 years before the present. As sea level rose and Florida Bay began to fill with water, reefs opposite the major tidal passes began to decline due to nutrient-laden, high-salinity, variable-temperature water. Shinn *et al.* (1989) reported reef development off Long Key to have been stunted from the movement of water from Florida Bay out to the reef tract, and hypothesized this to be due primarily to the movement of high- or low-temperature water onto the reef tract.

3.3.1.2 BISCAYNE BAY

3.3.1.2.1 Introduction

Biscayne Bay can be examined as a potential source of poor quality water to the FKNMS. Biscayne Bay receives various forms of flow from the City of Miami, other local municipalities, and Metro-Dade County. Water quality for this waterbody has been described in various documents, as listed in **Table 2-17**. These documents and unpublished data from the SFWMD and Metro-Dade County Department of Environmental Resources Management (Metro-Dade CDERM) form the basis for the following assessment of the potential for water quality of Biscayne Bay to adversely affect water quality within the Sanctuary.

Water quality can be generally described based on physical location within the Bay and on circulation patterns. For these purposes, the Bay can be divided into north Biscayne Bay, extending from Dumfoundling Bay to Rickenbacker Causeway; South Bay, from Rickenbacker Causeway to the Arsenicker Keys; and extreme South Bay, Card Sound, and Barnes Sound (from the Arsenicker Keys in South Bay to US Route 1).

3.3.1.2.2 North Biscayne Bay

Water quality in the north section of Biscayne Bay is largely defined by urban input. This area receives runoff from the cities of Hialeah, North Miami, Miami Beach, and Miami, as well as from smaller municipalities.

Table 2-15. Summary of water quality measurements reported from estuaries (Whitewater Bay, Shark Slough Estuary, and Buttonwood Canal) in Everglades National Park [From SFWMD 1991].

Period of Study	Salinity (ppt)	Water Temp. (°C)	Dissolved Oxygen (ppm)	pH	Turbidity (NTU)	Number of Stations	Number of Samples	Frequency of Measurement	Sources
1937/1938	26.9-17.5	—	—	—	—	—	6	Irregular	Davis (1980)
Mar-May 1955-1957	14.0-40.82	19.0-33.0	—	—	—	4	187	Weekly	Finucance and Dragovitch (1959)
Aug-Jun 1957-1959	0.0-43.8	14.4-34.0	1.47-6.90	7.47-9.45	—	26	772	Monthly	Tabb *et al.* (1959)[a]
Sep-Feb 1957-1967	0.0-39.8	16.0-32.5	0.0-6.39	7.7-8.3	—	25	559	Monthly	Tabb and Dubrow (1962a,b)[a]
Apr-Mar 1962-1967	0.0-40.0	—	—	—	—	44	1209	Monthly	Marshall and Jones unpublished[a]
Jan-Jun 1964-1965	15.5-45.2	15.8-34.0	—	—	—	1	89	Bimonthly	Roessler (1970)
Jun-Jun 1963-1964	22.0-51.5	14.0-31.1	—	—	—	1	145	Weekly	Beardsley (1967)
1964-1975	0-28	15.5-33.0	43.3-10.4	6.4-8.5	0.0-27.0	9	158	Irregular	USGS and McPherson[a]
Oct-Sep 1965-1966	0.0-30.3	14.8-32.2	—	—	0.7-9.6	17	—	Monthly	Tabb *et al.* (1974)

Table 2-15. Summary of water quality measurements reported from estuaries (Whitewater Bay, Shark Slough Estuary, and Buttonwood Canal) in Everglades National Park [From SFWMD 1991]. (continued)

Period of Study	Salinity (ppt)	Water Temp. (°C)	Dissolved Oxygen (ppm)	pH	Turbidity (NTU)	Number of Stations	Number of Samples	Frequency of Measurement	Sources
Jan-Dec 1966-1967	23.5-37.4	16.4-31.8	—	—	—	1	66	Weekly	Janke (1971)
Dec-Feb 1966-1967	0.0-16.8	—	1.3-6.8	—	—	22	132	Monthly	Tabb and Kenny (1967)
Oct-Dec 1967-1968	0.0-27.4	—	—	—	—	3	12	Monthly	Odum (1971) Heald (1971)
Sep-Nov 1968-1969	2.6-30.9	15.9-32.1	5.0-9.0	—	—	8	135	Monthly	Clark (1971)
May-Feb 1971-1972	18.0-36.9	21.0-29.9	—	—	—	6	236	Quarterly	Lindall *et al.* (1973)
Oct-Sep 1973-1974	0.1-41.6	13.2-31.8	0.0-9.5	5.8-8.5	0.4-41.0	26	416	Hourly Monthly	Davis and Wilsenbeck (1974)
1966-1969	0.0-50.8	13.7-35.5	—	—	—	5	42	Irregular	Rouse (1970)[a]

[a]Citation not available.

Table 2-16. Summary of chemical water quality data collected in estuarine and marine waters of Florida Bay in Everglades National Park, 1945-1976. [From SFWMD 1991; Schmidt and Davis 1978]

PESTICIDES (µg/L)	Chlorinated		
Aldrin	ND[a]	DDT	0.00-0.02
Dieldrin	0.00-0.05	Silvex	ND
Endrin	ND	Toxaphene	ND
Chlordane	ND	2, 4-D	0.00-0.05
Lindane	ND	2, 4, 5-T	ND
DDD	0.00-0.01	Heptachlor	ND
DDE	0.00-0.01	Heptachlor Epoxide	ND
	Nonchlorinated		
Ethion	ND	Diazinon	0.00-0.01
Trithion	ND	Methyl Parathion	ND
Methyl trithion	ND	Parathion	0.00-1.00
Malathion	ND		
CARBONATE SYSTEM (mg/L)			
Calcium Carbonate ($CaCO_3$) 11-315		Carbon dioxide (CO_2)	1.2-23
Bicarbonate (HCO_3^-) 104-439		Total inorganic carbon	16.8-72
Carbonate (CO_3^{-}) 0-17			
NUTRIENTS (mg/L)	Nitrogen		
NH_3^-	0.00-2.8	Organic N	0.36-8.4
NO_2-	0.00-7.0	Total N	0.02-9.3
NO_3^-	0.00-39	Kjeldahl N	0.23-2.0
NO_2^- and NO_3^-	0.00-6.3		
	Phosphorus		
Total ortho P	0.00-1.1	Total ortho PO_4^{-3}	0.07-1.3
Total P	0.00-1.4	Inorganic PO_4^{-3}	0.00-3.5
Dissolved PO_4^{-3}	0.00-6.9	Dissolved PO_4^{-3}	0.01-0.10
Total PO_4^{-3}	0.00-15.5		
	Carbon	Silicon	
Organic carbon	0-61	SiO_2	0.00-20
Total carbon	49-104	SiO_4^{-2}	0.00-7.0
METALS	Dissolved		
Iron (µg/L)	0.00-810	Lead (µg/L)	0-5
Magnesium (mg/L)	1.1-1,800	Zinc (µg/L)	3-40
Strontium (µg/L)	0.2-9,500	Copper (µg/L)	2-40
Sodium (mg/L)	8.6-14,000	Cobalt (µg/L)	ND
Potassium (mg/L)	0.2-14,000	Chromium (µg/L)	0-1
Arsenic (µg/L)	0-10	Cadmium (µg/L)	ND
Aluminum (µg/L)	0.8-40	Calcium (mg/L)	7.3-1,910
Manganese (µg/L)	0-80		

[a]Not detected
[b]No units provided in original citation (SFWMD 1991)

Table 2-16. Summary of chemical water quality data collected in estuarine and marine waters of Florida Bay in Everglades National Park, 1945-1976. [From SFWMD 1991; Schmidt and Davis 1978]. (continued)

	Particulate (μg/L)		
Lead	0-8	Chromium	10
Manganese	0-70	Cobalt	ND
Arsenic	1	Copper	ND
Cadmium	ND	Zirconium	10
	Total (mg/L)		
Aluminum	2-210	Nickel	0-47
Arsenic	0-12	Chromium	0-10
Cadmium	0-10	Cobalt	
Mercury	0.1-5.6	Lithium	0-0.15
Iron	0-3,100	Boron	1.1-6.0
Manganese	0-280	Copper	0-10
Lead	0-24	Zinc	1.5-60
NONMETALS			
Sulfate	0-3,870	Total bromine	0-66
Chloride	13-25,000	Total iodine	0-0.25
Fluorine	0-1.8		
MISCELLANEOUS PARAMETERS			
PCB (μg/L)	0.00-0.00	Biochemical oxygen demand (mg/L)	0-7.4
Dissolved Solids (mg/L)		Hardness (mg/L)	
Residue at 180 °C	161-41,400	Calcium, Magnesium	105-8,700
Calculated	0.168-40,200	Noncarbonate	4-8,600
Sum of Constituents	139-45,400	Sodium Absorption Ratio	1.0-48[b]
kg/m^3	0.2-35.0	Protein	0.0-18.5[b]
ton/day	0.57	Carbohydrates	0.0-15.4[b]
Oil and Grease (mg/L)	0-15		
Color (PCU)	5-160		

[a]Not detected
[b]No units provided in original citation (SFWMD 1991)
PCU: platinum-cobalt color unit.

Table 2-17. Documents summarizing water quality in Biscayne Bay and the Miami watershed.

Alleman, R.W. 1985. Biscayne Bay water quality: baseline data and trend analysis report, 1979-1983. Metro-Dade County Department of Environmental Resources Management. 79 pp.

Church, P., K. Donahue, and R. Alleman. 1979. An assessment of nitrate concentration in south Dade County groundwater. Metro-Dade County Department of Environmental Resource Management.

City of Miami, Department of Public Works. 1986. Storm Drainage Master Plan. Miami, FL.

Corcoran, E.F., M.S. Brown, and A.D. Freay. 1984. The study of trace metals, chlorinated pesticides, polychlorinated biphenyls and phthalic acid esters in sediments of Biscayne Bay. University of Miami, Rosenstiel School of Marine and Atmospheric Science, Miami, FL. 58 pp.

Corcoran, E.F., M.S. Brown, F.R. Baddour, S.A. Chasens, and A.D. Freay. 1983. Biscayne Bay hydrocarbon study final report. University of Miami Rosenstiel School of Marine and Atmospheric Sciences, Miami, FL.

McNulty, J.K. 1970. *Effects of Abatement of Domestic Sewage Pollution on the Benthos, Volumes of Zooplankton, and the Fouling Organisms of Biscayne Bay, Florida.* University of Miami Press, Coral Gables, FL. 107 pp.

McQueen, D.E. 1980. Underground disposal of storm water runoff at Miami International Airport. Prepared for Dade County Aviation Department by Lloyd and Associates, Inc., Vero Beach, FL. 83 pp.

Metro-Dade County Department of Environmental Resources Management. 1978. An initial assessment of nitrate concentration of the Biscayne Aquifer in Dade County. Miami, FL.

Metro-Dade County Department of Environmental Resources Management. 1979. A water quality assessment of metropolitan Dade County, Florida. Miami, FL.

Metro-Dade County Department of Environmental Resources Management. 1981a. An inventory of stormwater pollutant discharges and their loadings into major surface water bodies within Dade County, Florida. Miami, FL.

Metro-Dade County Department of Environmental Resources Management. 1981b. Biscayne Bay today: A summary report on its physical and biological characteristics. Miami, FL.

Metro-Dade County Department of Environmental Resources Management. 1983a. Biscayne Bay: A survey of past mangrove mitigation/restoration efforts. Draft Final Report. Miami, FL.

Metro-Dade County Department of Environmental Resources Management. 1983b. Biscayne Bay water quality: Reporting period March 1981-February 1982. Miami, FL.

Metro-Dade County Department of Environmental Resources Management. 1983c. Bottom communities of Biscayne Bay. Miami, FL. Map with text.

Metro-Dade County Department of Environmental Resources Management. 1985. Biscayne Bay water quality baseline data and trend analysis report 1979-1983. Miami, FL.

Table 2-17. Documents summarizing water quality in Biscayne Bay and the Miami watershed. (continued)

Metro-Dade County Department of Environmental Resources Management. 1987. Biscayne Bay and Miami River: A water quality summary, Biscayne Bay through 1984 and Miami River through 1985. Miami, FL.

Metro-Dade County Planning Department. 1962. A planning study of the Miami River. Miami, FL.

Metro-Dade County Planning Department. 1986. Biscayne Bay aquatic preserve management plan. Draft, September 30, 1986. Miami, FL. 360 pp.

Metro-Dade County Planning Department. 1988. Proposed coastal management element, year 2000 and 2010, comprehensive development master plan. Metro-Dade County, FL. April, 1988. 258 pp.

Miami River Task Force. 1984. Miami River Outfall Study. Miami, FL.

Pierce, R.H., and R.C. Brown. 1986. A survey of coprostanol concentrations in Biscayne Bay sediments. First quarterly report; Task I. Metro-Dade County. Department of Environmental Resources Management, Miami, FL. 16 pp.

Ryan, J.D., F.D. Calder, L.C. Burney, and H.L. Windom. 1985. The environmental chemistry of Florida estuaries: Deepwater ports maintenance dredging study. Tech. Rep. #1; Port of Miami and the Miami River. Office of Coastal Management, Florida Department of Environmental Regulation, Tallahassee, FL. 41 pp. + appendices.

Ryan, J.D., F.D. Calder, and L.C. Burney. 1985. Deepwater ports and maintenance dredging manual: A guide to planning, estuarine chemical data collection, analysis, and interpretation. Florida Department of Environmental Regulation, Tallahassee, FL.

Ryan, J.D., F.D. Calder, L.C. Burney, and H.L. Windom. 1985. The environmental chemistry of Florida estuaries: Deepwater ports maintenance dredging study. Tech. Rep. Florida Department of Environmental Regulation, Tallahassee, FL.

Schaiberger, G.E., T.D. Edmond, and C.P. Gerba. 1982. "Distribution of enteroviruses in sediments contiguous with a deep marine sewage outfall." Water Resources 16:1425-1428.

Shinn, E.A., and E. Corcoran. 1988. Contamination by landfall leachate South Biscayne Bay, Florida. Final report to Sea Grant, University of Miami, Miami, FL. 11 pp.

Major tributaries to this area include Snake Creek, Arch Creek, Biscayne Canal, Little River, and the Miami River. This portion of Biscayne Bay is connected to the ocean via three tidal inlets: Bakers Haulover Inlet, Government Cut, and Norris Cut. Residence time (i.e., the average time that a theoretical water particle remains in an area) for North Bay ranges from 3.2 to 13.2 days and is defined by the exchange characteristics of the area being examined (van de Kreeke and Wang 1984). Transport of water from offshore Miami south to the Sanctuary depends upon the prevailing physical circulation of the coast and the presence of a longshore countercurrent moving south (S. Baig, NOAA, personal communication, 1991).

Water quality in North Bay is contaminated by large numbers of anthropogenic sources, including manufacturing, boat building and repair, urban runoff, raw sewage from illegal connections, degraded systems, and overflows during heavy rains. Poor water quality exists in several areas of North Bay. Corcoran *et al.* (1983; 1984) indicated that 96% of all samples collected had phthalate acid ester (PAE) contamination. In addition, several sites in north Bay show high levels of organic contamination, generally in conjunction with marinas or boat repair facilities (SFWMD 1989; Corcoran *et al.* 1983, 1984). Average chlorophyll, coliform bacteria, and turbidity are relatively high in north Biscayne Bay and have not shown significant changes over time. (SFWMD 1989). Biochemical oxygen demand (BOD_5) is elevated in north Biscayne Bay and is particularly high in the Miami River and its outflow.

3.3.1.2.3 Miami River

The Miami River consistently has the poorest water quality in Biscayne Bay. Tributyltin (TBT), an organotin antifouling paint for boats, has been banned for most uses in the United States because of its severely toxic effects on marine organisms. TBT was found in water-column samples from the Miami River, ranging from 3 to 90 parts per trillion (pptr) (SFWMD, unpublished data). Florida State standards for this compound in the water column are 10 pptr in freshwater and 20 pptr in saltwater (SFWMD 1989). Miami River sediments were found to be of extremely poor quality [United States Army Corps of Engineers (USACE) 1986]. A 1991 sample series of Miami River sediments failed to pass the toxicity tests necessary for ocean disposal of sediments (USACE, unpublished data). Potential plans to dredge the Miami River and dispose of sediments offshore may have implications to the maintenance of acceptable water quality levels within the Sanctuary. In 1990, the USACE dredged the Miami Harbor for a turning basin and disposed of sediments offshore. During this process, a turbidity plume was created that carried extremely turbid water (>200 NTU) north in Biscayne Bay to the 79th Street Causeway. Another extremely large turbidity plume was created offshore along the entire path of the dredging vessel and its disposal site offshore (R. Alleman, SFWMD, personal communication, 1991). Offshore disposal of Miami River sediments may potentially have detrimental effects on the Biscayne National Park reef tract and the FKNMS reef tract owing to longshore transport from the north.

3.3.1.2.4 Metro-Dade County Offshore Sewage Outfall

The Metro-Dade County offshore sewage outfall discharges treated sewage in 30 m of water off Miami Beach. This outflow is currently being examined as part of the National Oceanic and Atmospheric Administration (NOAA) Southeast Florida Outfalls Experiment. Results from Phase 1 of this work show that the movement of water plumes from this outfall were erratic and tended to move as isolated parcels of water that resist mixing (Dammann *et al.* 1991). Countercurrents in this area are documented, making it extremely difficult to predict the fate of this plume (S. Baig, NOAA, personal communication, 1991). The potential exists for effluent from this outfall to reach the Sanctuary, but probably in very low concentrations.

3.3.1.2.5 South Biscayne Bay

South Biscayne Bay extends from Rickenbacker Causeway to the Arsnicker Keys. This area generally realizes low input of external contamination, attributed to a lower urban density and the presence of only a few external sources of contamination. Circulation within this area has been modeled by Swakon and Wang (1977). Exchange with the ocean occurs across three major areas: Bear Cut, the Safety Valve, and Caesars Creek. The northern part of South Biscayne Bay is a region of high salinity, with waters that are vertically homogeneous and controlled by flow over the Safety Valve (Chin Fatt and Wang 1987). The southern part of South Bay is generally well mixed, with salinity contours running north to south owing to restricted circulation (Chin Fatt and Wang 1987). Water exchange rates in this area are primarily wind- and tide-driven. Residence times range from 6 to 22 days (SFWMD 1989). Card Sound has poor circulation and long residence times of up to 1 year (SFWMD 1989; Lee and Rooth 1972). Localized contaminants other than extremely fresh or extremely saline water would be unlikely to reach the Sanctuary because of the extreme residence times and restricted circulation.

Potential contaminant sources for South Biscayne Bay include agricultural runoff into adjacent canals, runoff and leachate from the landfills located at Black Point, freshwater input attributed to canal operation, and hypersaline water resulting from restricted circulation. Southern Dade County has extensive agriculture that represents a potential source of agricultural chemicals. Major nitrate loading occurs in the South Bay from the C-103 (Mowry Canal) and C-102 (Princeton Canal) canals (R. Alleman, SFWMD, personal communication, 1991; Cheesman 1989; Scheidt and Flora 1983) (Figure 2-8). Under the SFWMD Pesticide Monitoring Program, pesticides have been detected at various places on an irregular basis (SFWMD 1991). Compounds detected in the water column of local canals include chlordane, DDT, DDE, DDD, and atrazine (Pfeuffer 1991). There have been no reports of these compounds in the water column in South Biscayne Bay (R. Alleman, SFWMD, personal communication, 1991). Mercury and arsenic have also been detected in canal and Bay sediments. However a source for these compounds has not been determined (SFWMD 1989).

Other nonagricultural sources of contaminants include Homestead Air Force Base and the Black Point Landfill site. Homestead Air Force Base and Military Canal are sources of metals and of organic compounds. Two EPA-designated Superfund sites are located in Homestead Air Force Base. These are the result of extreme contamination within select areas of the base (E. Barnett, FDNR, personal communication, 1991). Military Canal contains severely toxic components that have not been thoroughly characterized (R. Alleman, SFWMD, personal communication, 1991). United States Air Force plans to dredge the canal have been indefinitely delayed. Dredging of this canal poses a severe threat to the water quality of Biscayne National Park and the FKNMS.

The Black Point landfill site consists of two landfill locations. One, located to the south of Goulds Canal, is the old South Dade Dump. This site is not lined and has documented leachate problems. The second, the newer South Dade Landfill, is located north of Goulds Canal. This second site also has leachate problems due to methods utilized in the initial construction of Cells No. 1 and 2 (Alleman 1990). Ammonia has been documented in both surface water and groundwater. Ammonia in surface water is about one order of magnitude above the Metro-Dade County surface-water standard for ammonia (Alleman 1990). Organic contamination was documented by Shinn and Corcoran (1988) in groundwater between the Black Point landfill and Biscayne Bay. However, the extent of this contamination was not investigated further (E. Shinn, United States Geological Survey Center for Coastal Geology, personal communication, 1991). The signature of a surface-water plume has been documented in the vicinity of the landfill. This signature has been documented for only a short distance and it has not been found to extend far enough to affect the Sanctuary.

Groundwater movement represents a potential mechanism for the transport of contaminants. The Everglades SWIM Plan documents the extent of groundwater contamination under South Dade agricultural areas. The direction, flow, and movement of groundwater under Biscayne Bay has not been well documented. As a result, this contaminant transport mechanism (i.e., to the Sanctuary) has not been verified. It is likely that the shallow aquifer located under the northern Florida Keys and Biscayne Bay has realized saltwater intrusion so that the

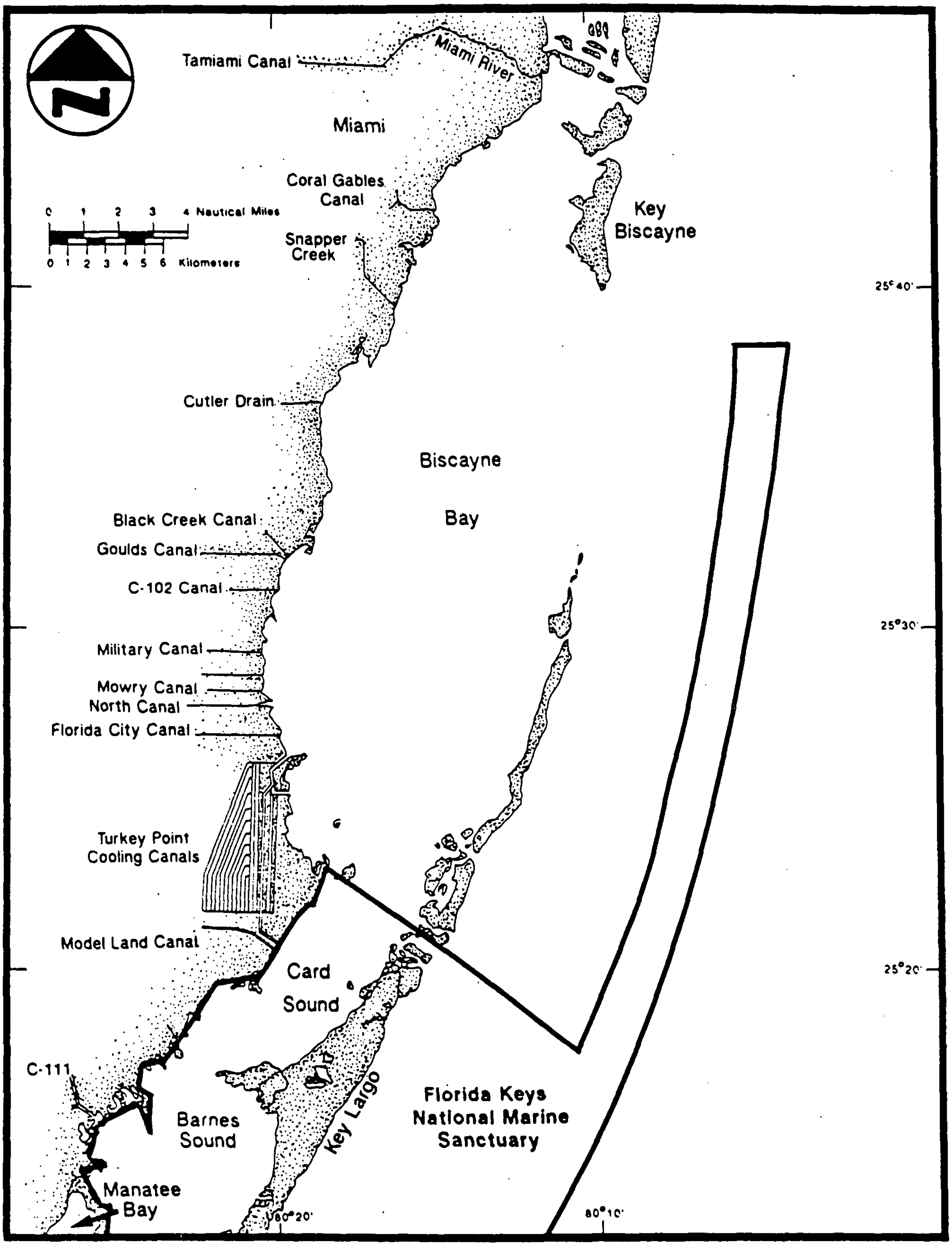


Figure 2-8. Biscayne Bay and associated canals.

movement of fresh or brackish water would be controlled by hydraulic pumping on the mainland. To date, none of the work necessary to define and further address these problems has been done (E. Shinn, United States Geological Survey Center for Coastal Geology,, personal communication, 1991).

Freshwater or extremely hypersaline water also represents a potential contaminant to the reef tract. Due to the restricted circulation of Card Sound, Barnes Sound, and South Biscayne Bay, large volumes of freshwater introduced into these areas remain as water masses that move as discrete parcels (Lee 1975; Lee and Rooth 1972). This is a potential problem when there are large freshwater releases from the Everglades-South Dade canals. However, due to the restricted circulation and increased residence time of this region, such large freshwater releases would most likely damage not the reef tract but Card and Barnes Sounds. Such an occurrence was documented in 1988, when a large-scale release caused the destruction of bottom habitat in this area (SFWMD 1991).

3.3.2 Areas Removed from the Sanctuary

It has been suggested that potential contaminant loading in the FKNMS can be attributed to the transport of anthropogenic compounds from distant sources via water-mass movement. The magnitude of this problem and the probability of this occurrence depend upon the physical oceanographic and circulation features of the region. The Loop and Florida Currents are the main oceanographic features. As discussed in greater detail in Section 2.1, the Loop Current is formed by water from Caribbean drift that is piled up by the trade winds on the western side of the Yucatan Peninsula. This current then funnels into the western side of the channel (that becomes the Straits of Florida), moving through the Straits as the Florida Current.

Potential geographic sources of contaminants to be carried by these currents include the west coast of Florida, the Mississippi River drainage and subsequent outflow, contributions from Central America, contributions from northern South America (Orinoco Flow), and the island nations throughout the Caribbean. Only flows from the Mississippi and Orinoco Rivers represent sufficient volume flux to remain sufficiently undiluted over large distances. The large distance of the Orinoco plume from the Sanctuary and the flow's relative dilution rate decrease the likelihood that this is a major source of contaminants. The Mississippi River represents one of the world's largest riverine outflows (by volume). Its physical characteristics are such that it is possible for water to be entrained along the west coast of Florida. Further, there is potential for this riverine-derived water to move into Sanctuary waters (S. Baig, NOAA, personal communication, 1991). Water flowing out of the Mississippi River into the Gulf is positively buoyant relative to ambient coastal water. Under conditions of large outflow and minimal mixing, it is possible that water from the Mississippi River could remain at the surface, flow around the Gulf, and be entrained into the Loop Current, the major current bringing water through the Straits of Florida.

Because currents of the southwest Florida shelf are wind-driven, the Loop Current dominates the oceanography of the eastern Gulf. The full northern extent of intrusion by the Loop Current is variable (S. Baig, NOAA, personal communication, 1991). As an eastern boundary current within the eastern Gulf of Mexico (west Florida), the Loop Current turns quickly to the south at the coast, generally in the vicinity of Tampa/Ft. Meyers/Naples. However, precisely where it turns is variable and it has been traced as far north as Desoto Canyon by the NOAA National Weather Service Hurricane Center (S. Baig, NOAA, personal communication, 1991). Other potential sources of contaminants have been described by Lee *et al.* (to be published) and are made up primarily of discrete parcels of water that move up from depth under various oceanographic and meteorologic conditions. In addition, Jaap (1984) noted that on rare occasions, entrained Mississippi River spring runoff is carried along the inshore side of the Florida Current. Salinity reductions to 32 to 34 ppt have been observed, and this water could serve as a potential source of contaminants. These latter sources should be considered minor and insignificant.

4.0 WATER QUALITY

The quality of waters within the bounds of the FKNMS can be assessed through a review of five major studies that evaluate the present status and trends in water quality of the Florida Keys. These studies were selected because they provided the best overview of the water quality in the region encompassing the Sanctuary. Three of the reviewed studies (FDER 1985; Lapointe and Clark 1990; Szmant 1991) occupied sampling stations throughout the Florida Keys. In two studies (FDER 1987; 1990), sampling efforts were concentrated in limited areas of the Keys. The locations of the study areas sampled during these investigations are presented in **Figures 2-9** and **2-10**. Other studies and data sources that were identified and evaluated in this assessment are presented in **Table 2-18**. These other studies were not summarized because they did not add significantly to the overall assessment of water quality. The raw data were not evaluated because of the extensive time required to determine sampling locations, methods, and quality control procedures. Additional studies are identified and summarized in **Task 5 — Nearshore and Confined Waters Assessment.**

4.1 OVERVIEW

4.1.1 Florida Department of Environmental Regulation — 1985

The FDER (1985) reported the results of an extensive water-quality survey of the Florida Keys. The purpose of this study was to provide baseline water-quality data in natural and manmade waters of the Florida Keys in conjunction with a proposal to designate the waters surrounding the Florida Keys as Outstanding Florida Waters. Water-quality data and samples were collected at 165 stations that ranged from Key Largo to Key West. An approximately equal sampling effort was expended on the Florida Bay and on the Atlantic Ocean sides of the Keys. Ninety-five stations in ambient waters were occupied. Most of these stations were positioned about 0.25 mile from shore, but occasionally stations were located within mangrove creeks. The remainder of the stations (70) were in artificial waterways, which included canals, boat basins, and marinas located adjacent to trailer parks, single- and multiple-family dwellings, and commercial operations.

The results of this survey are summarized in **Table 2-19**. DO levels below 6 mg/L were not observed at the ambient stations. In contrast, levels in the artificial waterways were hypoxic at a number of locations, and measurable DO was absent from one sample. The ranges of nutrient parameter concentrations overlapped between the two station groups, but higher levels were observed at the artificial waterway stations in all cases. The FDER (1985) reported that a majority of artificial waterway stations had higher levels of total phosphorus, total Kjeldahl nitrogen, and ammonia. These investigators concluded that many of the artificial waterways showed evidence of degradation, and they suggested that reduced circulation with influence from stormwater runoff, septic leachate, and accumulation of floating organic debris contributed to the degraded water quality.

4.1.2 Applied Biology, Inc. — 1985

Applied Biology, Inc. (1985), reported the results of a water-quality survey that was conducted as part of the Key Largo National Marine Sanctuary Water Quality Assessment and Modeling Program. The objective was to measure the quality of the seawater, which was related to the biology of the reef tract in the Key Largo National Marine Sanctuary. This survey was conducted from August 1982 to November 1983. These data were to be used to calibrate a predictive model. Water-quality parameters measured during the survey included temperature, salinity, DO, pH, turbidity, nitrate nitrogen, nitrite nitrogen, ammonia nitrogen, and phosphate phosphorus. Data were collected at stations that had been selected to represent several environments. A series of stations was aligned along the Atlantic coastline off Key Largo to represent Hawk Channel, the reef tract,

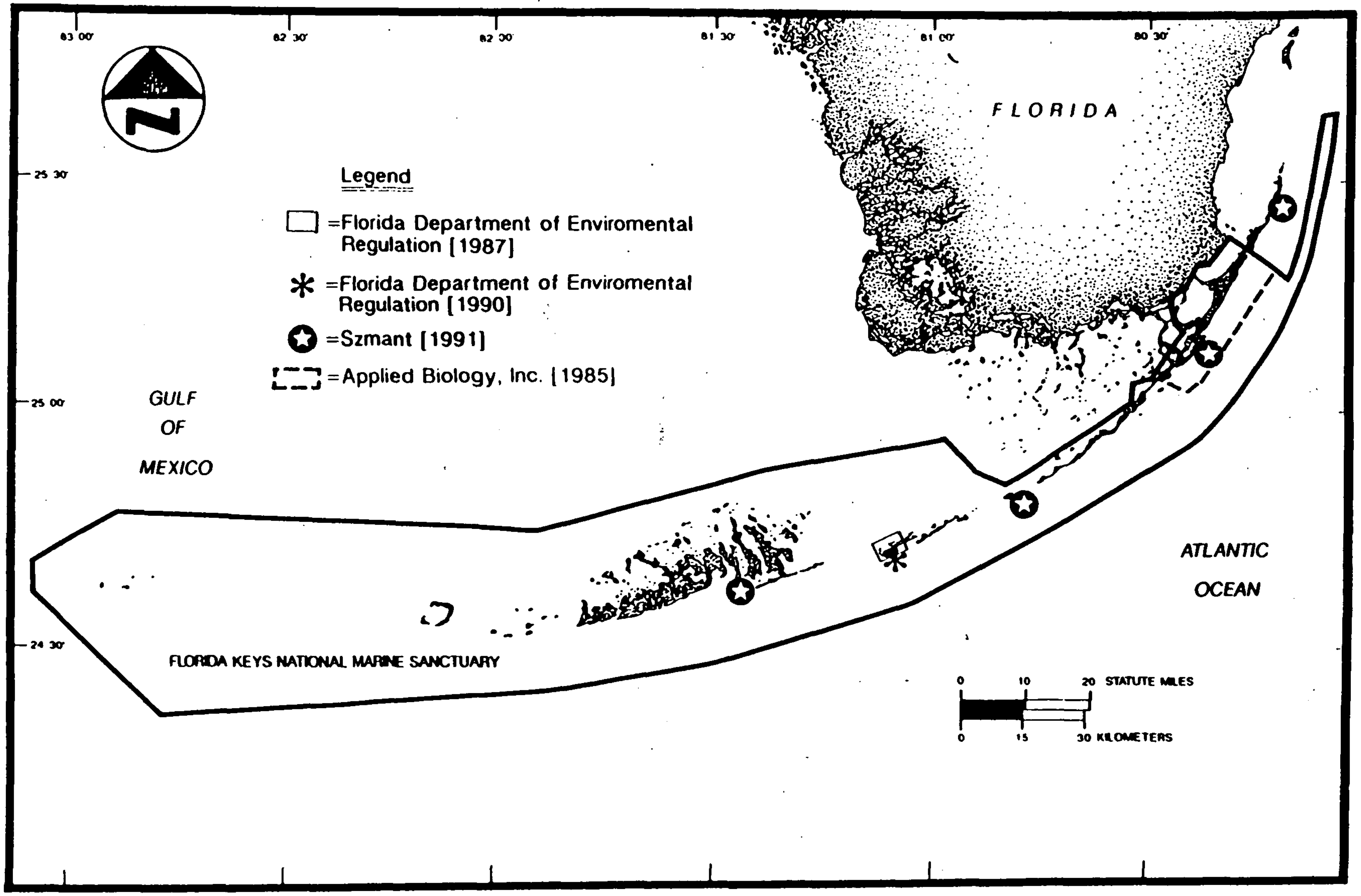
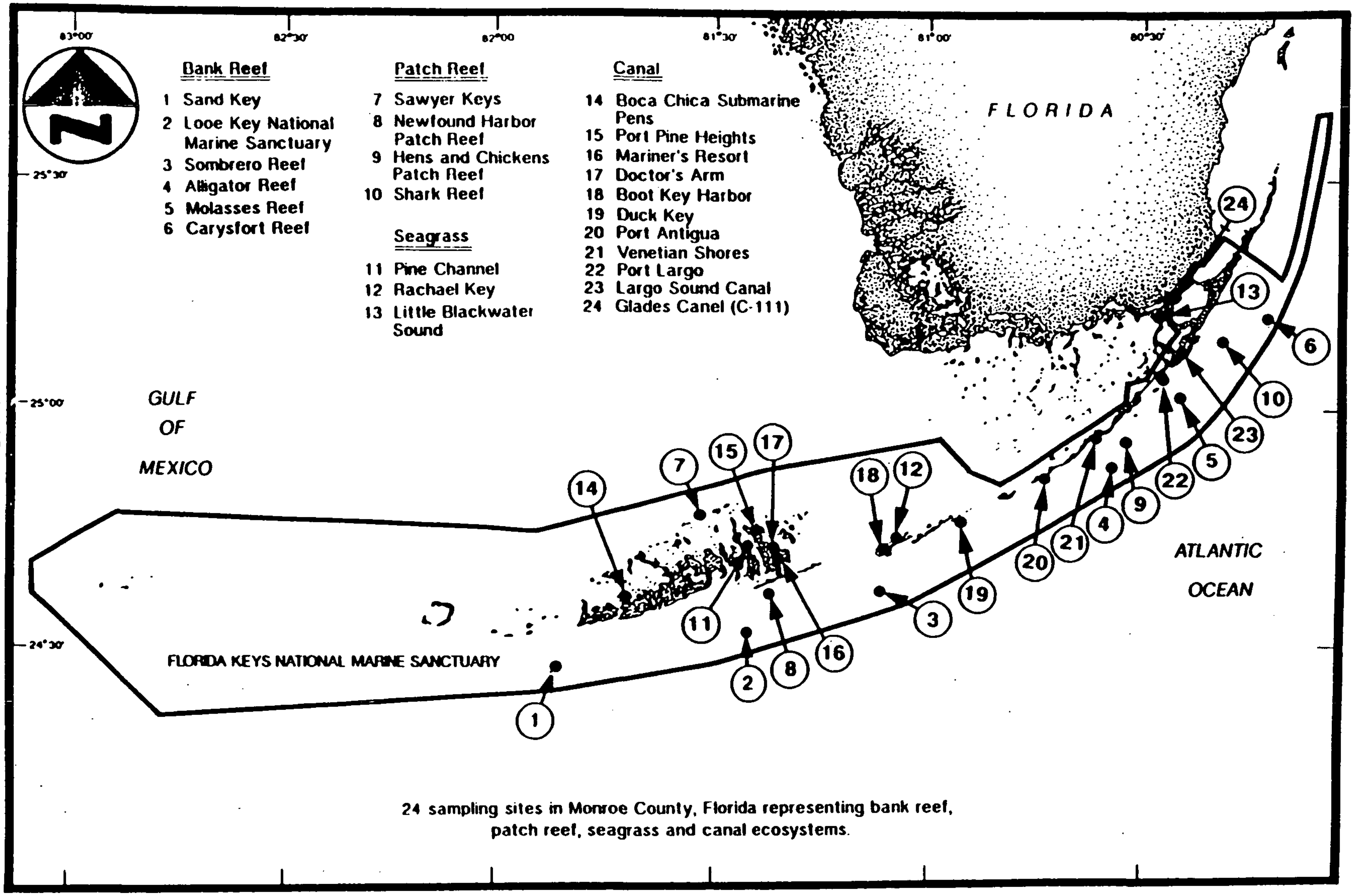


Figure 2-9. Sampling locations summarized by the Florida Department of Environmental Regulation, Szmant, and Applied Biology, Inc.



24 sampling sites in Monroe County, Florida representing bank reef, patch reef, seagrass and canal ecosystems.

Figure 2-10. Sampling locations summarized by Lapointe and Clark [1990]. [Adapted from Lapointe and Clark 1990]

Table 2-18. Additional data sources and documents pertaining to water quality in the Florida Keys region, including waters of the Florida Keys National Marine Sanctuary.

REPORTS

Bader R.G., and M.A. Roessler. 1971. An Ecological Study of South Biscayne Bay and Card Sound. Progress report to the United States Atomic Energy Commission (AT(40-1)-3801-3) and Florida Power & Light Company.

Nnaji, S. 1987. South Biscayne Bay water quality: A twelve year record for Biscayne National Park. A report for the Biscayne National Park, National Park Service, Department of the Interior, Washington, DC. 79 pp.

Schmidt, T.W., and G.E. Davis. 1978. A summary of estuarine and marine water quality information collected in Everglades national Park, Biscayne National Monument, and adjacent estuaries from 1879 to 1977. A report by the National Park Service, South Florida Research Center, Everglades National Park, Homestead, FL. 59 pp.

Skinner, R.H., and W.C. Jaap. 1986. Trace metal and pesticides in sediments and organisms in John Pennekamp Coral Reef State Park and Key Largo Natural Marine Sanctuary. Report to the Florida Department of Environmental Regulation Coastal Zone Management Office.

Skinner, R.H., and E.F. Corcoran. 1989. John Pennekamp Coral Reef State Park Water Quality Monitoring Program. Assessment of water quality data from five stations, Volume 1. A report for the Florida Department of Natural Resources. 47 pp.

Strom, R.N., R.S. Braman, W.C. Jaap, P. Dolan, K.B. Donnelly, and D.F. Martin. 1990. Analysis of selected trace metals and pesticides offshore of the Florida Keys. Final Report to the Florida Institute of Government star grant 88-009. 46 pp.

DATA SOURCES

Biscayne Bay National Park

Dade-Metro Department of Environmental Resources Management

Florida Department of Environmental Regulation STORET database

National Oceanographic Data Center

Environmental Protection Agency STORET database

Table 2-19. Ranges of water-quality parameters measured during a survey to support designation of the Florida Keys as Outstanding Florida Waters. [From FDER 1985]

Water-Quality Parameter	Ambient Stations (mg/L, except pH)	Artificial Waterway Stations (mg/L, except pH)
Dissolved oxygen	6.0-9.4	0.0-9.6
pH	7.0-8.4	7.0-8.3
Total phosphorus	0.001-0.054	0.005-0.083
Total Kjeldahl nitrogen	0.128-0.693	0.196-1.15
Ammonia nitrogen	0.051-0.160	0.057-0.239
Organic nitrogen	0.019-0.580	0.066-0.850
Nitrate plus nitrite	0.000-0.027	0.002-0.054

and the ocean. In addition, stations were located at potential system (Sanctuary) inputs, such as the Snake, Broad, and Caesar Creeks, and in Biscayne Bay.

The results of the water-quality survey are presented in **Table 2-20**. Seasonal mean temperatures in Biscayne Bay and the creeks tended to be lower than the offshore mean temperatures. Inshore (creeks and Biscayne Bay) seasonal mean salinities were lower than those at the offshore stations, which reflected the influence of freshwater drainage in Biscayne Bay. Strong differences between inshore and offshore mean DO concentrations were not apparent, but mean oxygen saturations were lower at the inshore stations as a result of the lower temperatures and salinities observed there. For the offshore station types (Hawk Channel, Florida Reef Tract, and ocean), the ranges of the mean values suggest that the turbidity tended to decrease as the distance from shore increased. Levels at the inshore stations tended to be higher than at the reef tract and ocean stations. Mean nitrogen nutrients did not appear to vary much among the offshore station types and were generally higher inshore. Distinct differences among mean phosphate levels were not apparent among the station types.

4.1.3 Florida Department of Environmental Regulation — 1987

The FDER conducted an EPA-funded 205(j) study at Marathon, Florida, to determine the impact of five pollution sources on water quality (FDER 1987). The five pollution sources of interest included

- Raw sewage and petroleum hydrocarbon discharges from live-aboard vessels in marinas
- Discharges from seafood processors and commercial fishing operations
- Discharges from stormwater collection systems
- Treated effluent from sewage treatment plants
- Septic tank leachate through groundwater seepage

To evaluate these pollution sources, five study sites were selected. These study sites were isolated as much as possible to avoid compounding the impact of the pollution sources and thereby avoid hindering interpretation of study results. The sites selected for study included

- Faro Blanco Marina (marina with live-aboard vessels)
- City Fish Market (seafood processor)
- Winn-Dixie Shopping Center (parking lot drainage)
- Key Colony Beach (sewage treatment plant)
- 90th Street Canal (leachate from septic tanks)

The primary station at each study site was located in a canal in the immediate vicinity of the pollution source. A secondary station was located near the mouth of the canal to investigate dispersion of the water-quality impacts away from the pollution source. In addition, two ambient control stations were also established, one in Atlantic Ocean waters (i.e., oceanside) and the other in Florida Bay (i.e., Bayside).

Water-quality measurements were collected over 12 months. Temperature, pH, DO concentration, conductivity, Secchi depth, turbidity, and fecal coliform concentration were measured weekly. Total coliform concentration, total suspended matter concentration, biochemical oxygen demand (BOD_5), chlorophyll *a* concentration, nitrite, nitrate, total Kjeldahl nitrogen (total and dissolved components), ammonia (total and dissolved components), phosphorus (total and dissolved components), and orthophosphate (total and dissolved components) were measured monthly.

A summary of the water-quality results is presented in **Tables 2-21** through **2-24**. This summary was prepared from summary STORET printouts provided by the FDER. Investigators found that DO levels in the canals were reduced as compared to the ambient controls for the five sites. The levels at the canal mouth stations were also reduced, indicating that water quality was impaired in the nearshore waters. The pH levels also tended to be lower at the canal stations as compared to those at the ambient sites. The lowest pH value of 6.9 was

Table 2-20. Ranges of mean temperature, salinity, dissolved oxygen, dissolved oxygen saturation, pH, turbidity, ammonia nitrogen, nitrate nitrogen, nitrite nitrogen, and phosphate phosphorus at stations sampled by Applied Biology, Inc. (1985). Stations are grouped by their location — Hawk Channel, Florida Reef Tract, Ocean, Creeks, and Biscayne Bay.

	Hawk Channel	Florida Reef Tract	Ocean	Creeks	Biscayne Bay
Temperature (°C)	25.2-25.5	26.0-26.3	26.3-26.5	24.7-25.3	24.4-24.7
Salinity (ppt)	36.13-36.67	36.67-36.87	35.92-36.86	34.01-35.77	32.75-35.81
Dissolved Oxygen (mg/L)	6.10-6.23	6.02-6.32	5.93-6.09	5.80-6.02	5.79-6.36
Dissolved Oxygen Saturation (%)	91-95	93-96	92-94	85-95	85-88
pH	8.02-8.09	8.04-8.13	8.02-8.12	7.92-8.12	8.01-8.03
Turbidity (NTU)	0.80-1.09	0.30-0.49	0.27-0.36	0.91-1.40	0.68-0.76
Ammonia Nitrogen (μM)	0.45-0.88	0.56-0.16	0.56-0.95	1.28-1.81	0.77-1.66
Nitrate Nitrogen (μM)	0.16-0.20	0.17-0.20	0.17-0.23	0.50-0.64	0.21-1.03
Nitrite Nitrogen (μM)	0.03-0.04	0.02-0.03	0.02	0.06-0.11	0.06-0.11
Phosphate Phosphorus (μM)	0.14-0.21	0.14-0.26	0.20-0.22	0.16-0.21	0.17-0.29

Table 2-21. **Ranges of water temperature, conductivity, dissolved oxygen, and pH measured at stations occupied during the 205(j) study conducted at Marathon, FL. [From FDER STORET database[a]]**

Study Site	Station	Temperature (°C)	Conductivity (mmho/cm)	Dissolved Oxygen (mg/L)	Dissolved Oxygen (% saturation)	pH
Faro Blanco Marina	Canal	15.1-31.3	52.4-57.8	2.8-7.3	31.8-79.5	7.4-7.9
	Canal mouth	14.6-31.1	52.2-58.1	3.2-7.4	41.0-90.8	7.4-7.9
City Fish Market	Canal	17.0-31.5	50.6-58.4	0.0-7.4	0.0-97.4	6.9-7.8
	Canal mouth	14.7-31.1	52.2-58.6	3.7-7.8	47.4-93.4	7.3-7.9
Winn Dixie	Canal	17.1-31.5	46.4-58.1	0.2-7.2	-	7.2-7.9
Shopping Center	Canal mouth	13.0-31.2	51.2-57.9	3.6-9.0	-	7.4-8.0
Key Colony Beach	Canal	15.9-31.7	50.7-56.9	3.2-9.3	42.1-107.6	7.4-8.1
Sewage Treatment Plant	Canal mouth	15.5-31.8	51.6-56.8	2.9-9.3	36.7-110.3	7.5-8.1
90th Street Canal	Canal	11.9-31.1	50.5-57.2	0.0-7.4	0.0-86.4	7.0-7.9
	Canal mouth	12.2-31.2	51.2-57.2	2.5-10.0	32.1-119.0	7.5-8.0
Bayside ambient	Control	15.1-30.9	51.5-58.1	4.4-8.4	56.8-100	7.6-8.1
Oceanside ambient	Control	15.3-31.4	51.8-57.5	5.1-8.0	63.0-101.3	7.6-8.1

[a]:Minimum values reported in the STORET database for some ranges are detection limits and not numerical measurements.

Table 2-22. Ranges of nitrite, nitrate, total Kjeldahl nitrogen, and ammonia measured in water samples collected at stations occupied during the 205 (j) study conducted at Marathon, FL. [From FDER STORET database[a]]

Study Site	Station	Nitrite (mg/L)	Nitrate (mg/L)	Total Kjeldahl Nitrogen (mg/L)	Total Dissolved Kjeldahl Nitrogen (mg/L)	Total Ammonia (mg/L)	Dissolved Ammonia (mg/L)
Faro Blanco Marina	Canal	0.006	0.06	0.31-0.68	0.25-0.63	0.02-0.14	0.03-0.10
	Canal mouth	0.006	0.06	0.21-0.54	0.11-0.54	0.02-0.07	0.02-0.08
City Fish Market	Canal	0.006	0.06-0.09	0.65-1.79	0.37-1.08	0.05-0.42	0.03-0.31
	Canal mouth	0.006	0.06	0.19-0.51	0.02-0.56	0.02-0.14	0.02-0.12
Winn Dixie Shopping Center	Canal	0.006	0.06-0.08	0.18-0.58	0.19-0.55	0.02-0.08	0.02-0.08
	Canal mouth	0.006	0.06-0.07	0.23-0.55	0.19-0.53	0.02-0.07	0.02-0.10
Key Colony Beach Sewage Treatment Plant	Canal	0.006-0.220	0.06-0.12	0.33-0.60	0.09-0.59	0.02-0.15	0.03-0.11
	Canal mouth	0.006	0.06	0.27-0.56	0.25-0.50	0.02-0.13	0.02-0.13
90th Street Canal	Canal	0.006	0.06-0.08	0.26-0.53	0.16-0.53	0.02-0.09	0.02-0.08
	Canal mouth	0.006	0.06	0.11-0.62	0.15-0.56	0.02-0.06	0.02-0.06
Bayside ambient	Control	0.006	0.06	0.20-0.52	0.11-0.45	0.02-0.06	0.02-0.07
Oceanside ambient	Control	0.006	0.06-0.46	0.06-0.49	0.18-0.45	0.02-0.07	0.02-0.07

[a]: Minimum values reported in the STORET database for some ranges are detection limits and not numerical measurements.

Table 2-23. Ranges of phosphorus, orthophosphate, and chlorophyll *a* measured in water samples collected at stations occupied during the 205(j) study conducted at Marathon, FL. [From FDER STORET database[a]]

Study Site	Station	Total Phosphorus (mg/L)	Dissolved Phosphorus (mg/L)	Total Orthophosphate (mg/L)	Dissolved Orthophosphate (mg/L)	Chlorophyll (µg/L)
Faro Blanco Marina	Canal	0.010-0.030	0.010-0.020	0.002-0.018	0.004-0.016	0.00-4.46
	Canal mouth	0.010-0.230	0.010-0.190	0.002-0.008	0.002-0.006	0.00-1.79
City Fish Market	Canal	0.030-0.136	0.020-0.084	0.009-0.082	0.005-0.085	0.00-69.38
	Canal mouth	0.010-0.023	0.010-0.020	0.002-0.008	0.002-0.008	0.00-10.25
Winn Dixie	Canal	0.010-0.040	0.010-0.027	0.002-0.010	0.002-0.010	0.00-8.56
Shopping Center	Canal mouth	0.010-0.020	0.010-0.014	0.006-0.005	0.002-0.005	0.00-3.42
Key Colony Beach	Canal	0.020-0.087	0.010-0.060	0.003-0.060	0.002-0.056	0.00-8.26
Sewage Treatment Plant	Canal mouth	0.010-0.040	0.010-0.040	0.002-0.029	0.002-0.029	0.00-5.98
90th Street Canal	Canal	0.010-0.040	0.010-0.023	0.002-0.006	0.002-0.016	0.00-29.02
	Canal mouth	0.01-0.031	0.010-0.020	0.002-0.007	0.002-0.007	0.00-5.56
Bayside ambient	Control	0.010-0.020	0.010-0.013	0.002-0.006	0.002-0.005	0.00-29.16
Oceanside ambient	Control	0.010-2.000	0.010-2.000	0.002-0.006	0.002-0.005	0.00-4.41

[a]: Minimum values reported in the STORET database for some ranges are detection limits and not numerical measurements.

Table 2-24. Ranges of biochemical oxygen demand, fecal coliform concentration, total suspended matter concentration, turbidity, and Secchi depth measured in water samples collected at stations occupied during the 205(j) study conducted at Marathon, FL. [From FDER STORET database[a]]

Study Site	Station	Biochemical Oxygen Demand (mg/L)	Fecal Coliform (#/100mL)	Total Suspended Matter (mg/L)	Turbidity Depth (NTU)	Secchi (cm)
Faro Blanco Marina	Canal	0.4-1.2	5-2,100	1-15	0.7-4.9	137-264
	Canal mouth	0.1-0.9	0-1,960	2-19	0.4-8.1	112-231
City Fish Market	Canal	1.8-6.2	0-910	4-15	0.8-12.0	36-295
	Canal mouth	0.3-1.6	0-300	3-14	0.7-5.8	140-259
Winn Dixie Shopping Center	Canal	0.3-2.2	0-990	3-9	0.2-2.1	208-368
	Canal mouth	0.0-1.2	0-18	2-40	0.2-3.6	104-178
Key Colony Beach Sewage Treatment Plant	Canal	0.2-1.2	0-3,400	4-12	0.9-4.2	137-300
	Canal mouth	0.3-1.4	0-210	4-14	0.8-14.5	155-239
90th Street Canal	Canal	0.5-1.5	0-1,220	3-14	0.7-4.6	137-295
	Canal mouth	0.2-2.0	0-65	3-17	1.4-9.0	71-152
Bayside ambient	Control	0.0-1.1	0-120	0.6-15	0.7-9.2	122-257
Oceanside ambient	Control	0.0-0.8	0-12	2-25	0.6-33.0	43-290

[a]: Minimum values reported in the STORET database for some ranges are detection limits and not numerical measurements.

observed on two occasions at the station near the seafood processing plant. Elevated fecal coliform concentrations were observed at the three sites exposed to discharges of raw sewage, whereas fecal coliforms evidently somewhat controlled at the sewage treatment plant site. BOD_5 was elevated at the five canal sites as compared to BOD_5 at their respective ambient sites.

Nitrate and nitrate concentrations were similar among the canal, canal mouth, and ambient sites. Ammonia concentrations were similar, except near the seafood processing plant, where concentrations at the canal station were elevated in comparison to those at the offshore ambient site. Total Kjeldahl nitrogen concentrations were elevated at three canal stations but not at the canal station exposed to septic leachate. Total phosphorus concentrations were elevated at the canal stations located near the marina and seafood processing plant. Orthophosphate and chlorophyll *a* were also elevated at three canal sites.

4.1.4 Florida Department of Environmental Regulation — 1990

The FDER conducted an extensive study to assess and document the water quality in Boot Key Harbor and to examine the impacts of various pollution sources on the water quality, as reported by FDER (1990). Investigators measured water-quality parameters over 1 year (January 1989 to February 1990) at 14 stations. Stations were designated by STORET number and divided into three major categories. Stations were located in artificial (manmade) canals and basins, Outstanding Florida Waters within the Harbor, and offshore Outstanding Florida Waters. Station designations and their respective locations are summarized in **Table 2-25**.

Temperature, conductivity, pH, and DO concentrations were determined during monthly surveys, using *in situ* instrumentation. Also, water samples were collected with a Van Dorn sampler. Samples were analyzed to determine fecal coliform concentration and turbidity at monthly intervals. Chlorophyll *a*, total Kjeldahl nitrogen, total phosphorus, and nitrate plus nitrite concentrations were determined every other month.

A summary of the water-quality results of the program are presented in **Table 2-25**. Mean DO concentrations in artificial canals and basins ranged from 3.4 to 4.9 mg/L as compared to mean levels of 5.9 to 6.5 mg/L at the ambient control stations. Mean concentrations at the Outstanding Florida Waters Harbor stations were intermediate between the artificial waterway and ambient control stations, ranging from 4.8 to 5.7 mg/L. The FDER (1990) attributed this pattern to differences in flushing and the nature of the poorly flushed canals to serve as sinks for organic matter. The FDER (1990) also noted that during the summer the DO values in the study area were lower because the oxygen solubility decreased as temperature increased. However, DO levels in the artificial canals and basins were reduced throughout the year.

Mean pH levels for all stations exceeded 7.0; however, the mean levels at the artificial canal and basin stations were lower than at the ambient control stations. At one station (2804-2298), pH values below 7.0 were observed. The FDER (1990) suggested that this might be due to the presence of sulfides generated from anaerobic decomposition of organic material in the sediments at this station. The sulfides would lower pH in the water column.

The highest mean concentrations of coliform bacteria were observed at artificial waterway stations. They exceeded concentrations at ambient control stations, where the coliform bacteria were practically absent. Because coliform bacteria commonly are considered as indicators of sewage in water and because these organisms do not survive well at higher salinities, their presence probably indicated substantial contamination. The FDER (1990) concluded that leakage from septic tanks and discharges from live-aboard vessels were responsible for these elevated coliform counts.

In addition, the two Outstanding Florida Waters Harbor stations that had elevated fecal coliform levels were located in close proximity to live-aboard facilities. The FDER (1990) observed that the highest fecal coliform counts generally occurred during the winter months at the stations where live-aboard vessels were anchored on a

Table 2-25. Mean values for water quality parameters measured at Boot Key Harbor Study stations. [From FDER 1990]

	Station Location	Total Dissolved Oxygen (mg/L)	Fecal Coliform[b] (#/100mL)	Kjeldahl Nitrogen (mg/L)	Total Phosphorus (mg/L)	Chlorophyll *a* (µg/L)	pH	Turbidity (NTU)
Artificial Waterway								
Station 2804-2290[a]	Boat basin marina; operational pumpout facilities	4.9	45.1	0.513	0.031	1.4	7.7	2.5
2804-2292	Residential canal; septic tank systems	4.1	5.0	0.469	0.037	1.7	7.7	2.1
2804-2299	Basin with commercial fishing docks	4.5	34.2	0.493	0.037	1.0	7.6	2.5
2804-2298	Boat basin; poor water circulation; exposure to charter fishing-boat, live-aboard, septic-tank discharges	3.4	13.6	0.446	0.041	5.7	7.5	2.2
Outstanding Florida Waters								
Harbor								
Station 2804-2289	Near seafood marine	4.8	13.1	0.444	0.027	1.0	7.7	2.8
2804-2291	Near no site where discharges could impact water quality	5.5	2.6	0.444	0.029	1.2	7.8	2.2
2804-2294	Edge of tidal channel; well-flushed by tidal currents. *Potential exposure to septic-tank, surface-runoff discharges from nearby subdivision.*	5.7	1.6	0.417	0.027	1.0	7.8	2.2
2804-2295	Near condominium complex with STP discharging into injection well	5.6	4.4	0.474	0.029	1.6	7.8	3.0
2804-2296	Dredged area used by live-aboards as main anchorage	5.6	8.2	0.479	0.035	1.5	7.8	3.0
2804-2316	Adjacent to navigational channel; natural substrate inhabited by turtle grass	5.1	7.6					
2804-2297	Near live-aboards, with no pumpout facility	5.4	15.5	0.470	0.039	1.9	7.7	3.8
2804-2317	Natural turtle grass area	5.6					7.6	
Offshore (Outside Harbor)								
Station 2804-2288	*Ambient control station* In turtle seagrass bed	5.9	0.3	0.397	0.029	1.1	7.9	1.9
2804-2293	*Ambient control station* In hard-bottom, with turtle seagrass patches	6.5	0.0	0.406	0.027	1.1	7.9	1.1

NTU: Nephelometric turbidity unit.
STP: Sewage treatment plant.
[a]STORET number.
[b]NTU: Geometric mean.

seasonal basis, and that the highest coliform counts were observed at stations associated with on-site disposal systems or septic tanks after a heavy rainfall.

Mean total Kjeldahl nitrogen and total phosphorus concentrations were elevated at the artificial waterway stations as compared to the ambient control stations. Outstanding Florida Water harbor stations exhibited concentrations that were intermediate between these two station groups. The FDER (1990) suggested that important factors in the nutrient enrichment at the artificial waterway stations were anthropogenic sources of nutrients (i.e., sewage, industrial discharges, and surface runoff) and the decomposition of wind-blown weed wrack and other organic debris trapped in the canals. Mean chlorophyll *a* concentrations also were elevated at some of the artificial waterway stations, compared to the ambient control stations. Elevated mean turbidities were noted at artificial waterway and Outstanding Florida Waters stations compared to the ambient control stations.

4.1.5 Lapointe and Clark — 1990

Lapointe and Clark (1990) conducted a study between 12 September 1989 and 19 September 1990 to investigate the water quality in nearshore areas throughout the Florida Keys. During this study, water-quality parameters were measured at 30 monitoring sites. The monitoring sites were located in canals, seagrass beds, patch reefs, and bank reefs. Sampling sites located in the FKNMS were

- **Canals**
  Boca Chica "sub pens," Port Pine Heights, Doctors's Arm, Mariner's Resort, Boot Key, Duck Key, Port Antiqua, Venetian Shores, Ocean Shores, Largo Sound, and Glades Canal (C-111)
- **Seagrass beds**
  Pine Channel, Rachel Key, Blackwater Sound
- **Patch reefs**
  Newfound Harbor, Sawyer Key, Hens and Chickens, and Shark Reef
- **Bank reefs**
  Sand Key, Looe Key National Marine Sanctuary, Sombrero Reef, Alligator Reef, Molasses Reef, and Carysfort Reef

Sampling at each site was performed along an onshore/offshore transect. Samples were collected at 0.5 m below sea surface and at 0.5 m above the seafloor. Water-quality parameters determined during the study included temperature, salinity, turbidity, pH, and chlorophyll *a* concentration. Nutrient water-quality parameters included measurements of DO, nitrate plus nitrite, ammonium, soluble reactive phosphorus, total dissolved nitrogen, total dissolved phosphorus, particulate carbon, particulate nitrogen, and particulate phosphorus. Temperature, salinity, pH, and DO were measured *in situ*. Water samples were collected using a 5.0-L Niskin bottle. Three aliquots from each water sample were filtered and analyzed for chlorophyll *a*, particulate phosphorus, and particulate carbon and nitrogen. Chlorophyll *a* was determined by fluorometry. Particulate carbon and nitrogen were determined by using an elemental analyzer, and particulate phosphorus was determined via persulfate oxidation. Filtered-water samples were analyzed for ammonium, nitrate plus nitrite, total dissolved nitrogen, total dissolved phosphorus, and soluble reactive phosphorus. Ammonium, nitrate plus nitrite, total dissolved nitrogen, and total dissolved phosphorus were determined with an autoanalyzer. Soluble reactive phosphorus was determined by spectrophotometry. Turbidity was determined with a turbidimeter.

A summary of the results for this study is presented in Tables 2-26 and 2-27. Water temperature at the study sites varied with season, whereas salinity generally was consistent over time at individual study sites and more variable among the sites, depending on location. DO concentrations generally were higher at stations located offshore (bank reef stations) as compared to the stations in the nearshore. Although not specifically reflected in the mean DO concentrations of Table 2-26, oxygen levels at some canal stations were at time hypoxic, particularly during the summer. At Doctor's Arm Canal, DO concentrations were below 4 mg/L near the surface and bottom at several stations during summer and winter; at one near-bottom location, the concentration

Table 2-26. Mean values of water temperature, salinity, turbidity, pH, chlorophyll *a*, and dissolved oxygen at locations sampled by Lapointe and Clark (1990).

Location	Survey	Temperature (°C)	Salinity (ppt)	Turbidity (NTU)	pH	Chlorophyll *a* (μg/L)	Dissolved Oxygen (mg/L)
Sand Key	Summer	29.77	36.8	0.46	—	0.087	6.64
	Winter	24.74	36.2	0.57	7.96	0.031	6.58
Looe Key National Marine Sanctuary	Summer	30.20	36.6	0.20	—	0.091	6.25
	Winter	24.90	36.3	0.47	7.97	0.049	6.42
Sombrero Reef	Summer	29.96	36.5	0.60	—	—	6.58
	Winter	25.14	36.4	0.27	8.00	0.044	6.71
Alligator Reef	Summer	30.65	36.8	0.34	7.72	0.230	6.05
	Winter	24.48	36.5	0.15	8.02	0.038	6.77
Molasses Reef	Summer	29.92	35.6	0.16	8.02	0.422	5.86
	Winter	24.76	36.4	0.27	8.01	0.046	6.41
Carysfort Reef	Summer	30.18	35.4	0.17	8.02	0.250	5.81
	Winter	24.44	36.5	0.57	7.90	0.052	6.51
Sawyer Key	Summer	30.28	38.7	0.57	—	0.482	6.52
	Winter	23.98	37.4	1.20	8.01	0.112	6.83
Newfound Harbor	Summer	30.83	36.5	1.12	—	0.156	5.66
	Winter	24.19	37.1	0.66	8.02	0.081	6.65
Hens and Chickens	Summer	30.16	36.6	0.59	7.73	0.221	6.49
	Winter	25.19	36.2	0.41	8.12	0.058	6.77
Shark Reef	Summer	30.56	35.6	0.23	8.03	0.186	6.14
	Winter	24.80	36.4	0.17	7.98	0.053	6.65
Pine Channel	Summer	31.67	37.5	0.57	—	0.141	6.49
	Winter	22.67	38.0	0.36	8.12	0.075	7.03
Rachael Key	Summer	29.34	38.7	1.60	—	0.069	6.42
	Winter	25.06	38.1	1.78	7.96	0.059	6.60
Little Blackwater Sound	Summer	31.00	29.9	0.70	8.00	0.600	6.40
	Winter	26.94	42.4	3.86	7.85	0.160	5.66
Boca Chica Submarine Pens	Summer	29.96	42.5	0.63	—	0.305	5.35
	Winter	23.16	40.0	1.12	8.02	0.092	6.04
Port Pine Heights	Summer	31.49	39.0	0.49	—	0.542	5.30
	Winter	23.39	37.8	0.48	8.07	0.114	6.40

Table 2-26. Mean values of water temperature, salinity, turbidity, pH, chlorophyll *a*, and dissolved oxygen at locations sampled by Lapointe and Clark (1990). (continued)

Location	Survey	Temperature (°C)	Salinity (ppt)	Turbidity (NTU)	pH	Chlorophyll *a* (μg/L)	Dissolved Oxygen (mg/L)
Doctor's Arm Canal	Summer	30.02	37.0	1.43	—	2.374	3.65
	Winter	23.79	38.1	1.58	7.76	0.263	4.41
Mariner's Resort Canal	Summer	27.20	41.0	1.85	—	—	4.75
	Winter	22.31	38.8	1.43	7.82	0.396	5.46
Boot Key Harbor	Summer	29.40	37.8	2.34	—	2.350	5.07
	Winter	25.48	37.9	4.59	7.94	0.762	5.84
Duck Key Canal	Summer	29.51	36.9	5.69	—	0.257	5.70
	Winter	25.46	38.0	8.62	8.04	0.295	6.25
Port Antigua Canal	Summer	30.42	39.7	0.74	—	0.517	5.38
	Winter	22.00	40.3	0.50	8.00	0.299	6.77
Venetian Shores	Summer	30.48	40.9	0.52	7.60	0.675	4.92
	Winter	24.96	37.8	1.38	7.86	0.111	5.57
Port Largo Canal	Summer	29.90	37.5	0.38	7.18	15.510	4.17
	Winter	24.02	32.6	3.14	7.76	0.324	5.02
Largo Sound Canal	Summer	31.80	46.8	0.42	7.58	1.177	4.41
	Winter	26.14	39.2	0.85	7.72	0.206	5.29
Glades Canal (C-111)	Summer	31.10	33.0	2.10	7.56	0.801	2.78
	Winter	24.20	42.2	0.69	7.90	0.415	6.20

Table 2-27. Mean values of nutrient parameters at locations sampled by Lapointe and Clark (1990).

Location	Survey	Nitrate plus Nitrite (µM)	Ammonium (µM)	Soluble Reactive Phosphorus (µM)	Total Dissolved Nitrogen (µM)	Total Dissolved Phosphorus (µM)	Particulate Carbon (µg/L)	Particulate Nitrogen (µg/L)	Particulate Phosphorus (µg/L)
Sand Key	Summer	0.51	0.09	0.12	2.66	0.35	175.34	18.95	3.38
	Winter	0.17	UD	0.07	2.40	0.28	146.96	12.32	2.80
Looe Key National Marine Sanctuary	Summer	0.62	0.10	0.08	2.85	0.33	188.40	18.17	3.22
	Winter	0.07	UD	0.04	4.19	0.22	132.59	9.63	2.20
Sombrero Reef	Summer	0.51	0.08	0.07	3.33	0.26	203.86	10.06	3.43
	Winter	0.45	0.09	0.04	2.04	0.16	74.60	11.83	2.03
Alligator Reef	Summer	0.27	UD	0.04	3.00	0.12	121.43	15.76	3.50
	Winter	0.11	UD	0.03	4.66	0.13	73.41	7.81	2.10
Molasses Reef	Summer	0.23	UD	UD	2.32	0.13	98.88	13.85	2.82
	Winter	0.18	UD	0.03	2.14	0.13	76.87	9.12	1.87
Carysfort Reef	Summer	0.25	0.25	UD	2.74	0.06	81.02	12.00	2.85
	Winter	0.19	0.21	0.04	3.55	0.22	158.63	22.54	3.05
Sawyer Key	Summer	0.13	0.13	0.08	4.77	0.34	180.93	23.09	3.73
	Winter	0.17	0.11	0.06	3.19	4.09	225.30	18.08	3.67
Newfound Harbor	Summer	0.21	0.11	0.12	4.95	0.37	209.53	23.17	5.65
	Winter	0.28	0.11	0.05	2.88	0.31	148.30	12.68	2.98
Hens and Chickens	Summer	0.30	UD	0.06	2.52	0.11	129.81	14.35	3.12
	Winter	0.12	0.14	0.05	2.89	0.13	104.41	9.10	1.22
Shark Reef	Summer	0.11	0.39	0.06	2.21	0.13	83.67	12.32	2.90
	Winter	0.05	UD	UD	2.25	0.14	71.79	8.47	8.47
Pine Channel	Summer	1.42	1.61	0.10	4.57	0.36	148.30	20.96	3.35
	Winter	0.32	0.27	0.06	2.97	0.12	113.28	9.50	2.46
Rachael Key	Summer	0.25	0.20	0.12	4.21	0.35	314.56	32.13	8.30
	Winter	0.39	0.19	0.06	3.97	0.38	571.74	22.41	3.08
Little Blackwater Sound	Summer	0.40	1.60	0.10	13.30	0.20	236.40	21.50	3.70
	Winter	2.59	2.20	0.06	8.12	0.13	476.91	29.39	4.82
Boca Chica Submarine Pens	Summer	0.78	0.17	0.18	5.84	0.42	143.61	20.72	3.58
	Winter	0.52	0.20	0.07	4.18	0.10	145.10	19.67	2.95
Port Pine Heights	Summer	1.86	0.21	0.16	6.82	0.39	189.03	27.35	3.67
	Winter	0.99	0.64	0.09	4.59	0.14	153.46	14.62	3.55
Doctor's Arm Canal	Summer	0.79	1.63	0.35	6.93	0.79	415.13	63.30	13.23
	Winter	1.52	2.18	0.10	4.97	0.28	330.34	30.35	7.33

Table 2-27. Mean values of nutrient parameters at locations sampled by Lapointe and Clark (1990). (continued)

Location	Survey	Nitrate plus Nitrite (μM)	Ammonium (μM)	Soluble Reactive Phosphorus (μM)	Total Dissolved Nitrogen (μM)	Total Dissolved Phosphorus (μM)	Particulate Carbon (μg/L)	Particulate Nitrogen (μg/L)	Particu' Phosp (μg/L)
Mariner's Resort	Summer	0.77	0.83	0.75	10.36	1.35	—	—	—
Canal	Winter	0.59	2.43	0.11	4.83	0.69	368.67	43.69	10.65
Boot Key Harbor	Summer	0.26	0.22	0.40	5.98	0.71	490.77	59.10	9.93
	Winter	0.38	0.37	0.13	3.38	0.44	714.73	47.44	8.63
Duck Key Canal	Summer	0.52	0.09	0.06	3.66	0.33	771.69	52.28	7.50
	Winter	0.23	0.36	0.06	2.84	0.12	699.44	46.57	7.83
Port Antigua Canal	Summer	1.34	0.38	0.36	6.25	0.69	272.49	28.66	5.50
	Winter	1.91	0.75	0.28	4.12	0.36	167.21	23.63	3.20
Venetian Shores	Summer	0.69	0.73	0.17	7.72	0.32	261.17	34.32	6.72
	Winter	2.73	0.54	0.09	6.02	0.16	284.62	25.23	4.38
Port Largo Canal	Summer	0.48	0.77	0.32	3.17	0.80	395.25	41.17	41.30
	Winter	1.33	0.67	0.11	5.06	0.19	382.98	30.39	9.37
Largo Sound Canal	Summer	0.58	0.39	0.15	12.31	0.22	171.35	25.37	8.12
	Winter	1.34	0.16	0.09	4.52	0.17	196.43	22.51	5.02
Glades Canal	Summer	1.22	2.96	0.12	5.81	0.24	143.72	16.54	6.97
(C-111)	Winter	0.99	0.86	0.07	8.71	0.21	441.90	38.82	4.90

was 0.36 mg/L. Extremely low concentrations were also observed near the bottom at one Boot Key Harbor sampling station (0.06 mg/L) and at one near-bottom sampling station at Glades Canal (0.16 mg/L) during the summer. Reduced DO concentrations also were observed at other canal sampling sites, including Boca Chica Submarine Pens, Port Pine Heights, Mariner's Resort Canal, Port Antigua Canal, Port Largo Canal, and Largo Sound Canal. DO concentrations occasionally were reduced (<4 mg/L) at sampling sites that Lapointe and Clark (1990) designated as seagrass sites (i.e., Pine Channel and Little Blackwater Sound).

Dissolved nutrient concentrations generally were elevated at designated canal sites as compared to designated bank reef sites, the latter of which were located in offshore waters of the Sanctuary. Mean ammonium levels at the canal sites ranged from 0.09 to 2.96 and from 0.16 to 2.43 μM in the summer and winter, respectively. By comparison, mean ammonium levels at bank reef sites ranged from undetected to 0.25 μM and undetected to 0.21 μM (summer and winter, respectively). Mean nitrate plus nitrite levels at the bank reef sites ranged from 0.25 to 0.62 μM and from 0.07 to 0.47 μM in the summer and winter, respectively. Mean concentrations of these nutrients at canal sites were 0.26 to 1.86 and 0.23 to 2.73 μM at the canal sites (summer and winter, respectively). Mean soluble reactive phosphorus levels at the canal sites ranged from 0.06 to 0.75 and from 0.06 to 0.28 μM in the summer and winter, respectively. By comparison, mean soluble reactive phosphorus levels at the bank reef sites ranged from undetected to 0.16 and 0.03 to 0.07 μM (summer and winter, respectively). Lapointe and Clark (1990) suggested that these elevated levels, particularly soluble reactive phosphorus, were associated with development around the canals. This suggestion was based on the fact that the soluble-reactive phosphorus concentration at the station located in the Boca Chica submarine pens, where there has been little development, was similar to the corresponding station located in Outstanding Florida Waters. These investigators concluded that this indicated no significant enrichment of soluble reactive phosphorus within this canal.

4.1.6 Szmant — 1991

As part of the first phase of the SEAKEYS Program, Szmant (1991) investigated the water quality at four sites on the ocean side of the Florida Keys. The objective of the study was to collect data on the distribution of nitrogen and phosphorus macronutrients and chlorophyll *a* in the water and sediments of the Florida Reef Tract. Although the primary emphasis of this Program was to determine select nutrients in the vicinity of the Florida Reef Tract, the surveys were performed in a manner to provide information from nearshore oceanic waters.

During this phase of the study, Szmant (1991) sampled stations located on seven transects. For purposes of sampling, Hawk Channel marked the point of separation of inshore areas (where there are few patch reefs) from the offshore Florida Reef Tract and associated waters.

Transects were oriented inshore/offshore from shore locations where potential sources of nutrients were located. Sampling at inshore stations was expected to result in elevated nutrient levels, particularly in developed areas or within inter-Key passes. At offshore stations, oligotrophic (low-nutrient) conditions were expected. Four stations minimum were located on each transect, with stations located in both inshore and offshore areas.

Transects were located at the following locations (as shown in Figure 2-9)

- **Biscayne National Park**
  6 stations during summer and winter (high and low tide)
- **Long Key**
  13 stations sampled during summer and winter (high and low tide)
- **Key Largo**
  35 stations during summer and 13 stations during winter
- **Looe Key**
  7 stations sampled during spring and summer

Water samples were collected with Niskin bottles. Samples were collected 1 m below the sea surface and 1 m above the seafloor. In the laboratory, total nitrogen and phosphorus concentrations were determined from unfiltered subsamples. Filtered subsamples were analyzed to determine chlorophyll *a*, nitrate plus nitrite, phosphate, and ammonium concentrations.

Szmant (1991) presented the data for the concentrations of the measured parameters as bar graphs. Actual values will be published later. Inshore/offshore trends and concentrations were examined and interpreted from Szmant's (1991) graphical presentation.

At the Biscayne National Park sampling site, Szmant (1991) observed that nitrogen in the water column was primarily organic or particulate. Inshore concentrations at Caesar's Creek ranged from less than 10 to about 40 μM; offshore concentrations at Pacific Reef ranged from below detection to about 35 μM. Szmant (1991) observed that storms had an important impact on total nitrogen levels. During stormy periods, when particulates were suspended in the water column, total nitrogen concentrations exceeded 40 μM in some samples. During calm periods, concentrations of total nitrogen generally were between 8 and 12 μM. Ammonium concentrations generally were below detection limits. However, a concentration of approximately 1.25 μM was observed on one survey at Pacific Reef. Szmant reported that nitrate concentrations were generally below 0.3 μM. However, because the methods indicated that water samples were analyzed for nitrate plus nitrite, it was assumed that this concentration was for nitrate plus nitrite. Phosphate levels were generally less than about 0.1 μM. Total phosphorus levels were generally about 0.25 μM or less, but total phosphorus did reach concentrations of 1 μM during storms. Chlorophyll *a* concentrations were low, typically not exceeding 0.25 μg/L.

Szmant (1991) observed that organic and inorganic concentrations of nitrogen and phosphorus were higher in canals and inshore stations at the Key Largo study site. During the summer survey, total nitrogen and phosphorus concentrations at the canal stations reached approximately 38 and 4.5 μM, respectively. Concentrations at the offshore stations did not exceed approximately 13 and 1.3 μM for total nitrogen and phosphorus, respectively. Ammonium reached concentrations exceeding 0.3 μM at four of seven inshore stations and was not detected at the seven stations located farthest offshore. Similarly, nitrate plus nitrite concentrations at six of seven of the inshore stations exceeded 0.5 μM but did not exceed 0.5 μM at any of the seven offshore stations during the summer survey. Chlorophyll *a* also was elevated at some of the canal and inshore stations during the summer survey, exceeding 1 μg/L in one instance. During this survey, chlorophyll *a* concentrations at the offshore stations were less than 0.4 μg/L.

Szmant (1991) observed that the nutrient concentrations observed at Long Key generally were higher than those observed at the Biscayne National Park and Key Largo study sites and that the nutrient concentrations were higher at stations located in Florida Bay than at oceanside stations. Total nitrogen, ammonium, and nitrate plus nitrite concentrations tended to be higher during low tide than high tide, an observation that Szmant (1991) suggested may indicate that Florida Bay was a source for elevated nitrogen levels observed at some stations located on the Florida Reef Tract. On one occasion, the ammonium concentration at one Bayside station reached 2 μM. During low tide, nitrate plus nitrite concentrations exceeded 1.5 μM at several bayside, inshore, and Hawk Channel stations. No obvious differences between Florida Bay, inshore, and offshore waters were noted for phosphate levels; phosphate concentrations generally were between 0.20 and 0.25 μM. Total phosphorus concentrations generally were low (<0.25 μM), and higher concentrations were sometimes observed at the offshore stations. Chlorophyll *a* concentrations were higher than those observed at the Biscayne National Park and Key Largo study sites, exceeding 0.5 μg/L on only two occasions.

Szmant (1991) reported water-quality data for only one sampling period at the Looe Key study site. Total nitrogen concentrations ranged from approximately 10 to 15 μM and obvious inshore/offshore trends were not apparent. Higher concentrations of ammonium and nitrate plus nitrite were observed at the station located in Bahia Honda Channel, reaching or exceeding 0.5 and 1 μM, respectively. Total phosphorus concentrations were consistently less than 0.5 μM and phosphate concentrations did not exceed 0.15 μM. With the exception of a sample collected within a wrack of decaying seagrass, chlorophyll *a* concentrations were generally less that 0.5 μg/L.

Szmant (1991) concluded that nutrient and chlorophyll *a* concentrations were elevated at inshore areas, particularly marinas and developed canals, in the upper Keys (i.e., Biscayne National Park and Key Largo sampling sites); however, the water quality improved with increasing distance from shore, approaching oligotrophic conditions within a few hundred meters of shore. Storms were also found to affect the concentrations of total nitrogen and phosphorus because sediments are suspended into the water column. In the middle Keys (Long Key), Szmant (1991) concluded that exchanges through passes between Florida Bay and the Atlantic Ocean were responsible for the pattern of nutrient distributions. The data supported the contention that water quality is poorer in developed canals and some adjacent nearshore area than it is farther offshore, but they do not support assertions that extensive nutrification is occurring in offshore areas.

4.1.7 Lapointe *et al.* — 1992

Lapointe *et al.* (1992) investigated potential transport of nutrients through channels in the lower Keys to the reef tract, specifically the reefs in Looe Key National Marine Sanctuary. Data were collected from October 1986 to October 1988. The objective of the study was to determine the potential for nutrients generated in nearshore waters to be transported to the reef tract. This was done by comparing data on water currents and water column nutrients to water transport and nutrient fluxes.

Sampling occurred at 11 stations. Stations were located in South Pine Channel, Newfound Harbor Channel, Bahia Honda Channel, and Moser Channel. A single station was located in Hawk Channel, between the keys and the reef tract. Six stations were located at the reef — Deep Fore Reef, East Back Reef, East Fore Reef, West Fore Reef, West Back Reef, and Central Back Reef.

Near-bottom current meter data were collected in channels in the lower Keys (Newfound Harbor, Bahia Honda, and Moser Channels) and at stations located on the fore and back reef in the Looe Key National Marine Sanctuary. Current data were evaluated as progressive vector diagrams for the stations located at the reef and net cumulative displacement was determined for the along-channel direction for stations located in the channels. The net water flow through the channels was found to be predominantly from the Gulf of Mexico into Hawk Channel. Flow in Hawk Channel was generally westward along the channel but seaward displacement was observed.

From 3 January to 12 February 1983 at the station in South Pine Channel, water samples were collected at midday twice per week to evaluate the effects of terrestrial runoff on nutrient concentrations in nearshore waters of the Keys. Sampling at the other stations was conducted at three-week intervals from 17 October 1986 to 18 January 1988. Water samples were collected with 5-L Niskin bottles, filtered to remove particulate material, and preserved until analysis. Water-quality parameters included temperature, ammonium, nitrate plus nitrite, soluble reactive phosphorus, chlorophyll *a*, turbidity and Secchi depth. Ammonium and nitrate plus nitrite were determined using an autoanalyzer. Soluble reactive phosphorus in samples collected at South Pine Channel was determined by autoanalyzer and by spectrophotometer for the other stations. Turbidity was determined using a turbidimeter. Rainfall data were obtained from the NOAA weather service at the Key West airport.

Ammonium concentrations were positively correlated with rainfall at the South Pine Channel station for the six week study. Concentrations were generally less than 0.10 μM during the two weeks before a major rainfall period, and exceeded 4.5 μM after the last week in January 1983 when 30 cm of rainfall was observed. Soluble reactive phosphorus was undetected after the period of heavy rainfall.

For the longer term study, nutrient and chlorophyll *a* data were pooled into "wet" and "dry" categories based on the quantity of rainfall for the seven days prior to each sampling. Mean concentrations of ammonium observed during wet periods were twice those observed during dry periods. Significant ammonium increases during wet periods were observed at the Newfound Harbor Channel, Bahia Honda Channel, Central Back Reef, West Fore Reef, and Deep Reef stations. Ammonium was significantly correlated with the quantity of rainfall. Ammonium concentrations were also observed to increase relative to the soluble reactive phosphorus concentrations during wet periods.

The investigators combined the near-bottom current data with the water column nutrient data to calculate ammonium flux. Flux values ranged from 0.1 to 0.8 moles $NH_4/m^2/d$ during dry periods to 0.5 to 2.4 moles $NH_4/m^2/d$. Ammonium flux was greater at the nearshore channel stations and decreased with increasing distance from shore. At all channel stations, the ammonium flux was southward from the Gulf of Mexico to Hawk Channel. At the reef stations, the flux was primarily west-southwestward, along Hawk Channel, but seaward flux was observed.

Chlorophyll *a* concentrations were elevated during wet periods at most stations. Chlorophyll *a* levels were significantly correlated with ammonium concentrations. Chlorophyll *a* concentrations ranged from 0.1 to 1.1 μg/L. The pattern of chlorophyll *a* flux was similar to that of ammonium.

Turbidity values ranged from 0.1 to 6.0 NTU and were significantly correlated with rainfall and wind speed. Higher turbidity was generally observed at nearshore stations compared to offshore stations. Highest values of turbidity were associated with high wind stress such as the passage of Hurricane Floyd (12 October 1987) and cold fronts during winter.

The investigators concluded that near-bottom transport of nutrients from nearshore waters across Hawk Channel to the reefs in Looe Key National Marine Sanctuary is a likely nutrient source to sustain long-term nutrient input. In addition, they argue that nutrients generated by human activities in the Keys have increased the ammonium flux to nearshore waters, and these nutrients contribute to the nutrient wake from the land masses to the reef tract. In addition, nutrients from Florida Bay passing through the channels were thought to contribute to the nutrient wake.

4.2 SUMMARY

The studies summarized previously not only provide an overview of the water quality in the FKNMS, but they also indicate the relative paucity of data presently available to assess the water quality of the Keys. Available data were insufficient to demonstrate temporal changes in water quality because no well-designed, long-term studies have been conducted.

Nearshore/offshore trends were very evident in all of the studies reviewed during this assessment. Artificial waterways and canals in developed areas are subjected to nutrient loading and the commensurate changes in increased organic matter and reduced DO concentration. For the most part, nearshore Outstanding Florida Waters are not subjected to the same level of nutrient loading as are artificial canals and waterways. In areas of development, however, the data do indicate that there may be some nutrient loading. The studies reviewed do not indicate that offshore Outstanding Florida Waters are undergoing degradation. However, anecdotal information suggests that these waters may be undergoing degradation. Overall, the data indicate that well flushed areas (e.g., by exchange of water with the offshore oceanic region) tend to have good water quality. In nearshore areas where there is no adequate flushing (i.e., areas subjected to anthropogenic influx of nutrients), the water quality tends to be poor.

This determination agrees with the water assessment performed by the FDER as part of a 305(b) study (FDER 1990). During this study, water quality was examined through an inventory of their STORET database for the period 1980 to 1989. It was determined that water quality in the Florida Keys generally was good in areas that were well flushed because of exchanges with the Gulf of Mexico and Atlantic Ocean. Reduced flushing, however, exacerbated water-quality problems in many manmade canals and marinas.

5.0 PROJECTED WATER QUALITY (YEAR 2010)

The future water quality in FKNMS waters depends on the natural and on the anthropogenic pollutant loadings that take place. The temporal and spatial variability of the loadings will also significantly affect the water quality. The factors that will probably most affect the anthropogenic loadings will be population growth, spatial distribution of the population increase and land use, required treatment efficiencies of wastes from the existing and increased population, and selected disposal mechanisms of the wastes.

5.1 POPULATION AND LAND USE

5.1.1 Population

For the past several years, Monroe County and its municipalities have been preparing local comprehensive plans in accordance with the requirements of Section 163.3161, Florida Statutes, and Rule 9J-5, Florida Administrative Code (FAC). The plans serve as the local governments' primary growth management tool. Once local governments complete drafting their plans, they must submit them to the State planning agency, the Florida Department of Community Affairs (FDCA), for review and comment. This statutory requirement directs the FDCA to identify where the local comprehensive plans might conflict with adopted State and regional policy or provisions of the planning statute or Rule 9J-5 FAC that have gone unaddressed, or where there might be technical deficiencies. On conclusion of their review, the FDCA issues an Objections, Recommendations and Comment (ORC) report, and transmits it to the local governments.

Monroe County submitted their Plan to FDCA, which issued an ORC report identifying areas of conflicts and deficiencies. One area of conflict involved the methodology used to develop population projections. To assist the County in addressing this and other cited objections, the County contracted with the firm of Wallace Roberts & Todd and their subcontractors (WRT team).

Monroe County is unique; it is different from every other County in Florida. It does not have a ready supply of potable water; it contains extensive areas of environmentally sensitive lands; it has severe restrictions relative to safe hurricane evacuation. Due to the severe constraints to growth, the WRT team concluded that the level of growth defined in its Comprehensive Plan must be based on a carrying-capacity approach rather than simply on historical growth patterns (Wallace Roberts & Todd *et al.* 1991a).

On 13 November 1991, the Board of County Commissioners reviewed a WRT team report that evaluated the impact that various carrying-capacity constraints (i.e., traffic circulation, hurricane evacuation, potable water, sanitary sewer, drainage, recreation/open space, and solid waste) would have on future growth in Monroe County. Hurricane evacuation-clearance time was determined to pose the most severe restriction on future growth. The Board determined to allocate net growth capacity over a 10-year period (1992-2002) and to allocate approximately 31% to the three municipalities of Key West, Layton, and Key Colony Beach. Thus, the amount of growth to be allocated by Monroe County in the unincorporated area over the next 10 years was determined to be some 2552 units or approximately 255 equivalent residential units per year (Wallace Roberts & Todd *et al.* 1991b).

Further, the WRT team recommended a compact pattern for future residential growth allocation. This will support "infill" development within existing developed areas. "Because the prospective future allocation of residential growth is very small relative to the quantity of development already in place, the impact of this future growth allocation, regardless of the pattern selected will be relatively small as well" (Wallace Roberts & Todd *et al.* 1991b).

5.1.2 Land Use

The Keys are grouped into three general regions, the upper, middle and lower Keys. The upper Keys comprise all areas north of the Whale Harbor Bridge. The middle Keys extend from Whale Harbor Bridge on the north to Seven Mile Bridge on the south. The lower Keys comprise the islands south and/or west of the Seven Mile Bridge to and including the City of Key West.

Residential activities are the predominant type of activity in the Keys. More than 10,200 acres were in residential use in 1986 (Monroe County 1986). Residential acreage reflects more than just the homes of the permanent, year-around residents. There are more than 20 resorts in the Keys that serve primarily the seasonal dweller. Roughly 43% (4400 acres) of all residential land is situated in the upper Keys, 9% (940 acres) in the middle Keys, and 48% or 4865 acres in the lower Keys (Monroe County 1986; Solin 1991; A. Tallerico, South Florida Regional Planning Council, personal communication, 1992). In the middle and lower Keys, most of the residential use is situated in the two urban centers, Marathon and Key West.

Commercial activities are closely tied to serving the retail and personal service needs of the permanent population or activities such as motel, hotels, and restaurants that serve the seasonal population. General commercial activities, e.g, retail, service-related businesses, are generally concentrated in four areas, Key Largo, upper Matecumbe Key, Marathon, and Key West (Monroe County 1986; Solin 1991).

Tourist-related uses, especially campgrounds, are scattered throughout the Keys. The presence of major tourist attractions such as Looe Key National Marine Sanctuary and John Pennekamp Coral Reef State Park, have produced a tourist-oriented local economy that is based on diving and snorkeling the reefs. There are numerous dive shops, reef boats and private charters, party boats, and backcountry fishing expeditions (Rockland 1988).

With many military installations in the Keys, it is not surprising that over 6500 acres of land is utilized by the United States Navy and the United States Coast Guard (Monroe County 1986; Solin 1991). The largest installation is situated on Boca Chica Key: the Boca Chica Naval Air Station. There are military lands to be found on Saddlebunch and Cudjoe Keys as well as Marathon.

Another major-use category is conservation. These generally are lands that have been designated by the Fish and Wildlife Service, the State of Florida, and Monroe County as being either wildlife refuge land or land acquired for conservation purposes. There are approximately 20,000 acres designated as conservation lands in the Keys (Monroe County 1986).

The WRT team is in the process of completing a land-use survey of the Keys (G. Garrett, Monroe County, personal communication, 1991). The firm has also prepared alternative future land-use concepts as part of Monroe County's 1990-2010 Comprehensive Plan (Wallace Roberts & Todd *et al.* 1991b).

5.2 WATER-QUALITY STANDARDS

The State has a series of administrative rules that impact wastewater effluent. Rule 17-600, Florida Administrative Code (FAC), titled Domestic Wastewater Facilities, establishes a set of rules for the treatment and reuse or disposal of domestic wastewater. The rule is to assure that all waters of the State shall be free from components of domestic wastewater discharges which, alone or in combination with other substances are (1) acutely toxic; (2) present in concentrations which are carcinogenic, mutagenic, or teratogenic to humans, animals, or aquatic species; or (3) otherwise pose a serious threat to the public health, safety, and welfare.

There are a number of minimum secondary treatment effluent standards that apply to facilities discharging via ocean outfall, as well as standards for treatment facilities discharging via underground injection. Some of the effluent parameters include biochemical oxygen demand (BOD_5), TSS, DO, pH, fecal coliform, and chlorine residual.

It can be stated generally that there are no adopted comprehensive statewide nutrient limitations placed on the effluent generated from domestic dischargers. Section 403.086, Florida Statutes, addresses nutrient limits; however, they apply only to a portion of the State in the vicinity of Tampa Bay. A similar statute sets effluent requirements for the Indian River Lagoon (B. DeGrove, FDER, personal communication, 1992). The nutrient limits set for the Tampa Bay area are:

- Total Nitrogen, expressed as N — 3 mg/L
- Total Phosphorous, expressed as P — 1 mg/L

Rules 17-610.510 FAC and 17.610.560 FAC provide for a 12 mg/L limit on nitrates for rapid rate and absorption field discharges. Around the State there are golf courses that utilize treated wastewater for irrigation purposes. The public golf course on Stock Island is considering implementing such a system (J. Bottone, FDER, personal communication, 1992; K. Williams, CH_2M Hill, personal communication, 1992).

Monroe County has not addressed nutrient standards in its Comprehensive Plan, but the proposed Sanitary Wastewater Master Plan will determine the necessary level of treatment throughout Monroe County. The Wastewater Master Plan will research the feasibility of implementing the adopted policy of 60% nutrient removal (Wallace Roberts & Todd *et al.* 1991a).

For the past year and a half, the City of Key West has been monitoring the effluent from its wastewater treatment facility. Besides BOD_5, TSS, and fecal coliform, the City is monitoring for nitrogen, ammonia, and phosphorous (Solin 1991).

Further, the City of Key West has addressed nutrient standards in its Comprehensive Plan (Solint 1991). The Plan states that, if the City is to minimize eutrophication of ocean waters, the following standards for nitrates and phosphates in effluent discharged into ocean water should be adopted:

- Total nitrogen: 6 mg/L
- Total phosphorus: 4 mg/L

5.3 NUTRIENT LOADINGS

Based on the limited data available for water quality and biotic resource effects (Tasks 3 and 4), it appears that organic loading/nutrients represent a serious long-term threat to the FKNMS. There may be other potential threats, but a comprehensive water-quality monitoring program is needed to evaluate these possibilities.

Camp Dresser and McKee, Inc. (1990) summarized nutrient loadings to marine coastal waters in the upper (Sand Key to south of Plantation Key) Keys for the years 1990 and 2010. The nutrient loadings were used in conjunction with a model and water-quality data to study the relative contribution of the nutrient sources to nutrient availability in the vicinity of offshore coral reefs. Scenarios to limit nutrient availability were investigated. An attempt was made to summarize nutrient inputs from wastewater treatment plants, OSDSs, stormwater, and boat live-aboards. Literature values were used for levels of nutrients. The values presented show no nitrate loadings from OSDS; however, conventional OSDS effluent undergoes a moderate degree of nitrification in the drainfield, and aerobic treatment units discharge a fully nitrified effluent. Tables 2-28(a) and (b) show the estimated wastewater loadings. Tables 2-29(a) and (b) compare the estimated wastewater and

Table 2-28. Summary of wastewater pollution loads discharged to the upper Florida Keys study area. [From Camp Dresser and McKee 1990]

(a) Winter

Pollutant	Package Plants (lb/day)	Live-Aboard Boats (lb/day)	On-site Disposal Systems (lb/day)	Total (lb/day)
Land Use Scenario: Existing (1990)				
SS	16	32	120	168
BOD	16	60	224	300
PO_4	6	5	18	29
NH_3	20	13	240	273
$NO_2 + NO_3$	140	0	0	140
Land Use Scenario: Future (2010)				
SS	19	36	148	203
BOD	19	68	278	365
PO_4	8	5	22	35
NH_3	24	15	298	337
$NO_2 + NO_3$	169	0	0	169

(b) Summer

Pollutant	Package Plants (lb/day)	Live-Aboard Boats (lb/day)	On-site Disposal Systems (lb/day)	Total (lb/day)
Land Use Scenario: Existing (1990)				
SS	8	0	77	85
BOD	8	0	144	152
PO_4	3	0	11	14
NH_3	10	0	155	165
$NO_2 + NO_3$	70	0	0	70
Land Use Scenario: Future (2010)				
SS	10	0	98	108
BOD	10	0	182	192
PO_4	4	0	14	18
NH_3	12	0	195	207
$NO_2 + NO_3$	85	0	0	85

Table 2-29. Comparison of pollution loads discharged to the upper Florida Keys study area. [From Camp Dresser and McKee 1990]

(a) Winter

Pollutant	Wastewater[a] Effluent (lb/day)	Wastewater[a] Effluent (%)	Stormwater Runoff (lb/day)	Stormwater Runoff (%)	Total (lb/day)
Land Use Scenario: Existing (1990)					
BOD	300	72	114	28	414
PO_4	29	91	3	9	32
NH_3	273	99	4	1	277
$NO_2 + NO_3$	14	67	7	33	21
Land Use Scenario: Future (2010)					
BOD	365	73	138	27	503
PO_4	35	90	4	10	39
NH_3	337	99	4	1	341
$NO_2 + NO_3$	169	95	8	5	177

[a]Includes on-site disposal systems, package plants, and live-aboard boats.

(b) Summer

Pollutant	Wastewater[a] Effluent (lb/day)	Wastewater[a] Effluent (%)	Stormwater Runoff (lb/day)	Stormwater Runoff (%)	Total (lb/day)
Land Use Scenario: Existing (1990)					
BOD	152	34	291	66	443
PO_4	14	61	9	39	23
NH_3	165	94	11	6	176
$NO_2 + NO_3$	70	81	16	19	86
Land Use Scenario: Future (2010)					
BOD	192	36	346	64	538
PO_4	18	62	11	38	29
NH_3	207	95	12	5	219
$NO_2 + NO_3$	85	82	19	18	104

[a]Includes on-site disposal systems, package plants, and live-aboard boats.

stormwater loadings. In the winter, wastewater was estimated to contribute more than 90% of the nutrient loads and 75% of the BOD_5 loads under existing as well as future conditions. In the summer, wastewater production was assumed to be significantly reduced since only the year-around resident population was considered in generating the loading estimates. In addition, the seasonal distribution of rainfall within the upper Florida Keys study area projects increased stormwater source loads in summer relative to winter conditions. As a result, stormwater pollutant loads contribute nearly 40% of the phosphorus load during summer conditions. The accuracy of the estimates is unknown because a number of assumptions of unknown validity were made. Additionally, constituent values from outside the Florida Keys were extensively used. Based on available data, it is not possible to reliably update these estimates of nutrient loadings for the Florida Keys.

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CORAL COMMUNITY ASSESSMENT
Task 3

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TASK 3 — CORAL COMMUNITY ASSESSMENT

1.0 INTRODUCTION

Coral reef communities are an assemblage of tropical and subtropical marine plants and animals growing together creating complex shallow-water limestone structures. These structures provide the physical framework and habitat for large numbers of other plants, invertebrates, and fishes. There are many factors limiting the distribution of coral reefs, including temperature, salinity, light, nutrient availability, and ocean circulation patterns. These factors define the predominant plant and animal communities, based upon the optimal requirements of each community.

The greatest accumulation of hard, reef-forming corals, and other associated biota occurs on coral reefs. However, these biota are also present elsewhere at a number of other density levels. These densities range from isolated individuals to more extensive accumulations. *Hard bottom, hard grounds, live bottom, coralgal banks,* and *patch reefs* are some of the terms used to describe these accumulations. The term *coral communities* is used in this Section to describe these various density levels.

The purpose of this Section is to provide a brief description of the Florida Keys National Marine Sanctuary (FKNMS) coral communities. Both natural and human-induced factors affecting the vitality of coral communities in the FKNMS are described, based upon a review of the available scientific data and literature as well as conversations with acknowledged coral community experts.

2.0 CORAL COMMUNITY TRENDS

2.1 CORAL COMMUNITY DISTRIBUTION

Hard-bottom areas, patch reefs, and bank reefs in the Florida Keys are found from almost intertidal habitats to 13 km offshore, in depths ranging from less than 1 to 41 m. They extend from Cape Florida south and west to the Dry Tortugas (**Figure 3-1**), due in part to the warm Florida Current and its role in moderating winter temperatures, bringing plankton to the reefs, and providing recruitment to the area (Jaap 1984). The distribution of coral communities in the Florida Keys is directly related to regional water quality. Extensive reefs occur where barriers to the transport of potentially lower-quality waters (i.e., Florida Bay, Biscayne Bay) are in place. These barriers are formed by the large islands in the upper and lower Keys. In the middle Keys, only limited reef development has taken place because of the many channels connecting Florida Bay to the Straits of Florida. These Bay waters may have temperature and salinity ranges, turbidity levels, and quantities of nutrients that are incompatible with coral reef development or survival (Ginsburg and Shinn 1964; Lidz and Shinn 1991).

The reefs of the FKNMS are high-latitude coral reefs. In high latitude reefs, corals exist at the maximum limits of their range. Under these conditions, many temperate and subtropical algal species may be found at near optimal conditions and minor shifts in water temperature, nutrient level, or grazing activity allow the subtropical algae to out-compete the corals (Johannes *et al.* 1983b; Crossland *et al.* 1984; Smith 1988).

Within the FKNMS, there are an estimated 19,420 ha of reef and 110,635 ha of low-relief hard-bottom (BLM and FDNR 1979; FWS and MMS 1983; CSA and GMI 1991). The reef habitat includes coral patch reefs and the interspersed sediments and seagrass, bank reefs, and coral reef flats. The low-relief hard-bottom designation comprises sparse though dense hard-bottom communities as well as areas of finger corals, octocorals, and coralline algae. The total estimated area of the seagrass and algal bottom habitat is 591,045 ha; the remaining unmapped bottom area of the newly designated FKNMS is 260,000 ha (H. Norris, Florida Marine Research Institute, personal communication, 1991).

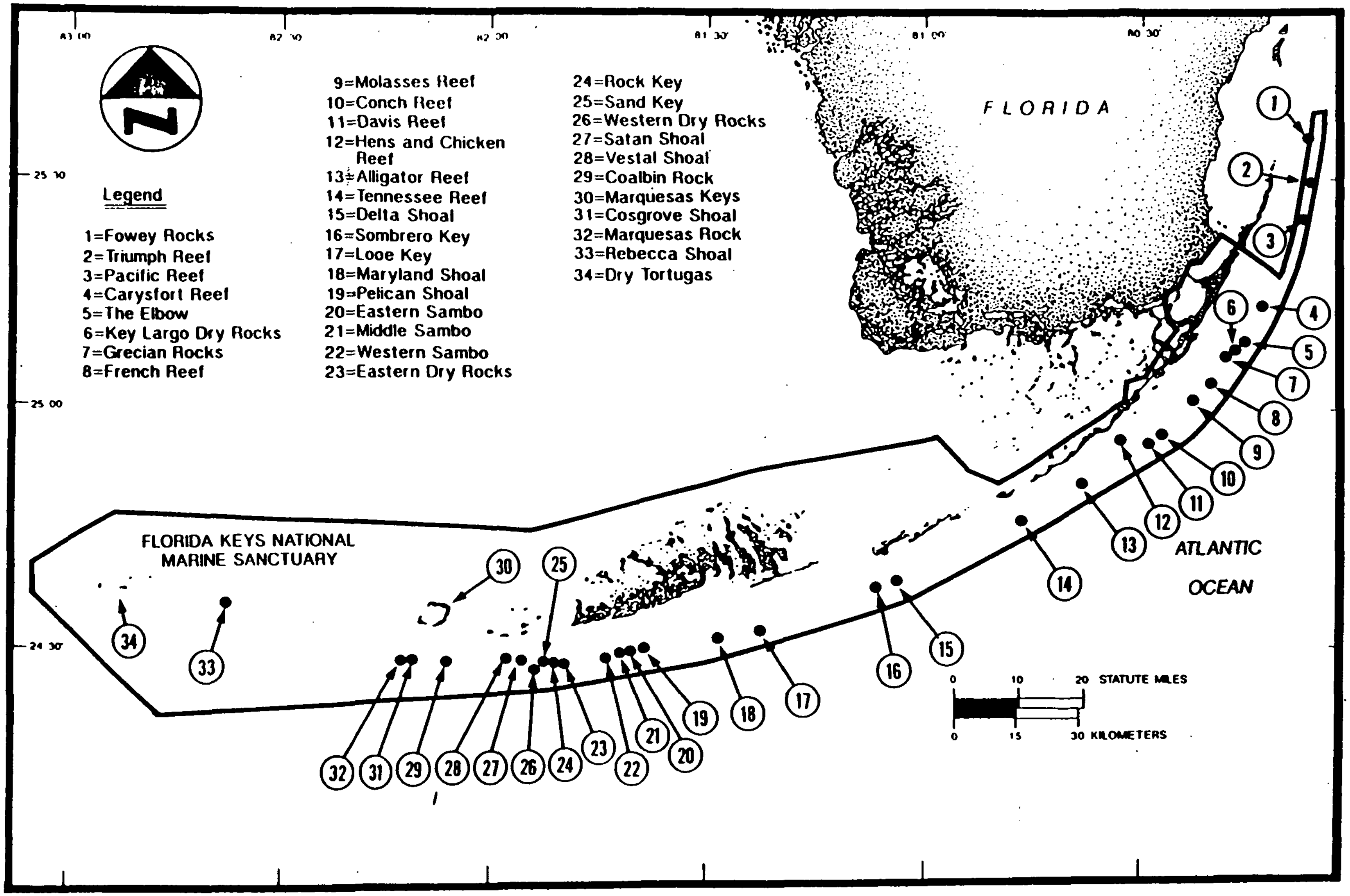

Figure 3-1. Major reefs of the Florida Reef Tract.

Hard-bottom or live-bottom communities are found closest to shore, in depths that range from less than 1 m to greater than 30 m. These areas are composed of exposed rock substrate colonized by algae, sponges, hydrozoans, octocorals, small hard corals, bryozoans, and ascidians. The hard corals found in these communities are generally small and are not actively building reef structures.

Patch reefs typically are found offshore of Hawk Channel and inside the bank reefs in water depths of up to 9 m, although a few may be found in nearshore areas (Jaap and Hallock 1990). Patch reefs are relatively randomly distributed among the seagrass and hard-bottom areas, and thereby they provide structure and increase the complexity of the habitats. The massive star and brain corals form the bulk of the reef; algae, sponges, octocorals, and bryozoans fill in the framework.

Bank reefs are found seaward of Hawk Channel and the patch reefs, and are situated parallel to shore. As mentioned previously, most bank reefs are found in the upper and lower Keys where land masses shield them from Florida Bay waters. Bank reefs typically consist of spur-and-groove formations that extend offshore, perpendicular to the coastline or depth contours. The spurs are long reef structures that are covered with corals, sponges, and other reef biota. The grooves run parallel to and between the spurs and contain coralline rubble and sand.

Dustan and Halas (1987) documented significant changes between 1974 and 1982 in the hard-coral community of Carysfort Reef. They used repetitive line transects to measure the individual colonies along the transects to determine changes in the mean colony size, abundance, and cover. They found that the community had changed significantly over 8 years, with the corals having increased in abundance in the shallow reef areas and decreased in abundance on the deeper fore reef. The increased abundance in the shallow reef areas appears to have resulted from the fragmentation of larger colonies of *Acropora palmata* into smaller colonies by vessel groundings, anchor damage, and diver activities.

Porter (manuscript in preparation), during surveys of permanent monitoring quadrats on reefs at Looe Key and Key Largo, detected a 4% loss in coral cover per year between 1984 and 1986. Unpublished data indicate that this loss in coral cover may have increased since 1986. The causes for the decline appear to be a higher incidence of coral disease during the most recent survey and coral bleaching (J. Porter, University of Georgia, personal communication, 1991). Additional quantitative surveys are currently being undertaken by Porter at specific locations in the Biscayne National Park.

Sullivan *et al.* (1992) summarized data collected for two hard-bottom communities in sites off Long Key. These sites, Fiesta Key on the Florida Bay side of Long Key and Craig Key on the ocean side of Channel 5, represent inshore and nearshore hard-bottom communities, respectively. These sites can be characterized as follows:

	Craig Key	Fiesta Key
Total area	810,900 m^2	100,763 m^2
% Sand	8.6%	4.1%
% Hard bottom	54.6%	16.7%
% Seagrass	36.8%	74.4%
% Land	0%	4.8%

The results of this work showed that Fiesta Key has experienced a greater rate of change in community structure than Craig Key. On Fiesta Key, the largest change in structure occurred between the Fall 1989 and Fall 1990 sampling when the Fiesta Key site showed a decrease in octocoral and sponge abundance. A second result of this work was that although both reefs fall into the same general community designation, they are very different; Fiesta Key is an algal-dominated reef and Craig Key is an octocoral/sponge-dominated reef.

2.2 CORAL BIOLOGY

The corals present in the Florida Keys are composed of hydrozoan corals, including *Millepora* (fire coral), octocorals (sea whips and fans), and scleractinian corals (hard or stony corals). Tables 3-1 and 3-2 list the scleractinian and shallow-water octocoral species found on the reefs of southeast Florida and the Florida Keys, as noted by Jaap (1984).

The fire corals *Millepora alcicornis* and *M. complanata* are common to western Atlantic tropical reefs. These species have very high concentrations of zooxanthellae in their tissues, giving them a golden brown color. Although growth-rate data for these two species are limited, upward growth is estimated by Jaap (1984) to approach 10 cm annually.

Octocorals are generally the most common coral observed on Florida Keys reefs, with documented densities of up to 27 colonies per square meter (Opresko 1973); unpublished data indicate densities as high as 73 colonies per square meter (Wheaton and Jaap 1988). Life history information on most octocoral species is scarce; the taxonomy and systematics of this group are also confusing. As noted by Bayer (1961), a single species may have different growth forms and variations in the shape of its skeletal spicules, based upon the conditions of its immediate environment (e.g., water depth, turbulence, light intensity, etc.). Growth rates of 10 to 40 mm per year for *Plexaura homomalla* have been reported by Kinzie (1974), whereas Cary (1918) reported most reef-dwelling species of octocorals from the Dry Tortugas region reached a medium size in 3 to 5 years, with slower growth rates evident with increasing coral age.

Scleractinian corals are the major reef builders. They have life spans ranging from just a few years for the small finger corals up to hundreds of years for the more massive star corals and brain corals (Jaap and Hallock 1990). Growth rates for a number of hard-coral species from Florida and the Bahamas are presented in Table 3-3. These rates ranged from 3.5 mm/year for the plate coral *Agaricia agaricites* to greater than 100 mm/year for the rapid growing branching coral *Acropora cervicornis*. Growth rates for the massive, head-forming corals are relatively slow, with *Montastrea annularis* averaging approximately 8 mm/year on the nearshore reefs of the Key Largo National Marine Sanctuary (Hudson 1981). Jaap (1984) gives a more detailed description of some of the other basic components of the coral reef ecosystem, including algae, sponges, reef fishes, and plankton, along with a discussion of coral reef ecology.

2.3 CORAL ZOOXANTHELLAE

Hard corals and octocorals are hosts to symbiotic algae. These algae, collectively called zooxanthellae, are dinoflagellates that naturally exist in both the free-living and symbiotic state. These algae were once assigned by systematists to the genera *Symbiodinium* and *Gymnodinium* (Darley 1982), but have most recently been proposed for reclassification based upon the genetic relationship in small ribosomal subunit RNA nuclear genes (Rowan and Powers 1991).

The exact size of a population of zooxanthellae within a coral polyp cannot be measured *in situ*, but can be estimated by using techniques such as the average mitotic index (Muscatine 1990). This method assumes a constant algal division rate and estimates the number of algae, based on the number of dividing cells.

Relationship between Zooxanthellae and Coral Polyps

There is a complex relationship between the zooxanthellae symbiont and its cnidarian host, the coral (animal). Many components of this relationship and its physical and physiological benefits have been examined and

Table 3-1. Southeast Florida reef Scleractinia. [From Jaap 1984]

ORDER SCLERACTINIA

SUBORDER ASTROCOENIINA Vaughan and Wells 1943

Family Astrocoeniidae Koby
- *Stephanocoenia michelini* (Milne Edwards and Haime)

Family Pocilloporidae Gray
- *Madracis decactis* (Lyman)
- *M. formosa* Wells
- *M. mirabilis* (*sensu* Wells)

Family Acroporidae Verrill
- *Acropora palmata* (Lamarck)
- *A. cervicornis* (Lamarck)
- *A. prolifera* (Lamarck)

SUBORDER FUNGIINA Verrill

Superfamily Agariciicae Gray

Family Agariciidae Gray
- *Agaricia agaricites* (Linné)
- *A. agaricites agaricites* (Linné)
- *A. agaricites danai* Milne Edwards and Haime
- *A. agaricites carinata* Wells
- *A. agaricites purpurea* (LeSueur)
- *A. lamarcki* Milne Edwards and Haime
- *A. undata* (Ellis and Solander)
- *A. fragilis* (Dana)
- *Helioseris cucullata* (Ellis and Solander)

Family Siderastreidae Vaughan and Wells
- *Siderastrea radians* (Pallas)
- *S. siderea* (Ellis and Solander)

Superfamily Poriticae Gray

Family Poritidae Gray
- *Porites astreoides* (Lamarck)
- *P. porites* (Pallas)
- *P. porites divaricata* LeSueur
- *P. porites furcata* Lamarck
- *P. porites clavaria* Lamarck
- *P. branneri* Rathbun

SUBORDER FAVIINA

Superfamily Faviicae Gregory

Family Faviidae Gregory
- *Favia fragum* (Esper)
- *F. gravida* (Verrill)
- *D. clivosa* (Ellis and Solander)
- *Diploria labyrinthiformis* (Linné)
- *D. strigosa* (Dana)
- *Manicina areolata* (Linné)
- *M. areolata mayori* (Wells)
- *C. amaranthus* (Müller)
- *C. breviseralis* Milne Edwards and Haime
- *Colpophyllia natans* (Houttyn)
- *Cladocora arbuscula* (LeSueur)
- *M. annularis* (Ellis and Solander)
- *Montastraea cavernosa* (Linné)
- *S. bournoni* Milne Edwards and Haime
- *Solenastrea hyades* (Dana)

Family Rhizangiidae d'Orbigny
- *Astrangia astreiformis* (Milne Edwards and Haime)
- *A. solitaria* (LeSueur)
- *Phyllangia americana* Milne Edwards and Haime

Family Oculinidae Gray
- *Oculina diffusa* Lamarck
- *O. varicosa* LeSueur
- *O. robusta* Pourtales

Family Meandrinidae Gray
- *Meandrina meandrites* (Linné)
- *M. meandrites braziliensis* Milne Edwards and Haime
- *Dichocoenia stellaris* Milne Edwards and Haime
- *D. stokesii* Milne Edwards and Haime
- *Dendrogyra cylindrus* Ehrenberg

Table 3-1. Southeast Florida reef Scleractinia. [From Jaap 1984] (continued)

Family Mussidae Ortmann
- *Mussa angulosa* (Pallas)
- *Scolymia lacera* (Pallas)
- *S. cubensis* Milne Edwards and Haime
- *Isophyllia sinuosa* (Ellis and Solander)
- *I. multiflora* Verrill
- *Isophyllastraea rigida* (Dana)
- *Mycetophyllia lamarckiana* Milne Edwards and Haime
- *M. danaana* Milne Edwards and Haime
- *M. ferox* Wells
- *M. aliciae* Wells

SUBORDER CARYOPHYLLIINA Vaughan and Wells 1943

Superfamily Caryophylliicae Gray

Family Caryophylliidae Gray
- *Eusmilia fastigiata* (Pallas)
- *Paracyathus pulchellus* (Philippi)

SUBORDER DENDROPHYLLIINA Vaughan and Wells 1943

Family Dendrophylliidae Gray
- *Balanophyllia floridana* Pourtales

Table 3-2. Octocoral fauna in shallow southeast Florida reef communities. [From Jaap 1984; Wheaton 1987; Wheaton and Jaap 1988; Dustan *et al.* 1991]

Species	Patch Reef	Bank Reef
Briareum asbestinum	x	x
Ellisella barbadensis		x
E. elongata		x
Erythropodium caribaeorum	x	x
Eunicea palmeri	x	x
E. pinta	x	x
E. mammosa	x	x
E. succinea	x	x
E. fusca	x	x
E. laciniata	x	x
E. tourneforti	x	x
E. asperula	x	x
E. clavigera	x	x
E. knighti	x	x
E. calyculata	x	x
Gorgonia ventalina	x	x
Iciligorgia schrammi	x	x
Lophogorgia hebes	x	
Muricea muricata	x	x
M. atlantica	x	x
M. laxa		x
M. elongata	x	x
Muriceopsis flavida	x	x
M. petila		x
Nicella schmitti		x
Plexaura homomalla	x	x
P. flexuosa	x	x
Pseudoplexaura porosa	x	x
P. flagellosa	x	x
P. wagenaari	x	x
P. crucis	x	x
Plexaurella dichotoma	x	x
P. nutans	x	x
P. grisea	x	x
P. fusifera	x	x
Pseudopterogorgia bipinnata	x	x
P. kallos	x	x
P. rigida	x	x
P. acerosa	x	x
P. americana	x	x
P. elisabethae	x	x
P. navia		x
Pterogorgia citrina	x	x
P. anceps	x	x
P. guadalupensis	x	
Swiftia exserta		x

Table 3-3. Growth rates of scleractinian species from Florida and the Bahamas[a]. [From Jaap 1984]

Species	Growth rate[b] (mm/year)	Location	Source
Acropora cervicornis	40.0 H	Dry Tortugas	Vaughan and Shaw 1916[c]
	109.0 H	Key Largo Dry Rocks	Shinn 1966
	115.0 H	Eastern Sambo	Jaap 1974
A. palmata	39.5 H	Goulding Cay, Bahamas	Vaughan and Shaw 1916
	105.0 B	Eastern Sambo	Jaap 1974
A. prolifera	37.2 H	Goulding Cay, Bahamas	Vaughan and Shaw 1916
Agaricia agaricites	3.5 H	Dry Tortugas	Vaughan and Shaw 1916
Dendrogyra cylindrus	10.4 H	Dry Tortugas	Vaughan and Shaw 1916
Dichocoenia stokesii	6.7 D	Dry Tortugas	Vaughan and Shaw 1916
Diploria labyrinthiformis	7.8 D	Dry Tortugas	Vaughan and Shaw 1916
D. clivosa	17.3 D	Dry Tortugas	Vaughan and Shaw 1916
D. strigosa	6.9 H	Dry Tortugas	Vaughan and Shaw 1916
	5.0 H	Carysfort	Shinn 1975
Eusmilia fastigiata	5.8 H	Dry Tortugas	Vaughan and Shaw 1916
Favia fragum	4.9 D	Dry Tortugas	Vaughan and Shaw 1916
Isophyllia sinuosa	5.1 D	Goulding Cay, Bahamas	Vaughan and Shaw 1916
Manicina areolata	8.2 D	Dry Tortugas	Vaughan and Shaw 1916
M. areolata mayori	14.0 D	Dry Tortugas	Vaughan and Shaw 1916
Montastraea cavernosa	4.4 H	Dry Tortugas	Vaughan and Shaw 1916
M. annularis	9.0 H	Key West	Agassiz 1890
	5.0 - 6.8 H	Dry Tortugas	Vaughan and Shaw 1916
	10.7 H	Carysfort	Hoffmeister and Multer 1964
	8.4 H	Carysfort	Shinn 1975
	8.0 - 9.7 H	Key Largo area	Hudson 1981
Oculina diffusa	14.3 H	Dry Tortugas	Vaughan and Shaw 1916
Porites porites	17.9 H	Dry Tortugas	Vaughan and Shaw 1916
P. astreoides	17.6 D	Dry Tortugas	Vaughan and Shaw 1916
Siderastrea radians	4.3 D	Dry Tortugas	Vaughan and Shaw 1916
S. siderea	6.3 D	Dry Tortugas	Vaughan and Shaw 1916

[a]Goulding Cay, Bahamas data were used only when Tortugas information was unavailable.
[b]B: Increase in branch length. D: Increase in diameter. H: Increase in height.
[c]Multiple values from Vaughan and Shaw (1916) were averaged.

characterized. Direct benefits to the algal symbiont and its coral host, along with the exact mechanisms of nutrient transfer, are less well understood (Miller and Veron 1990; Muscatine 1990). Possession of algae are believed to benefit corals by supplying nutritional requirements when they cannot be met heterotrophically (Cook and D'Elia 1987; Muller-Parker *et al.* 1988). The coral can obtain nutrition heterotrophically by capturing prey with its tentacles or autotrophically through its symbiont algae, the latter of which translocate photosynthetically fixed material (Porter 1976; Muscatine and Porter 1977). Zooxanthellae photosynthesis also aids in the coral's production of its carbonate skeleton by providing the coral with energy for calcification (Goreau and Goreau 1959a,b).

Debate in the literature has traditionally centered on the percentage of energy supplied to the coral by capturing prey versus energy from photosynthetically fixed carbon, the mechanism of transfer, and the nature of control exerted between the coral and its symbiont algae (D'Elia and Cook 1988; Miller and Yellowlees 1989). Hallock (1981) estimated that the energy available to the host for growth and respiration is 1 to 2 orders of magnitude above that available to a heterotroph that does not have a symbiont. However, values for photosynthetic and respiratory quotients for reefs have not been empirically established (Muscatine 1990). Research using stable isotopic ratios indicates that corals living at depths down to 50 m use carbon from photosynthesis by zooxanthellae, but that carbon from direct feeding by coral becomes increasingly important with increasing depth (Muscatine *et al.* 1989).

3.0 FACTORS OR PROCESSES STRESSFUL TO CORAL COMMUNITIES

A number of factors, both natural and human-induced, affect the vitality of coral reefs, including reefs in the Florida Keys. These include biological competition, predation, disease, stress from various types of pollution, algal fouling and smothering, sedimentation, temperature extremes, salinity variations, decreases in water clarity, and physical damage. Many of these factors are interrelated and synergistic in their effects on the coral community (e.g., warm or cold water stressing coral colonies and making them more susceptible to disease). This Section attempts to cover most of these factors, with the exception of physical damage, but concentrates on potential and known detrimental effects due to water-quality deterioration.

3.1 BIOLOGICAL INTERACTIONS

There are numerous ways in which corals are adversely affected by other members of the community in which they live. Competition among and between hard-coral species has been documented extensively and includes chemical defenses (Cameron 1974; Sullivan *et al.* 1983), digestion of competing species tissues by the extension of mesenterial filaments (Lang 1971, 1973), and actual overgrowth and shading of slower growing species by those with a more rapid growth rate (Shinn 1975, 1989).

Hard corals are also killed by damselfish, which will destroy the coral tissue and then farm the algae that colonize the dead coral skeleton (Kaufman 1977). Parrotfish (Scaridae), butterflyfish (Chaetodontidae), and other damselfish (Pomacentridae) are also known to feed upon hard corals (Glynn 1973). The polychaete worm *Hermodice carunculata* is also known to feed on coral species (Marsden 1962; Ebbs 1966; Lizama and Blanquet 1975). The long-spined sea urchin, *Diadema antillarum*, although primarily an herbivore that rasps algae off the limestone reef providing coral larvae with new attachment sites, may also remove these newly settled larvae while feeding (Sammarco 1980).

Boring sponges have been shown to rapidly erode hard-coral skeletons by dissolving any organic matter and etching away the carbonate rock with acid (Rutzler and Rieger 1973; Pomponi 1977). In work done in Belize by Highsmith *et al.* (1983), boring sponges had caused 85% to 94% of the erosion of cavities in the massive corals studied. Hein and Risk (1975) analyzed eight heads of several species of reef corals from Hens and

Chickens Reef near Tavernier, Florid_ **ral skeletal structure reworked by**
boring sponges, spionid polychaetes, ar **and that surface bioerosion of dead**
Montastrea annularis **heads was initi**. **ng sponges followed by increased**
erosion by parrotfish (Scaridae) and th **rum. Risk and MacGeachy (1978)**
included bacteria, fungi, boring algae, **sipunculids, barnacles, and bivalve**
molluscs as important reef bioeroders.

Octocorals are not immune to the eff **has been documented by Wahle**
(1980) that colonies of the fire coral **rby colonies of octocorals, grow**
toward, and then overgrow the imm **od molluscs** ***Cyphoma*** **spp. are a**
common predator upon certain octocoral

A variety of diseases can cause coral **la,b, 1985; Bak and Criens 1981;**
Gladfelter 1982; Peters 1984). They **pristine as well as from heavily**
polluted areas. These include various **(or black-line) disease and white-**
band disease being the most well-kno **weakened corals (Jaap 1985; Te**
Strake ***et al.*** **1988); calicoblastic neop**l **tous green algal tumors (Morse** ***et***
al. **1981). Black-band disease and** **ow. Bacterial disease was also**
suspected of decimating the long-spin **lations throughout the Caribbean**
during 1983-1984. The urchins have st **evels.**

Black-band disease was described origi **ed by the common blue-green alga**
Oscillatoria submembranacea. **Subse**q **scribed the causative agent as the**
cyanobacteria ***Phormidium corallyticu*** **om the characteristic black band,**
composed of cyanobacteria and decomp **across the surface of the coral as**
the disease spreads. Hard corals have **black-band disease either while**
suffering from white-band disease, after **species, or when a dense band of**
filamentous green algae occurs along **The white-band disease and the**
digestion of competing species tissues **living tissue in the affected coral,**
exposing the coral's endoderm to infec **tous green algae buildup along a**
coral margin causes a chafing of the co **ater movement, also exposing the**
coral tissue to infection. Once infected **head at up to 1 cm/day during**
daylight hours, although the rate diminis **81b).**

Black-band disease seems to be more **nian corals. Of these,** ***Diploria***
strigosa **and** ***Montastrea annularis*** **are** **Species of western Atlantic hard**
corals that are less frequently obs **isease include** ***D. clivosa, D.***
labyrinthiformis, M. cavernosa, Colp **nd** ***Siderastrea siderea.*** **In the**
Florida Keys, ***Montastrea annularis*** **is** **large colonies at Carysfort Reef**
having been killed from 1978 to 1985 **s also reported that bla k b d**
disease was seriously infecting corals **not alone in being a**
black-band disease — the octocorals ***G*** ***ra homomalla, P.***
Pseudopterogorgia acerosa **have also** **(Antonius 1985**
including penicillin, erythromycin, and **l black band c**
1981b).

3.2.2 White-Band Disease

White-band disease is similar to black-band disease in the way that it progresses across the coral surface in an observable line, although the line in this case is approximately 1 cm wide and white. The zooxanthellae-containing coral tissue and mucus slough off the coral as the disease spreads. Unlike black-band disease, white-band disease is not affected by antibiotics and the speed of advance does not diminish at night (Antonius 1981b). On branching forms of coral, the disease starts at the base and proceeds out to the branch tips. On lobate forms, the disease typically begins in a shady area or crack where there is some type of algal growth (Antonius 1981b). Peters (1984) suggests that an unusual gram-negative bacteria that is resistant to antibiotics may be responsible for some of the cases of white-band disease; in other cases in which microorganisms cannot be seen, the disease may be due to physiological stress caused by high nutrient levels or excessive sedimentation. White-band disease shows a distinct seasonality in Bermuda and Florida waters, with occurrences peaking during the warmest months of the year and disappearing in late fall. Black-band disease also shows this seasonality, but lags slightly behind the white-band disease (Antonius 1981a,b).

Dustan (1977) described this disease as a plague in work that he had performed at Carysfort Reef off Key Largo in 1975. He observed the disease in *Mycetophyllia ferox*, *M. lamarckiana*, and *Colpophyllia natans* and found *M. ferox* to be extremely susceptible to the disease, with death usually occurring within 4 months. Other Caribbean corals known to commonly contract the disease include *Acropora cervicornis*, *A. palmata*, *A. prolifera*, *Diploria strigosa*, and *Montastrea annularis* (Antonius 1981b). The disease appears to affect various species with differing frequencies, depending upon geographic location. *Acropora palmata* is the most affected coral species in the Virgin Islands, with the disease starting at the base of the coral and progressing to the tips of the branches (Gladfelter 1982). On 44 of 45 colonies studied by Gladfelter (1982) in St. Croix, Virgin Islands, the disease destroyed the entire colony. In Florida and Belize populations of *A. palmata*, the disease is seldom observed (Antonius 1981b). Table 3-4 lists hard-coral species from the Caribbean Sea found to have white-band disease, black-band disease, or both, as observed in the field.

3.3 TEMPERATURE

Thermal stress can adversely affect a coral reef system and, because of the Florida Keys' location on the northern edge of the subtropics, both heat and cold stress are frequently experienced. Annual mean seawater temperatures in the Florida Keys range from 18 to 30 °C (Jaap 1984). Cold-water stress occurs in the Keys when a winter cold front extends into south Florida and cools the shallow waters of Florida Bay and nearshore water of the Keys. As this cool, dense water moves south out of Florida Bay through the passes, it sinks under the warmer surrounding waters, hugging the bottom, and exposing the reefs to cold temperatures. Numerous occurrences of coral mortality have been reported for the Florida Keys in recent years. During a January 1977 cold front, temperatures dropped below 16 °C for 8 days. This caused the death of 91% of the shallow-water *Acropora cervicornis* at Loggerhead Key in the Dry Tortugas (Roberts *et al.* 1983). The same cold front also caused the death of 96% of the living corals in depths less than 2 m at Dry Tortugas reefs (Porter *et al.* 1982). A cold-water mass was implicated in the death of as many as 90% of the corals at Hens and Chickens Reef off Plantation Key in the winter of 1969-1970 (Hudson *et al.* 1976). In January 1981, record low temperatures were the cause of cold-water mortalities of hard corals near Elliot Key in the upper Keys and at Looe Key (Walker *et al.* 1982).

Elevated water temperatures can also stress corals, principally causing zooxanthellae expulsion (or coral bleaching). In more severe cases, disease and death have been reported. High water temperatures may be more localized than are cold-water events and typically occur during periods when seas are calm and when low tides coincide with high midday temperatures. Since 1973, there have been four major zooxanthellae expulsions in the Florida Keys and South Florida that were caused by increased water temperatures. Corals at Middle

Table 3-4. Corals observed to contract black-band or white-band disease in the Caribbean. [From Antonius 1981b]

Species	Occurrence		
	Frequent	Seldom	Never
Acropora palmata	W		B
A. prolifera	W		B
A. cervicornis	W		B
Agaricia agaricites	W		B
A. tenuifolia	W		B
Siderastrea siderea		WB	
S. radians		W	B
Porites astreoides	W		B
Favia fragum	W	B	
Diploria clivosa		B	
D. labyrinthiformis		B	
D. strigosa	WB		
Colopophyllia natans		B	B
Montastrea annularis	WB		
M. cavernosa		WB	
Dichocoenia stokesi		B	W
Dendrogyra cylindrus			WB
Mycetophyllia lamarcki		W	B
M. ferox	W		B
Millepora sp.			WB
Gorgonia ventalina		B	W
G. flabellum		B	W

W: White-band disease
B: Black-band disease
WB: Both white- and black-band diseases.

Sambo Reef, near Boca Chica Key, expelled their zooxanthellae in late September but most regained their zooxanthellae within 6 weeks (Jaap 1979). During September 1983, there was extensive coral bleaching from Key Largo to the Dry Tortugas owing to high water temperatures (Jaap 1985). A very extensive zooxanthellae expulsion began in July 1987, and lasted for 6 months. It extended from Palm Beach to the Dry Tortugas and was reported throughout the Caribbean and into the northern Gulf of Mexico as well (Jaap 1988). The most recent coral bleaching occurred in 1990 and 1991 and was likely caused by elevated seawater temperatures and potentially increased exposure to ultraviolet illumination (W. Jaap, Florida Marine Research Institute, personal communication, 1992). The 1983 and 1987 bleaching events were also experienced in the eastern, central, and western Pacific (Glynn 1984; Williams and Williams 1988). The 1982-1983 El Niño Southern/Oscillation apparently caused the first documented case of species extinction from a warming event. An undescribed species of *Millepora* that was endemic to the Gulf of Chiriqui off the west coast of Panama apparently did not survive the severe bleaching of early 1983 and is therefore presumed to be extinct (Glynn and De Weerdt 1991).

Although coral bleaching is discussed relative to elevated water temperatures, this stress response also manifests itself because of other factors. These can include low water temperatures, low light conditions, exposure to air, low salinities, increased levels of sedimentation, and various pollutants (D'Elia *et al.* 1991).

3.4 WATER TRANSPARENCY AND SEDIMENTATION

Coral development and growth is dependent upon water clarity because the zooxanthellae need sunlight to photosynthesize. In the waters of high clarity that are typical on coral reefs, phytoplankton efficiently absorb available nutrients and increase their division rates to outcompete larger organisms (Geider *et al.* 1986; Smith *et al.* 1981). An increase in water-column phytoplankton densities that can be caused by higher levels of nutrients in the water results in a decrease in light penetration and, in turn, may stress the corals (Hallock *et al.* 1988).

Increases in waterborne particulate matter also cause decreased light penetration through the water column. Water clarity over the Florida Keys reefs varies from extremely clear (following extensive periods of calm weather) to virtually opaque (after sustained storms and hurricanes when fine sediments become resuspended) (Jaap 1984). Decreased light penetration caused by sediment suspension is only one of the problems that beset corals living near dredging activities (Rogers 1990).

Sedimentation adversely affects corals because it causes the corals to increase mucus production. For example, corals increase mucus production to slough away materials that settle out on the colonies, thereby diverting energy that would normally be utilized for growth (Lasker 1980; Marszalek 1981; Rogers 1983; Kendall and Powell 1988). Increased mucus production due to sedimentation has also been implicated as a cause of increased incidence of disease in corals. The higher output of mucus provides a substrate for bacterial and other pathogenic growth (Mitchell and Chet 1975; Loya 1976a,b; Loya and Rinkevich 1980). Sedimentation causes the burial of hard substrates, reducing the available hard substrate for coral settlement and recruitment. Sedimentation also adversely affects hard corals when the coral margin is covered with tufts of filamentous algae. These algae tufts tend to trap fine sediments and form a dense mat that eventually overgrows the coral margin (Dustan 1977; Gittings 1988).

Dredging for beach nourishment is now the major type of dredging activity taking place in southeast Florida (Rogers 1990). In many cases, the constant resuspension of sediments finer than those originally on the beach causes recurring damage more severe than any initial impacts (Marszalek 1981; Rogers 1990). In the Florida Keys, treasure hunting activities, utilizing "mail-box blowers" which divert propeller wash to the bottom, suspend large amounts of sediment thereby increasing turbidity (W. Jaap, Florida Marine Research Institute, personal communication, 1992).

3.5 NUTRIENTS

Many factors control the development and survival of a coral reef. Of these factors, climate and nutrient availability are thought to be the dominant influences. Climate determines the broad distribution of organisms. Nutrient availability influences the species composition of a reef (D'Elia and Wiebe 1990). Coral reefs classically are located in oligotrophic environments where the water is clear, warm, and has low or undetectable nutrient levels.

A coral reef system is especially adapted to utilize nutrients from the water column when these compounds are at very low concentrations. Coral reefs can also utilize nitrogen fixed from the atmosphere and taken up from groundwater. The balance of species in a reef community can be altered by a change in concentration and availability of nutrients to that system. The effects of nutrients on a reef ecosystem can be modified by other physical factors, including biozoogeography (the relative distribution of organisms), geographic location (physical factors associated with the geographic location), competition between species, the type of nutrients available, the zone of the reef being examined, and the relative abundance of these nutrients.

Nutrients affect corals by interfering with calcification, providing an environment suitable to increased levels of phytoplankton, macroalgae, blue green algae, bacteria, and bioerosion (Mitchell and Chet 1975; Dustan 1977; Kinsey and Davies 1979; Antonius 1981b; Highsmith 1980; Te Strake *et al.* 1988; Hallock 1988; Hallock and Schlager 1986). Each of these factors potentially causes the decline of coral species and a shift in ecosystem biomass to one that is less dominated by coral.

3.5.1 Nutrient Cycling

Organisms exist in an elemental equilibrium that is defined by the interbalance of carbon, nitrogen, and phosphorus, or the C:N:P ratio. This value, 106:16:1, which was defined for marine phytoplankton by Redfield (1958), is known as the Redfield ratio. He concluded that nitrogen and phosphorus are available in amounts that are limiting to plant growth, depending upon their sources, as cited by Smith (1984). However, it has recently been observed that the Redfield ratio does not apply generally to all systems; it may be misleading when applied to coral systems (Kinsey 1991). In marine systems, elements and compounds (such as iron, silicon, and trace elements) that occur in small, often trace, amounts are known as *micronutrients*. Elements (such as nitrogen and phosphorus) that occur in larger amounts are known as *macronutrients*. Nitrogen and phosphorus are generally the nutrients of concern when eutrophication has overtaken a system. Depending on the part of the coastal area being examined, the primary limiting nutrient may be either nitrogen or phosphorus. In carbonate environments, the limiting macronutrient is primarily phosphorus because it chemically binds to calcium carbonate ($CaCO_3$; R. Jones, Florida International University, personal communication, 1991).

Nitrogen fixation is the process converting atmospheric nitrogen gas into compounds that can be utilized by organisms. The reverse process by which these compounds are changed back into the gaseous state is denitrification. Many organisms on the reef tract have symbiotic bacterial associations that fix nitrogen and make it available to other organisms in biologically utilizable forms. Phosphorus, the other macronutrient of interest, is available only from the breakdown of natural components, including the recycling of organic matter. Because phosphorus is found in organisms in a relatively lower ratio, it was once assumed that it was needed in small quantities and so would be less likely to be limiting for plant growth. It is now known that the determination of the limiting macronutrient (nitrogen or phosphorus) depends upon the location and component of the system being examined (Smith 1988). Reef systems represent an integrated relationship among many diverse parts that move nutrients among components, with productivity depending upon the component being examined (Kinsey 1991).

3.5.2 Response to Increased Nutrients

A community response to increased nutrients is to shift toward systems that are less light-limited, because they can rapidly take up available nutrients (Birkeland 1977; Hallock and Schlager 1986; Hallock 1987, 1988; Hallock *et al.* 1988). Factors influencing ecological shifts that result from nutrient increase are growth rate, ability to utilize increased nutrients, ability to respond to rapidly increased nutrients, competition, larval recruitment, larval survival, and larval competition (Birkeland 1977; Hallock and Schlager 1986; Hallock 1987, 1988). Successful coral recruitment is inversely correlated with nutrient availability (Birkeland 1977), and high eutrophication can eliminate corals from a benthic community (Smith *et al.* 1981). Geologically, reefs are believed to have drowned in response to changes in circulation patterns and the increase in nutrient-laden water, essentially natural eutrophication (Hallock and Schlager 1986; Hallock *et al.* 1988; Hallock 1988).

3.5.3 Effects of Phosphorus

Calcium carbonate chemically binds phosphorus to form the mineral apatite, which is the dominant sink for soluble reactive phosphorus (Berner 1981). Due to this phenomenon, phosphorus is often the limiting nutrient in calcium carbonate sediments (R. Jones, Florida International University, personal communication, 1991). Available information for Florida Bay indicates that it is a phosphorus-limited system, a possibility that may also extend to the reef tract [Lapointe 1989; Powell *et al.* 1989, 1991; Fourqurean *et al.* to be published)].

Phosphorus, as an element in the reef nutrient cycle, is generally tightly coupled and not found in the water column (Pilson and Betzer 1973; Webb *et al.* 1975; D'Elia and Wiebe 1990). Carbonate sediments also recycle phosphorus very slowly (Hines and Lyons 1982). For these reasons, healthy systems of corals with zooxanthellae have adapted to remove phosphorus from waters with naturally low phosphorus concentrations (Pomeroy *et al.* 1974; D'Elia 1977; D'Elia and Wiebe 1990). Recycling of phosphorus and nitrogen is, therefore, tied to the regeneration of these components, principally at the sediment/water interface (Andrews and Muller 1983).

Phosphate pollution was recognized as a factor in the decline of reefs in Eilat, Red Sea (Loya 1975, 1976a,b; D'Elia and Wiebe 1990). It has been suggested that nutrient enrichment, together with algal competition and reduced temperatures, was responsible for reduction of growth rates of reefs adjacent to upwelling areas and during the Holocene transgression (Kinsey and Davies 1979). Evidence suggests that calcification may be affected by large increases in the phosphorus level in surrounding waters (Kinsey and Davies 1979).

Water-column dissolved inorganic phosphorus (DIP, also called soluble reactive phosphorus) concentrations of less than 0.4 μM to below detection level (0.03 μM) are common in reefs around the world (D'Elia and Wiebe 1990). Historic DIP concentrations were undetectable (less than 0.03 μM) from Biscayne Bay to Triumph Reef in an early south Florida survey (Smith *et al.* 1950). Historic values can be taken from Jones (1963), for an area at Margot Fish Shoal off Elliot Key, from the period November 1961 to May 1962, who reported total phosphorus values from 0.15 to 0.3 μg atoms/L and inorganic phosphorus values that ranged from undetectable to 0.1 μg atoms/L. Inorganic phosphorus levels along the Florida Reef Tract in 1990 generally ranged below 0.4 μM (Szmant 1991). Because of the small size of this data set, conclusions should not be drawn until large scale sampling over meaningful time frames can be conducted.

3.5.4 Sources and Effects of Nitrogen

Nitrogen is available to reefs from the atmosphere (i.e., fixed by organisms on the reef), the reef flat, terrestrial input, sediment regeneration, sediment pore waters, coral interstices, and groundwater [Kinsey and Domm 1974; Webb *et al.* 1975; Johannes 1980; D'Elia *et al.* 1981; Andrews and Muller 1983; Johannes *et al.*

1983a,b; Szmant-Froelich 1983; Corredor and Morell 1985; Hallock 1988; Hallock and Schlager 1986; Lee *et al.* (to be published)]. Nutrients are available to reef systems at low levels from the water column and from components of the reef capable of fixing nitrogen (Kinsey 1991). Nitrogen-fixing blue-green algae (cyanobacteria) are found in various components of the reef and include *Microcoleus lyngbyaceus*, *Schizothrix calcicola*, *Calothrix crustacea*, *Hormothamnion enteromorphoides*, and *Rivularia* sp. (Webb *et al.* 1975; Jaap 1984). In addition to this source of nitrogen, nitrogen and phosphorus compounds have both been found to be sequestered in cavities within corals and beneath the reef (Andrews and Muller 1983; Risk and Muller 1983; Szmant-Froelich 1983). Corredor and Morell (1985) reviewed sources of nitrogen in reef sediments and reported levels of dissolved inorganic nitrogen (DIN) found in interstitial pore waters of reefs.

Different components of the reef release various forms of nitrogen. Corredor *et al.* (1988) found that two sponges, *Chondrilla nucula* and *Anthosigmella varians*, released large amounts of nitrate — 600 nmol N/g (dry weight) and 19 nmol N/g (dry weight), respectively. Based upon aerial calculations, these sponges could together supply 50%-120% of the nitrogen required to sustain reef productivity. Ammonium was the dominant form of nitrogen available on Mona Island reefs, with concentrations ranging up to 40 μM (Corredor and Morell 1985). Nitrate was present at lower concentrations, and nitrite was present in only trace amounts. Computed flux rates of nitrogenous species ranged between 0.75 and 1.37 $\mu M\ m^{-1}\ h^{-1}$ and represented a significant source of recycled nitrogen on the reef tract. Bythell (1988) measured nitrogen and carbon budgets for *Acropora palmata* in the Virgin Islands on a back-reef zone and determined that 50% of the total nitrogen requirements were excreted as mucus.

3.5.5 Nutrient Flux and Availability

Reef productivity, nutrient uptake, and nutrient flux are related directly to the section of the reef being examined (Kinsey 1977; Kinsey and Davies 1979; Kinsey 1985; D'Elia and Wiebe 1990). Kinsey (1991) divides reefs based upon the productivity rates (determined from 11 worldwide reefs):

- Active reef parameters,
  where gross production (P) = 7 ($\pm$1) C m^{-2} $year^{-1}$, and the net production of carbonates (G) = 4 ($\pm$0.5) C m^{-2} $year^{-1}$.

- Sand and rubble,
  where P = 1 ($\pm$0.3) C m^{-2} $year^{-1}$ and G = 0.5 ($\pm$0.2) C m^{-2} $year^{-1}$.

Highest primary production is found to be associated with the seaward areas of a reef (Kinsey 1991). Due to the differences between sites on a specific reef, nutrient levels found at a given reef site are not necessarily applicable to all sites on that reef or to reefs in general (D'Elia and Wiebe 1990). D'Elia and Wiebe (1990) reviewed the biogeochemical nutrient cycles in coral reef ecosystems and their relationship to the portion of the reef being examined.

Productivity measurements made by Kanwisher and Wainwright (1968) on Scleractinian corals taken from reefs of Plantation Key (Hens and Chickens and the Rocks) show gross photosynthesis values that range between 4.0 C m^{-2} day^{-1} (for *Siderastrea siderea*) and 10.2 C m^{-2} day^{-1} (for *Porites divaricata*). This places the corals from these areas, at that time, near the values defined for active reef parameters by Kinsey (1991).

3.5.6 Groundwater Flow

Groundwater and water within the reef structure have been implicated as a source of nutrients by several investigators (Simmons *et al.* 1985; Simmons and Netherton 1987; Sansone *et al.* 1988). Much of this work was stimulated by the apparent coupling of septic systems, sewage ponds, and groundwater adjacent to reef areas (D'Elia *et al.* 1981; Lapointe *et al.* 1990). Carbonate platforms derived geologically from living coral reefs are extremely porous in structure. Potentially, there are interconnections that allow movement of groundwater great distances through these formations. Work has been done in Bermuda, Jamaica, and the Florida Keys on these phenomena (D'Elia *et al.* 1981; Simmons *et al.* 1985; Simmons and Netherton 1987; Lapointe *et al.* 1990; E. Shinn, Geological Survey, personal communication, 1991).

Bermuda, Jamaica, and the Florida Keys have shown elevated nutrient levels in adjacent marine waters. Municipal practices in these areas include the disposal of sewage waste in septic systems, septic ponds, and shallow injection wells, practices that are postulated to contaminate marine waters through fresh groundwater connection to the marine environment (D'Elia *et al.* 1981; Lapointe *et al.* 1990; Simmons and Netherton 1987; Jickells 1981). In Discovery Bay, Jamaica, seeps along the reef showed an inverse relationship (correlation coefficient, $r = -0.97$) between salinity and nitrogen concentration (D'Elia *et al.* 1981). In Key Largo, along the Florida Reef Tract, Simmons and Love (1984) report anthropogenic chemicals in lower salinity seeps into the marine environment. Although direct connections between the aquifer underlying the Florida Keys and the mainland portion of the Biscayne Aquifer have not been mapped, historic upwelling of freshwater is well-documented in Biscayne Bay and along portions of the ocean side of Key Largo (Kohout and Kolipinski 1967; Harlem 1979; VanArman *et al.* 1989). Based on these observations, shallow injection wells could be point sources for nutrients to enter the marine environment and the reef tract. Recently, a large sinkhole, approximately 300 m in diameter, was discovered off Key Largo near a reef that is experiencing a blue-green algae bloom (E. Shinn, United States Geological Survey, personal communication, 1991). Although the sinkhole is completely filled with marine sediments, it is thought that it may provide a pathway for groundwater with elevated nutrient levels to reach the reef. Monitoring wells were drilled around the sinkhole to test for elevated nutrient levels. To date, no elevated nutrient levels or unusual salinity readings have been detected from these monitoring wells.

Shallow injection wells in the Keys with depths of 30 to 90 ft inject freshwater sewage into a saltwater-intruded aquifer. The sewage is then a lens of freshwater overlying the more saline aquifer. Movement of this lens should be controlled by the hydraulic head of the Everglades/Dade County region acting on the Biscayne Aquifer. The lens of sewage would then be available to outwell wherever the Biscayne Aquifer connected to surface waters in the marine environment.

3.5.7 Impacts of Nutrients at Specific Sites

Large-scale eutrophication impacts on coral reef areas have been documented and closely monitored in a restricted number of sites worldwide. Nutrient enrichment and/or eutrophication effects have been reported many places, but are well-documented for only a few locations. That information is available for Kaneohe Bay in Hawaii. Other locations with research documenting nutrient effects include the Gulf of Aqaba and Bermuda.

3.5.7.1 KANEOHE BAY

Detailed examinations of the problem in Kaneohe Bay are given in Smith *et al.* (1973), Banner (1974), and Smith *et al.* (1981). Kaneohe Bay is the largest enclosed embayment in the Hawaiian Archipelago and is approximately 12.7 km long and 4.3 km wide (Banner 1974). This embayment received rainwater runoff from the Kaneohe watershed and primary and secondary sewage for a total peak flow of 1.9×10^4 m^3/day until approximately 1977-1978, when it was diverted offshore (Smith *et al.* 1981).

Changes in Kaneohe Bay were the result of siltation, freshwater runoff, and high sewage loads to the Bay (Smith *et al.* 1981). Areas in the southern basin nearest the outfall were the most devastated. These areas had been dredged and received sewage. They showed little live coral and massive growths of the algae *Acanthophora, Graciliara,* and *Hydroclathrus* (Banner 1974). Overgrowth of coral by the alga *Dictyosphaeria cavernosa* occurred throughout other portions of the Bay. Other community changes included increased water-column phytoplankton, shifts in the community structure of benthic macroalgae, decline in coral cover, and increased proportions of heterotrophic filter feeders (Banner 1974; Smith *et al.* 1981).

Toxicity to benthic organisms adjacent to the outfall was believed to be due to hydrogen sulfide in the sediments (Banner 1974). Benthic community metabolism was believed to be controlled primarily by particulate loading, but the limiting nutrient was found to be nitrogen (Smith *et al.* 1981). Due to the responses of rapid incorporation and recycling of nutrients, measurement of the limiting nutrient (nitrogen in this case) was not a good indicator of eutrophication (Smith *et al.* 1981). Response of the system relative to proximity of the outfall and changes observed after diversion of the outfall indicated that circulation and water movement were important to the impacts upon the system. The Kaneohe Bay situation was summarized by Marszalek (1987, p. 82), including the following points.

> "Phytoplankton and zooplankton grazers increased dramatically, especially in the southeast sector
>
> "Populations of benthic filter-feeders (e.g., sponges and zooanthids, the latter of which is a type of encrusting soft coral) increased in response to increased food supply (i.e., plankton and organic detritus)
>
> "The sediment-feeding sea cucumber *Ophiodesoma spectabilis* appeared in large numbers on organic-rich sediments in the southeast sector
>
> "The growth of benthic algae, especially the 'bubble algae' *Dictospharea cavernosa,* was greatly stimulated
>
> "Corals decreased in abundance. . ."

Upon cessation of sewage flow, the ecosystem slowly began to shift back to presewage conditions (Smith *et al.* 1981; Marszalek 1987).

3.5.7.2 REEFS OF THE FLORIDA KEYS

In the reef waters of the Florida Keys, either nitrogen and/or phosphorus can be limiting, depending upon conditions. In Florida Bay, however, there is an abundance of nitrogen that may be available to the reefs, depending upon transport mechanisms (R. Jones, Florida International University, personal communication, 1991; Smith 1991; Szmant 1991). Very few nutrient data are available for the Florida Reef Tract. Historical data are summarized by Jaap (1984). Nutrient levels in the water column in Looe Key at control sites sampled during enrichment showed normal oligotrophic values. Littler *et al.* (1986) indicated the following nutrient ranges: NO_3: 0.51-2.44 μM; NH_4: 0.10-0.20 μM; PO_4: 0.10-0.38 μM.

Samples for nutrient analysis were taken under the SEAKEYS Program managed by the Florida Institute of Oceanography during 1990. Szmant (1991) and Lee *et al.* (to be published) sampled along seven inshore/offshore transects from Biscayne National Park to Looe Key National Marine Sanctuary and offshore in the Florida Current. Concentrations of total nitrogen were found to be within the range typical for oligotrophic reef waters (i.e., 8- to 12-μM range), except during windy days when sediments had been resuspended into the water column (Szmant 1991). Reactive and organic phosphorus concentrations were also low for this area. This pattern was generally mirrored in the entire sampling set from Key Largo to Looe Key, with some exceptions.

Major exceptions to oligotrophic conditions in the Keys coastal area were seen in samples taken off inshore canals, the Ocean Reef Club development, Algae Reef, and Long Key. Samples taken near inshore canals and marinas showed elevated levels of NH_4, NO_3, and PO_4. Samples taken from near the Ocean Reef Club development showed elevated organic and inorganic phosphorus levels (Szmant 1991). Samples taken off Long Key generally were higher than those taken elsewhere along the Keys. Results of sampling suggested that high nitrogen values for samples taken offshore indicate that Florida Bay may be a source of nitrogen on outgoing tides. Chlorophyll *a* values, a measure of phytoplankton productivity, were twice as high for the Long Key area as for the other sample areas.

Nutrient transport from nearshore waters in the lower Florida Keys to reefs in the Looe Key National Marine Sanctuary has been examined (Lapointe *et al.* 1992). Current meter data indicate a long-term net flow from the Gulf of Mexico through three tidal channels (Newfound Harbor Channel, Bahia Honda Channel, and Moser Channel) to the Atlantic Ocean. Water flow in Hawk Channel was predominantly westward along-channel with some seaward deflection. Elevated ammonium concentrations, at times exceeding 4.5 μM, were observed after rainfall events, and ammonium concentrations were elevated during wet periods compared to dry periods. Soluble reactive phosphorus concentrations were low to undetectable and did not vary between wet and dry periods. Lapointe *et al.* (1992) suggested that this was due to rapid uptake of soluble reactive phosphorus by microbes and plants. Chlorophyll-*a* concentrations were elevated at most stations during wet periods compared to dry periods.

Lapointe *et al.* (1992) concluded that a broad "island mass effect" transports nutrients seaward from the lower Florida Keys. They suggested that anthropogenic sources, such as sewage disposal into septic tanks, increase nutrient concentrations in groundwater, which is flushed into nearshore waters during rainfall events. These anthropogenic nutrients were thought to be major contributors to the "wake" of nutrients existing between land mass and the reefs. The investigators believe that nutrients entering the nearshore waters of the Florida Keys are transported across Hawk Channel in near-bottom layers toward the reefs in Looe Key National Marine Sanctuary, and that this nutrient flux contributes to eutrophication and reef coral stress.

An unidentified species of the blue-green alga *Lyngbya* sp., with filaments up to 46 cm long, has caused severe damage to the octocoral community of a reef off Key Largo, Florida, for the past 2 years. The algae, which are most prevalent from May through the end of October, have killed an estimated 95% of the octocorals on Algae Reef (L. Richardson, Florida International University, personal communication, 1991). The algal fouling had been confined to Algae Reef, but there is now evidence that it is spreading to nearby Horseshoe Reef. Since the algal growth is fairly localized, elevated nutrient levels in groundwater leaching out from the reef substrate are theorized to be involved. Dr. Richardson has also observed increased incidence of black-band disease in hard corals on this reef.

An algal outbreak has also been occurring during the summer months off the southeast coast of Broward and Palm Beach Counties for at least 3 years, although the alga is not a blue-green form. Large concentrations of the green alga *Codium isthmocladum* have been fouling the reefs from depths of greater than 100 ft inshore to the nearshore reefs (W. Parks, tropical fish collector, personal communication, 1991). The algae are brought in from deeper water by currents during the summer and pile up on the downcurrent sides of reefs and ledges to a depth of approximately 1 m. This has resulted in the temporary burial and subsequent death of significant numbers of sponges, hard corals, octocorals, and other attached organisms.

There was also a reported heavy bloom of the brown algae *Dictyota* sp. in the summer of 1989 at Sand Key in the Key West area (B. LaPointe, Florida Keys Land and Sea Trust, personal communication, 1991).

3.5.7.3 OTHER REEF LOCATIONS

Reefs in the northern Gulf of Aqaba on both the Sinai and Arabian Peninsulas have been subjected to a variety of human-related impacts, including oil spills, dredging, sewage, and phosphate dust (Mergner 1981). Phosphorus levels were five times higher in the area of a phosphate loading platform near Eilat than in the area south of Eilat. In the area near Aqaba, where phosphate is loaded for export, there was an increase in water turbidity, extensive new algal areas, and an increase in herbivorous fish and sea urchin populations. The changes noted by Mergner (1981) conspicuously mirror those seen in Kaneohe Bay.

Bermuda is located on the edge of the oligotrophic Sargasso Sea. Sewage on the island has been disposed of via septic systems and cesspits that are connected through the porous limestone formation with groundwater. This groundwater, in turn, is connected to local marine waters (Simmons *et al.* 1985). Lapointe and O'Connell (1989) reported an increase of *Cladophora prolifera* in Harrington Sound and attributed this increase to underground seepage of nitrogen-enriched groundwater. Concentrations of NH_4 ranged from 23 to 40 μM; concentrations of PO_4 ranged from 0.3 to 0.49 μM in pore waters under the *Cladophora* mats. Analysis of nutrient concentrations in Bermuda inshore waters has shown that enclosed waters, specifically Harrington Sound, are more affected by potential eutrophication problems (Jickells 1981). In this case, eutrophication resulted in algae blooms in an enclosed body of water.

3.6 OIL AND ASSOCIATED CONTAMINANTS

There is a very small body of information on the effects of oil (primarily various forms of refined oil and crude oil treated with dispersants) on corals and coral communities. Available information indicates detrimental effects of oil pollution on coral reproduction, growth, colonization, and behavior (Loya and Rinkevich 1980). Data show that areas with chronic oil pollution in the Red Sea near Eilat have much lower recruitment than do oil-free areas (Loya and Rinkevich 1979) although these same areas are also impacted by airborne phosphate from a fertilizer plant as noted by Mergner (1981), and the low recruitment could be a synergistic effect. Loya and Rinkovich (1979) report abortion effects in corals induced by oil pollution. *Diploria strigosa* was found to accumulate high levels of phenanthrene, a polycyclic aromatic hydrocarbon (PAH), from the water column. This species exhibited slow elimination rates when compared to elimination rates for these compounds in other invertebrates (Knap *et al.* 1982). Twenty-four-hour exposure of *Diploria strigosa* to oil/water mixtures and oil-dispersant/water mixtures showed sublethal effects on the corals (Wyers *et al.* 1986). It should be pointed out that more severe effects were seen at longer doses. Long-term followup examinations to determine chronic secondary disease effects or impacts on reproduction remain to be completed.

A 1986 oil spill on the Caribbean coast of Panama caused extensive damage to subtidal corals. Coral cover had decreased by up to 76% on heavily oiled shallow reefs 1 year after the spill. The still-living corals showed signs of stress, including zooxanthellae expulsion, excess mucus production, and bacterial infections (Jackson *et al.* 1989; Guzman *et al.* 1991). This spill was treated with oil dispersants which may have increased its toxicity to corals by putting the crude oil into solution.

In 1964, a 500 gallon spill in the Dry Tortugas was reported to cause widespread damage to shallow water corals (DOI 1987). Following a 1975 spill of heavy oil in the Florida Keys, Jaap (1984) reported little evidence of damage to the reefs or individual corals. Minimal information on the effects of oil and other hydrocarbons is available for the FKNMS region. There is, however, heavy tanker traffic close to the reef line (see Task 6) and frequent reports of floating oil or tar balls on the reef tract (H. Hudson, Key Largo National Marine Sanctuary, personal communication, 1991). The relative magnitude and impact of these conditions are not known.

Shinn (1989) immersed colonies of staghorn and star coral in crude oil-seawater solutions for over one hour in 1970 with no obvious detrimental effects to the colonies after 14 days of observation. The staghorn coral was also reported to survive a one-half hour total immersion in Louisiana crude oil; however, processed oils or crude oil treated with dispersants killed the corals.

3.7 PESTICIDES, HERBICIDES, AND ORGANIC CHEMICALS

Analyses for pesticides, herbicides, and organic chemicals have been performed on various components of coral communities. Organisms on a reef comprise a broad cross section of feeding strategies, including a large number of filter feeders. These organisms would be susceptible to biofiltration and bioconcentration effects. Due to the extreme dilution effects, such accumulations would be most possible for those organisms that have had long periods of time (e.g., 10s to 100s of years) to accumulate and biomagnify these compounds. To date, analyses for these compounds have been performed only on the Florida Reef Tract by a small number of researchers, and there have been no substantial data to either support or reject this theory to date.

Researchers who have analyzed and published pesticide, herbicide, or organic chemical data for sediments, organisms, or water samples from the Florida Reef Tract include Simmons and Love (1984), Braman *et al.* (1989), Glynn *et al.* (1989), and Skinner and Corcoran (1989). Simmons and Love (1984) analyzed a submarine groundwater discharge into the reef tract off Key Largo and found it to have several chlorinated pesticide peaks that could not be positively identified. The only positively identified compound was a nematocide, O-Ethyl S, S-dipropyl phosphorodithioate, at 0.061 μg/L. The other compounds were assumed to be organophosphates, phthalates, and/or phenoxyherbicides; however, positive identification could not be made.

Braman *et al.* (1989) analyzed sediment and organisms (producers and consumers) from the entire Florida Reef Tract out to the Dry Tortugas. The producers included the seagrasses *Syringodium filiforme* and *Thalassia testudinum* and the algae *Dictyota* spp., *Halimeda* spp., and *Sargassum* spp. Consumers consisted of the sponges *Haliclona rubens*, *Spheciospongia vesparium*, and *Xestospongia muta*, and the colonial mat anemone *Palythoa caribaeorum*. They reported chlorinated pesticide levels to be below detection limits (<5 μg/kg for sediments and <500 μg/kg for organisms) for all compounds tested via standard procedures (EPA Standard 608) (Table 3-5) and pesticide identities were confirmed by using mass spectroscopy/gas chromatography (MS/GC).

Glynn *et al.* (1989) analyzed various hard corals and octocorals from two distinct patch reefs within Biscayne National Park for pesticide concentrations by using gas chromatography. Their study, conducted in 1985, found levels of organochlorine pesticides, including lindane, heptachlor, chlordane, and DDT in the colonies' tissues (Table 3-5).

Compounds detected by Skinner and Corcoran (1989) in John Pennekamp Coral Reef State Park include phthalate acid esters (plasticizers), polychlorinated biphenyls (PCB), lindane, heptachlor, heptachlor epoxide, dieldrin, DDE, DDD, DDT, and aldrin. Methods reported for this work do not indicate the use of mass spectrometry to verify compounds detected by gas chromatography. The potential presence of these compounds in the water column is highly significant, however, and shows a current and persistent source if these data are verified.

3.8 TRACE ELEMENTS AND HEAVY METALS

Scott (1990) reports that enhanced uptake of contaminants, primarily metals, potentially results from additional disturbance of the ecosystem as shown by Hong Kong coral communities. Values reported for the hard coral, *Porites sinensis*, for the following metals (in $\mu g\ g^{-1}$ dry wt) were: aluminum 2.0-4.0, cadmium 0.2-3.0, copper

Table 3-5. Pesticide compounds within sediments and biota from the Florida Reef Tract, as analyzed by Braman *et al.* (1989), and hard corals and octocorals, as analyzed by Glynn *et al.* (1989).

Braman *et al.* 1989 Sediments (μg/kg)	Braman *et al.* 1989 Biota (μg/kg)	Compound	Glynn *et al.* 1989 Hard Corals[a] (ng/g wet weight)	Glynn *et al.* 1989 Octocorals[b] (ng/g wet weight)
<5 each	<500 each	4,4' DDD 4,4' DDE 4,4' DDT	10.08	321.05
<5 each	<500 each	Aldrin Dieldrin	0.37	41.05
<5 each	<500 each	SLPHA-BHC		
<5 each	<500 each	B-BHC		
<5 each	<500 each	Endosulfan I Endosulfan II	0.00	88.95
<5 each	<500 each	Endosulfan Sulfate		
<5 each	<500 each	Endrin	99.51	0.00
<5 each	<500 each	Endrin Aldehyde		
<5 each	<500 each	Gamma-BHC		
<5 each	<500 each	Heptachlor Heptachlor Epoxide	4.18	546.57
<5 each	<500 each	Methoxychlor	0.00	0.00[c]
<5 each	<500 each	PCB 1016		
<5 each	<500 each	PCB 1221		
<5 each	<500 each	PCB 1232		
<5 each	<500 each	PCB 1242		
<5 each	<500 each	PCB 1248		
<5 each	<500 each	PCB 1254		
<5 each	<500 each	PCB 1260		
<5 each	<500 each	Toxaphene		
ND	ND	Lindane	23.60	314.40
ND	ND	α and γ chlordane	177.64	2415.83
ND	ND	Mirex	4.19	0.00

ND: No data.
[a]30 specimens.
[b]11 specimens.
[c]One speciman had a concentration of 768.64 ng/g.

7.9-8.5, lead 0.2-0.8, uranium 1.3-5.8, vanadium 0.05-8.5, and yttrium 0.04-0.16. This work shows growth rates to be significantly lower in more polluted sites with declines first appearing in shallow communities and grading out to deeper, more distant sites.

Trace and heavy metals from the Florida Reef Tract have been analyzed by Manker (1975), Simmons and Love (1984), Braman *et al.* (1989), Skinner and Corcoran (1989), Glynn *et al.* (1989), and Strom *et al.* (1991). Manker (1975) examined the Keys Reef Tract for metals in the sediments and reported elevated levels of mercury, zinc, lead, and cobalt. Braman *et al.* (1989) and Strom *et al.* (1991) report results for the same data set collected from Biscayne National Park to the Dry Tortugas. Ranges for these data are given in **Table 3-6**.

Glynn *et al.* (1989) also analyzed hard corals and octocorals from Biscayne National Park for heavy metals. They found the following ranges of concentrations within the organisms' tissues: arsenic <0.5 to 40 ppm; cadmium <0.2 to 0.3 ppm; copper 2.5 to 90 ppm; iron <10 to 117 ppm; mercury <0.1 to 2.7 ppm; and lead <1 to 11.5 ppm (**Table 3-6**). Skinner and Corcoran (1989) measured the concentration of metals in water from John Pennekamp Coral Reef State Park. Concentrations of samples were arsenic <10 μg/L; copper <1 μg/L; lead <10 μg/L; mercury <0.5 μg/L; cadmium <5 μg/L; iron <30 μg/L; and zinc <30 μg/L.

3.9 FRESHWATER

Freshwater affects coral reef growth because corals have restricted salinity requirements. In a study on Atlantic and Pacific corals, Marcus and Thorhaug (1981) found the salinity range for Florida Keys *Porites porites* to be between 15 and 45 ppt whereas, Hawaiian corals in this study exhibited a much narrower range of salinity tolerance (between 20 and 40 ppt). Isdale (1984) has used the natural incorporation of fluorescence into corals as a tracer of the history of freshwater input to coral. Smith *et al.* (1989) and Hudson *et al.* (1989) showed a correlation between freshwater discharge and fluorescent banding in an isolated head of *Solenastrea bournoni* in the Peterson Keys in Florida Bay. Hudson *et al.* (1989) compared the core taken by Smith *et al.* (1989) to another core taken on the Hens and Chickens patch reef on the Atlantic side of the Keys. They found that fluorescent banding, as a measure of freshwater discharge, may not be a good record of hurricane activity but may show a possible cause-and-effect relationship between human-induced perturbations (such as development and the resulting large-scale changes in water management) and long-term coral growth rates.

Discharge of freshwater from canals in south Biscayne Bay tends to remain as a cohesive water mass and move unmixed out over an area adjacent to the canal (Lee and Rooth 1972; Chin Fatt and Wang 1987). Water moving in this manner from the extreme southern canals of Dade County should mix before it reaches the ocean through Angelfish or Caesars Creeks owing to the extended residence time for water in this area (Lee 1975; Lee and Rooth 1972). Since water mass movement in this area is wind- and tide-driven, mixing would depend upon meteorological conditions. It is also possible that water could move north of Key Largo through Buttonwood Sound and out through the Adams Waterway to the ocean. The required time and distance, however, reduce the likelihood that this water would remain as a coherent, freshwater mass (S. Baig, NOAA, National Hurricane Center, personal communication, 1991).

4.0 SUMMARY

Factors that influence the health of the Florida Keys reefs can be separated into two categories: natural and man-induced. Natural parameters include biological competition and predation, disease, light, temperature, salinity, and storms. Man-induced parameters are nutrient enrichment, sedimentation, turbidity, pesticides and PCBs, hydrocarbons, heavy metals, and freshwater. Despite being able to identify most of these factors, understanding the mechanisms is difficult because of the many different interactions between various parameters and the diverse ways in which they affect specific areas. Further confounding the problem is the fact that the

Table 3-6. Mean concentrations and ranges of selected trace metals in sediment and biota from the Florida Reef Tract. [From Braman *et al.* 1989 and Glynn *et al.* 1989]

Trace Metals	Braman *et al.* 1989 (ppm dry weight)			Glynn *et al.* 1989 (μg/g wet weight)	
	Sediments Mean (Range)	Producers Mean (Range)	Consumers Mean (Range)	Hard Corals Mean (Range)	Octocorals Mean (Range)
Arsenic	0.071 (0.000-0.315)	0.94 (0.00-9.73)	0.71 (0.03-6.6)	4.16 (<0.5-40)	6.54 (3-9)
Cadmium	0.52 (0.13-1.2)	0.54 (0-1.8)	5.48 (0.7-22)	0.18 (<0.2-0.3)	0.20 (<0.3)[a]
Copper	1.58 (0.65-4.7)	1.71 (0.4-3.5)	9.01 (1.5-38)	10.93 (2.5-90)	9.0 (6-12)
Iron	ND	ND	ND	39.03 (<10-63)	74.55 (23-117)
Lead	2.08 (0.81-4.5)	2.54 (1-5.1)	11.08 (1.3-60)	2.62 (<1-11.5)	0.09[a] (<1)
Mercury	0.061 (0.002-0.242)	0.64 (0.00-7.00)	0.09 (0.002-0.434)	0.21 (<0.1-2.7)	0.07 (0-0.1)
Tin	0.034 (0.002-0.208)	0.10 (0.00-0.60)	1.77 (0.1-13.1)	ND	ND

ND: No data
[a]No range provided

Florida Reef Tract is already living at the climatic threshold for a coral reef and any additional changes in the environment could cause major impacts on the community.

There is a general consensus among researchers that both natural and anthropogenic factors are affecting the coral community of the FKNMS. Although there appears to be a severe problem, there are not sufficient baseline and research data available from most locations to scientifically document the extent of the problem. Since what constitutes natural conditions is in many cases unknown, discerning natural changes from anthropogenic perturbations is extremely difficult. The workshop on Coral Bleaching, Coral Reef Ecosystems, and Global Climate Change was held June 1991 in Miami (D'Elia *et al.* 1991). A major conclusion of the workshop was that "much subjective evidence exists to indicate that there is a worldwide decline in the overall 'health' of coral reefs and related ecosystems, but there are not adequate baseline and survey data to provide a vigorous scientific assessment of the nature and extent of the problem."

5.0 STATEMENTS OF PROBLEMS

A key part of Phase I of the Water Quality Protection Program is the identification of water quality problem areas to be addressed during Phase II. A two-step approach was used to identify and obtain agreement among members of the scientific community on known, suspected, or potential water-quality problems affecting the natural resources of the Sanctuary. Initially, information gathered during the literature review was used to derive a series of statements describing potential water-quality related problems (presented in Section 5.1). These problem statements were then refined through discussions with EPA Region IV Coastal Programs staff and State of Florida environmental staff and delivered to workshop participants to provide focal points for discussions at technical workshops. The participants in each workshop were charged with coming to a consensus, where possible, on the problem statements developed for each workshop resource area. A matrix analysis of each workshop resource area (Appendix B) was the tool used to develop consensus on the problem statements. Specific descriptive terms were used to complete the matrix based on the discussions with the expert panels assembled for each workshop (Appendix B). Public comments were also heard during the course of each workshop. To assist EPA Region IV and the State of Florida to direct their limited resources, each expert panel was asked to rank the overall significance of the water-quality related problems at the end of each daily workshop. The consensuses developed at the workshops are summarized in Section 5.2 and presented in more detail in Appendix B.

5.1 PROBLEMS IDENTIFIED DURING THE LITERATURE REVIEW

The following lists either known, suspected, or potential problems, exclusive of mechanical destruction (not addressed in this document), related to coral reef communities in the FKNMS. However, to state a problem does not of itself mean or imply that the stated problem actually exists. There is a divergence of views on what actually constitutes either real or potential problems for the FKNMS.

In many instances, the data are insufficient to assess the true importance or validity of a given problem, so called. For this reason, there is a "data sufficiency" question posed under each statement of a problem. No references are supplied for statements made in this Subsection — the statements made here represent an evaluation of the data and referenced studies presented in the preceding text.

Diseases are making major impacts on the FKNMS coral reef community. — Black-band disease, caused by the blue-green alga *Oscillatoria submembranacea*, is widespread within the FKNMS. It has been reported as occurring extensively in the Key Largo and north Key Largo areas and as a significant feature in the Looe Key area. There is some debate whether white-band disease, which may result from bacterial infection or may represent a response by the coral to physiological stress, occurs in the FKNMS. Data are sufficient to say that disease is a very significant problem for the coral reef community in the FKNMS and suggest that infections of black-band disease may have increased over the past 20 years. Additionally, research on other potential coral diseases is minimal. The relationship of coral disease to water quality is not known.

Water-temperature fluctuations are a major cause of impacts on the FKNMS coral communities. — The effects of cold stress, which occurs when cold fronts chill the waters of Florida Bay and the shallow, nearshore waters of the Keys, are more pronounced in the middle Keys and along channels because reefs along the upper Keys are shielded from the cooled waters of Florida Bay by Key Largo. Heat stress, resulting from elevated water temperatures occurring during calm, low-tide periods of the summer, causes corals to expel their zooxanthellae. This coral bleaching can occur at virtually any reef area in the FKNMS. Data indicate that the effects of temperature fluctuations are moderately significant in the Keys — cold-water stress may be the mechanism controlling reef distribution along the Florida Keys and coral bleaching may result in colony death. Temperature stress is water-quality related, but is not usually anthropogenic. The draining of so much of south Florida has resulted in reduced water flow to the Everglades, affecting the thermal buffer that may have previously protected the waters of Florida Bay from cold fronts.

Reduced water transparency and sedimentation may be affecting the FKNMS coral reef communities. — Reduced light availability in the water column because of increased phytoplankton abundance as a result of increased nutrient concentrations or increased particulate matter may be widespread in the Keys, although its specific extent is unknown. Although data are sufficient to say that this phenomenon does cause problems for coral reef communities, they are insufficient to establish long-term, water-clarity trends in the FKNMS. Also, there are no well-established links between decreased water clarity and specific coral community deterioration at any sites in the FKNMS. This problem is potentially very significant and is related to water quality. Anthropogenic sources are suggested for the increasing levels of nutrients and for contributing to the suspended sediments in the FKNMS waters.

Anthropogenically increased nutrient levels in the water column may be adversely affecting the FKNMS coral reef communities. — Contamination of ground water in some areas by septic tank and shallow well injection of sewage may result in increased nutrient levels. Increased nutrient levels can cause increases in abundance of phytoplankton, macroalgae, blue-green algae, and bacteria. Increased nutrient levels may also interfere with calcification in hard corals. Increased nutrient levels in groundwater have been demonstrated, and the results of one study suggest that the anthropogenic nutrients may be transported offshore to the reefs. Massive blue-green algal blooms on a specific reef off Key Largo are being studied in relation to possible seasonal fluxes in nutrient levels from groundwater flow. There are very few data on nutrient levels within the Florida Reef Tract and there is no historical water quality database with which to assess nutrient trends along the offshore reefs. What data have been collected do not, as a general rule, show alarmingly high nutrient values along the reef tract. The possibility of seasonal fluxes in nutrient levels from groundwater flow has not been fully investigated, nor can the currently available nutrient database be considered conclusive. This problem is related to water quality and is potentially very significant.

Contamination from spilled oil and petroleum products may be adversely affecting the FKNMS coral reef communities. — Small-scale or chronic impact of hydrocarbon pollution, resulting from chronic small spills and "tar balls" in the environment, may be widespread throughout the FKNMS. Short-term, major impacts from a catastrophic oil spill would be localized to the area impacted by such a spill. The effects of petroleum spills include reduced recruitment, accumulation of hydrocarbon contaminants in some species, and other sublethal effects. Minimal information on the effects of oil and other hydrocarbons within the FKNMS area is available. During the one major spill of heavy oil in the Florida Keys, there was little evidence of damage to reefs or individual corals. The problem of chronic hydrocarbon contamination to the FKNMS coral community has not been investigated. The significance of this water-quality related problem is not known.

Pesticides, herbicides, and organic chemicals may be adversely affecting the FKNMS coral communities. — There is little evidence of pesticide, herbicide, or organic chemical contamination in reef sediments from the FKNMS. Elevated levels of organochlorine pesticides have been reported from Biscayne National Monument, and there is one report of elevated pesticide and polychlorinated biphenyls (PCB) from the water column of John Pennekamp Coral Reef State Park. Potential sources of such contamination include sewage outfalls, terrestrial runoff, agricultural runoff transported by water-mass movement, groundwater seepage, upwelling, and ocean currents transporting contaminants from remote areas. The mosquito control programs conducted by Monroe, Dade, and Collier Counties are also potential sources of pesticides. The data are insufficient to determine if a problem exists with pesticide contamination in the FKNMS coral communities. The significance of this water-quality related problem is not known.

Trace element and heavy metals may be adversely affecting the FKNMS coral communities. — No impacts from trace elements or heavy metals have been reported in the FKNMS coral communities. Some studies have reported elevated levels of mercury, zinc, lead, and cobalt from the sediments adjacent to the FKNMS Reef Tract, but no connection with any observable impact has been made. Sources of such contamination may include sewage outfalls, terrestrial runoff, agricultural runoff transported by water-mass movement, groundwater seepage, upwelling, ocean currents transporting contaminants from long distances away, airborne contamination from solid waste incinerators, and boat traffic and the local marine industry. Although studies to date are not comprehensive, they suggest that trace-element or heavy-metal contamination is not a significant problem along the outer reefs of the FKNMS. This problem is related to water quality.

Freshwater discharges and changes in freshwater flow patterns may be having an adverse effect on the FKNMS reefs. — Reduced salinities, caused by freshwater input, impact coral communities by reducing colony growth rates and, if low salinity conditions persist, by causing colony death. Freshwater input in the FKNMS may originate from the discharge of freshwater from canals into lower Biscayne Bay and the Card Sound/Barnes Sound area of the FKNMS. A possible future source may result from restored freshwater flow through the Everglades and its subsequent discharge into Florida Bay. No impacts, other than possible increased coral growth in Florida Bay, as a result of reductions of freshwater input, have been attributed to freshwater along the FKNMS outer reef tract. Massive freshwater discharges from canals in the Card and Barnes Sounds portions of the FKNMS have caused community disruption in the benthic communities seen there, but these are not coral-dominated communities. Data indicate that freshwater input does not presently appear to present a significant problem for the FKNMS coral community. This problem is related to water quality.

Long-term climate changes may be adversely affecting the FKNMS coral reef communities. — All FKNMS coral reef communities are vulnerable to large-scale environmental disruptions resulting from global warming (increased air and water temperatures, sea-level rise) and ozone depletion (increased shorter wavelength irradiance reaching the Earth's surface). Large-scale evaluations of potential community changes due to global climate change are being conducted by a number of United States and international research agencies. There are studies in progress, although not mentioned in this report, that are assessing possible community shifts in tropical marine ecosystems resulting from global climate change. None of these studies has specifically targeted the FKNMS, but their results should be indicative of the potential problems faced here. Possible indirect effects on water quality may result from changes in precipitation patterns. While this problem is real, its specific impact on the FKNMS coral reef communities has not been assessed. From a FKNMS management point of view, this problem is too large-scale and long-term to be of immediate significance in the FKNMS planning process. The possibility of synergistic effects between global climate change and local near-term stresses in the environment should be considered in any long-term monitoring plan developed for the Sanctuary.

5.2 PROBLEMS IDENTIFIED AT THE CORAL COMMUNITY ASSESSMENT WORKSHOP

Eight problems identified and discussed by the workshop panel were coral disease, coral bleaching, problematic algal growth, *Lyngbya* growth, lack of recruitment, growth rate (individual), decline in coral abundance, and decline in species diversity (abundance and richness). The parameters for analysis and the matrix used for the discussion are included in Appendix B.

Coral disease and problematic algal growth are the problems most directly related to water quality. Therefore they should also have a high priority in the Water Quality Protection Program. In addition, the lack of information regarding the decline in biodiversity indicates that additional work needs to be done regarding this problem. Generally, there is a lack of data regarding all of the above problems; more research and data are needed to determine how the water quality parameters affect each of the problems.

Coral disease is widespread with patchy occurrences, and its severity is increasing in the Keys. — The cause of coral disease is possibly water-quality related. Temperature (significantly) and salinity (slightly) affect coral disease. Parameters that require more investigation regarding their effects on this problem are nutrients, turbidity, toxics/pesticides, bacteria, and viruses. In addition, more data are needed to determine the cause of coral diseases (epidemiology) and there is a need to determine whether there is a global influence on coral disease. The overall significance of coral disease from a water-quality perspective is high.

Coral bleaching is species-dependent and known to occur in the Keys. — The trend for bleaching events is known to be increasing, but the events vary in their severity. This problem is water-quality related; temperature significantly affects bleaching of coral communities and salinity is also thought to be a contributor to the bleaching. More data are needed on the effects of nutrients, turbidity, and toxics/pesticides on the bleaching of coral communities. The overall significance of coral bleaching from a water-quality perspective is high.

Temporally, problematic algal growth is known to occur in localized "hot spots" and this trend is increasing. — The potential exists for problematic algal growth to be water-quality related, however it is not yet seen as a problem. Temperature and nutrients significantly affect this problem. More data are needed on the effects of toxics/pesticides and bacteria on problematic algal growth. The overall significance of problematic algal growth from a water-quality perspective is moderate.

Occurrence of the Lyngbya *bloom is localized, spreading, and increasing.* — The recent (fall 1988 bloom) and rapid increase in *Lyngbya* occurrence could potentially occur with other species within the algal community. The severity of this problem is high in the Keys and is definitely water-quality related. Temperature and nutrients significantly affect *Lyngbya* growth; however, more data are needed on the effects of toxics/pesticides and bacteria on *Lyngbya* growth. The overall significance of *Lyngbya* growth from a water-quality perspective is high.

Areas exhibiting a lack of recruitment are patchy in the Keys. — Recruitment is species-dependent and driven by the reproductive cycle of the organism. The trend of this problem is unknown, however, the severity of the problem is high in the Keys. It is possible that this problem is water-quality related. All of the water-quality parameters discussed have an unknown effect on the problem; more research is needed. The overall significance of the lack of coral recruitment from a water-quality perspective is high.

Cases of impaired growth rates of individual corals are known and isolated. — The trend of this problem is variable and the severity is localized in the Keys. This problem is known to be water-quality related; temperature and turbidity significantly affect individual growth rates. More data are needed to determine if nutrients, toxics/pesticides, bacteria, and viruses affect individual growth rates. Additionally, physical damage to corals is a concern and coral diseases are known to affect growth rates. The overall significance of growth rates of individual corals from a water-quality perspective is high.

The decline in coral abundance is known to be a seasonal, long-term problem (geographically). — The severity of the decline is high and the rate of the decline over time is unknown; there is a lack of data. It is probable, in the historical sense, that this problem is water-quality related. Water-quality parameters that significantly affect this problem are temperature and turbidity. Salinity has been an historically significant problem; however, it is currently insignificant. More data are needed on the effects of nutrients, toxics/pesticides, bacteria, and viruses on the decline in coral abundance. Additionally, cyanobacteria diseases are known to affect coral abundance. The overall significance of the decline in coral abundance from a water-quality perspective is high.

Temporally, the decline in species diversity (abundance and richness) for species other than coral is extremely variable (from hours to years) and widespread for the width of the Keys. — Species diversity is declining particularly because of the commercial harvest of several species, although the available data relate to harvested species and few data exist for other species. It is probable that the decline in species diversity is water-quality related for the nearshore breeding species and possibly water-quality related for offshore breeding species. Temperature significantly contributes to the decline while the effects of nutrients on this problem are slight to moderate. Salinity is a slight contributor to this problem, and toxics/pesticides are a slight contributor offshore. It is unknown if turbidity, bacteria, viruses, and dissolved oxygen (DO) affect the problem; more data are needed. The overall significance of the decline in species diversity from a water-quality perspective is unknown.

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SUBMERGED AND EMERGENT AQUATIC VEGETATION ASSESSMENT

Task 4

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TASK 4 — SUBMERGED AND EMERGENT AQUATIC VEGETATION ASSESSMENT

1.0 INTRODUCTION

Seagrass meadows and emergent mangrove forest represent two critical communities within the boundaries of the Florida Keys National Marine Sanctuary (FKNMS). As applied here, the term community refers to a complex structure of interacting plant and animal assemblages. The exact composition of these communities may vary from place to place, but seagrass and mangrove plant species always form the matrix around which the communities develop. Without these framework species, these respective communities cease to exist. This Section represents a compilation and summarization of information on these submerged and emergent vegetative species in relation to the ambient and projected water quality in the Florida Keys. The potential effects of water-quality deterioration are discussed, and the current status and trends within each community are assessed based on the available scientific data. Data evaluated include published scientific literature, unpublished data sets, and interviews with acknowledged experts. In many instances, scientific opinion varies as to the extent of impact or the specific mechanisms causing impact. In such circumstances, available data have been objectively evaluated; respective interpretations have also been presented.

2.0 BACKGROUND AND CURRENT CONDITIONS

2.1 HISTORY

Submerged vegetation within the boundaries of the FKNMS consists mainly of the vascular seagrass species *Thalassia testudinum* (turtle grass), *Syringodium filiforme* (manatee grass), and *Halodule wrightii* (shoal grass). Occasionally, sprigs or clumps of *Halophila decipiens* (paddle grass) or *H. engelmannii* (star grass) are seen growing in and around the fringes of the major bed-forming species, but both these species are diminutive and their biomass is minuscule as compared to the three major species. Also, a large number of macroscopic algal species are associated with the seagrass beds and sand bottom areas of the Florida Keys.

For the purposes of this analysis, emergent vegetation consists entirely of the mangroves and dwarf mangroves seen along the island chain. Mangrove forests once stretched along almost the entire coastline of the Florida Keys. Coastal development has reduced their abundance, but there are still significant stands present in certain areas. Of particular significance in the FKNMS Program are the mangrove islands of the Marquesas, the smaller mangrove-covered islands along the Gulf side of the lower Florida Keys, and the extensive mangrove coastlines of Rodriquez Key and John Pennekamp Coral Reef State Park off Key Largo. In addition, there are many acres of mangrove swamp still in private ownership. Large tracts in many areas also exist adjacent to the FKNMS in Everglades and Biscayne National Parks.

The Florida Keys have been undergoing development since the time of the Calusa Indians, 500 years before the arrival of Columbus. The City of Key West was founded in the early 1800s, and had a population of only 12,927 in 1940 (Wallace, Roberts, & Todd *et al.* 1991). In 1912, the Florida East Coast Railway was extended to Key West, prompting the first large-scale destruction of seagrass beds and emergent vegetation associated with development.

In Key West, large areas of bottom were dredged to create anchorage. This same dredged material was used to fill other areas of shallow bottom. Today, over one-third of Key West is built on manmade land. Dredging and land filling have had significant impact on nearshore submerged and emergent vegetative communities throughout the Florida Keys.

In addition to man's activities, both the submerged and the emergent vegetative communities in the Florida Keys are impacted by storms and hurricanes. While seagrass communities appear quite resilient to these periodic disturbances, a major hurricane such as Hurricane Donna (1960), can produce long-term changes in the emergent vegetation community (Tabb and Jones 1962).

2.2 ESTIMATED EXISTING ACREAGES OF SUBMERGED AND EMERGENT VEGETATION IN THE FLORIDA KEYS NATIONAL MARINE SANCTUARY

At present, there are an estimated 565,094 ha (1,396,345 acres) of seagrass and 22,560 ha (55,744 acres) of mangrove within the designated boundaries of the FKNMS (BLM and FDNR 1979; FWS and MMS 1983; CSA and GMI 1991).

To facilitate comparison of different areas within the FKNMS, five subdivisions are designated based on geographic parameters and resource utilization patterns (**Figure 4-1**).

1. Western Extension
   Extending from Dry Tortugas Bank eastward to just west of Key West

2. Lower Keys
   Extending from Key West to the middle of the Seven Mile Bridge

3. Middle Keys
   Extending from the middle of the Seven Mile Bridge to Craig Key

4. Upper Keys
   Extending from the Long Key/Lower Matecumbe Channel to North Key Largo (Broad Creek)

5. Northern Extension
   Encompassing the small extent of the reef tract north of Broad Creek that lies outside Biscayne National Park and extends northward to just off the southern end of Key Biscayne.

Table 4-1 presents the estimated acreages of submerged and emergent vegetation within each of these individual subdivisions of the Sanctuary. There are several State- and Federally designated marine preserves within the boundaries of the FKNMS. These include Fort Jefferson National Monument in the Western Extension, Looe Key National Marine Sanctuary (in the lower keys), and John Pennekamp Coral Reef State Park, and the Key Largo National Marine Sanctuary (in the upper keys). In addition to these marine reserves actually contained within the boundaries of the FKNMS, both the Everglades National Park and the Biscayne National Park border the Sanctuary and both are considered critical adjacent habitats (**Table 4-1**). Submerged and emergent vegetative habitats have been presented separately in **Table 4-1** for all marine preserves completely contained within the Sanctuary. For the portions of the Biscayne and Everglades National Parks that border the Sanctuary, only the submerged vegetative community figures are presented. Emergent vegetation in these parks is located too far beyond the borders of the Sanctuary to be significant in this discussion.

Because of the nature of the mapped data sources (e.g., from which information in **Table 4-1** is taken), it is not possible to differentiate among individual plant species. Further subdivision of the habitat categories *submerged* and *emergent* is not possible on a regional basis.

The three species of perennial seagrasses, *Thalassia testudinum*, *Syringodium filiforme*, and *Halodule wrightii*, persist from year to year in the same general location and form large, complex, and extremely significant biological habitats. The seagrass beds formed by these species are one of the most, if not the most, biologically productive habitats within the FKNMS.

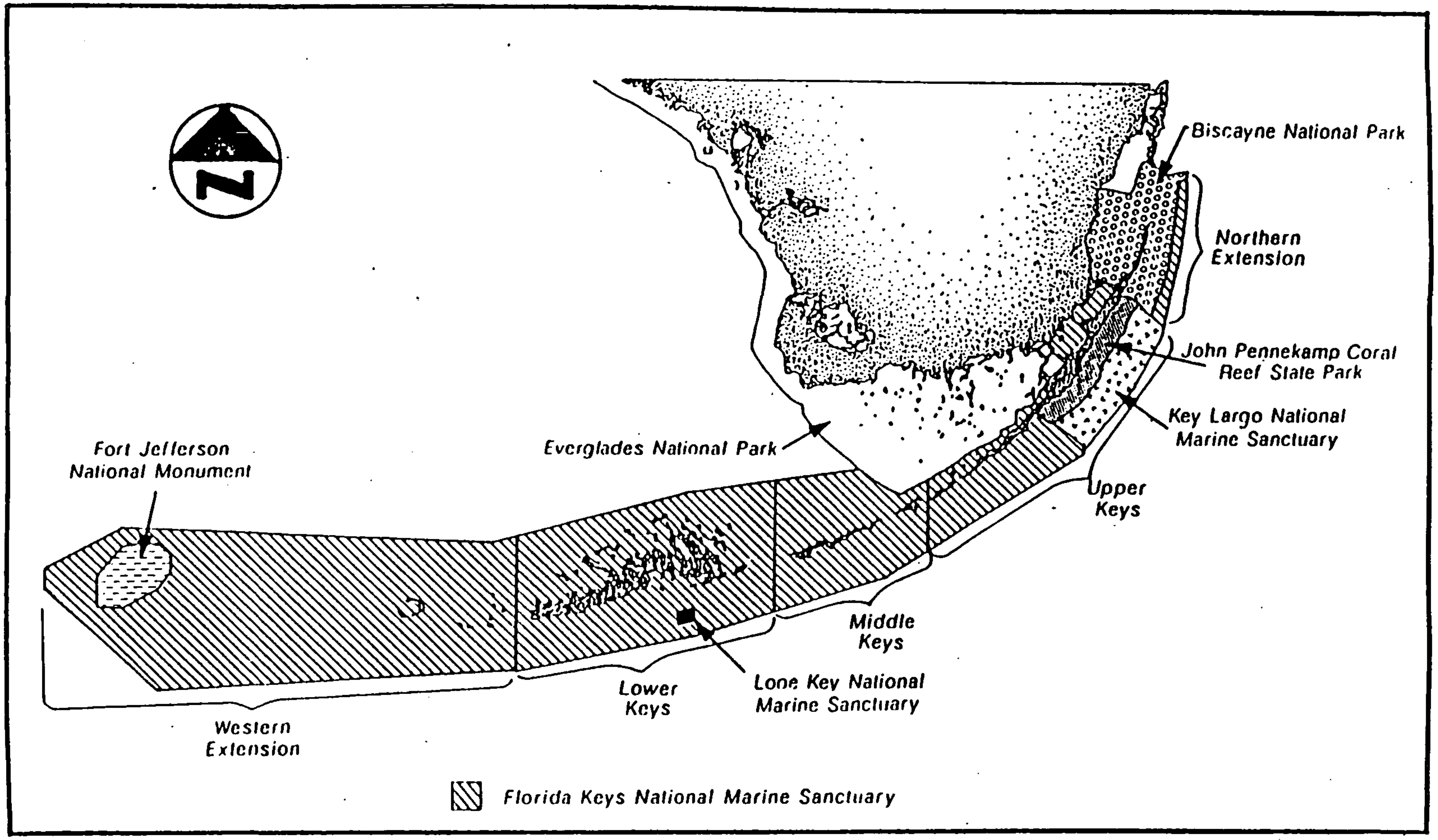

Figure 4-1. Geographic subdivisions of the Florida Keys National Marine Sanctuary.

Table 4-1. Estimated Hectares (Acres) of submerged and emergent vegetation in the Florida Keys National Marine Sanctuary, in existing proximal marine reserves, and in critical adjacent areas[a].

Subdivision or Area	Submerged Vegetation Hectares (Acres)	Submerged Vegetation Coverage (%)	Emergent Vegetation Hectares (Acres)	Emergent Vegetation Coverage (%)	Size of Total Area Hectares (Acres)
Florida Keys National Marine Sanctuary					
Western Extension (Dry Tortugas Bank eastward to just west of Key West)	326,041 (805,648)	69	1,257 (3,105)	0.3	473,281 (1,169,476)
Lower Keys (Key West to the middle of the Seven Mile Bridge)	117,851 (291,207)	48	12,664 (31,293)	5	246,241 (608,438)
Middle Keys (The middle of the Seven Mile Bridge to the Long Key/Lower Matecumbe Channel)	79,238 (195,797)	64	1,215 (3,003)	1	124,613 (307,914)
Upper Keys (The Long Key/Lower Matecumbe Channel to North Key Largo at Broad Creek)	67,914 (167,814)	43	7,423 (18,343)	5	(158,280) (391,101)
Northern Extension (The reef tract north of Broad Creek that lies outside Biscayne National Park, and extends northward to just off the southern end of Key Biscayne)	0	0	0	0	10,667 (26,357)
Totals:	565,094 (1,396,345)	56	22,560 (55,744)	2	1,013,082 (2,503,286)
Existing Marine Reserves					
Fort Jefferson National Monument	20,959 (51,790)	80	6 (16)	0.02	26,048 (64,330)
Looe Key National Marine Sanctuary	237 (584)	13	0	0.00	1,818 (4,493)
John Pennekamp Coral Reef State Park	18,375 (45,405)	78	1,242 (3,068)	5	23,581 (58,286)
Key Largo National Marine Sanctuary	7,574 (18,716)	21	0	0	35,772 (88,268)
Critical Adjacent Areas					
Everglades National Park	222,585 (550,000)	—	—	—	NC
Biscayne National Park	36,154 (89,334)	—	—	—	NC

[a]Submerged habitat data were provided by the Florida Department of Natural Resources (FDNR) and were compiled from maps published by BLM and FDNR (1979) and by CSA and GMI (1991). These map sets have been digitized by the FDNR and submerged habitat area calculations were made electronically. Emergent habitat estimates were derived by planimetry from the maps published by FWS and MMS (1983).

The two annual, vascular plant species reported from the Sanctuary area, *Halophila decipiens* and *H. engelmannii*, are much smaller than the perennial bed-forming species. They are propagated by seed dispersion, and do not form permanent seagrass beds. Because they are capable of surviving at reduced light levels, they are generally seen in deeper water than the major, bed-forming species. They may, however, occasionally be found growing in and around the bases of the larger seagrass species. Zieman (1982), quoting from an earlier but unidentified source, reports *H. engelmannii* occurring in the Dry Tortugas area. Extensive field surveys by Continental Shelf Associates, Inc., in that area in 1988 (CSA and GMI 1991), failed to identify any *H. engelmannii*. However, due to the ephemeral nature of this species growth patterns, it is difficult to say whether or not its absence in 1988 is significant.

It is estimated, based on data from Zieman and Fourqurean (1985) and CSA and GMI (1991), that the seagrass species of *Thalassia testudinum*, *Syringodium filiforme*, and *Halodule wrightii* comprise 75% to 85% of the submerged vegetation acreage estimates presented in **Table 4-1**. These species also provide approximately 95% of the submerged vegetative biomass within the entire FKNMS (Zieman 1991).

Benthic macroalgae making a significant contribution to the submerged vegetation habitat component of the FKNMS include various species of *Batophora*, *Caulerpa*, *Acetabularia*, *Penicillus*, *Halimeda*, *Udotea*, *Rhipocephelus*, *Dasya*, *Gracilaria*, and *Laurencia* (Tabb *et al.* 1962; Zieman and Fourqurean 1985; Merriam 1989; and Montague *et al.* 1989). Geologically, the calcareous algae such as *Halimeda*, *Udotea*, and *Penicillus* have been of importance in creating the calcareous sediments seen throughout the Sanctuary (Ginsburg *et al.* 1971; Merriam 1989). Biologically, such temporally transient species as *Laurencia* make up an important and poorly studied component of the FKNMS ecosystem. Drift algal clumps of *Laurencia* and other algal species may provide various habitats for colonization by many small molluscan and arthropod species. There is evidence to suggest the presence of these seasonal drift algal mats provides a settling cue for post larvae *Panulirus argus*, thus forming critical habitat for the Florida lobster.

Three mangrove species are present in the Sanctuary: red mangrove (*Rhizophora mangle*), white mangrove (*Laguncularia racemosa*), and black mangrove (*Avicennia germinans*). These three species form six recognized vegetative communities: overwash, fringe, riverine, basin, hammock, and scrub or dwarf (Odum *et al.* 1982).

Overwash mangrove forests dominated by red mangrove are seen on islands such as the Marquesas, the smaller keys on the Gulf side of the lower Keys, in Florida Bay, and the islands and sounds on the Atlantic side of the upper Keys off Key Largo. Fringing mangrove forests are typically seen along rather narrow stretches of the coastline. Fringing mangrove stands may contain all three species in specific zones defined by tidal inundation. Riverine mangrove forest within the FKNMS are limited primarily to red mangrove stands in the tidal creeks of the lower and upper Keys. Basin mangroves and hammock forest mangroves within the Sanctuary are limited almost exclusively to the depressions and sink holes seen in the interior of some of the lower Keys. These communities usually are dominated by black and white mangroves. Hammock mangrove communities are found in the same general areas, but they occur on slightly higher elevations, and all three mangrove species may be present. The scrub or dwarf mangrove communities are seen in the hard, limestone substrates on both sides of the Florida Keys. They are more common in the upper and lower Keys than in the middle Keys.

3.0 KNOWN WATER-QUALITY CAUSES OF ADVERSE IMPACTS ON SUBMERGED AND EMERGENT AQUATIC VEGETATION

The seagrass beds of south Florida, including those in Florida Bay and along the Florida Keys reef tract, cover an estimated 5500 km^2 (Iverson and Bittaker 1986), making them among the most extensive areas of seagrass in the world. In spite of their extent, there is very little documented information on man's impact on this system. Almost all of the information concerning declines in the seagrass beds of this region is anecdotal and speculative. In a recent review of anthropogenic impacts on seagrass beds in Florida, Livingston (1987) found very few data from the Florida Keys. Because of this general lack of information, it is necessary to analyze information from other parts of the world to assess the possible adverse impact of degradation in water quality on submerged vegetation within the boundaries of the FKNMS.

In this Section, the magnitude and extent of worldwide declines in seagrass beds are presented by briefly reviewing some of the literature on historical changes in seagrass beds. The specific water-quality-related mechanisms most often implicated in the declines of seagrasses and mangroves are then addressed.

3.1 MAGNITUDE AND GEOGRAPHICAL EXTENT OF WATER-QUALITY-RELATED DECLINES IN SEAGRASS BEDS

In many places around the world, increases in human development in the coastal zone during the past 50 years have coincided with loss of seagrass beds. These losses are well documented for many areas of Europe, Australia, and North America. In the following Sections, a few examples of studies examining the extent and causes of declines from these geographic areas are presented. Special emphasis is placed on Florida seagrass beds.

3.1.1 Europe

Prior to the 1930s, the eelgrass (*Zostera marina*) beds were large enough to support an important industry based on the harvest of seagrass in the northwestern part on the Netherlands. In 1932, an epidemic known as the wasting disease reached the Netherlands and wiped out the sublittoral *Z. marina* beds (Den Hartog and Polderman 1975). At the same time, the Dutch government completed the enclosure of the Zuyder Zee, severely changing the hydrological conditions in areas that had supported *Z. marina* beds prior to the wasting disease. Elsewhere in Europe, *Z. marina* beds that had been lost to the epidemic began to slowly recover, but the sublittoral beds in the Waddenzee never recovered. Littoral beds did recover, however. Beginning in 1965, these littoral beds started to decline anew, and a 30% to 60% decline in the remaining beds was recorded between 1971 and 1973 (Den Hartog and Polderman 1975). It has been argued (Den Hartog and Polderman 1975; Giesen *et al.* 1990) that both the failure of the sublittoral beds to recover and the more recent declines in the littoral populations were due to progressively increasing turbidity throughout the century. Increases in turbidity have been caused by eutrophication, mining, and dredging activities (Giesen *et al.* 1990).

Other areas in Europe have also experienced marked seagrass declines. In the Gulf of Marseilles on the French Mediterranean coast, an impressive decrease in seagrass beds dominated by *Posidonia australis* was reported (Peres and Picard 1975). General eutrophication of the area caused the loss of the deeper beds between 1948 and 1955. Engineering the Rhône River for hydroelectric power has also contributed to this decline by changing the flood frequency and strength, and therefore sediment characteristics, of the Gulf.

3.1.2 Australia

There have been widespread and extensive declines in seagrasses reported from many areas of Australia (see Shepherd *et al.* 1989 for review). The losses were recorded from both temperate and subtropical areas in Australia. Diverse seagrass communities were affected, with major losses of at least nine seagrass species, including *Amphibolis antarctica, Halophila ovalis, Heterozostera tasmanica, Posidonia angustifolia, P. australis, P. sinuosa, Ruppia megacarpa, Zostera capricorni*, and *Z. muelleri*. A variety of proximal mechanisms have been postulated to explain these losses, but all of these are a direct result of human activities in the coastal zone.

3.1.3 Florida

Seagrass beds in Florida have been particularly hard hit by the rapid population growth and industrialization that has occurred over the past 50 years. In two embayments on the west coast of Florida, Pensacola Bay and Tampa Bay, the problem is most severe. Seagrass beds have been substantially reduced in Pensacola Bay over the period from 1949 to 1979, concurrent with the urbanization and industrialization of the watershed for the Bay, and the resulting eutrophication, industrial waste discharge, and dredging and filling (Livingston 1987). The same causes have been suggested as the reason for the 81% reduction of the seagrass beds of Tampa Bay, where total coverage has been reduced from 30,970 ha to 5750 ha in the period from 1948 to 1980 (Lewis *et al.* 1985). Significant loss of seagrasses has also occurred over the last 20 to 40 years in Choctawahatchee Bay, Apalachee Bay, Charlotte Harbor, Biscayne Bay, and the Indian River (reviewed in Livingston 1987). While all of these losses are well-documented, exact mechanisms for the declines are not known, but they all occurred as the watersheds of the embayments were progressively developed.

3.2 WATER-QUALITY FACTORS THAT HAVE BEEN IMPLICATED IN DECLINES IN SUBMERGED AND EMERGENT VEGETATION

Most documented losses of seagrasses have been attributed to the general development of the watershed and coastline that influence the beds. The primary reason that exact mechanisms often can not be identified is that human activities tend to alter many water-quality characteristics simultaneously. In some instances, alterations in the physical parameters of temperature, salinity, and sediment stability have been documented to affect seagrass beds. The effects of toxic materials (such as herbicides, detergents, and petroleum products) have also been blamed for losses of seagrass beds. Most often, however, the reduction of the quantity and quality of light that reaches the seagrasses is cited as the reason for the destruction of seagrass beds. Two primary factors are responsible for increases in light attenuation: increases in suspended sediments in the water and water-column eutrophication from nutrient input.

3.2.1 Temperature

Abnormally high temperatures have been implicated in the decline of seagrass beds. In the temperate zone, Rasmussen (1973) reported a correlation between high summer temperatures and the disappearance of *Zostera marina* beds in Danish coastal waters during the 1930s. High temperatures may also cause problems in tropical and subtropical areas, because the upper thermal limit of tropical organisms is often no greater than that of organisms from warm temperate regions (Zieman 1975a). Glynn (1968) observed that leaves of *Thalassia testudinum* were killed when temperatures exceeded 35 °C on a reef flat in Puerto Rico, but that the rhizomes of these seagrasses were apparently unaffected by virtue of being insulated in the sediment. Under prolonged temperature stress, the roots and rhizomes of seagrasses may also be affected (Wood and Zieman 1969). Higher than normal late summer and autumn temperatures may have a role in the recent die off of seagrasses from Florida Bay, as discussed in greater detail in Section 4.3.3.

High-temperature stress to seagrass beds may result from human activity, primarily from the use of ambient water for cooling systems of power plants (Zieman 1982). Prior to the construction of a 270-km network of cooling canals, the effluent from the nuclear power plant at Turkey Point caused decreased productivity of *Thalassia testudinum* beds and extirpation of 40 ha of seagrass beds from Biscayne Bay (Zieman and Wood 1975). Relatively small (4 °C) temperature increases were responsible for these impacts (Roessler and Zieman 1969).

3.2.2 Salinity

While most seagrasses can tolerate some variation in salinity, most experience reduced photosynthetic rate and growth at salinities that are much higher or lower than normal. The degree to which salinity affects photosynthesis and growth varies among species, however. For the species that dominate seagrass beds of South Florida, *Thalassia testudinum* and *Syringodium filiforme* are more susceptible to salinity deviations than is *Halodule wrightii* (McMillan and Moseley 1967). Salinity levels near normal (35 ppt) may support lusher and more productive seagrass beds than do mesohaline conditions (Zieman and Zieman 1989).

Seagrasses can survive in salinities far outside of their normal range, but only for short periods. Even after short exposures to low or high salinity, extensive leaf loss is common (Zieman 1982). In the aftermath of Hurricane Donna in 1960, it has been speculated that more damage was done to *Thalassia testudinum* beds in Biscayne Bay by lowered salinity than by wind and wave action from the storm (Thomas *et al.* 1961).

Human activity can alter the salinity regime of seagrass beds, and thereby cause changes to the beds. It has been speculated that the diversion of freshwater and the changing of hydroperiod of the Everglades drainage has changed the historic salinity regime in Florida Bay from a variable, mesohaline system to a more stable, polyhaline to hypersaline system. These changes may be responsible for the observed shift in Florida Bay seagrass communities from *Halodule wrightii* dominance to *Thalassia testudinum* dominance (Zieman 1982).

3.2.3 Sediment Stability

Dredging activity can be deleterious to seagrass beds in many ways. Not only are beds removed or buried by dredging, but the resulting change in the amount of current and wave energy reaching surrounding seagrass beds may be changed. In Botany Bay, Australia, dredging of a ship channel increased wave energy to the point that even minor storms caused damage to established seagrass beds. This storm damage is thought to be one of the primary factors behind a 58% reduction in the *Posidonia australis* beds of Botany Bay (Larkum and West 1990). Increased currents and tidal fluctuations brought on by the enclosure of the Waddenzee are thought to have altered the bottom-sediment characteristics so severely that *Zostera marina* was unable to recolonize following its demise caused by the wasting disease (Den Hartog and Polderman 1975).

3.2.4 Toxic Substances

Anionic detergents are a common component of domestic sewage. Detergents carried into seagrass beds adsorbed to clay particles have been implicated in the decline of *Posidonia oceanica* beds of the French Mediterranean (Peres and Picard 1975). Den Hartog and Polderman (1975) hypothesize that toxic effects of detergents may also have played a role in the modern decline of intertidal seagrass beds in the Dutch Waddenzee.

Seagrasses are susceptible to some herbicides (see Thayer *et al.* 1984 for review). The decline in submerged aquatic vegetation in the upper and middle Chesapeake Bay has been correlated with the use of the herbicide atrazine (Correl and Wu 1982). The toxicity of the breakdown products of common herbicides to seagrasses is not known.

Little is known about heavy metal toxicity to seagrasses, but at least some seagrasses concentrate heavy metals in their tissues (Drifmeyer *et al.* 1980). The possible effects of bioaccumulation of heavy metals in the animals occurring in seagrass beds are unknown.

Seagrasses are generally not strongly affected by acute contact with petroleum products (see Zieman 1982; Phillips 1984 for reviews), but Thayer *et al.* (1984) point out that the effects of long-term, chronic exposure to petroleum and related products are not known. The animals in seagrass beds are highly susceptible to poisoning by oil and related compounds (Zieman 1982).

3.2.5 Light Attenuation

In areas where physical and sedimentary characteristics are amenable to seagrass growth, light availability is considered one of the primary physical factors limiting seagrass distribution (see Dennison 1987 for review). The availability of light limits seagrass distribution by controlling the maximum depth at which seagrasses can survive. Shoreward, or minimum depth limits, of seagrass beds are often set by the ability of seagrasses to survive exposure to low-tide conditions (e.g., Bridges and McMillan 1986). The offshore extent of seagrass beds often occurs where the water depth reaches the maximum depth at which the seagrasses receives enough light to survive.

The relationship between maximum depth of seagrass beds and light availability is illustrated by the relationship between maximum depth and measures of water clarity. For example, the maximum depth of *Thalassia testudinum* in Puerto Rico (Vicente and Rivera 1982) and *Zostera marina* near Woods Hole, Massachusetts (Dennison 1987), are both closely correlated with the mean annual Secchi disk depth. On the western Florida shelf, the depth limits of seagrass beds dominated by *T. testudinum*, *Syringodium filiforme*, and *Halodule wrightii* correspond to the depth to which approximately 10% of the incident surface irradiance penetrates (Iverson and Bittaker 1986). The depth to which 10% of surface irradiance penetrates is a good general rule of thumb to predict maximum depth distribution of seagrasses: in a review of published depth limits of seagrasses from around the world, Duarte (1991) found that seagrass depth limits, on average, were at the depth to which 10.8% of the surface irradiance penetrated.

Many factors act to attenuate light in the water column that overlies seagrass beds (Gallegos *et al.* 1991). The total absorption of light in the water column may be partitioned into the contributions of the absorption by pure water and the absorption of material dissolved and suspended in the water. Dissolved organic matter can contribute substantially to the attenuation of light in the water column. Suspended materials that may play a major role in absorbing light include mineral matter, organic detritus, and phytoplankton.

Due to the importance of light availability in determining seagrass distributions, any factor that decreases the amount of light penetrating the water column may have a significant impact on seagrass beds. Not all factors that decrease light penetration will have the same effect on the seagrasses, however (Gallegos *et al.* 1991). The dissolved organic matter that results from the decomposition of mangroves and salt-marsh plants can lead to tea-colored water that appears very dark, yet the specific wavelengths of light that are directly utilized by seagrasses for photosynthesis are not as strongly attenuated as total visible light. Since phytoplankton and seagrasses utilize similar specific wavelengths of light for photosynthesis, the portion of the total light spectrum that is absorbed by phytoplankton has a much greater effect on the growth of seagrasses than does a similar amount of light absorbed by suspended mineral matter.

3.2.5.1 SEDIMENT LOAD AND TURBIDITY

Increased suspended sediment loads are harmful to seagrasses in three ways: (1) suspended sediments decrease the light penetration of the water column, (2) sediments can coat seagrass blades and block light, and (3) settling of the suspended load can bury seagrass beds.

Any process that affects the sediment load of the water column overlying seagrasses may have negative impacts on seagrasses. The cultivation of land for agriculture is correlated with increases in turbidity in nearby coastal waters, and has been shown to result in decreased growth of seagrasses (Thayer *et al.* 1975). Turbidity and increased sedimentation rates caused by the construction of the Julia Tuttle Causeway may have been responsible for the reduction in seagrass beds in Biscayne Bay, even after the diversion of a domestic sewage outfall from the Bay (McNulty 1961).

Suspended solids in the water may have been responsible for the loss of seagrasses in Western Port, Australia, not while in suspension, but after settling on leaf surfaces (Shepherd *et al.* 1989). A fine mud coating on the leaves may have blocked light from reaching the leaves. The problem was especially severe in intertidal seagrasses because fine muds became permanently adhered to leaf surfaces upon exposure to the air.

A positive feedback exists in the effects of turbidity on seagrasses. The ability of seagrasses to trap and bind sediments is well known. When seagrasses are killed, they no longer hold the sediments out of the water column. In this way, the death of seagrasses due to shading can lead to greater turbidity in the overlying water column, causing even greater attenuation of light. After the loss of *Zostera marina* to the wasting disease in the 1930s, sediments in the Waddenzee were no longer stabilized, and turbidity increased dramatically, thereby precluding the recolonization of the former seagrass beds (Giesen *et al.* 1990).

Heavy suspended loads of fine, flocculent material can kill mangroves by clogging the lenticels and pneumatophores on the roots, thereby preventing aeration of the roots. Untreated sugar cane wastes, pulp mill effluent, and ground bauxite and other ore particles all have been implicated as deleterious sources of fine, flocculent sediments (Odum and Johannes 1975).

3.2.5.2 NUTRIENTS

Seagrasses are faced with a paradox in their environmental requirements. As with all autotrophs, seagrasses need light to survive, but they are rooted underwater, a medium that attenuates light much more strongly than air. In addition to light, they require mineral nutrients to photosynthesize and build tissue. The density of many seagrass beds is limited by the nutrient supply. Experimental additions of nutrients to both sediments and the water column of seagrass beds can greatly increase seagrass biomass and growth rate (e.g., Orth 1977; Harlin and Thorne-Miller 1981; Powell *et al.* 1989). In south Florida, nutrient additions can influence the species composition of seagrass beds, with *Halodule wrightii* replacing *Thalassia testudinum* after 3 years of nutrient addition (Powell *et al.* 1991). It is important to note that all these nutrient addition experiments were all conducted on temporal and spatial scales.

Unfortunately for seagrasses, long-term increases in nutrients in the overlying water column of large geographic areas cause the attenuation of light to increase dramatically, often leading to extirpation of seagrass beds (Zieman 1975b; Orth and Moore 1983; Cambridge and McComb 1984; Giesen *et al.* 1990; Larkum and West 1990). Seagrasses are, therefore, usually found in areas with relatively low nutrient concentrations in the surface water. Nutrients can be brought into nearshore waters that support seagrasses by either surface runoff or groundwater discharge (Valiela *et al.* 1990). Two distinct phenomena contribute to the deleterious effects of elevated water-column nutrients on seagrasses: (1) nutrient-induced phytoplankton blooms that reduce the amount of light that penetrates to the seagrass beds and (2) enhanced growth of epiphytes that directly shade seagrasses.

3.2.5.2.1. Nutrient-Induced Phytoplankton Blooms

The increased growth of phytoplankton and the concomitant increase of light attenuation in eutrophic bodies of water is a well-known phenomenon. This reduction in light is a problem for seagrasses growing in deeper areas of affected coastal areas, but it has relatively little effect on seagrasses in shallow areas (Cambridge *et al.* 1986). In numerous estuaries in New South Wales, Australia, seagrass beds dominated by *Zostera capricorni* have been reduced by 50%, apparently due to the reduction of light penetration owing to eutrophication (Shepherd *et al.* 1989). Increases in nutrient concentrations due to pollution of the Rhine River have exacerbated the attenuation of light in the Dutch Waddenzee, and contributed to the continuing decline of local *Z. marina* populations (Giesen *et al.* 1990). In at least one instance, (Cockburn Sound, Australia) the reduction of anthropogenic nutrient loads has led to a decrease in phytoplankton biomass and an arresting of the loss of seagrass beds (Shepherd *et al.* 1989). In this case, the anthropogenic nutrient source was a domestic sewage outfall into a bay with limited circulation. Although no identical situations to this Australian experience exist in the FKNMS, there are several locations where seagrasses growing in nearshore areas with restricted flushing may be undergoing stress as a result of anthropogenic nutrient-induced eutrophication.

3.2.5.2.2 Nutrient-Induced Epiphyte Growth

Significant losses of seagrasses occur in coastal waters that receive anthropogenic nutrient loads, despite the minimal decrease in water clarity in some of these areas (e.g., Silberstein *et al.* 1986). Obviously, nutrient loading produces responses other than increases in phytoplankton biomass that affect seagrasses. One such phenomenon is the increase in epiphytization of seagrasses in areas of high-nutrient availability. Increased water-column nutrients have been shown to increase epiphyte loads in seagrass beds from many areas of the world (Sand-Jensen 1977; Kemp *et al.* 1985; Borum 1985; Silberstein *et al.* 1986; Dunton 1990; Tomasko and Lapointe 1991). Epiphytes directly shade seagrass leaves; the light attenuation through epiphytes is an exponential function of epiphyte biomass (e.g., Bulthuis and Woelkerling 1983, Silberstein *et al.* 1986). This reduction in light can greatly reduce photosynthesis and growth of seagrasses (Bulthuis and Woelkerling 1983; Silberstein *et al.* 1986; Tomasko and Lapointe 1991).

Increased epiphytism may be the primary mechanism through which human-induced eutrophication destroys seagrass beds. Increased nutrients from bird colonies and human sewage can lead to an increase in epiphyte loads, and therefore a decrease in biomass and shoot density. This phenomenon has been noted in *Thalassia testudinum* beds in the Florida Keys and the Caribbean (Tomasko and Lapointe 1991). Increased epiphytes have been identified as the primary factor contributing to the loss of seagrasses in Cockburn Sound (Cambridge *et al.* 1986) and in other estuaries in Australia (Shepherd *et al.* 1989). It has also been implicated in the loss of submerged aquatic vegetation from Chesapeake Bay (Kemp *et al.* 1985) and other coastal waters (Valiela *et al.* 1990).

3.3 RECENT DIE OFF OF SEAGRASSES IN FLORIDA BAY

Seagrasses dominate the bottom of Florida Bay (Zieman *et al.* 1989a), a critically important area adjacent to the FKNMS. Beginning in 1987, there has been a massive and unprecedented mortality of seagrasses in Florida Bay, mostly within the boundaries of Everglades National Park (Robblee *et al.* 1991). Since 1987, 4000 ha of seagrass beds have been completely denuded, and another 23,000 ha have been impacted to a lesser extent. This die off occurred in dense seagrass communities that were dominated by *Thalassia testudinum*, and at first spread very rapidly. Over the past 2 years, die off of seagrasses has continued at a slower pace, and the denuded areas that were previously covered with dense stand of *T. testudinum* have been recolonized by *Halodule wrightii*. It has been speculated in the popular press that water-quality degradation, and particularly enhanced nutrient loading, due to human activities has caused this seagrass mortality. Three years of intensive investigation by a team of researchers from the Florida Department of Natural Resources (FDNR), Everglades National Park, Florida International University, University of Georgia, and University of Virginia has all but ruled out anthropogenic pollution including nutrients as the cause of this die off (Robblee *et al.* 1991; J. Zieman, University of Virginia, personal communication, 1991; R. Jones, Florida International University, personal communication, 1991). The locations of the most severe die off are distant from surface-water pollution sources. Degradation in water quality, including increases in total nutrient concentrations and decreases in light penetration, have been observed in the water column overlying areas of this seagrass die off. These decreases have, in all cases studied, followed the beginning of mortality of the seagrass community and have not preceded it. At present, two potential causes of the mortality are under investigation: (1) a pathogenic marine slime mold and (2) imbalances in the respiration/photosynthesis balance within the plants themselves.

Muehlstein and Porter have isolated a pathogenic slime mold (*Labyrinthula* sp.) from *Thalassia testudinum* leaves from dying areas of Florida Bay (Robblee *et al.* 1991). This organism is closely related to the pathogen thought to be responsible for the *Zostera marina* wasting disease (Short *et al.* 1987; Muehlstein 1989) that devastated North Atlantic *Z. marina* eelgrass beds in the 1930s and has been recently recurring in New England (Short *et al.* 1987). No mortality has been induced in apparently healthy *Thalassia testudinum* stands by exposing them to this pathogen (D. Porter, University of Georgia, personal communication, 1991), indicating that, although this disease may contribute to the ultimate demise of the seagrasses, it is not the ultimate cause of the observed mortality.

Zieman *et al.* (1989b) proposed a conceptual model for the Florida Bay seagrass die off. It invokes two potential ultimate causes of the die off: (1) a long-term modification of the freshwater inputs into Florida Bay from the Everglades due to the diversion of freshwater for agricultural, industrial, and domestic use and (2) an abnormally long interval between major hurricane impacts on Florida Bay. Salinities in Florida Bay have been very hypersaline over the past few years, reaching year-average highs of over 55 ppt in central Florida Bay [Fourqurean *et al.* (to be published)]. Draining of the Everglades caused the diversion of runoff, which has been curtailed by as much as 59% from historical levels (Smith *et al.* 1989). Salinities of this magnitude can be fatal to seagrasses (McMillan and Moseley 1967). Reduction of freshwater would also allow *Thalassia testudinum* to invade areas that historically were too fresh or too variable for colonization by this species (Zieman 1982).

Hurricanes may function to remove accumulated organic matter and sediments from Florida Bay. There has been an abnormally long period since that last major hurricane affected Florida Bay, perhaps allowing accumulations of sediments and organic matter beyond historic levels. This may have allowed the overly dense beds of *Thalassia testudinum* to develop in portions of Florida Bay. These overly dense beds may now be experiencing the consequences of overdevelopment, and may be succumbing to the effects of respiration/photosynthesis balance or disease. Very hot summers and falls in 1987, 1988, and 1989 may be responsible for the beginning of the die off. High temperatures, especially in the fall, would enhance respiration rates more than photosynthetic rates would, and cause a decrease in the net production of the grass beds. Also, direct mortality of large amounts of shallow-water beds of *T. testudinum* occurred during the summers and falls of 1987 and 1988 (J. Fourqurean and G. Powell, unpublished data), which supplied large amounts of decomposing leaves to the basins that were subsequently affected by die off. The decomposition of these leaves may have led to hypoxic stress in the seagrass beds in deeper water, causing more seagrass mortality.

Even though the ultimate cause of the present seagrass die off has yet to be proven conclusively, it seems clear that anthropogenic nutrient input to the surface water is not responsible. Groundwater sources of nutrients have also been shown to affect seagrass beds (Lapointe *et al.* 1990; Valiela *et al.* 1990). While a definitive study of the potential for this type of input to Florida Bay has not been completed, there is no evidence for increased nutrient loadings of any kind to Florida Bay being responsible for the die off.

3.4 EMERGENT VEGETATION

The main anthropogenic threats to mangrove swamps are diking, flooding, impounding, and outright destruction by dredging and filling. In south Florida, the most significant impacts to mangrove communities, other than outright destruction, have resulted from alteration of the freshwater runoff and drainage patterns. Reductions and shifts in freshwater drainage patterns have had extensive effects in the estuarine mangrove community (Odum 1970). While many estuarine mangrove communities have shrunk as a result of increased freshwater input, the mangrove communities of Florida Bay and Everglades National Park have expanded due to the reduced freshwater discharge (Odum and McIvor 1990).

Mangroves are extremely susceptible to herbicides (Odum *et al.* 1974). At least 100,000 ha of mangroves were defoliated and killed by herbicides applied by the U.S. Army in Southeast Asia during the Vietnam War (Walsh et al. 1973). Not all mangrove species are affected equally by herbicides. In Florida, the red mangrove *(Rhizophora mangle)* is much more susceptible to herbicide damage than the black mangrove *(Avicennia germinans)* (Teas and Kelly 1975).

Petroleum and petroleum products have a number of deleterious effects on mangroves (see Lewis 1980; de la Cruz 1982; Zieman *et al.* 1984 for reviews). Damage to mangroves by oil results in the clogging of lenticels and pneumatophores on mangrove roots. As a result, disruption of oxygen transport within the plants and impacts from the toxic effects of the petroleum products occur. Odum and Johannes (1975) have suggested that the critical concentration of crude oil which may cause extensive damage in mangrove communities is between 100 and 200 ml/m^2. As with other intertidal communities, many of the fish, invertebrates, and macroalgal species associated with the mangrove community are severely impacted by spilled oil products.

In the FKNMS, all documented mangrove community loss has resulted from mechanical destruction (i.e., dredging and filling, cutting, channeling, and general clearing). There are some areas where surface runoff from cleared areas may have adversely impacted adjacent mangrove communities by clogging aerial root pneumatophores, but these areas have not been well studied. Continued land development represents the greatest current threat to the mangrove community of the FKNMS.

Mangrove systems provide shoreline stabilization and act as natural filters for terrestrial runoff entering the marine environment. The loss of these communities in highly developed areas of the FKNMS has contributed to problems associated with surface water runoff in these areas. It is important to remember that the nearshore mangroves, the seagrass beds, and the coral reefs are all part of one large ecosystem in the FKNMS. Loss of mangrove habitat to development contributes to loss of seagrass via increased nutrient loading and terrestrial runoff, which in turn contributes to loss of reef fish species and species diversity on the offshore coral reefs.

4.0 COMMUNITY TRENDS AND WATER-QUALITY-RELATED IMPACTS SEEN IN THE FLORIDA KEYS NATIONAL MARINE SANCTUARY

Historically there have been localized losses within both the submerged and emergent aquatic vegetation communities of the FKNMS. The most significant habitat losses in terms of acreage have been in emergent vegetation, but there have been localized losses in the seagrass community as well. Up through the 1990s these habitat losses resulted almost exclusively from the physical destruction of these communities by activities associated with development (e.g., land clearing, dredging and filling, highway construction, channel dredging, etc.). With increasing regulation of wetland habitat development, the pace of emergent vegetative community loss has slowed over the past few years. Many other activities associated with land development are now also coming under increasing regulation, and this is also expected to further slow wetland habitat loss in the Florida Keys.

The area encompassed by the FKNMS has never suffered, at least during recorded history, a loss of submerged vegetative habitat similar to that of the eel grass (*Zostera marina*) wasting disease of the 1930s. Similarly, a seagrass die-off event on the scale of the continuing die off of the turtle grass (*Thalassia testudinum*) beds seen in Florida Bay (Robblee *et al.* 1991) has not been realized. Originally there was considerable concern that this Florida Bay die off might spread to seagrasses throughout Florida, but it now appears that the die off in Florida Bay results from specific localized conditions. While there is the possibility that, if it continues unabated, it may eventually impact some seagrass communities within the Sanctuary, this phenomenon is not considered the threat that it once was. Currently, the only seagrass beds within the FKNMS to be affected by this die off are the bank-fringing *Thalassia* beds near Steamboat Channel on the Florida Bay side of upper Matecumbe Key (**Figure 4-2**).

The loss of historic seagrass habitat within the Sanctuary has resulted almost entirely from mechanical destruction. Over the entire estimated number of hectares lost since the turn of the century, approximately 2000 ha represents only 0.35% of the total seagrass acreage within the Sanctuary (565,094 ha).

5.0 STATEMENTS OF PROBLEMS

A key part of Phase I of the Water Quality Protection Program is the identification of water quality problem areas to be addressed during Phase II. A two-step approach was used to identify and obtain agreement among members of the scientific community on known, suspected, or potential water-quality problems affecting the natural resources of the Sanctuary. Initially, information gathered during the literature review was used to derive a series of statements describing potential water-quality related problems (presented in Section 5.1). These problem statements were then refined through discussions with EPA Region IV Coastal Programs staff and State of Florida environmental staff and delivered to workshop participants to provide focal points for discussions at technical workshops. The participants in each workshop were charged with coming to a consensus, where possible, on the problem statements developed for each workshop resource area. A matrix analysis of each workshop resource area (Appendix B) was the tool used to develop consensus on the problem statements. Specific descriptive terms were used to complete the matrix based on the discussions with the expert panels assembled for each workshop (Appendix B). Public comments were also heard during the course of each workshop. To assist EPA Region IV and the State of Florida to direct their limited resources, each expert panel was asked to rank the overall significance of the water-quality related problems at the end of each daily workshop. The consensuses developed at the workshops are summarized in Section 5.2 and presented in more detail in Appendix B.

5.1 PROBLEMS IDENTIFIED DURING THE LITERATURE REVIEW

The following lists either known, suspected, or potential problems, exclusive of mechanical destruction (not addressed in this document), related to submerged and emergent vegetative communities in the FKNMS. However, to state a problem does not of itself mean or imply that the stated problem actually exists. There is a divergence of views on what actually constitutes real or potential problems for the FKNMS.

In many instances, the data are insufficient to assess the true importance or validity of a given problem, so called. For this reason, there is a "data sufficiency" question posed under each statement of a problem. No references are given for statements made in this Subsection — the statements made here represent an evaluation of the data and referenced studies in the preceding text.

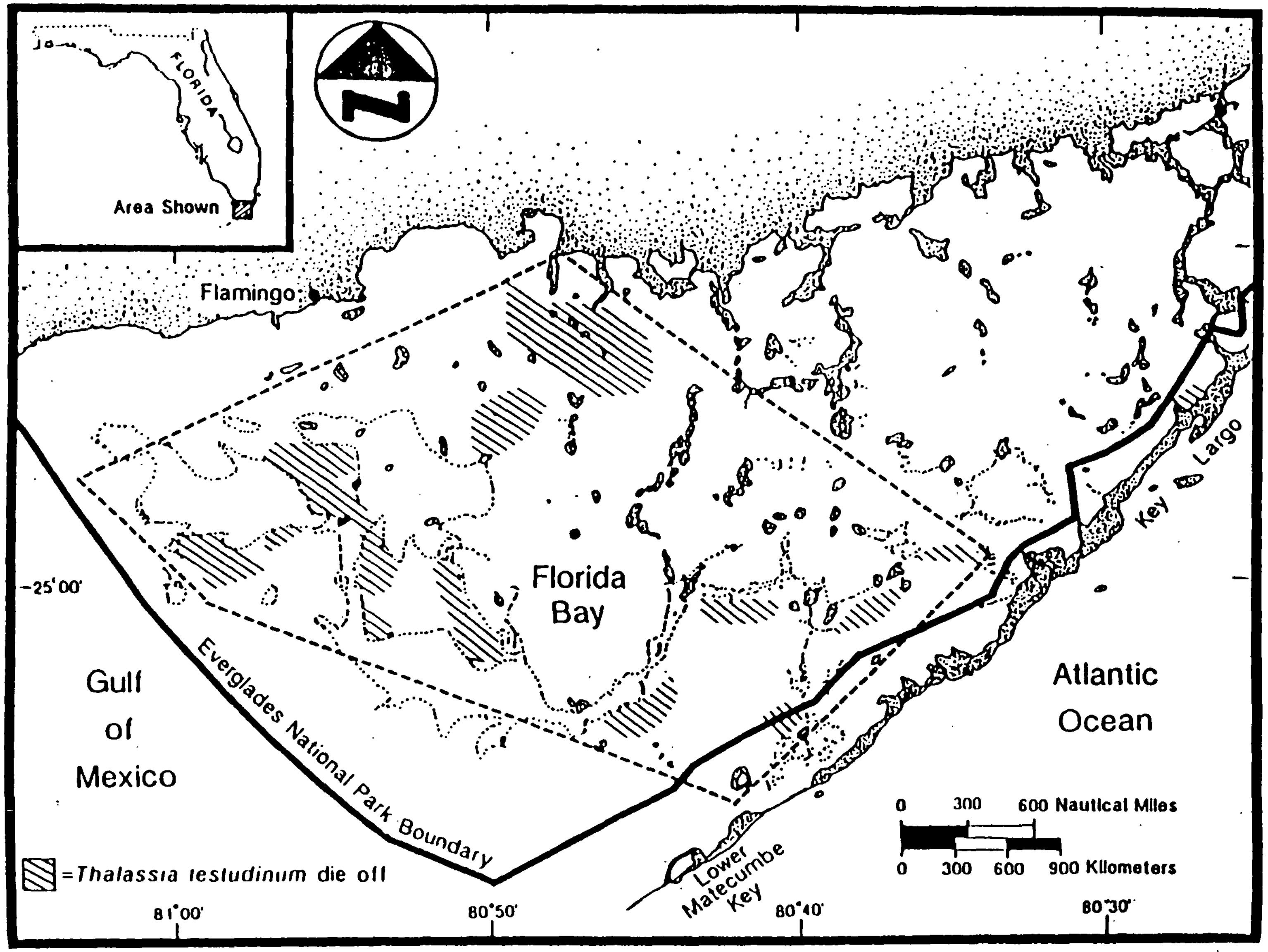

Figure 4-2. Distribution of *Thalassia testudinum* die off in Florida. [From Robblee *et al.* 1991]

Degraded water quality may be adversely affecting emergent vegetation in the FKNMS. — Because mangroves in general have been shown to be relatively resistant to problems caused by degraded water quality, and there are no reported areas where such habitat losses have occurred in the FKNMS, the data are considered sufficient to indicate that this water-quality related problem is not significant at this time.

Toxic substances may be adversely affecting submerged and emergent vegetative communities. — There are no reported cases of significant community impact from toxic substances — anionic detergents and heavy metals from domestic and industrial waste, herbicides from lawn and agricultural run off, and hydrocarbon contamination from spills of petroleum products — on either the submerged or the emergent vegetative community in the FKNMS. Critical areas where impacts from these sources might be seen are Card and Barnes Sounds (mainland agricultural runoff and canal discharge), in and adjacent to marinas with a large live-aboard population and/or bottom-scraping and painting operations, and adjacent to large point-source discharges. There are no specific data to evaluate the effects of anionic detergents, which have been suggested as causative agents for seagrass declines in some parts of the world, or heavy metals, which may be concentrated in the tissues of some seagrasses on vegetation communities within the FKNMS. Although emergent mangrove vegetative communities are extremely susceptible to certain types of herbicides, there has never been a major loss of mangrove habitat in the FKNMS because of a herbicide accident. Petroleum and petroleum products have been shown to have deleterious effects on mangroves and on the animal components of seagrass-bed communities which are highly susceptible to poisoning by oil and oil-related compounds. Significant oil spills have come ashore in the FKNMS in the past. This problem is related to water quality and is potentially very significant, particularly in nearshore areas.

Reduced light levels resulting from anthropogenic increases in sediment load and turbidity may be adversely affecting submerged vegetative communities. — Increased and more rapid terrestrial runoff resulting from land clearing and paving, direct turbidity resulting from coastal construction, and resuspension of sediments by boat traffic and normal wind/wave activity are the primary factors causing increased sediment loads and turbidity in Sanctuary waters. The impact resulting from these phenomena may be occurring throughout the FKNMS, but is potentially more significant in nearshore areas. Data are insufficient to evaluate long-term trends in turbidity levels throughout the FKNMS or the relationship between turbidity and seagrass health in the Sanctuary. This problem is related to water quality and is potentially significant.

Anthropogenic nutrients entering the FKNMS may be adversely affecting submerged vegetative communities. — Nutrient enrichment, resulting from lawn fertilizer runoff, live-aboard boaters sewage discharges, septic-tank leachate, municipal sewage-plant and package-plant discharges, and shallow- and deep-well injection of domestic sewage may be a problem throughout the FKNMS. However, the impacts of nutrient enrichment, which causes phytoplankton blooms and increased epiphyte growth would be expected to be most severe in nearshore and confined waters in the Sanctuary. Sufficient water-quality data from the FKNMS are not available for long-term trend analysis of nutrient levels or to effectively evaluate the impact of nutrient enrichment on the submerged vegetative community. Several studies have indicated that nutrient levels remain low along the outer reef line, whereas others have shown that nutrient levels may be rising in confined waters adjacent to developed areas. This problem is related to water quality and is potentially significant.

Disease may be a threat to the FKNMS submerged vegetative community. — Potentially, any seagrass bed in the FKNMS may be at risk from disease-causing agents such as slime molds (similar to those linked with the great European *Zostera* die off of the 1930s) and unknown viral, bacterial, or algal agents. The recent die off of *Thalassia* beds in Florida Bay is not thought to be disease-induced and there is no evidence of disease in the seagrass beds of the FKNMS. Nevertheless, a disease-related die off of submerged vegetation such as the *Zostera* event is always a possibility. The risk of a disease-related die off affecting the submerged vegetative community of the FKNMS is unknown, but considered slight because of the lack of reported disease in *Thalassia* beds worldwide. This problem is not water-quality related and is not considered significant.

Long-term climate changes may be adversely affecting the submerged and emergent vegetative communities in the FKNMS. — All submerged and emergent vegetative communities within the FKNMS are vulnerable to such large-scale environmental disruptions resulting from global warming (increased air and water temperatures, sea-level rise) and ozone depletion (increased shorter wavelength irradiance reaching the Earth's surface). Large-scale evaluations of potential community changes from global climate change are being conducted by a number of United States and international research agencies. Studies are in progress, although not mentioned in this report, that are assessing possible community shifts in tropical marine seagrass beds due to global climate change. None of these studies has specifically targeted the FKNMS, but their results should be indicative of the potential problems faced here. Possible indirect effects on water quality may result from changes in precipitation. While this problem is real, its specific impact on the submerged and emergent vegetative communities of the FKNMS has not been assessed. From a FKNMS management point of view, this problem is too large-scale and long-term to be of immediate significance in the FKNMS planning process. The possibility of synergistic effects between global climate change and local near-term stresses in the environment should be considered in any long-term monitoring plan developed for the Sanctuary.

5.2 PROBLEMS IDENTIFIED AT THE SUBMERGED AND EMERGENT AQUATIC VEGETATION ASSESSMENT WORKSHOP

The problems discussed at this workshop were divided into four areas — Seagrasses, Macroalgae, Mangroves/Buttonwoods, and Freshwater Influence. Problems regarding ***seagrass communities*** were increased epiphyte growth, seagrass historic growth rates (individual), declines in community diversity (other than seagrasses), decreased geographical extent, decreased recruitment of seagrasses, and hypoxia. Problems regarding ***macroalgae communities*** were increased epiphyte growth, macroalgae historic growth rates (individual), decreased community diversity (other than seagrasses), hypoxia, and diversity of algae. Problems regarding ***mangrove/buttonwood communities*** were decreased tree productivity (individual), decreased geographical extent, and functional value of habitat. Problems regarding ***freshwater influence*** were decreased productivity, decreased geographical extent, and functional value of the habitat. The parameters for analysis and the matrices used for discussion during the workshop are presented in Appendix B.

Currently, extremely saline waters from Florida Bay are believed to be causing reef damage (coral die-off). This extremely saline water is the result of the reduction of the historic and sporadic freshwater flow by canals such as the C-111 canal. This is the only anthropogenic effect on Florida Bay. The natural system in Florida Bay (50 years ago) would be better for more species of fish and vegetation than the present-day environment. The panel members commented that this freshwater flow to Florida Bay needs to be restored and that EPA should determine the extent of the previous coral community. In addition, it was suggested that a historical description of the area describing the communities that existed prior to the reduction of freshwater flow to Florida Bay is needed to determine how much the area has changed. The Florida Bay water quality issue must be included in the management of the FKNMS.

Seagrasses

Priority problems identified for the seagrass communities are epiphyte growth and anthropogenic nutrient loading; control measures are needed.

The problem of increased epiphyte growth on seagrasses is known to occur primarily in hot spots throughout the Keys and the trend is worsening. — This problem is definitely water-quality related in the hot spots and possibly water-quality related elsewhere in the Keys; more data are needed. Turbidity, and anthropogenic nutrients and dissolved oxygen (DO) significantly affect increased epiphyte growth in seagrass communities. The overall significance of this problem from a water-quality perspective is high.

Seagrass historic growth rates (individual) have decreased recently and the reductions are known to occur in hot spots associated with human activity throughout the Keys. — This problem is unknown yet suspected to occur elsewhere in the Keys. This problem is water-quality related in the hot spots and possibly water-quality related elsewhere; more data are needed. Temperature, salinity, anthropogenic nutrients and DO, and turbidity significantly affect growth rates of seagrasses. The overall significance of this problem from a water-quality perspective is high in the hot spots and slight elsewhere in the Keys.

Areas of declines in community diversity are isolated to hot spots and the trend is worsening; declines are unknown elsewhere. — This problem is water-quality related in the hot spots and probably water-quality related elsewhere in the Keys; more data are needed. Temperature, salinity, and anthropogenic DO significantly affect community diversity. The overall significance of this problem from a water-quality perspective is high in the hot spots and possible but unknown elsewhere in the Keys. Overfishing effects have an impact on community diversity. [*Note:* The problem was considered regarding anthropogenic changes.]

Decreased geographical extent (i.e., anthropogenic losses) is known to be isolated to hot spots and this trend is worsening. — Outside the hot spot areas, changes are taking place naturally; human effects here are slight. Temperature, anthropogenic nutrients and DO, salinity, and turbidity significantly affect this problem. The overall significance of this problem from a water-quality perspective is high in the hot spots and slight elsewhere in the Keys.

Decreased recruitment of seagrasses is isolated to hot spots and is worsening. — There is a general lack of data and information regarding this problem and because of the lack of data, no accurate assessment can be made. The problem is possibly water-quality related. Parameters thought to have a significant affect on the problem are temperature, salinity, turbidity, and anthropogenic DO. The overall significance of this problem from a water-quality perspective is unknown.

The problem of hypoxia depends on circulation patterns, flushing of an area, and climate effects and influence (drought, wet). — Hypoxia is definitely water-quality related and usually occurs in hot spots where it has the potential to be severe. Temperature and anthropogenic nutrients and DO significantly affect the problem. The overall significance of the problem from a water-quality perspective cannot be determined because it depends on circulation.

Macroalgae

Priority problems identified for the macroalgae communities are epiphyte growth and anthropogenic nutrient loading; control measures are needed.

The problem of increased epiphyte growth on macroalgae is known to occur primarily in hot spots throughout the Keys and the trend is worsening. — This problem is definitely water-quality related in the hot spots and possibly water-quality related elsewhere in the Keys; more data are needed. Turbidity and anthropogenic nutrients and DO significantly affect increased epiphyte growth in macroalgae communities. The overall significance of this problem from a water-quality perspective is high.

Macroalgae historic growth rates (individual) have increased over the last decade, are known to occur in hot spots throughout the Keys, and are widespread elsewhere. — This problem is water-quality related in the hot spots and possibly water-quality related elsewhere in the Keys. Temperature, turbidity, salinity, and anthropogenic nutrients and DO significantly affect growth rates of macroalgae. The overall significance of this problem from a water-quality perspective is high in the hot spots and slight elsewhere in the Keys. More data are needed regarding this problem.

Areas of decreased community diversity are isolated to anthropogenic hot spots and the trend is worsening. — Declines were unknown elsewhere; more data are needed. This problem is water-quality related in the hot spots and probably water-quality related elsewhere in the Keys. Temperature, salinity, and anthropogenic DO significantly affect community diversity. The overall significance of this problem from a water-quality perspective is high in the hot spots and possible but unknown elsewhere in the Keys. Overfishing effects have a negative impact on community diversity. [*Note:* This problem was considered regarding anthropogenic changes.]

The problem of hypoxia depends on circulation patterns, flushing of an area, climate effects and influence (drought, wet). — Hypoxia is definitely water-quality related and usually occurs in hot spots where it has the potential to be severe. Temperature and anthropogenic nutrients and DO significantly affect the problem. The overall significance of hypoxia from a water-quality perspective cannot be determined because it depends on circulation.

Diversity of the algae has decreased within the last decade. — This problem is isolated to hot spots, is worsening in the hot spots, and is widespread elsewhere in the Keys. Decreasing algal diversity is water-quality related; temperature, anthropogenic nutrients and DO, salinity, and turbidity significantly affect the problem. The overall significance of the problem from a water-quality perspective is high. Overfishing and grazing have an impact on this problem.

Mangroves/Buttonwoods

Priority concerns identified for the mangrove/buttonwood communities are preserving geographical extent and the functional value of the habitat.

The extent, trend, and severity of decreased tree productivity (individual) are unknown. — This problem is water-quality related. Temperature, salinity, turbidity and anthropogenic nutrients and DO significantly affect tree productivity. The overall significance of this problem from a water-quality perspective is unknown. A consequence of decreased tree productivity is increased flood sensitivity. Dredge and fill operations can cause changes in the community. Impoundment effects should be considered.

Decreased geographical extent is widespread and the continuing decline is characterized by large losses of mangroves and buttonwoods. — The severity of the problem, decreased geographical extent, is high. This problem is probably related to water quality. Parameters that have a significant effect on the problem are salinity, turbidity, and anthropogenic nutrients and DO. The overall significance of decreased geographical extent from a water-quality perspective is slight; however, this problem is a highly significant one.

The functional value of the habitat is affected by seasonal and episodic flooding and the trend of this problem is unknown but thought to be declining. — This problem is probably related to water quality. Toxics/pesticides and anthropogenic nutrients and DO significantly affect the functional value of the habitat. The overall significance of the problem from a water-quality perspective is high. Fragmentation is a critical component of the problem.

Freshwater Influence

For freshwater influence, the priority concern is preserving the geographical extent so that there is no further loss of mangrove/buttonwoods and coastal wetlands.

The spatial consideration, trend, severity, and certainty of the problem, decreased productivity, are unknown; however, the problem is probably related to water quality. — Temperature highs and lows, anthropogenic nutrients, and salinity significantly affect productivity; toxics/pesticides possibly affect productivity. The overall significance of the problem from a water-quality perspective is moderate to high. A climatic effect associated with decreased productivity is the lowering of the water table.

The problem of decreased geographical extent is continuing; losses have been high and the severity of the problem is high. — This problem is definitely water-quality related and impacted by nutrient additions and septic system runoff. The overall significance of how water quality affects this problem is high. Dredge and fill operations cause a direct loss of habitat due to development activities. Septic tanks and cesspools also contribute to the problem.

The functional value of the habitat continues to worsen and the problem is widespread in the Keys. — This problem is water-quality related (in part) and anthropogenic nutrients, salinity, turbidity, and toxics/pesticides significantly affect the problem. The overall significance of the problem from a water-quality perspective is high. Fragmentation is a critical component of the problem.

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NEARSHORE AND CONFINED WATERS ASSESSMENT
Task 5

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TASK 5 — NEARSHORE AND CONFINED WATERS ASSESSMENT

1.0 INTRODUCTION

The objectives of Task 5 were twofold: (1) to determine the extent and status of nearshore and confined waters within the Florida Keys National Marine Sanctuary (FKNMS) and (2) to identify and evaluate adverse impacts in the context of current trends in water and sediment quality and biological resources in the nearshore and confined waters within the FKNMS. This task was organized into four subtasks.

The first subtask was to map the extent of nearshore and confined waters in the Sanctuary. Maps of the Sanctuary are presented showing the canals and sounds in the Florida Keys (**Figures 5-1-1 through 5-1-13**), which are part of the nearshore and confined waters. The boundary between nearshore and offshore waters was not determined because there is not a standard definition of confined and nearshore waters. We know of no previous estimates of the area of confined waters in the Sanctuary, and those types of estimates would be difficult to determine without a generally agreed-upon definition.

The second subtask was to evaluate water quality, sediment, and biological quality trends in the confined waters of the Florida Keys. This task was done based on the Sanctuary specific data collected under Task 2 and published scientific literature on pollution effects from the Sanctuary. Interviews did not prove fruitful in gathering additional data but were of some value in developing the problem statements. The evaluation of water quality pertained to measurements of parameters from the water column. Similarly, data for sediments were evaluated. Data were not available to determine trends in biological quality (e.g., differences in quantified abundances of benthic species over time or between developed and undeveloped canals) in confined waters such as canals or to evaluate relationships between changes in water quality parameters and abundances of biota.

The third subtask was to evaluate the information gathered under Task 2 and the two preceeding subtasks to identify known and probable sources of water-quality impacts. The fourth subtask was to prepare this report.

2.0 STUDIES EXAMINING THE NEARSHORE AND CONFINED WATER ENVIRONMENT IN THE FLORIDA KEYS NATIONAL MARINE SANCTUARY

2.1 WATER QUALITY

2.1.1 Environmental Protection Agency — 1975

The Environmental Protection Agency (EPA 1975) investigated water quality at a canal near Marathon, Florida, located on Vaca Key (**Figure 5-1-8**) in August 1974. Although this canal was located in a subdivision (Sea Air Estates), housing density was low around the canal during the survey. Five stations were sampled, four of which were located within the canal and one in Florida Bay. Vertical profiles of dissolved oxygen (DO) indicated that oxygen levels were low in the canal, particularly deeper in the water column. At one station located at a dead end, the mean concentrations of DO were below 4.0 mg/L throughout the water column. These lower oxygen concentrations were thought to be related to the lack of flushing of the canal and possibly to the transfer of anoxic aquifer water into the canal system as this was a deep canal system. Temperature and salinity data indicated that the water column was not stratified. Nutrient concentrations at the canal stations were similar to those observed at the Florida Bay station.

In November 1973, EPA (1975) also investigated water quality in the lower Keys at two canals on Big Pine Key (**Figure 5-1-10**). One of the canals had been recently constructed at the time of sampling, and the other had some dwellings with septic tanks located along it. This permitted a comparison to be made between developed and undeveloped canals.

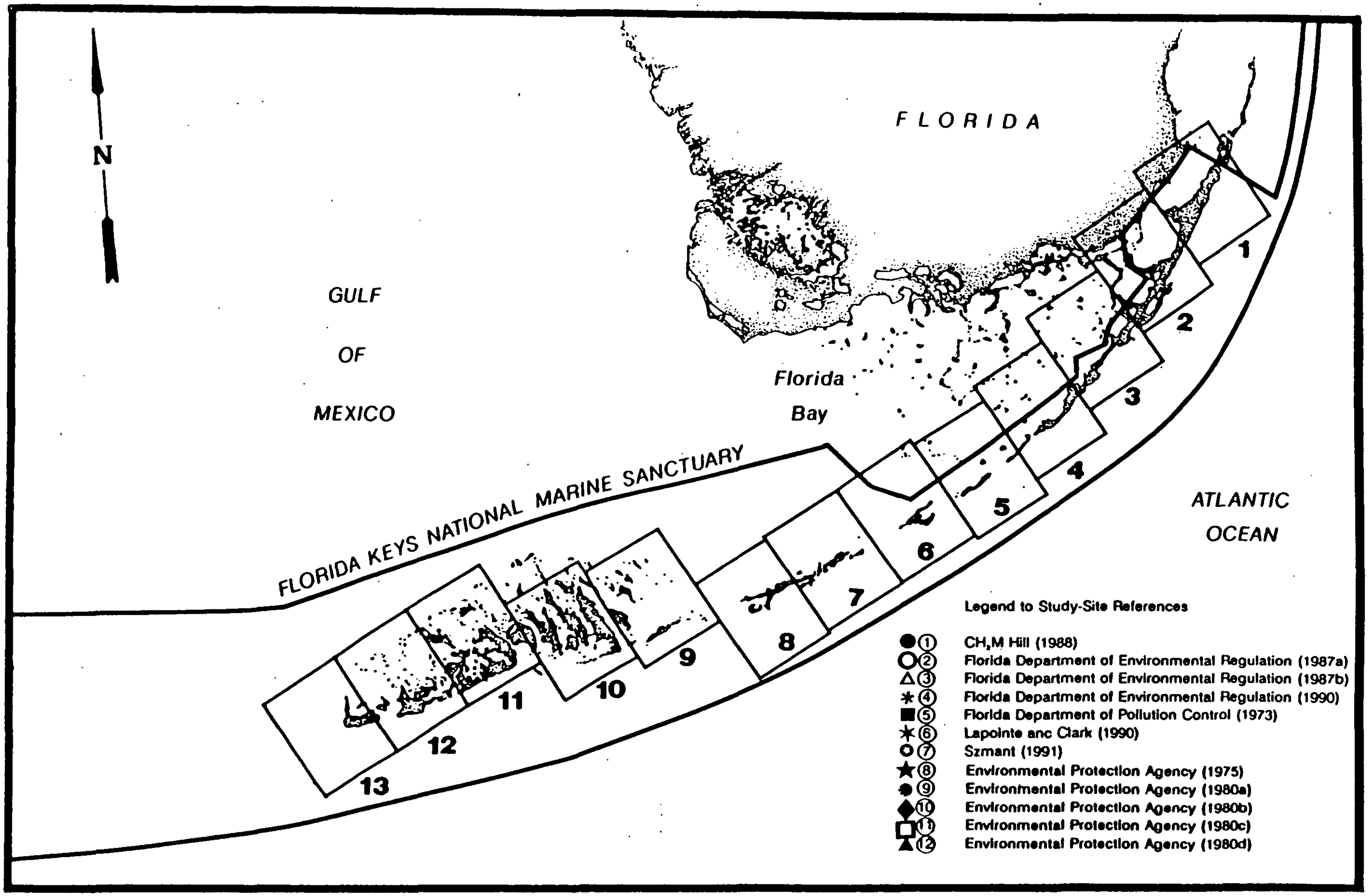

Figure 5-1. Locations sampled during ministudies investigating nearshore and confined waters. Base maps have been redrawn from maps provided by Wallace Roberts & Todd.

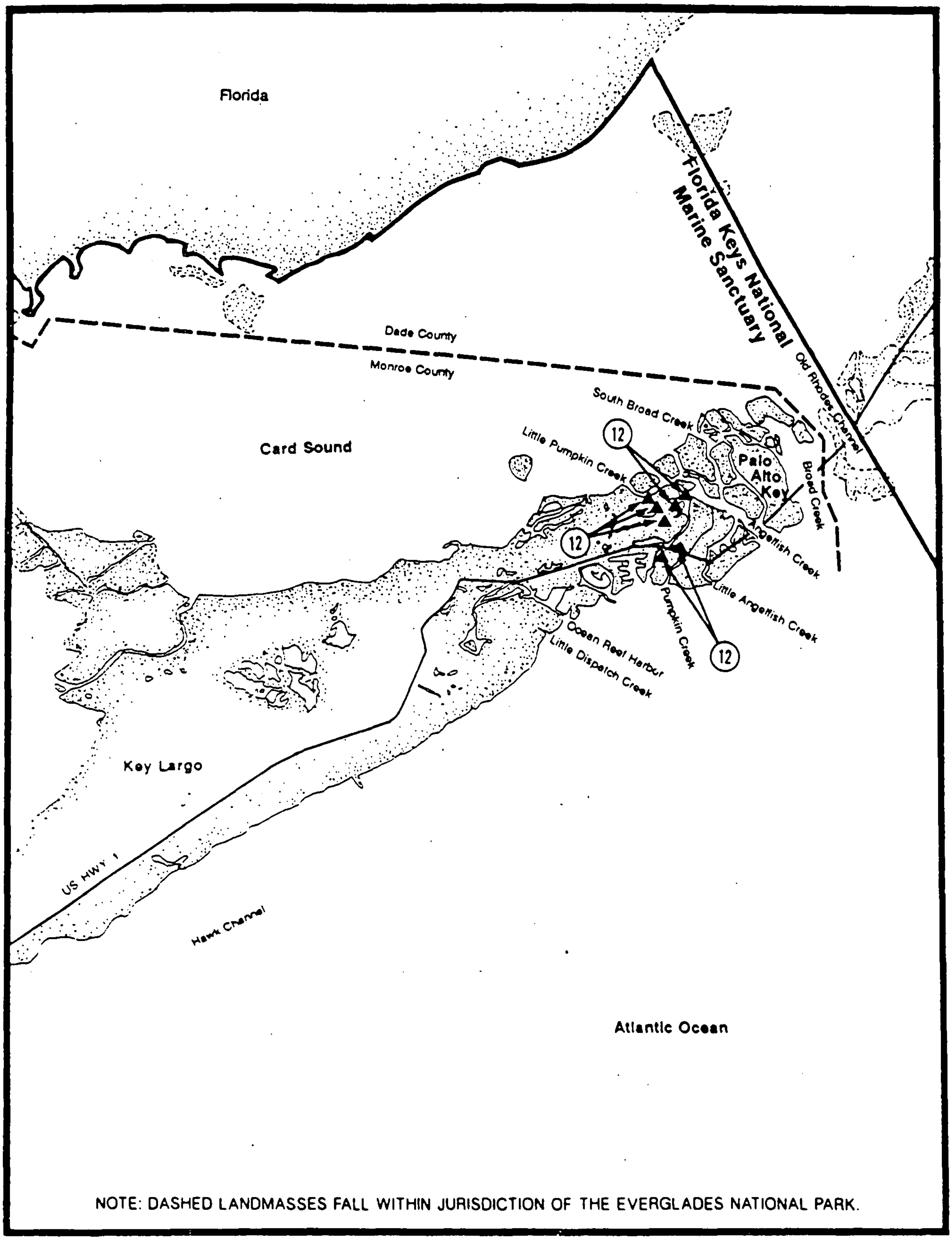

Figure 5-1-1. Locations sampled during ministudies investigating nearshore and confined waters. Base maps have been redrawn from maps provided by Wallace Roberts & Todd. (continued)

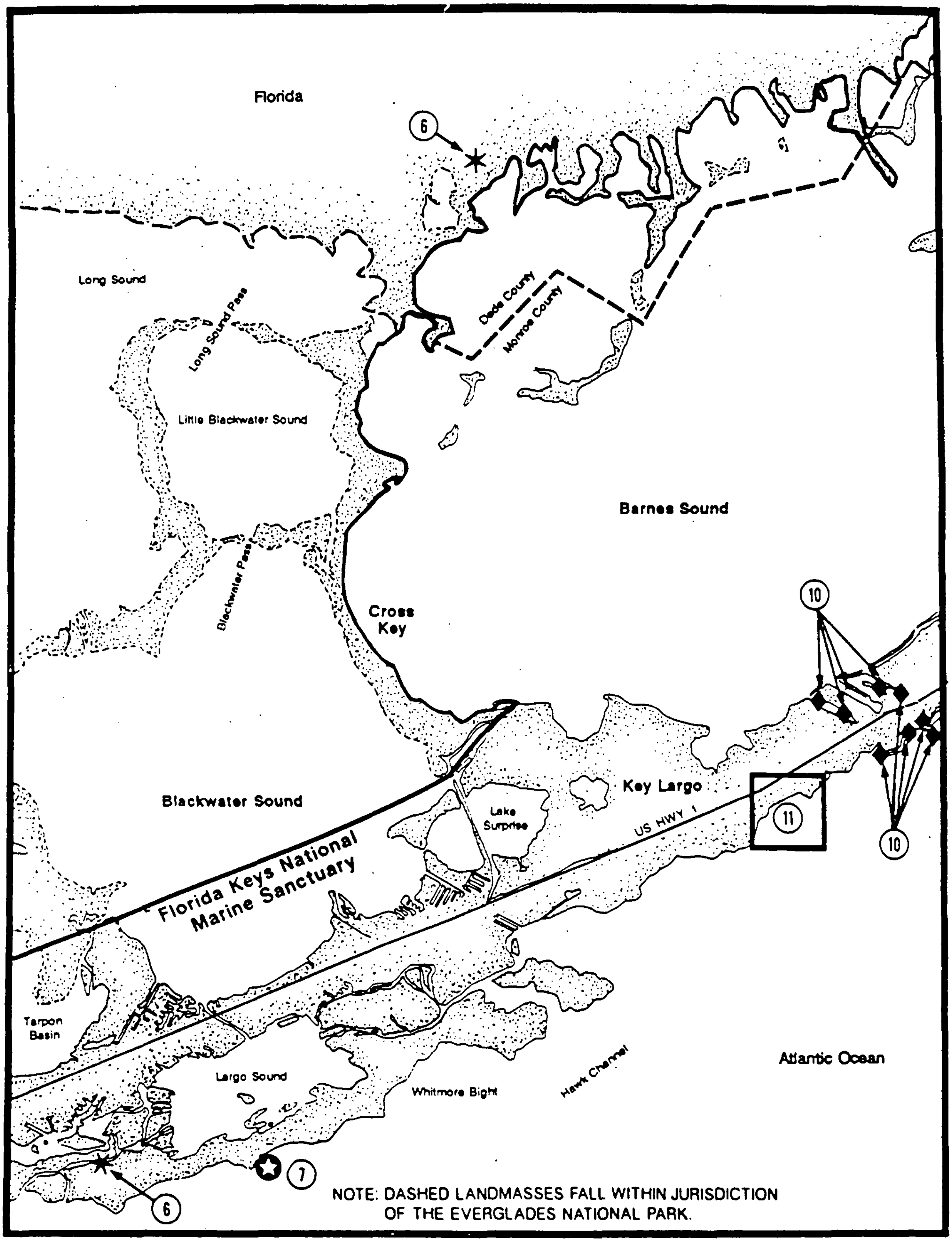

Figure 5-1-2. Locations sampled during ministudies investigating nearshore and confined waters. Base maps have been redrawn from maps provided by Wallace Roberts & Todd. (continued)

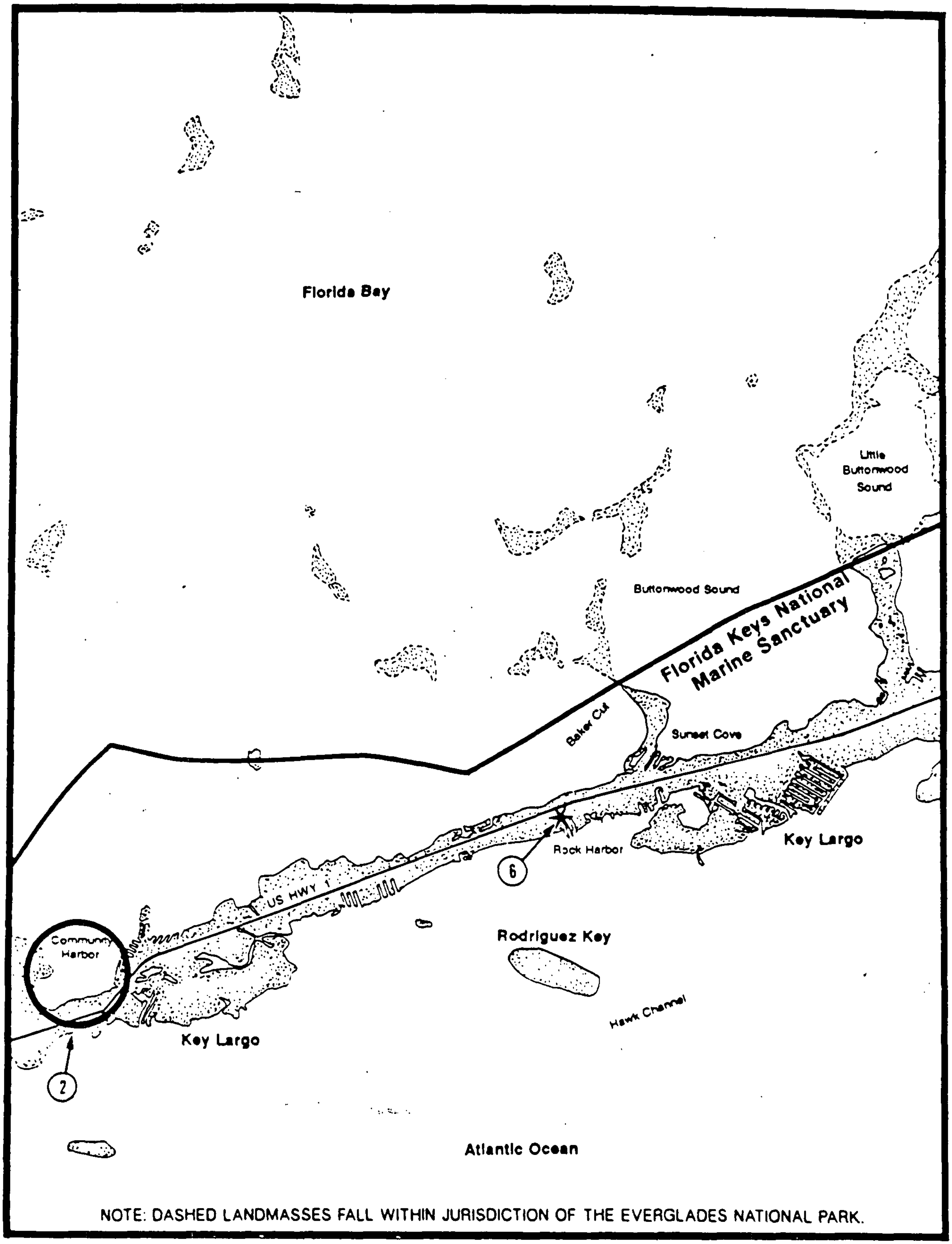

Figure 5-1-3. Locations sampled during ministudies investigating nearshore and confined waters. Base maps have been redrawn from maps provided by Wallace Roberts & Todd. (continued)

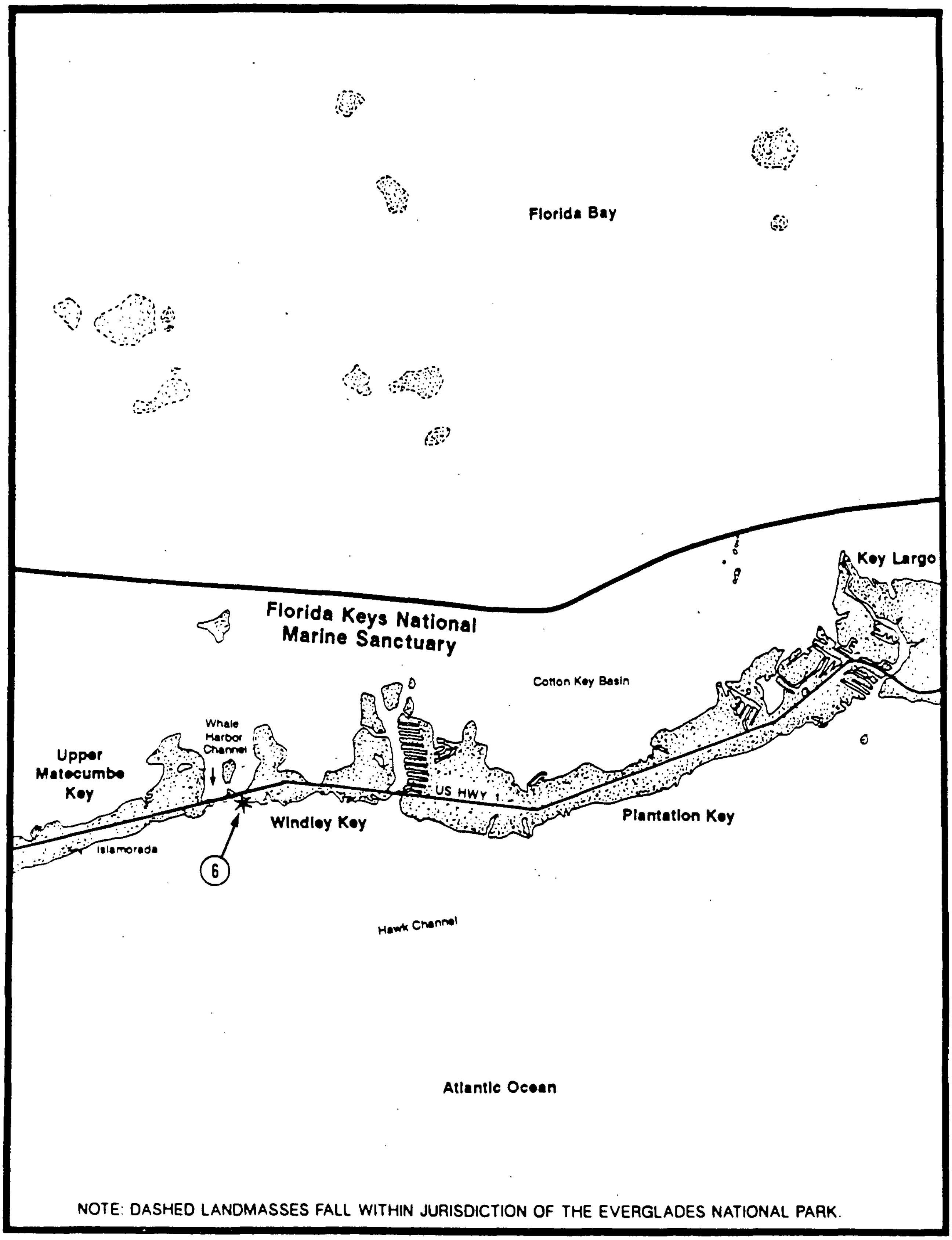

Figure 5-1-4. Locations sampled during ministudies investigating nearshore and confined waters. Base maps have been redrawn from maps provided by Wallace Roberts & Todd. (continued)

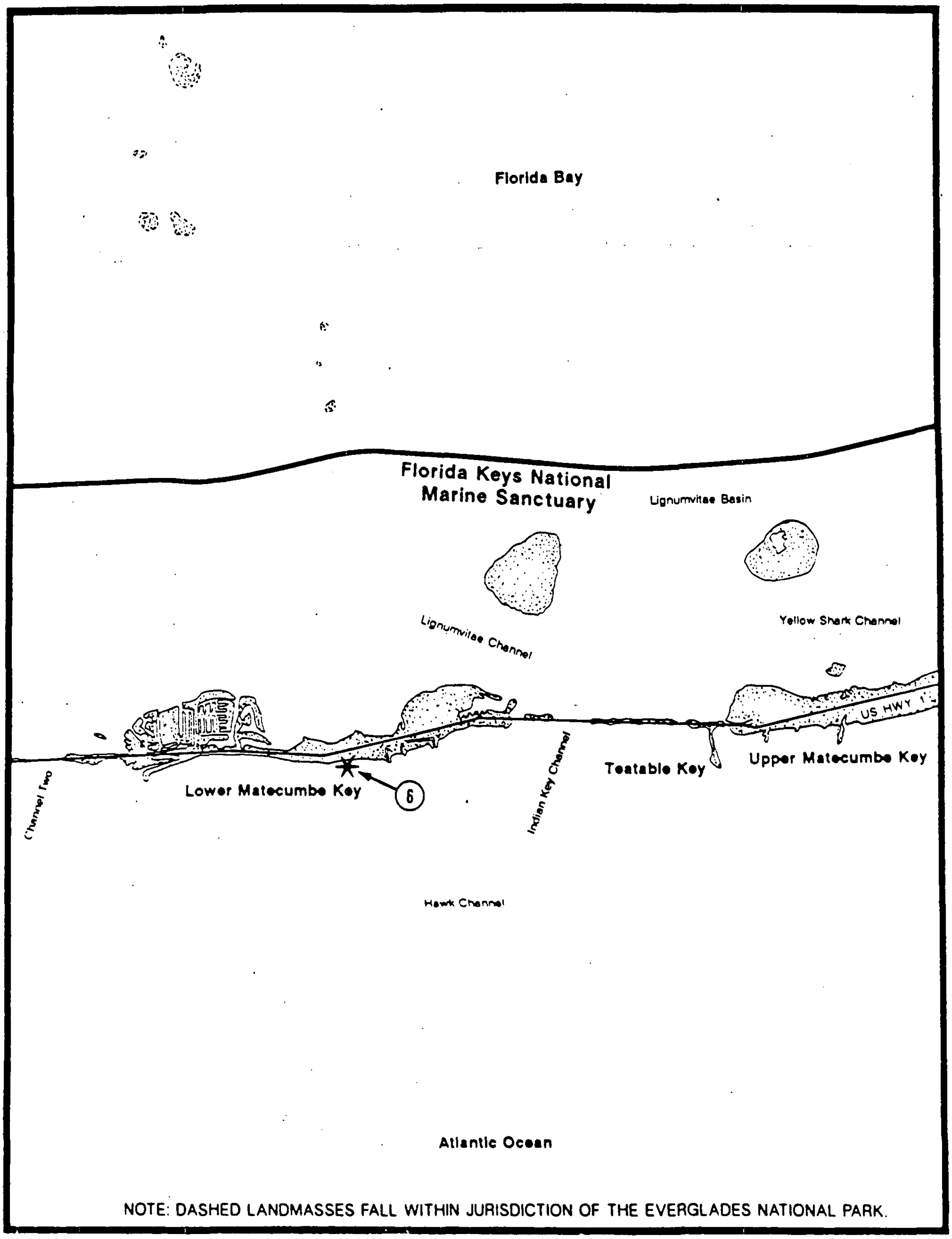

Figure 5-1-5. Locations sampled during ministudies investigating nearshore and confined waters. Base maps have been redrawn from maps provided by Wallace Roberts & Todd. (continued)

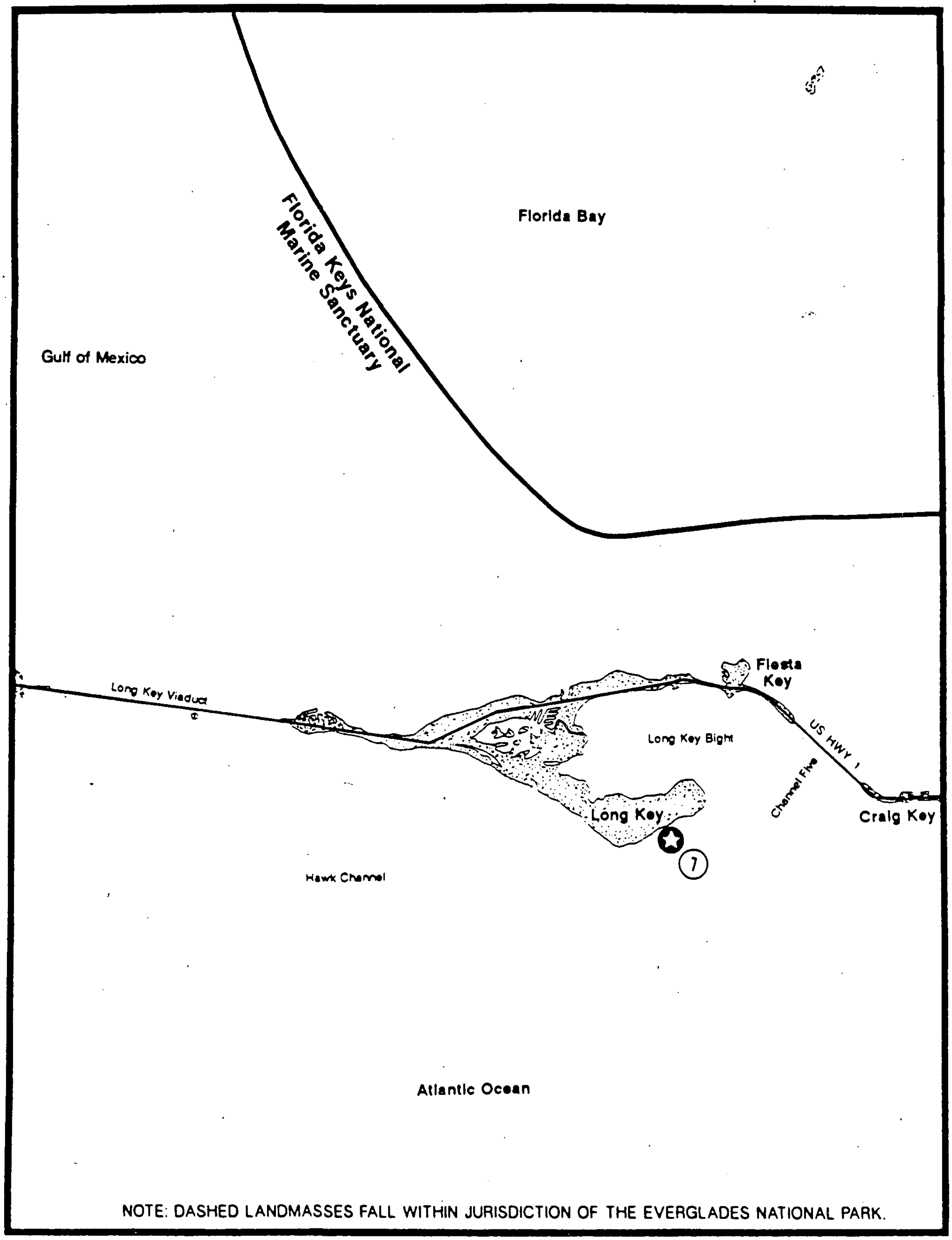

Figure 5-1-6. Locations sampled during ministudies investigating nearshore and confined waters. Base maps have been redrawn from maps provided by Wallace Roberts & Todd. (continued)

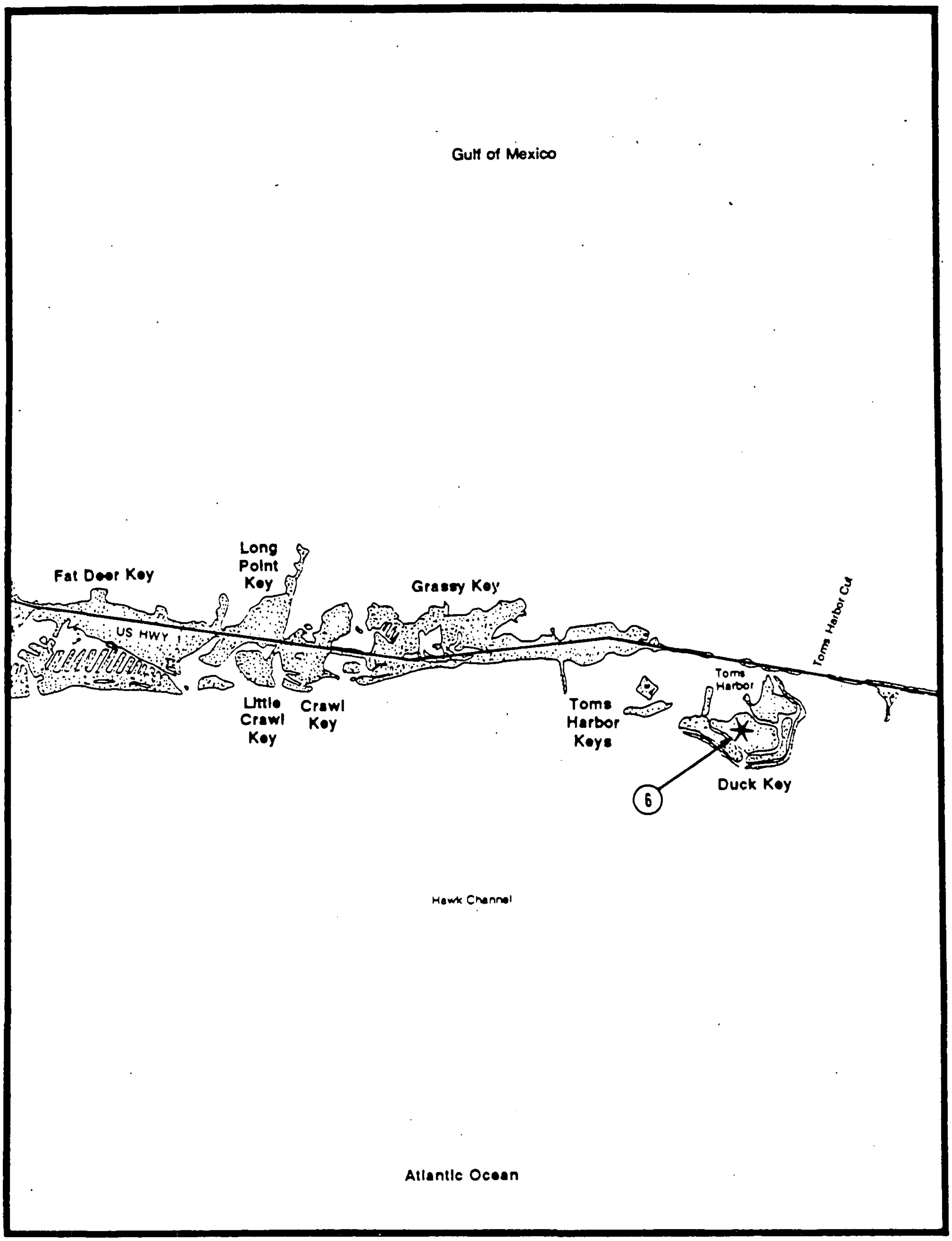

Figure 5-1-7. Locations sampled during ministudies investigating nearshore and confined waters. Base maps have been redrawn from maps provided by Wallace Roberts & Todd. (continued)

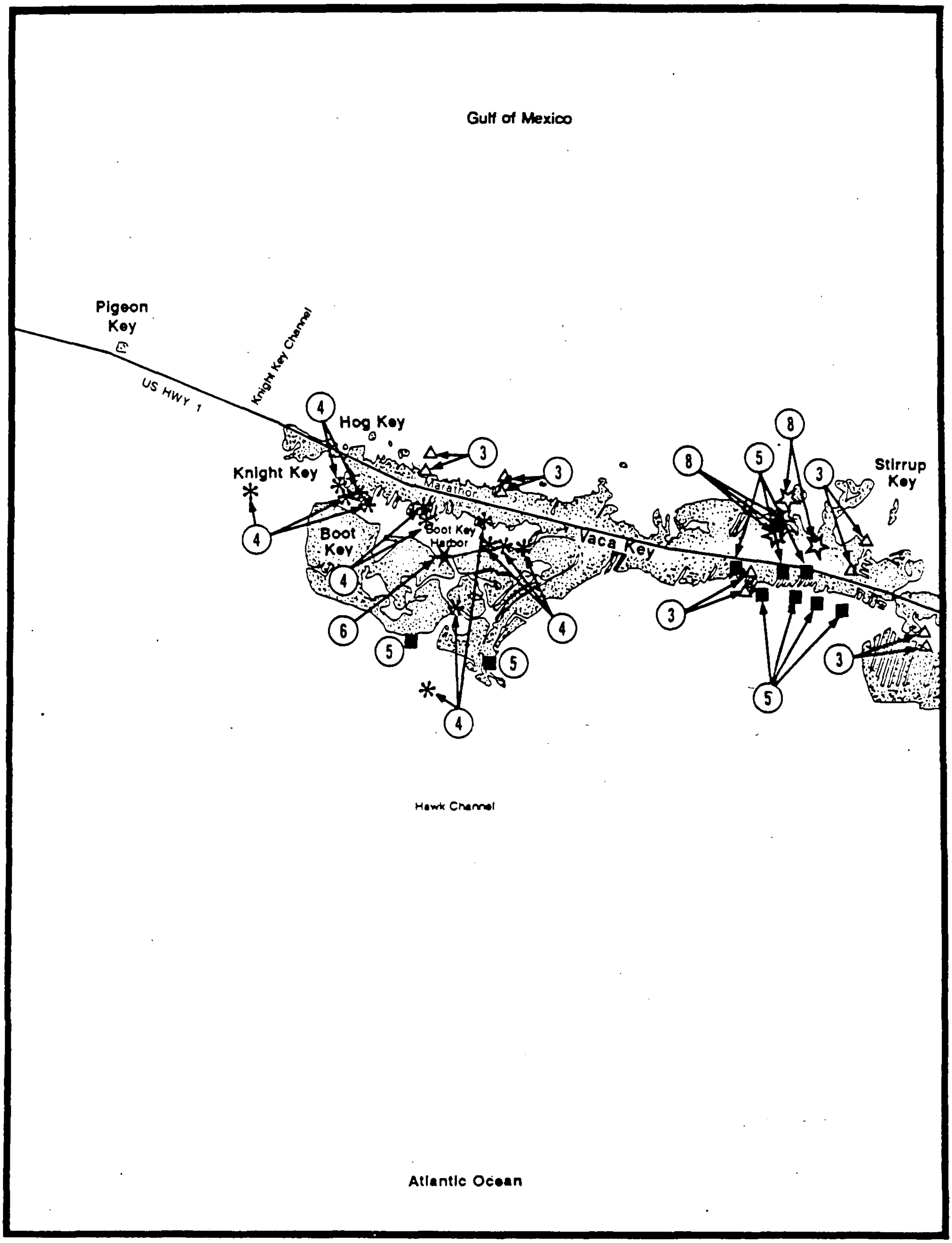

Figure 5-1-8. Locations sampled during ministudies investigating nearshore and confined waters. Base maps have been redrawn from maps provided by Wallace Roberts & Todd. (continued)

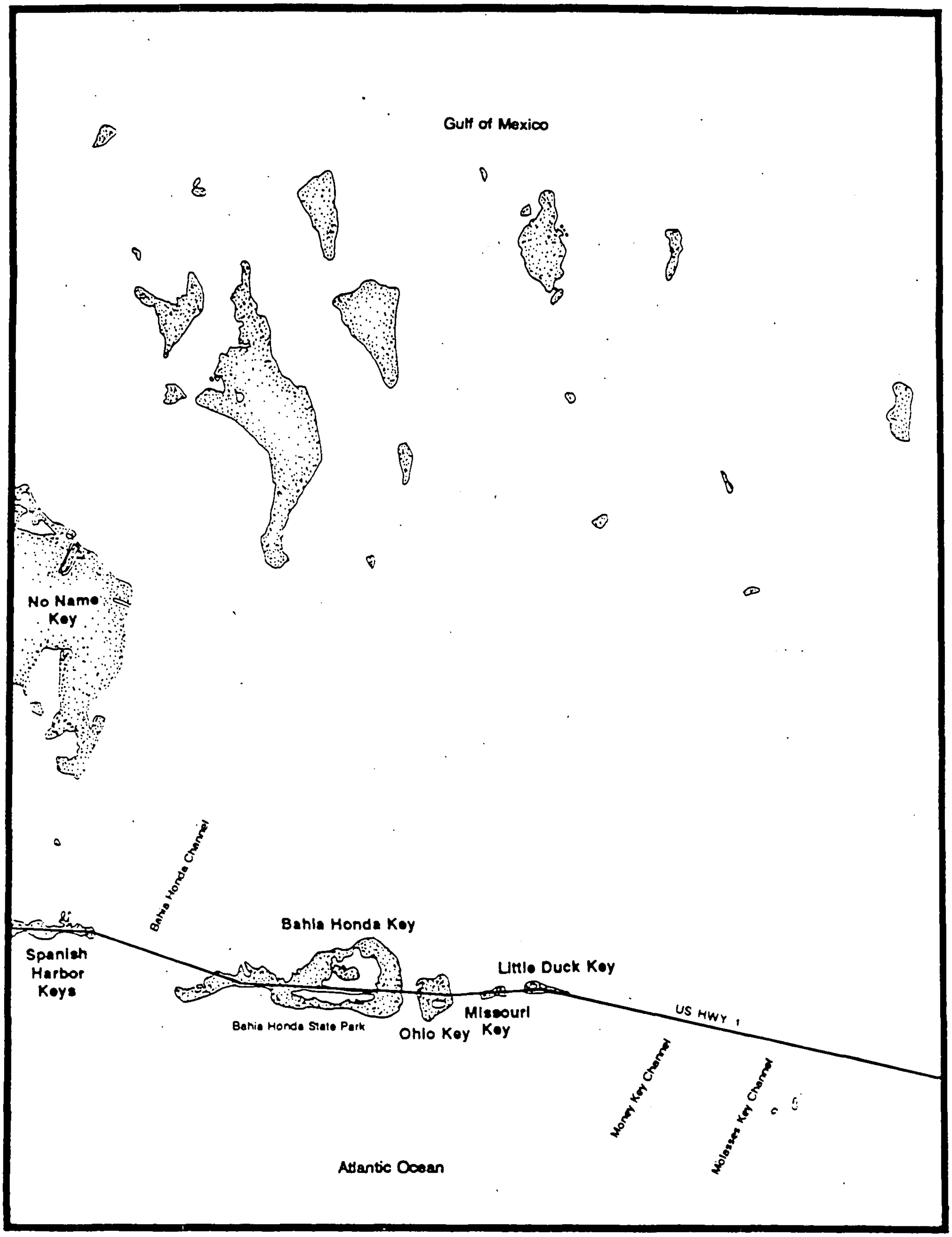

Figure 5-1-9. Locations sampled during ministudies investigating nearshore and confined waters. Base maps have been redrawn from maps provided by Wallace Roberts & Todd. (continued)

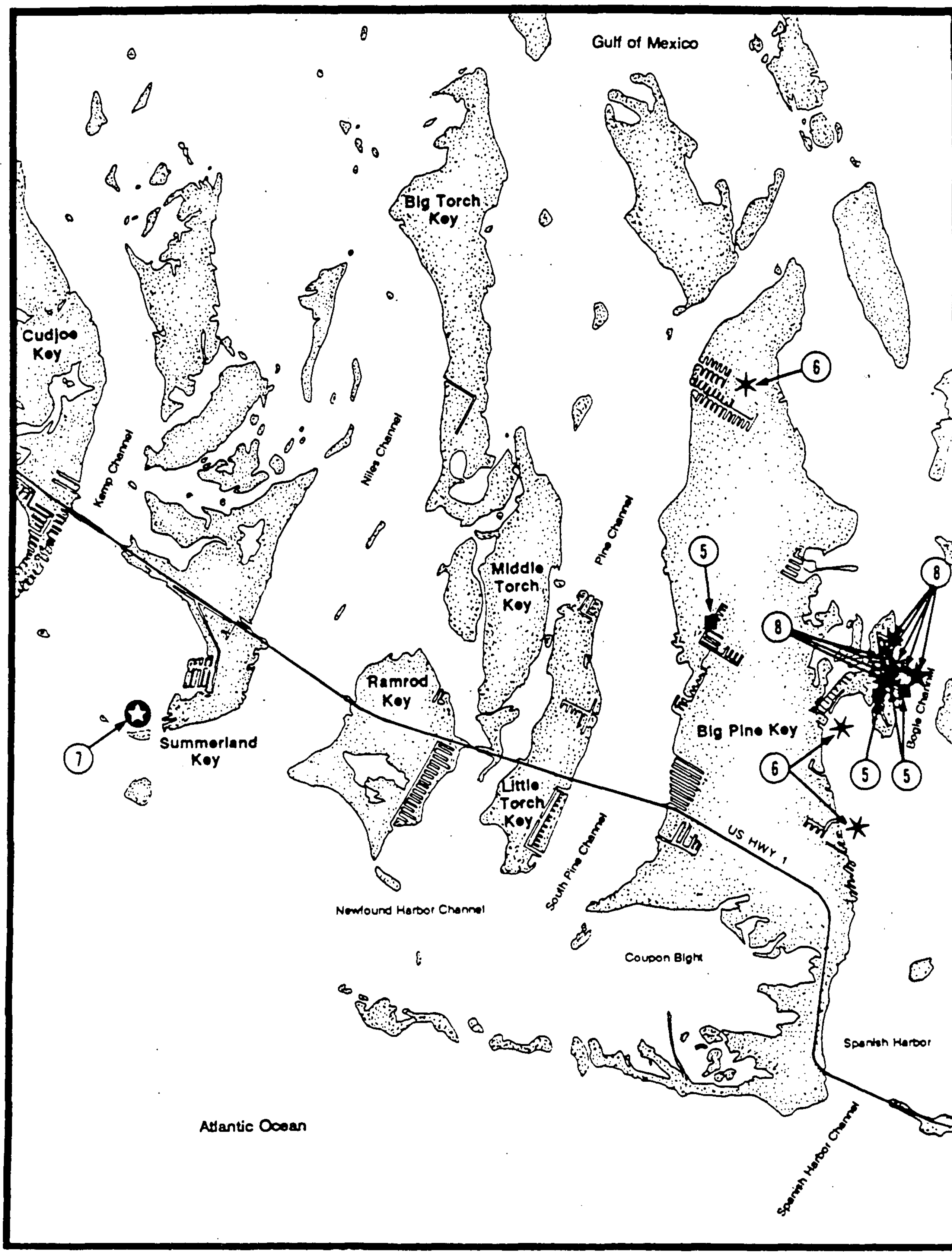

Figure 5-1-10. Locations sampled during ministudies investigating nearshore and confined waters. Base maps have been redrawn from maps provided by Wallace Roberts & Todd. (continued)

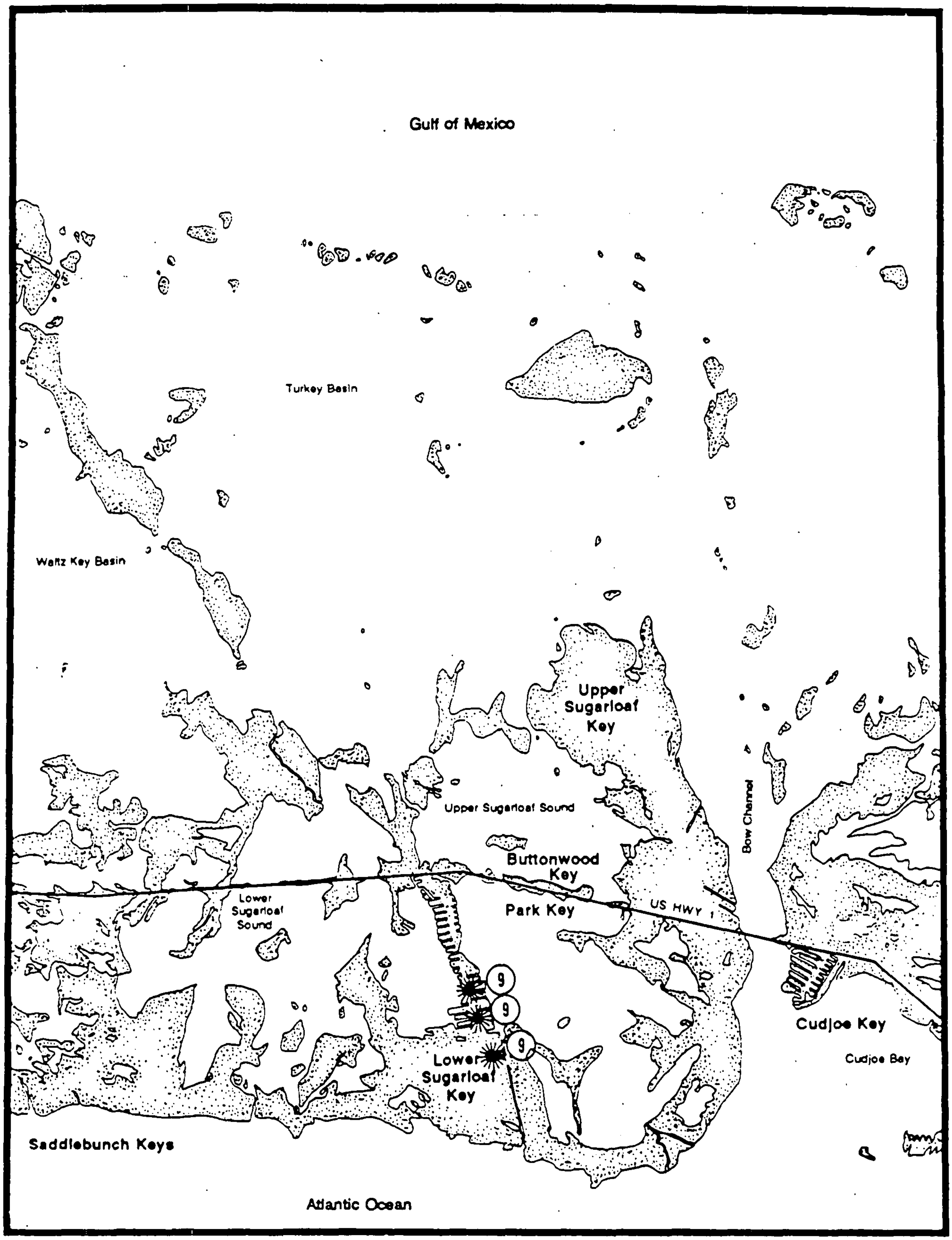

Figure 5-1-11. Locations sampled during ministudies investigating nearshore and confined waters. Base maps have been redrawn from maps provided by Wallace Roberts & Todd. (continued)

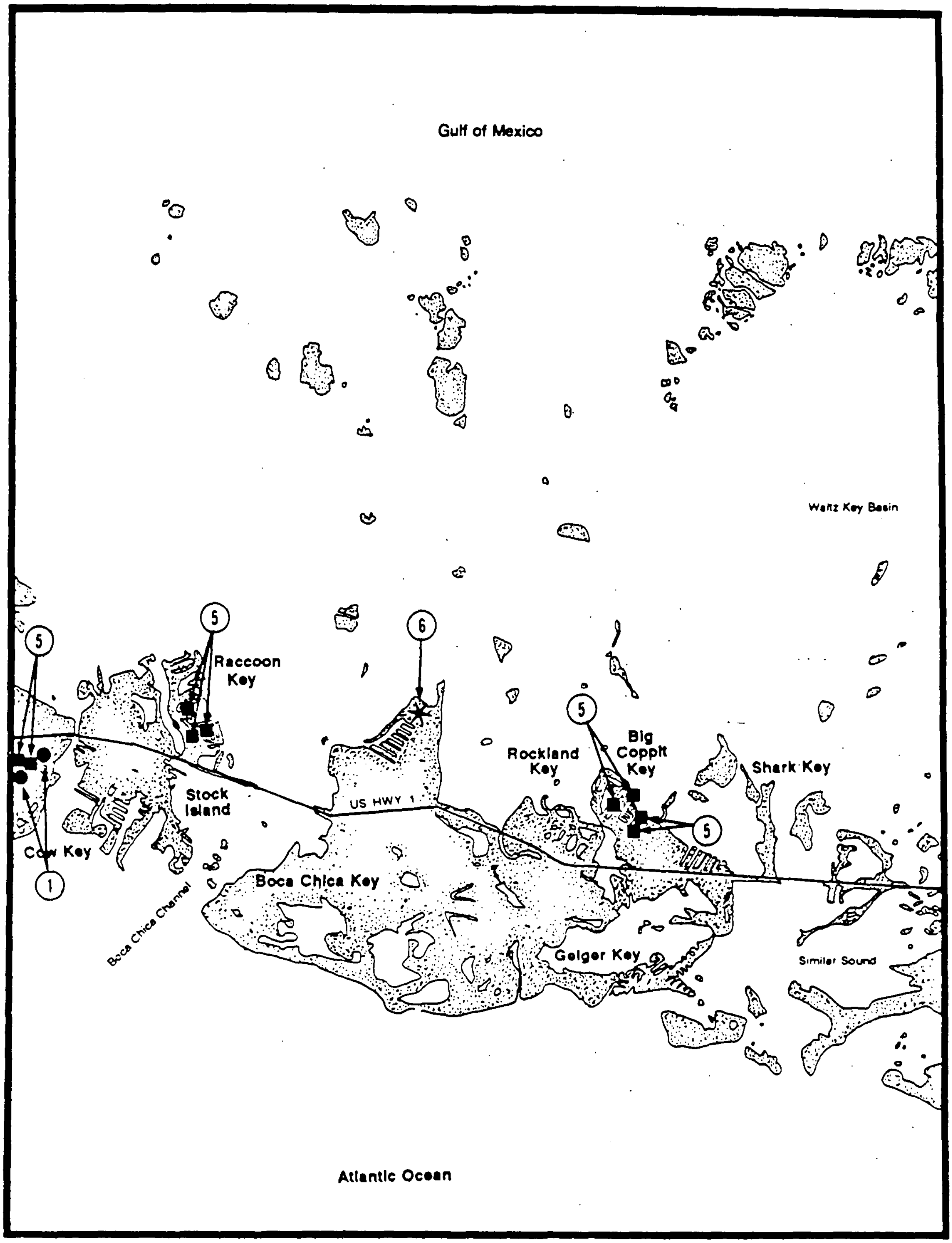

Figure 5-1-12. Locations sampled during ministudies investigating nearshore and confined waters. Base maps have been redrawn from maps provided by Wallace Roberts & Todd. (continued)

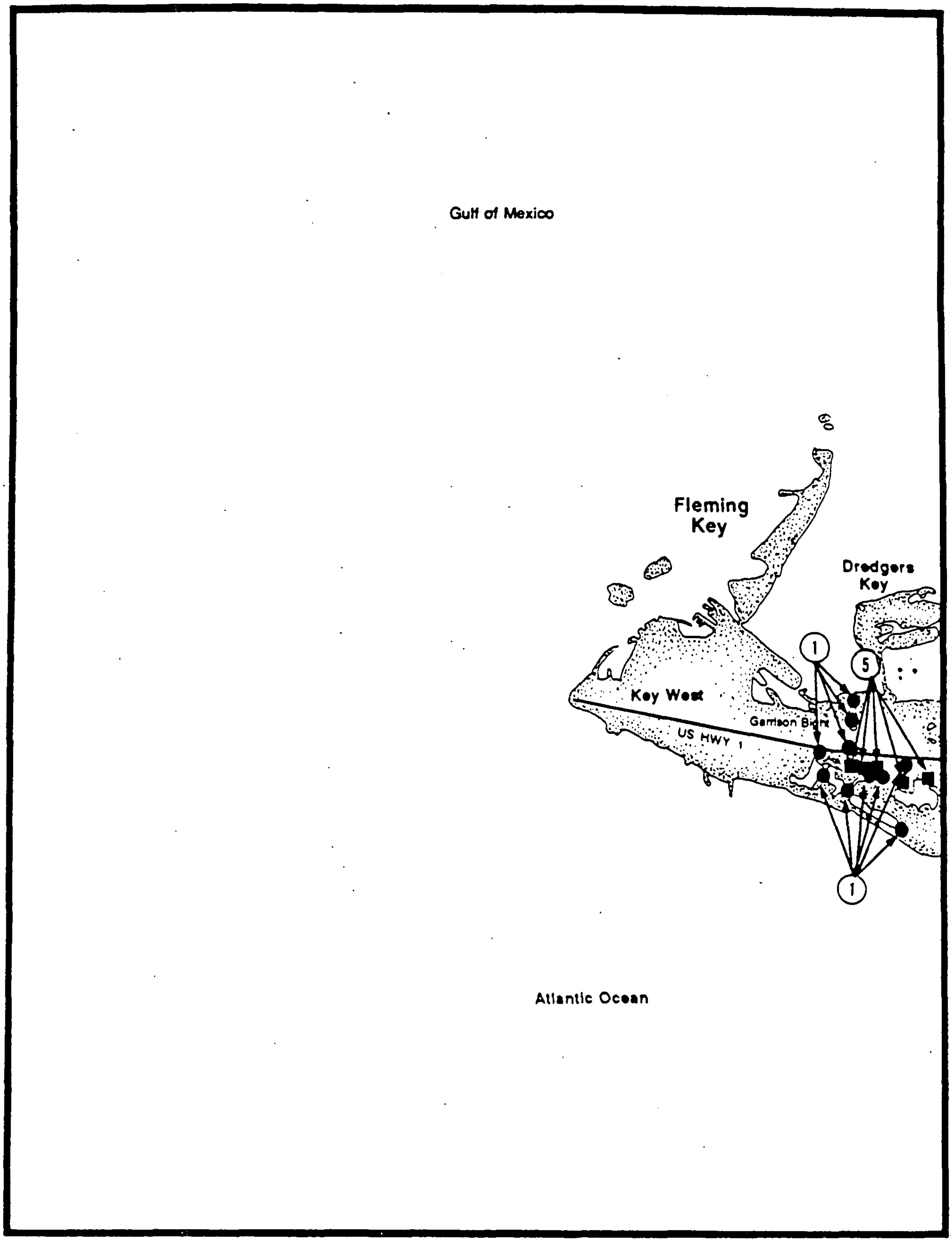

Figure 5-1-13. Locations sampled during ministudies investigating nearshore and confined waters. Base maps have been redrawn from maps provided by Wallace Roberts & Todd. (continued)

Three stations were established in the undeveloped canal, five in the developed canal, and one station in Bogie Channel (well-flushed ambient station located outside the canal system). Average DO concentrations in the undeveloped and developed canals ranged from 5.9 to 6.1 and from 3.0 to 5.2 mg/L, respectively. The average DO concentration in Bogie Channel was 6.4 mg/L. Although DO levels in the undeveloped canal appeared to be somewhat depressed relative to the ambient station, the levels in the developed canal were depressed below those of either of the other two sites. A similar pattern was observed in November 1973 for biochemical oxygen demand (BOD). Average concentrations were 0.5 to 0.6 mg/L in the undeveloped canal; <0.5 to 1.3 mg/L in the developed canal; and 0.6 mg/L in Bogie Channel. Average fecal coliform bacteria concentrations at the undeveloped and ambient stations were less that 5/100 mL in November 1973, whereas the average concentrations for the developed canal ranged from less than 5 to 18/100 mL. These differences indicated that the water quality in the canals was different from ambient conditions in a well-flushed area. However, these data suggested that development had some effect on water quality. No obvious differences among undeveloped canal, developed canal, and ambient conditions were indicated by nutrient concentrations for the November 1973 and August 1974 surveys.

2.1.2 Florida Department of Environmental Regulation — 1987b

The Florida Department of Environmental Regulation (FDER; 1987b) examined the water-quality condition at five nearshore sites in Marathon on Vaca Key (**Figure 5-1-8**). The five sites were selected to examine the impacts of potential pollution sources on water quality. To evaluate dispersion of discharges, a primary station was established near each pollution source at each of the five monitoring sites, and a secondary station was established at the mouth of the source canal. The results from the primary and secondary stations at each monitoring site were compared to corresponding ambient reference stations established in Florida Bay and the Atlantic Ocean. Surveys were conducted to study the sites for 1 year, beginning in February 1984.

At the first site (Faro Blanco Marina), the primary station was exposed to surface-water discharges from a marina that also had live-aboard vessels. The type of pollution was raw sewage and other vessel-related discharges. The investigators found that the levels of several water-quality parameters at this station were different from those observed at the ambient station, suggesting that discharges into the surface waters were affecting water quality. Annual mean DO concentrations were lower in the canal (primary station) and at the secondary station. The pH levels of the water were also lower. The secondary station had annual mean levels for DO and pH that were intermediate between the primary and ambient stations. Turbidity and the quantity of suspended solids did not appear to be affected by the discharges. Fecal coliform concentrations were greater at the primary station as compared to those at the ambient station, presumably because of raw sewage discharges from live-aboard vessels. There appeared to be a relationship between the number of boats anchored in the marina and the fecal coliform concentrations. These discharges also appeared to increase the BOD in the marina, probably as a result of the increase loading of organic matter from the discharges. Discharges appeared to increase total Kjeldahl nitrogen and total phosphorus levels in the marina. Annual mean chlorophyll *a* concentrations were similar for the primary, secondary, and ambient control stations, probably because there did not appear to be differences in inorganic nutrient concentrations.

The primary station at the second monitoring site on Vaca Key was established near a seafood processor in the boat basin of City Fish Market. The boat basin is connected to Florida Bay via a canal; the secondary station was established near the mouth of this canal. Water quality in the boat basin was thought to be affected by surface-water discharges of fish wastes, wastewater, and waste oil. Mean levels of DO and pH were lower at the primary site near the fish processor discharge than at the ambient reference station. BOD and fecal coliform concentrations were greater at the primary station. Levels of these parameters at the secondary station indicated that mixing quickly dispersed the effects of the pollution in the boat basin. Nutrient parameters increased by discharges from the seafood processor were total Kjeldahl nitrogen, ammonia, total phosphorus, and orthophosphate. The mean chlorophyll *a* concentration at the primary station was higher than at the secondary and ambient stations, possibly because the discharges increased the quantities of some inorganic nutrients (orthophosphate and ammonia).

The primary station at the third monitoring site was located in a residential waterway that received discharges from a stormwater collection system. The stormwater collection system serviced a parking lot from a nearby shopping center. The secondary monitoring station associated with this canal was located approximately 100 m from the opening of the main canal. Mean conductivity at the station located within the residential canal was reduced as compared to that of the secondary and ambient reference stations, probably as a result of freshwater input from the stormwater drainage system. DO concentrations were suppressed at the head of the residential canal (primary station). Monthly means at this station ranged from 3.06 to 4.93 mg/L; in contrast, oxygen levels at the canal mouth station (secondary station) were observed below 5.0 mg/L only once. pH levels were also suppressed at the head of the canal, but monthly mean levels did not fall below 7.0. Mean pH levels at the mixing zone (secondary station) were also reduced as compared to those at the ambient reference station, indicating that impacts from freshwater input to pH in the canal extended to the mouth of the canal. Freshwater input did not affect the concentrations of fecal coliform bacteria or biochemical oxygen demand. The only measured nutrient parameters that were greater at the head of the canal were total phosphorus and orthophosphate. The investigators suggested that septic tank leachate was partially responsible for decreased pH levels and increased levels of total phosphorus and orthophosphate at the canal head. Chlorophyll *a* concentrations did not differ among the primary, secondary, and ambient reference stations.

The primary station at the fourth monitoring site was located near the outfall from the Key Colony Beach sewage treatment plant, which discharged treated wastewater into the surface waters of Bonefish Bay. The secondary station was located approximately 60 m from the outfall. Discharges from the sewage treatment plant appeared to decrease the DO levels near the outfall and at the secondary station, where mixing was thought to occur; however, mean DO concentrations consistently exceeded 4.0 mg/L for the entire study at both stations. Effluent discharges also decreased pH levels at the outfall and secondary station. Conductivity was reduced in the vicinity of the outfall, indicating that the fresher effluent was diluting the ambient Bay water; conductivity was not altered at the secondary station, indicating that impacts on conductivity were localized around the outfall.

The fifth monitoring site was selected to monitor the potential for septic leachate to affect water quality. In contrast to the other sites where there were discharges to the surface water, potential discharges at this site consisted of septic leachate entering the canal via groundwater. The primary station at this monitoring site was located at the dead end of a residential canal that was surrounded by permanently located mobile homes. The secondary station was located near the mouth of the canal. Mean DO and pH were lower at the primary station than at the ambient reference station. Mean levels of these parameters at the secondary, mixing-zone station were intermediate between the extremes observed at the other two stations. Monthly mean DO concentrations at the canal head (primary station) were consistently 2 to 4 mg/L less than the corresponding monthly mean observed at the canal mouth (secondary station). Mean fecal coliform concentrations were elevated at the canal head relative to the other two stations. With a single exception, mean fecal coliform concentrations at the canal head exceeded the mean concentrations observed at the other two stations for the corresponding month. During the November sampling, the mean fecal coliform concentration at the canal head was similar to that observed at the canal mouth. The only nutrient parameter that appeared to be increased at the canal head was the concentration of orthophosphate. However, orthophosphate enrichment appeared to be restricted to the canal because levels at the secondary station were not appreciably different from the ambient reference site. The orthophosphate levels were distinctly elevated during the March, September, October, and January sampling surveys. Mean chlorophyll *a* concentrations were greater at the primary station than at the other two stations, although chlorophyll *a* concentrations were somewhat erratic temporally.

2.1.3 Florida Department of Environmental Regulation — 1990

The FDER conducted a study in Boot Key Harbor (Figure 5-1-8) to assess and document the nearshore water quality and to examine the impacts of various pollution sources on the water quality (FDER 1990). Sampling was conducted over a period of 1 year (January 1989 to February 1990) at 14 stations. The stations were located in artificial (manmade) canals and basins, Outstanding Florida Waters within the Harbor, and offshore Outstanding

Florida Waters. Outstanding Florida Waters is a designated regulatory status that prohibits direct discharges from lowering ambient water quality and indirect discharges from significantly degrading water quality. A water body can be Outstanding Florida Waters designated only if it has either exceptional ecological significance or exceptiona recreational significance (FDER 1985). Sites in artificial waterways included an artificial boat basin marina with operational pumpout facilities available, an artificial residential canal where septic tank systems were in use, commercial fishing docks, and an artificial boat basin where water circulation was poor and was exposed to discharges from charter fishing boats, live-aboard vessels, and septic tanks. Stations in Outstanding Florida Waters within Boot Key Harbor and near potential pollution sources were located near a marina with seafood processing facilities; near a live-aboard facility that lacked sewage pumpout facilities; near a condominium with a sewage treatment plant that discharged into an injection well; and in a dredged area used as main anchorage by live-aboard vessels. Four other stations were located in Outstanding Florida Waters within the Harbor. These were located at the edge of a well-flushed tidal channel and potentially exposed to impacts from septic tanks and surface runoff from a nearby subdivision; near a site where the seafloor substrate had been dredged; and two sites with natural substrate inhabited by turtle grass. Two ambient reference sites were located in Outstanding Florida Waters outside the Harbor.

Oxygen concentrations in the artificial waterways were generally lower than those observed at most Outstanding Florida Waters stations. This was attributed to differences in flushing as the poorly flushed canals serve as sinks for organic matter. DO levels in the artificial canals and basins were reduced throughout the year. Lower DO values were observed in the study area during the summer; the reduced solubility of oxygen with increasing temperature and salinity contributed to these lower DO concentrations.

Higher mean concentrations of coliform bacteria were observed at artificial waterway stations; coliform bacteria were practically absent from the ambient reference stations. The presence of coliforms may have indicated substantial freshwater sewage contamination because these organisms do not survive well at high salinities. Likely sources of contamination were leakage from septic tanks and discharges from live-aboard vessels at the artificial waterway stations. Two Outstanding Florida Waters Harbor stations had elevated fecal coliform levels; these were located in close proximity to live-aboard facilities. The highest fecal coliform counts generally occurred during the winter months at the stations with live-aboard vessels anchored on a seasonal basis. Highest coliform counts at stations associated with septic tanks were observed after a heavy rainfall.

As a group, artificial waterway stations exhibited higher mean total Kjeldahl nitrogen and total phosphorus concentrations as compared to the ambient reference stations, and concentrations at Outstanding Florida Waters Harbor stations were intermediate between the canal and ambient stations. The investigators attributed this to nutrients entering the canals from anthropogenic sources (sewage, industrial discharges, and surface runoff) and the decomposition of wind-blown weed wrack and other organic debris trapped in the canals. Elevated mean chlorophyll *a* concentrations were also observed at some of the artificial waterway stations, compared to the ambient control stations.

2.1.4 Lapointe and Clark — 1990

Lapointe and Clark (1990) investigated water quality in nearshore areas throughout the Florida Keys during a study conducted from 12 September 1989 to 19 September 1990 (**Figures 5-1-2 through 5-1-5, 5-1-7, 5-1-8, 5-1-10, and 5-1-12**). Water quality parameters determined during the study included temperature, salinity, DO, turbidity, pH, and chlorophyll *a* concentrations. Nutrient water quality parameters included the concentrations of nitrate plus nitrite, ammonium, soluble reactive phosphorus, total dissolved nitrogen, total dissolved phosphorus, particulate carbon, particulate nitrogen, and particulate phosphorus.

Monitoring sites were located in canals (Boca Chica submarine pens, Port Pine Heights, Doctors's Arm, Mariner's Resort, Boot Key, Duck Key, Port Antiqua, Venetian Shores, Ocean Shores, Largo Sound, and Glades Canal), seagrass beds (Pine Channel, Rachel Key, and Blackwater Sound), patch reefs (Newfound Harbor, Sawyer Key, Hens and Chickens, and Shark Reef), and bank reefs (Sand Key, Looe Key National Marine Sanctuary, Sombrero Reef, Alligator Reef, Molasses Reef, and Carysfort Reef). Sampling at the sites was performed along onshore/offshore transects, and samples were collected at two depths: 0.5 m below sea surface and 0.5 m above the seafloor.

Analysis of variance revealed that temperature varied seasonally and there were spatial differences among the sites. Salinity varied spatially. DO concentrations varied spatially and temporally. The spatial variability of DO was due primarily to the lower values observed at canal seagrass sites and higher values at the bank reef sites. Hypoxic conditions were observed in several canal systems, including Glades Canal, Boot Key Harbor, and Doctor's Arm. Dissolved and particulate nutrients varied spatially. Consistently low concentrations were observed at the bank reef sites and elevated concentrations were observed in nearshore waters. Higher chlorophyll *a* concentrations were observed at the nearshore sites. Over the whole study, chlorophyll *a* was correlated with ammonium, soluble reactive phosphorus, total nitrogen and phosphorus, and particulate carbon, nitrogen, and phosphorus. Reduced oxygen concentrations were related to higher concentrations of ammonium, nitrate plus nitrite, soluble reactive phosphorus, total nitrogen and phosphorus, chlorophyll *a*, and particulate nitrogen and phosphorus.

A comparison of developed canal systems (Port Antigua, Port Pine Heights, Doctor's Arm, and Mariner's Resort) with an undeveloped canal system (Boca Chica submarine pens) revealed that reduced oxygen concentrations were related to higher soluble reactive phosphorus concentrations. In the developed canals, stations located within the canal system had lower oxygen levels and higher soluble reactive phosphorus compared to their respective reference stations located in Outstanding Florida Waters. Levels in the canals measured at dawn were commonly hypoxic. At the Boca Chica submarine pens, levels of soluble reactive phosphorus at stations within the canal were not different from reference levels outside the canal; hypoxic conditions were not observed within the Boca Chica submarine pens canal as oxygen levels at stations located within the canal consistently exceeded 4.0 mg/L.

2.1.5 Szmant — 1991

Szmant (1991) investigated the water quality at five sites on the ocean side of the Florida Keys (**Figures 5-1-2, 5-1-6, and 5-1-10**). The primary emphasis of this program was to investigate nutrients (nitrogen and phosphorus) and chlorophyll *a* in the vicinity of the Florida Reef Tract. The surveys were performed to provide information from nearshore to oceanic waters. The sampling sites were Biscayne National Park (six stations sampled during summer and winter), Long Key (13 stations sampled during summer and winter), Key Largo (35 stations sampled during summer and 13 stations during winter), and Looe Key (seven stations sampled during spring and summer).

Stations were located on seven transects that were oriented inshore/offshore. A minimum of four stations were located on each transect; stations were located in both the inshore and offshore areas.

Szmant (1991) found that nutrient and chlorophyll *a* concentrations were elevated nearshore at the Biscayne National Park and Key Largo sampling sites. At the Looe Key sampling sites, elevated concentrations were especially associated with marinas and developed canals. Water quality improved with increasing distance from shore, approaching oligotrophic conditions within a few hundred meters of shore. Higher total nitrogen and phosphorus concentrations were observed during the winter because storms suspended sediments into the water column. Movement of water through passes between Florida Bay and the Atlantic Ocean was thought to control the distribution of nutrients at the Long Key sampling site. Szmant (1991) concluded that water quality in developed canals and some adjacent nearshore areas is poorer than farther offshore. The data did not support assertions of extensive nutrification in offshore areas.

2.1.6 Other Studies

The Florida Department of Pollution Control (FDPC 1973) reported the results of a water-quality investigation in waterways and canals of the Florida Keys that was performed in conjunction with an evaluation of dredge-and-fill permitting in the Keys. The field study was conducted in April 1973, and 10 sites were sampled. These sites were located from Key Largo in the upper Keys to Key West in the lower Keys. Measured water-quality parameters were temperature, conductivity, DO, pH, and Secchi depth. The results of this study indicated that DO concentrations are sometimes depressed in canals. DO levels below 4.0 mg/L were observed at some depths in a canal at Big Coppitt Key. At Doctor's Point on Big Pine Key, DO concentrations at stations located within the canal were predominantly less than 4.0 mg/L. A number of canals were sampled at Vaca Key, and most of the DO levels were less than 4.0 mg/L. Depressed levels of oxygen were observed in canals located in Lake Surprise Estates and Worlds Beyond Marina, Key Largo. Investigators noted that organic material that was imported into an artificial canal would tend to settle on the canal bottom, increasing the oxygen demand of the overlying waters. Additional sources of organic material listed by the investigators included urban runoff, effluents from septic tanks and inadequate sewage treatment plants, and wind blown debris (floating organic debris such as seaweed and dead fish moved into the canal by wind action).

The FDER (1987a) investigated the quality of the water in Campbell's Marina, which is located on the north side of the western end of Key Largo (Figure 5-1-3). This study was performed in response to concerns raised about the live-aboard vessels docked in the marina and suspected to be discharging directly into the marina's water. In addition, two septic tank systems were operating at the marina. Eight stations, include one reference, were sampled for fecal coliform concentrations. Comparison of the results from the marina stations with the reference indicated that surface waters were contaminated with fecal coliform bacteria.

Chesher (1974) reported the results of a water-quality survey conducted from July 1973 to March 1974 on 50 canal systems. Six of the canals were natural mangrove canals and the remainder were manmade. The author found that the water quality was degraded in only four of the canals and that the manmade canals supported biologically productive communities. The importance of circulation and flushing to water quality was discussed. The investigator observed that floating debris entering a dead end, poorly flushed canal increased the demand for oxygen in the canal. Chesher concluded that septic systems had no affect on water quality and generally ascribed depressed oxygen levels to movement of anoxic aquifer water into canals.

CH_2M Hill (1988) performed a study in Riviera Canal, Key West, to determine the effect of surface runoff on the quality of the water in the canal system (Figures 5-1-12 and 5-1-13). Sampling took place during the wet (September 1987) and dry (February 1988) seasons, and comparisons were made between the two surveys. Eight stations were established in the canal system and five were established in salts ponds near the canal. Temperature, salinity, DO, total dissolved solids, hydrogen sulfide, and fecal and total coliform bacteria concentrations were determined at each site. Measured nutrient parameters were nitrate plus nitrite nitrogen, ammonia nitrogen, total Kjeldahl nitrogen, orthophosphate, and total phosphate. DO concentrations near the bottom of the canal system were depressed during the summer survey as compared to the winter survey. This observation was attributed to increased temperatures during the summer. Elevated sulfide concentrations were observed at two canal stations (summer and winter) and one salt pond station (winter); however the exact sources for the sulfides could not be determined. Total nitrogen concentrations were markedly elevated during the summer at all stations, mainly because of increased nitrate plus nitrite concentrations. The investigators concluded that this was probably due to increased runoff during the wet season. Fecal coliform concentrations during the winter indicated some degree of contamination from leaking sewage lines.

EPA investigated several canal systems in the Florida Keys during April 1980. EPA (1980a) studied the water quality in two canals on Sugarloaf Key (Figure 5-1-11). Oxygen concentrations in the water column exceeded 5.0 mg/L at all sampling sites during the study. EPA (1980b) reported the results of a study of the Joseph Harrison canal system in upper Key Largo (Figure 5-1-2). Three canals were connected to Barnes Sound and two canals were connected to the Atlantic Ocean. DO concentrations in the soundside canals were generally greater than 5.0 mg/L. At the dead end of one of the oceanside canals, all DO concentrations were less than 1.1 mg/L. Nutrient data collected in the canal did not provide an explanation for the severely depressed DO levels. The oceanside canal was relatively deep (3 to 4 m); the investigators concluded that a hydrogen sulfide aquifer was penetrated during dredging of this canal. This conclusion was supported by observations of atmospheric liberation of hydrogen sulfide.

EPA (1980c) investigated the J.H.T. Incorporated Canal in Key Largo (**Figure 5-1-2**). Reduced DO levels (<4.0 mg/L) were observed near the bottom of the canal at a station located near the dead end of the canal. The investigators noted that the canal was isolated from ambient waters during low tide by a sill near the canal mouth. The isolation and commensurate reduction of mixing between water in the canal and ambient water contributed to maintaining reduced oxygen concentrations in the canal; mixing canal water with the more oxygenated ambient water increased oxygen levels in the canal.

EPA (1980d) reported the results of a water quality study conducted at the Ocean Reef Club, Key Largo (**Figure 5-1-1**). As part of the air conditioning system, hydrogen-sulfide-laden groundwater was pumped through the system, aerated, chlorinated, and then discharged into the basin. The area of the discharge was well-flushed and oxygen levels did not appear to be reduced at four stations in the vicinity of the discharge.

2.2 SEDIMENTS

Sediments can be an important sink for substances discharged into nearshore waters. Many substances, e.g., heavy metals, are associated with fine-grained sediment particles. Under certain conditions, sediments can also serve as a source of material previously scavenged from the water column. Unfortunately, sediment data in the Florida Keys are few and a complete evaluation is not possible.

The FDER (1987b) sampled the sediments quarterly at the monitoring sites at Marathon (**Figure 5-1-8**). Their data, as received in a summary STORET file, are summarized in **Table 5-1**. At the Faro Blanco Marina, boat-related activities were thought to be responsible for the contamination — copper and lead from antifouling paint, lead from fuel additives and battery casings, and iron and zinc from galvanized and other metal parts. High levels of fine-grained particles were also suggested as a possible reason for the elevated iron levels. The elevated concentrations at the City Fish Market were also ascribed to boat-related activities. Elevated iron concentrations in the sediment of the Winn Dixie Shopping Center canal were attributed to effluent pipe, septic tanks, discarded metal parts, and automobiles in the parking lot. Effluent discharges from the sewage treatment plant in Key Colony Beach were not thought to be responsible for the increased concentrations of iron, copper, and zinc observed at this site. These increases were thought to be from a nearby marina/boat storage facility or a charter boat operation in Bonefish Bay. Levels of these metals that were higher at the mixing-zone station than at the canal station supported this conclusion. Based on their analysis, the investigators concluded that the sediments in the 90th Street Canal were contaminated with iron, copper, lead, zinc, and mercury; the ranges of mercury levels overlapped between primary, secondary, and ambient stations (**Table 5-1**). The investigators suggested that discharges and leaching from boats in the 90th Street Canal were responsible for the elevated concentrations of copper, lead, zinc, and mercury at this site. They believed that leaching from septic systems was responsible for the elevated levels of iron in the sediments.

The FDER (1987b) also reported the results of a study of the distribution of coprostanol at three sites. Coprostanol is an excellent tracer of sewage, particularly in the marine environment where the viability of fecal coliform bacteria is reduced. Results were reported for Faro Blanco Marina, 90th Street Canal, and the Key Colony Beach sewage treatment plant outfall. The highest coprostanol concentrations (> 1000 ng/g) observed in Faro Blanco Marina were associated with discharges from live-aboard vessels. Concentrations decreased rapidly with increasing distance from the boat slips. Coprostanol was also observed in the vicinity of the sewage outfall, but the major source of this material was not from the outfall but from other areas, with the coprostanol being transported into the bay by tidal currents. The highest coprostanol concentration (2206 ng/g) observed during the study occurred in the 90th Street

Table 5-1. Sediment heavy-metal concentrations observed at Marathon, Florida, by FDER (1987b).

Sampling Site	Copper (mg/kg)	Lead (mg/kg)	Zinc (mg/kg)	Iron (mg/kg)	Mercury (mg/kg)
Faro Blanco Marina					
Canal	50.2 - 100.0	53.6 - 536.0	45.0 - 72.7	1051 - 2021	0.8 - 1.5
Canal mouth	11.1 - 18.4	50.2 - 58.0	11.8 - 21.1	341 - 645	0.2 - 0.3
City Fish Market					
Canal	9.8 - 223.3	41.2 - 131.3	7.5 - 173.7	845 - 3650	0.2 - 1.1
Canal mouth	9.2 - 15.5	43.3 - 58.4	6.8 - 14.0	523 - 830	0.2
Winn Dixie Shopping Center					
Canal	15.6 - 59.0	39.7 - 57.1	18.1 - 93.1	2982 - 6838	0.2 - 0.4
Canal mouth	7.7 - 13.6	40.4 - 52.3	12.4 - 17.3	829 - 1058	0.2
Key Colony Beach					
Canal	4.8 - 15.4	34.1 - 46.3	4.3 - 14.9	907 - 1539	0.2 - 0.3
Canal mouth	6.7 - 19.2	37.7 - 51.8	6.8 - 17.8	958 - 1394	0.2 - 3.4
90th Street Canal					
Canal	37.2 - 205.7	53.8 - 95.8	86.0 - 158.5	1217 - 5975	0.2 - 0.3
Canal mouth	9.5 - 14.0	37.6 - 49.5	6.8 - 16.9	1052 - 1469	0.2 - 0.3
Bayside ambient	5.2 - 7.3	36.6 - 51.3	4.8 - 7.0	506 - 818	0.2
Oceanside ambient	4.5 - 7.0	38.6 - 55.0	2.6 - 3.7	128 - 191	0.2

Canal. The high levels observed at this site were thought to be the result of leakage from septic systems located along the canal. Concentrations decreased with increasing distance from the canal dead end, probably along a flushing gradient.

Lapointe and Clark (1990) sampled metal concentrations in the sediments (**Figures 5-1-2 through 5-1-5, 5-1-7, 5-1-8, 5-1-10, and 5-1-12**). Their results for the designated nearshore sites in the Sanctuary are presented in **Table 5-2**. Metal concentrations were variable among the sampling sites. These investigators noted that concentrations of copper, iron, lead, zinc, and cadmium appeared to be higher in the developed canal systems and at sites in upper Florida Bay compared to offshore reef sites. Stormwater runoff was suggested as a potential source for zinc, lead, iron and copper. In addition, antifouling paints and sacrificial tabs were also suggested as sources for copper and zinc, respectively.

Szmant (1991) investigated total nitrogen and phosphorus levels in the sediments (**Figures 5-1-2, 5-1-6, and 5-1-10**). Sediments serve as a reservoir for nutrients and as a means of inshore/offshore transport. Nutrients entering the nearshore may be assimilated by nearshore plant communities (e.g., mangroves, seaweed, seagrass). Detritus produced by the plant communities is susceptible to being transported offshore by physical processes. Szmant (1991) observed a strong trend of decreasing nitrogen concentrations with increasing distance from shore. The gradient was steep, indicating that most of the nitrogen was remaining in the nearshore sediments. Sources for this sedimentary nitrogen include detritus from mangroves, seagrass, and seaweeds and input from anthropogenic sources.

3.0 FACTORS AFFECTING THE NEARSHORE AND CONFINED WATER ENVIRONMENT

A variety of mechanisms probably play a role in controlling the quality of the nearshore and confined waters in the FKNMS. These include physical and anthropogenic mechanisms. At present, the relative contributions of these different mechanisms (several of which have not been extensively studied) to the nearshore and confined waters are not known.

Winds can blow weed wrack and other organic debris into confined waters, as indicated by the FDER (1990). Oxygen in the canals is used during the decomposition of this organic material, and the DO levels decrease. This is exacerbated in areas of reduced flushing. Upwelling and exchanges with offshore water probably play a role in controlling the composition of nearshore waters. Szmant (1991) pointed out the potential role of upwelling in the Pourtales Gyre in providing nutrients to the Florida Reef Tract. This upwelled water could conceivably be transported to the nearshore by currents. Smith (1991) described movement of Florida Bay water through inter-Key passes into Hawk Channel. This water could also be involved in the distribution of nutrients in nearshore areas. Another physical mechanism that could affect nearshore water quality is atmospheric input of nutrients. Although atmospheric-input studies have not been performed in the Keys, Willey and Cahoon (1991) demonstrated that nitrates in rainwater enhanced chlorophyll *a* production in the surface waters of the Gulf Stream off North Carolina. Paerl *et al.* (1990) found that rainwater represented a potentially significant source of nitrogen in estuarine and coastal waters.

Several anthropogenic sources appear to affect nearshore water quality. Discharges of raw sewage from live-aboard vessels increase nutrient loads, which in turn may stimulate increased phytoplankton growth (FDER 1987b, 1990). In addition, DO concentrations are decreased because of the increased organic loading, particularly in confined waters where flushing is poor. Fecal coliform bacteria concentrations may increase as a result of discharges from live-aboard vessels. Effects of live-aboard vessels are probably limited to the immediate vicinity of the discharges. Other boat-related activities also have their effects, such as spills during fueling operations and leaching from antifouling paints.

Table 5-2. Results of the sediment sampling by Lapointe and Clark (1990) at nearshore sites in the Florida Keys National Marine Sanctuary.

Sampling Site	Copper (mg/kg)	Iron (mg/kg)	Lead (mg/kg)	Mercury (mg/kg)	Zinc (mg/kg)	Cadmium (mg/kg)
Boca Chica Submarine Pens	1.85	1,480	2.70	0.075	41.3	0.350
Port Pine Heights	<0.246	1,290	2.13	0.053	2.54	0.079
Mariners Resort	42.1	630	5.14	0.262	96.2	3.78
Doctor's Arm	35.0	656	6.39	<0.082	42.0	0.486
Boot Key Harbor	37.20	1,890	7.75	0.118	30.5	0.313
Duck Key	0.578	234	1.51	0.030	2.37	0.334
Port Antigua	9.30	1,330	4.34	0.061	11.9	0.158
Venetian Shores	14.9	1,330	7.80	0.262	11.8	0.417
Ocean Shores	11.8	4,860	7.71	0.079	15.4	0.172
Largo Sound	9.52	1,760	8.94	0.064	13.0	0.991
Glades Canal	4.86	4,890	6.92	0.102	20.4	0.213

Direct discharges from sewage treatment plant outfalls also affect nearshore water quality in their vicinity. Although not detected at the Key Colony Beach outfall by the FDER (1987b), nutrient enrichment would probably occur in areas that are not as well-flushed as Bonefish Bay. Stormwater runoff is also an important factor that can affect water quality in nearshore areas.

Leakage from onsite sewage disposal systems has been indicated as a source of nutrients to nearshore waters. Barada and Partington (1972) identified septic tanks as a problem around canals. Lapointe *et al.* (1990) suggested that nutrients build up in the groundwater during the winter dry season when tourist occupancy in the Keys is greatest. With the coming of the wet summer season, these nutrients are flushed from the groundwater into nearby marine waters by the hydraulic head developed from rainfall entering the sediments. The studies discussed above indicated that nutrient enrichment can occur from the movement of ground water into canals (e.g., 90th Street Canal in Marathon).

In an assessment of nonpoint sources for Florida, the FDER (1988) determined that most nonpoint-source problems in the Keys arose in the vicinity of Key West and Marathon. Locations in the Key West area that were identified as impaired by urbanization, live-aboard vessels, and boat and marina activities included Safety Harbor, Key West Harbor, Garrison Bight, Riviera Canal, and Cow Key Channel. Urbanization, septic tank seepage, and canals were identified as contributors to impairment of nearshore waters in the Marathon area. Other areas identified by the FDER (1988) as impaired from anthropogenic nonpoint sources included Tavernier Creek, Largo Lake, and a development on Windley Key.

Climate change and sea-level rise potentially may have long-term effects on the water quality in the Sanctuary. This was examined during the October 1991 Research Planning Workshop for the FKNMS held at the University of Miami Rosenstiel School of Marine and Atmospheric Science (CIMAS 1991). Increases in temperature were noted as a potential effect. This effect was not only maximum temperature but also seasonality changes such as warmer spring and milder winter. Changes in precipitation may result from climate change; such changes would alter salinity and groundwater flow. Rising sea level would change the landscape, causing widening of channels, submergence of islands, and changes in the circulation patterns in the Sanctuary. To adequately examine effects from climate change and sea-level rise, sophisticated modeling would be necessary because this problem is extremely complex. Such modeling is beyond the scope of this project and must wait for another expanded effort.

4.0 SUMMARY

The quality of nearshore waters in the FKNMS is critical as this area supports important biological communities (e.g., seagrass beds and patch reefs). Degradation of nearshore water quality would result in the loss or undesirable changes in the composition of these communities, leading to losses of fishery resources, impacts on the tourist industry, and other undesirable changes in the Sanctuary. Thus, it is beneficial to maintain and improve the water quality in nearshore and confined waters in the Sanctuary.

The results of the studies discussed above indicate that the nearshore water quality in some places in the FKNMS has been degraded, as indicated by the many occurrences of reduced DO. This degradation occurs primarily in developed artificial waterways that have received anthropogenic input from various sources. Lack of flushing contributes to the degradation. The relative contributions of various sources and their delivery mechanisms are not known (e.g., weed wrack versus septic leachate) and obviously vary according to the location. In addition, the ultimate fate of nutrients is not well understood.

During this phase of the project, it was important to identify areas where water quality degradation is known or suspected. Based on the results of discussions held during the Phase I workshop and communications with R. J. Helbling (FDER, Marathon, Florida), these areas were identified (Table 5-3, Figures 5-2-1 through 5-2-13).

Table 5-3. **Sites of known or potential water quality degradation. Sites based on correspondence with R.J. Helbling (FDER, Marathon, FL) and the results of the Phase I workshop.**

Fig. 5-2 ID #	Site	Location
1	Ocean Reef Marina	Key Largo
2	Phase I and Dispatch Creek	Key Largo
3	Worlds Beyond	Key Largo
4	C-111 Canal	South Florida Mainland
5	Sexton Cove and Lake Surprise Subdivisions	Key Largo
6	Grass Key Waterways Subdivision	Key Largo
7	Port Largo	Key Largo
8	Key Largo Fishery Marina	Key Largo
9	Marian Park and Rack Harbor Estates	Key Largo
10	Pirate Cove Subdivision	Key Largo
11	Winken, Blynken, and Nod	Key Largo
12	Blue Water Trailer Park	Key Largo
13	Hammer Point	Key Largo
14	Campbell's Marina	Key Largo
15	Tropical Atlantic Shores Subdivision	Plantation Key
16	Plantation Key Colony[a]	Plantation Key
17	Indian Waterways	Plantation Key
18	Plantation Yacht Harbor	Plantation Key
19	Treasure Harbor	Plantation Key
20	Venetian Shores	Plantation Key
21	Holiday Isle Resort	Windley Key
22	Port Antigua	Lower Matecumbe Key
23	White Marlin Beach	Lower Matecumbe Key
24	Lower Matecumbe Beach	Lower Matecumbe Key
25	Caloosa Cove Marina[a]	Lower Matecumbe Key
26	Kampgrounds of America Marina	Fiesta Key
27	Long Key Estates and City of Layton[a]	Long Key
28	Outdoor Resorts of America	Long Key
29	Conch Key	Conch Key
30	Coco Plum Beach[a]	Fat Deer Key
31	Bonefish Towers Marina[a]	Fat Deer Key
32	City of Key Colony Beach Sewage Treatment Plant Outfall	Fat Deer Key
33	Key Colony Subdivision[a]	Vaca Key
34	Sea-Air Estates	Vaca Key
35	90th Street Canal	Vaca Key
36	Winner Docks	Vaca Key
37	City Fish Market	Vaca Key
38	Faro Blanco Marina	Vaca Key
39	Boot Key Marina	Vaca Key
40	Boot Key Harbor	Vaca Key
41	Marathon Seafood	Vaca Key
42	Knight Key Campground	Knight Key
43	Sunshine Key Marina	Ohio Key
44	Bahia Shores	No Name Key

Table 5-3. Sites of known or potential water quality degradation. Sites based on correspondence with R.J. Helbling (FDER, Marathon, FL) and the results of the Phase I workshop. (continued)

Fig. 5-2 ID #	Site	Location
45	Doctors Arm	Big Pine Key
46	Tropical Bay	Big Pine Key
47	Whispering Pines Subdivision	Big Pine Key
48	Sands Subdivision	Big Pine Key
49	Eden Pines Colony	Big Pine Key
50	Pine Channel Estates	Big Pine Key
51	Cahill Pines and Palms	Big Pine Key
52	Port Pine Heights	Big Pine Key
53	Sea Lamp[a]	Big Pine Key
54	Coral Shores Estates	Little Torch Key
55	Jolly Roger Estates	Little Torch Key
56	Breezeswept Beach Estates[a]	Ramrod Key
57	Summerland Key Fisheries	Summerland Key
58	Summerland Key Cove	Summerland Key
59	Cudjoe Ocean Shore	Cudjoe Key
60	Venture Out Trailer Park	Cudjoe Key
61	Cutthroat Harbor Estates[a]	Cudjoe Key
62	Cudjoe Gardens Subdivision[a]	Cudjoe Key
63	Orchid Park Subdivision	Lower Sugarloaf Key
64	Sugar Loaf Shore Subdivision	Lower Sugarloaf Key
65	Sugar Loaf Lodge Marina[a]	Lower Sugarloaf Key
66	Bay Point Subdivision	Saddlebunch Keys
67	Porpoise Point[a]	Big Coppitt Key
68	Seaside Resort	Big Coppitt Key
69	Gulfcrest Park[a]	Big Coppitt Key
70	Boca Chica Ocean Shores	Geiger Key
71	Tamarac Park	Geiger Key
72	Submarine Pens[a]	Boca Chica Key
73	Key Haven Subdivision	Raccoon Key
74	Boyd's Trailer Park	Stock Island
75	Ming Seafood	Cow Key
76	Oceanside Marina	Cow Key
77	Safe Harbor	Cow Key
78	Alex's Junkyard	Cow Key
79	Key West Landfill	Key West
80	House Boat Row	Key West
81	Garrison Bight Marina	Key West
82	Navy/Coast Guard Marina and Trumbo Point Fuel Storage Facility	Key West
83	Truman Annex Marina	Key West
84	Key West Sewage Treatment Plant Outfall	Key West

[a] Site of potential water quality degradation.

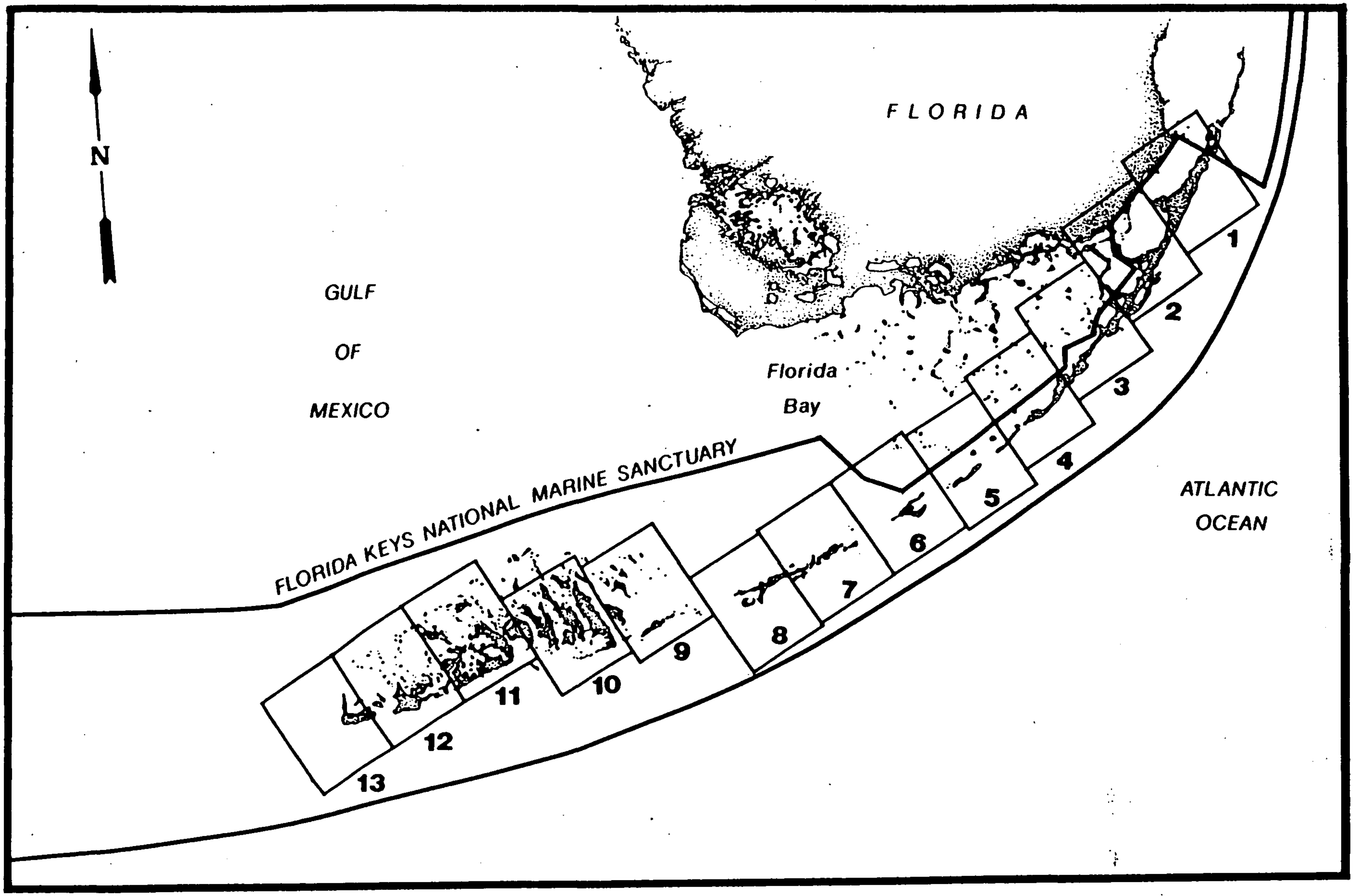

Figure 5-2. Locations of degraded and potentially degraded water quality in the Florida Keys National Marine Sanctuary (shaded areas). Location based on R.J. Helbling [FDER, Marathon, FL, personal communication, 1992] and results of the Phase I workshop. Numbers correspond to those in Table 5-3. Base maps redrawn from maps provided by Wallace Roberts & Todd.

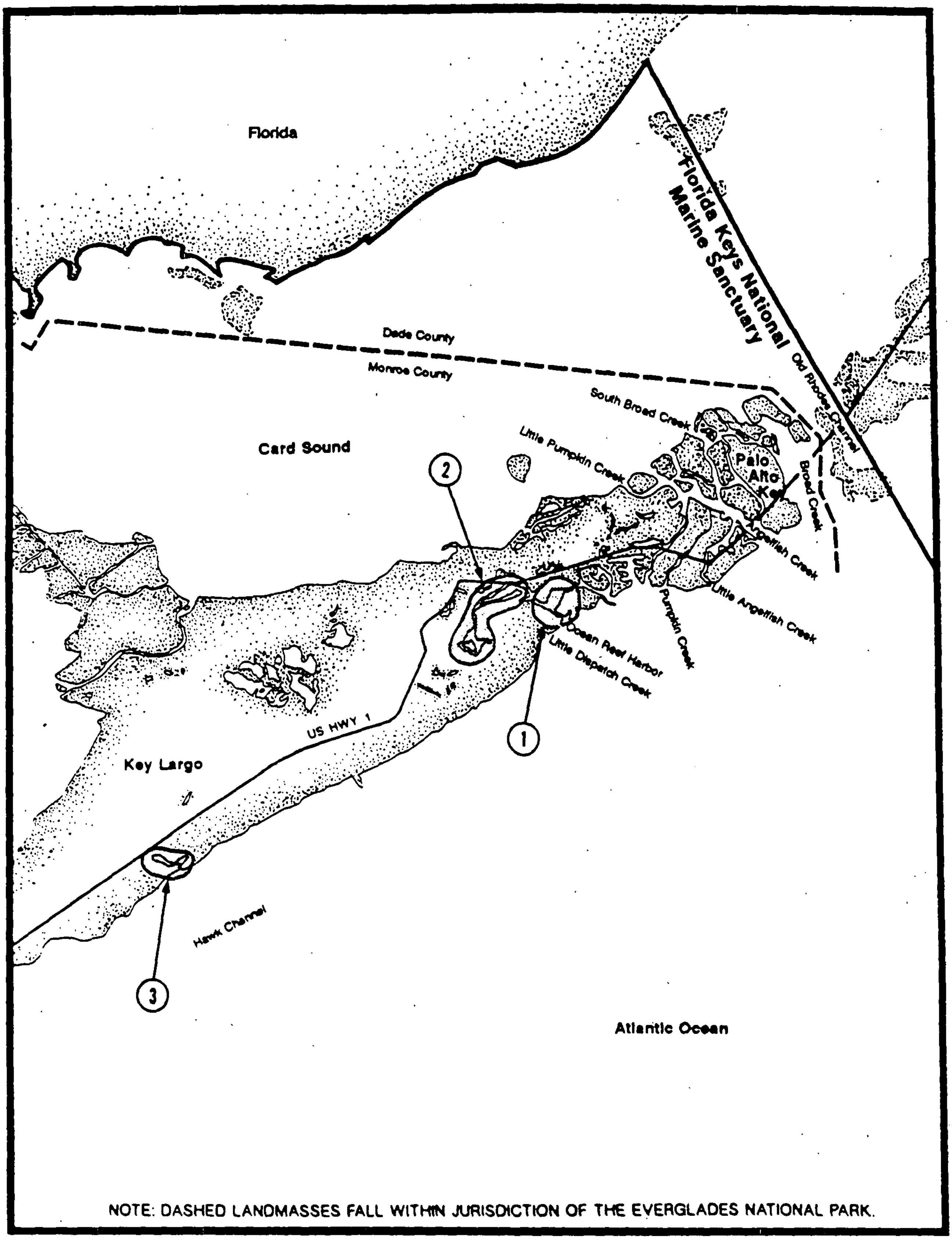

Figure 5-2-1. Locations of degraded and potentially degraded water quality in the Florida Keys National Marine Sanctuary (shaded areas). (continued)

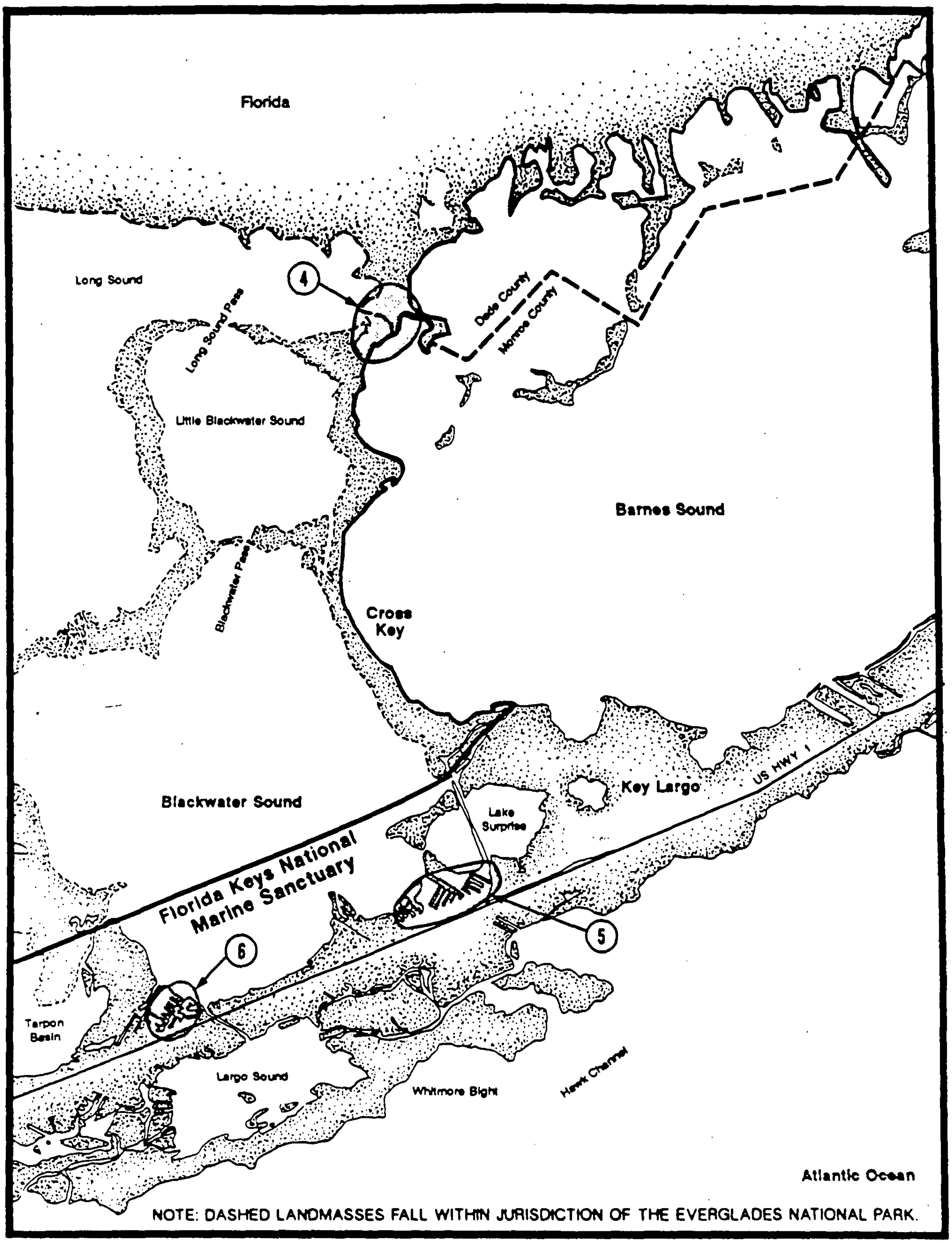

Figure 5-2-2. Locations of degraded and potentially degraded water quality in the Florida Keys National Marine Sanctuary (shaded areas). (continued)

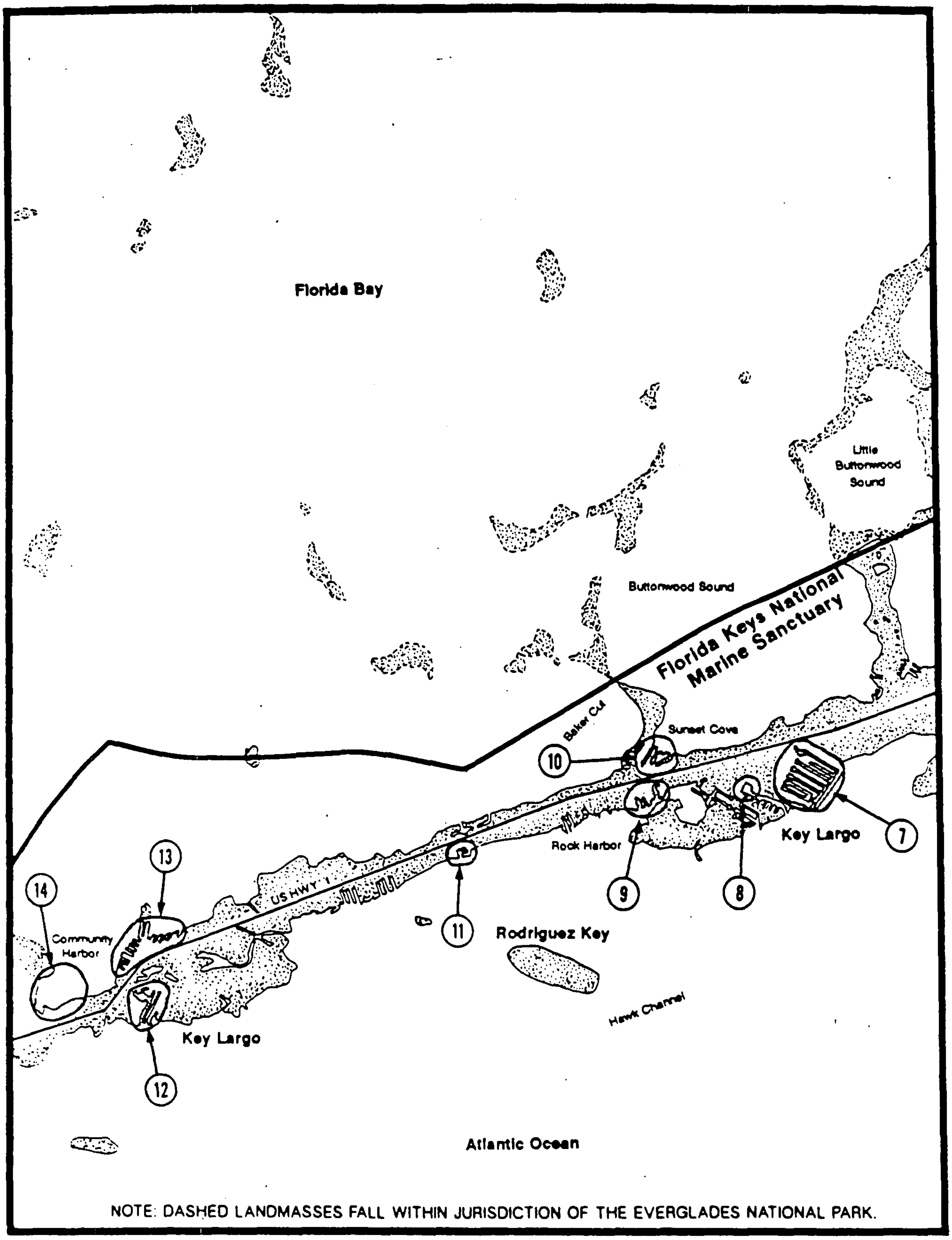

Figure 5-2-3. Locations of degraded and potentially degraded water quality in the Florida Keys National Marine Sanctuary (shaded areas). (continued)

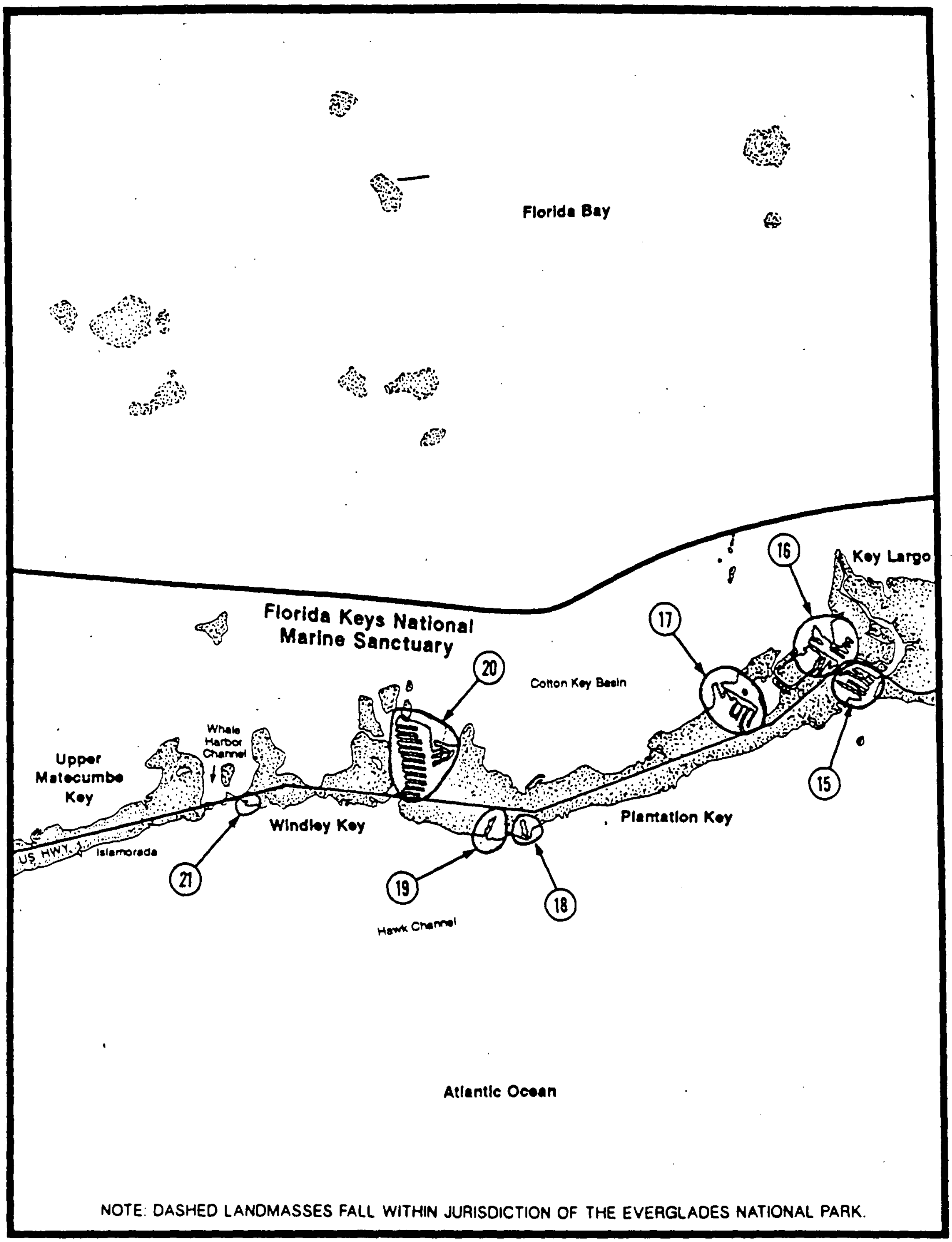

Figure 5-2-4. Locations of degraded and potentially degraded water quality in the Florida Keys National Marine Sanctuary (shaded areas). (continued)

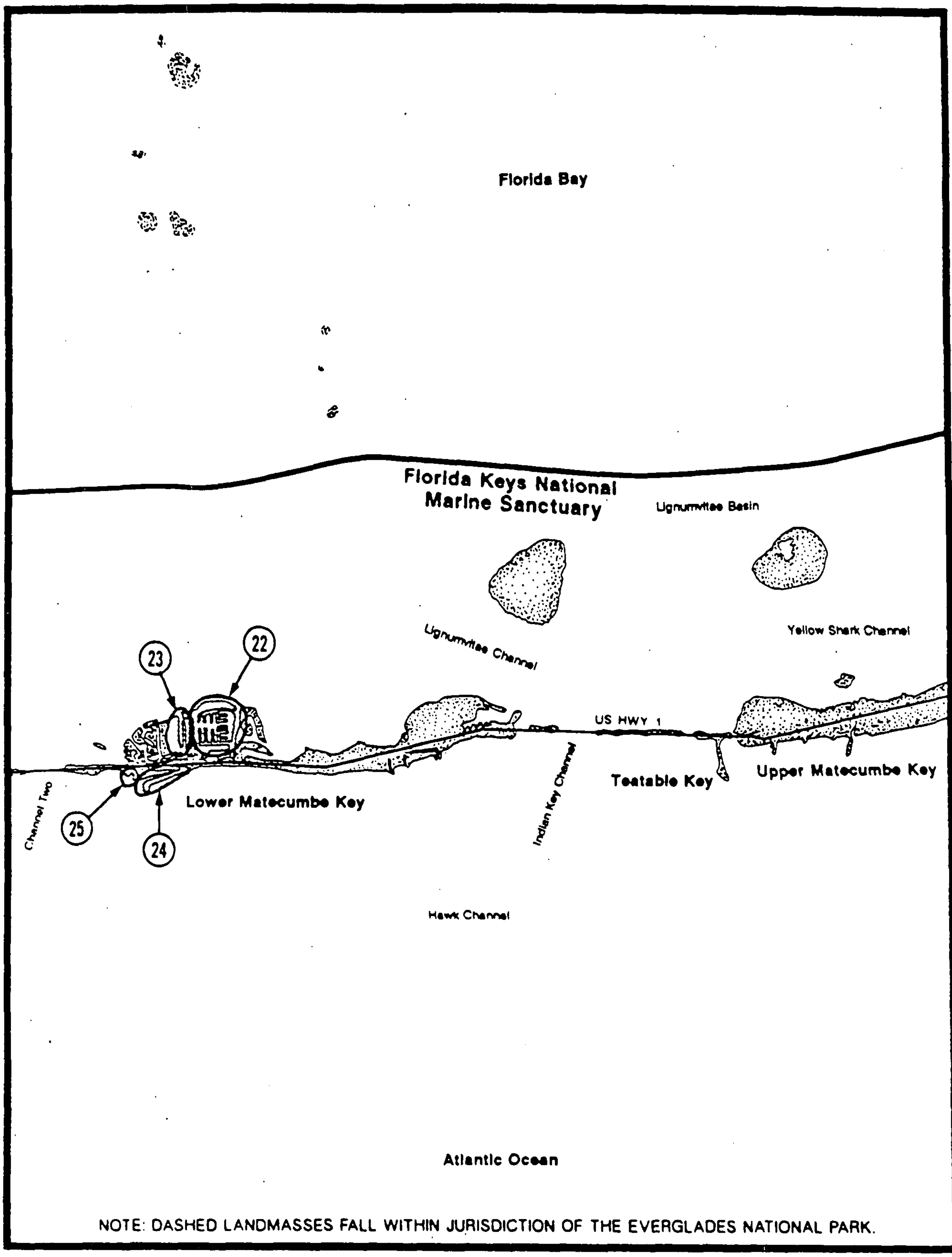

Figure 5-2-5. Locations of degraded and potentially degraded water quality in the Florida Keys National Marine Sanctuary (shaded areas). (continued)

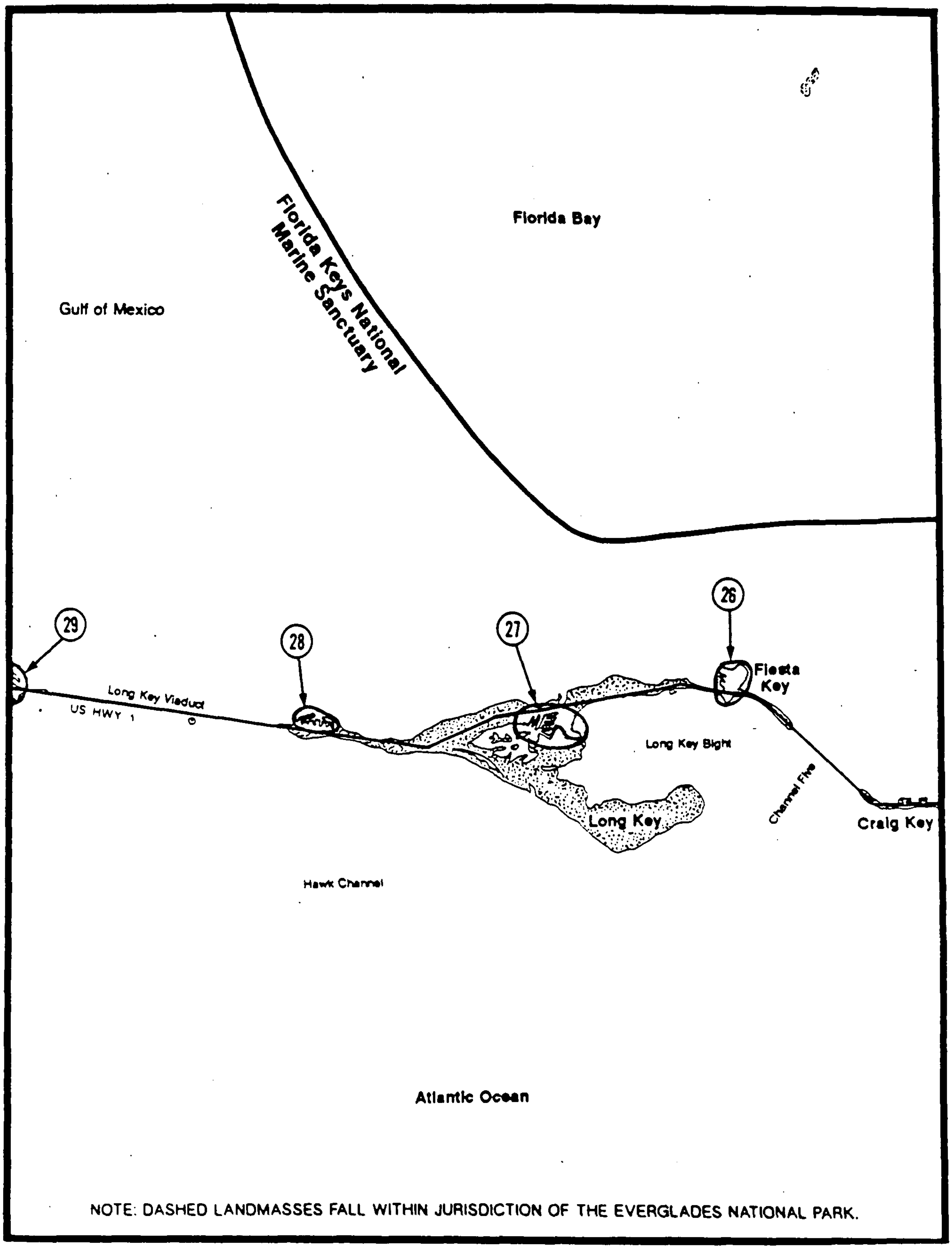

Figure 5-2-6. Locations of degraded and potentially degraded water quality in the Florida Keys National Marine Sanctuary (shaded areas). (continued)

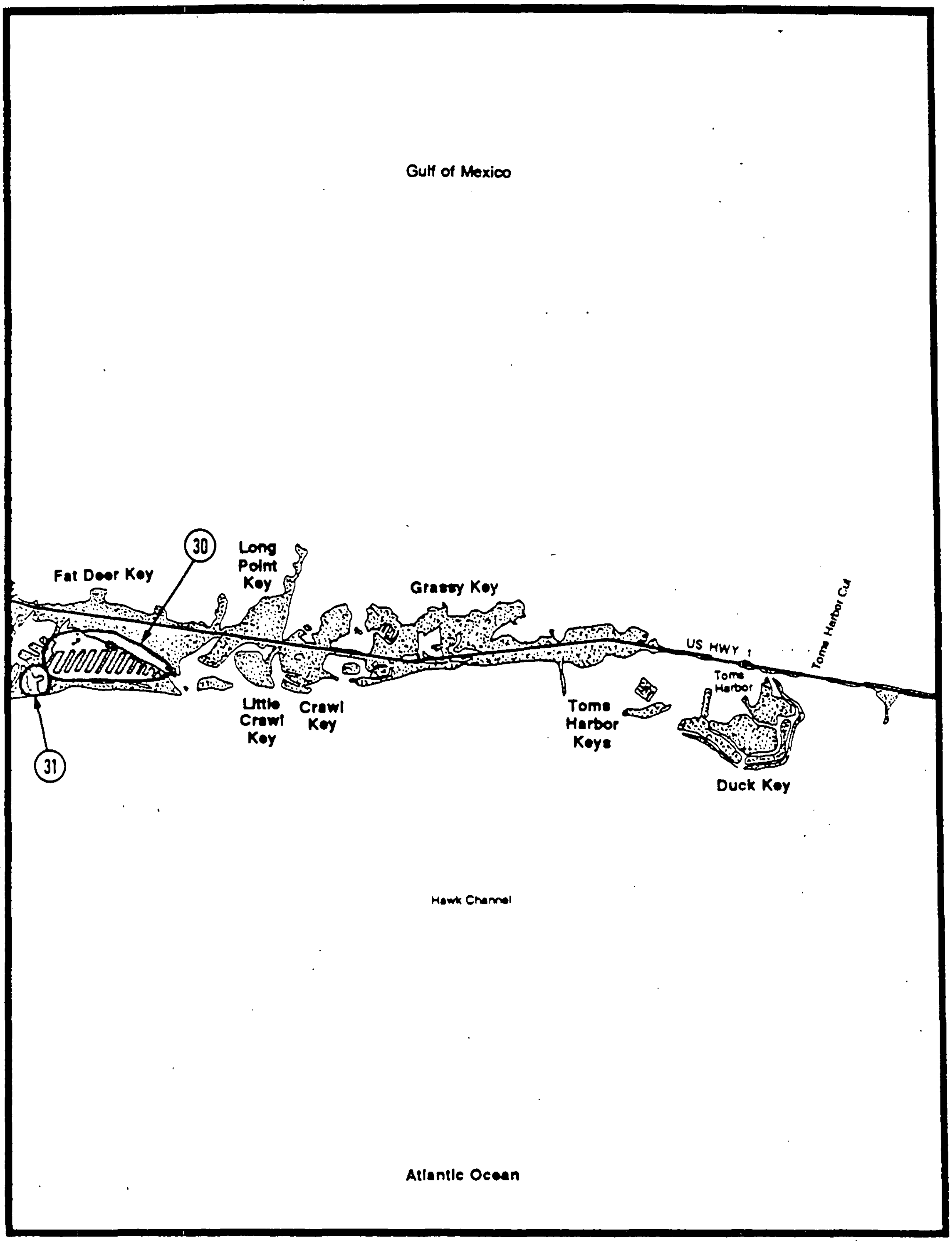

Figure 5-2-7. Locations of degraded and potentially degraded water quality in the Florida Keys National Marine Sanctuary (shaded areas). (continued)

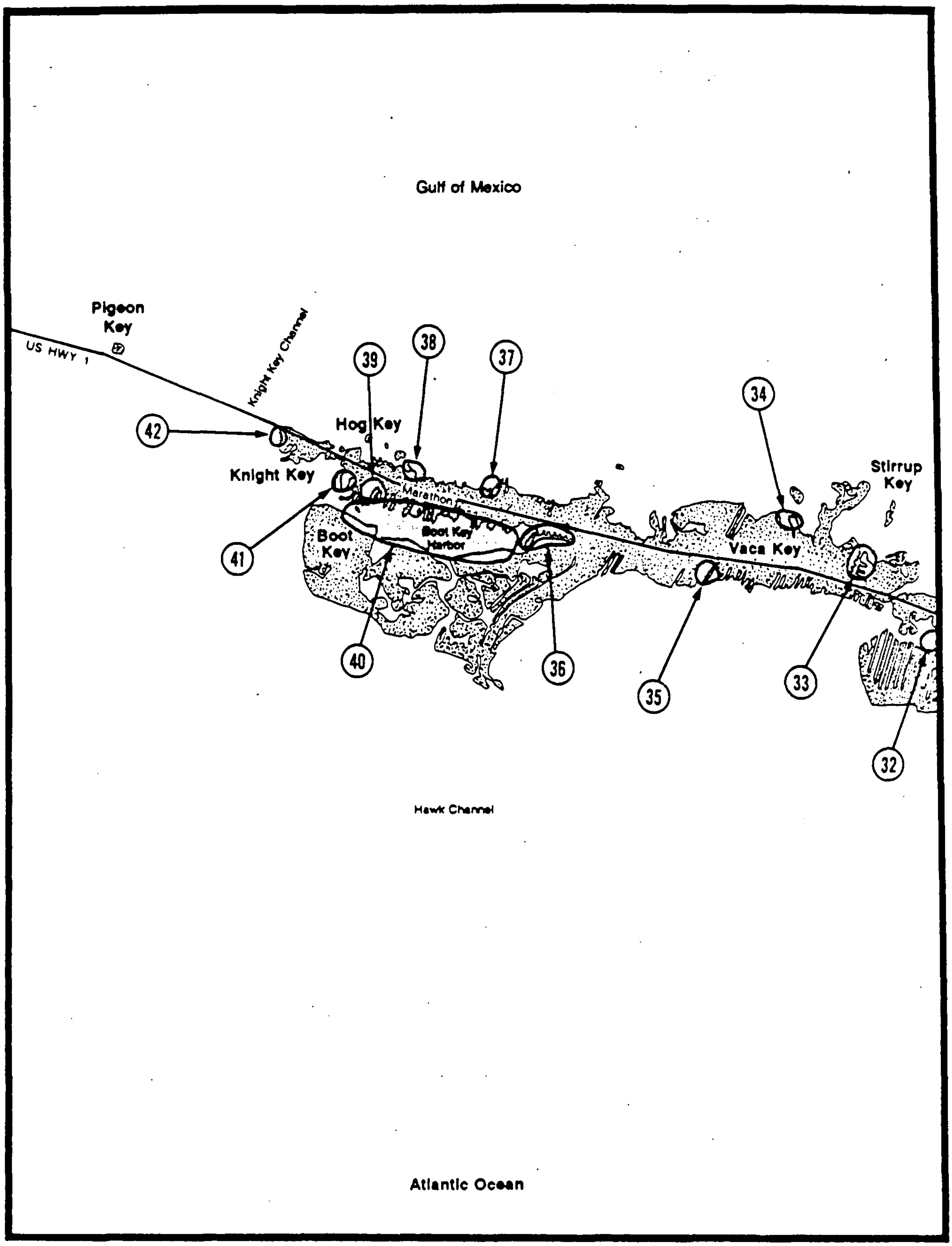

Figure 5-2-8. Locations of degraded and potentially degraded water quality in the Florida Keys National Marine Sanctuary (shaded areas). (continued)

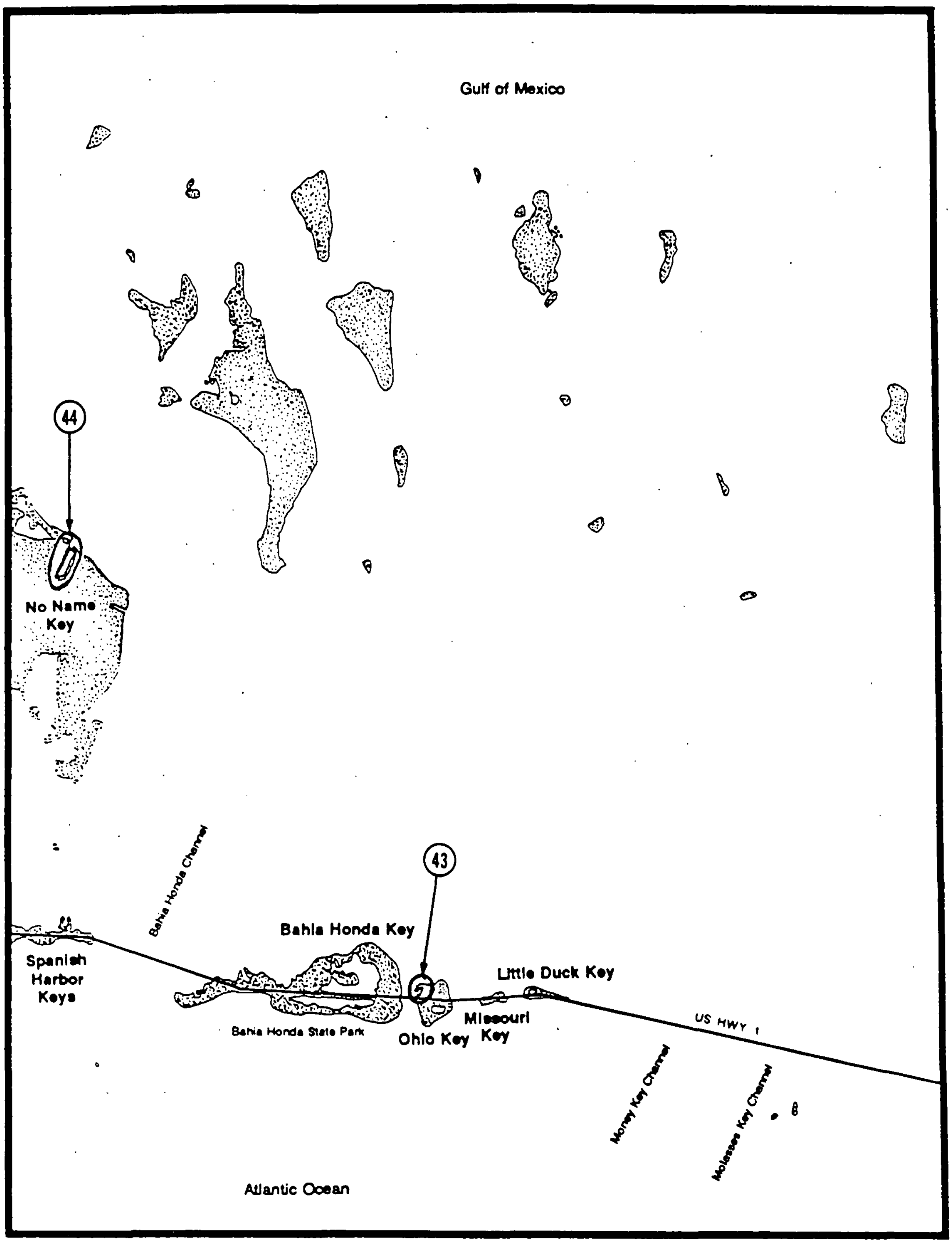

Figure 5-2-9. Locations of degraded and potentially degraded water quality in the Florida Keys National Marine Sanctuary (shaded areas). (continued)

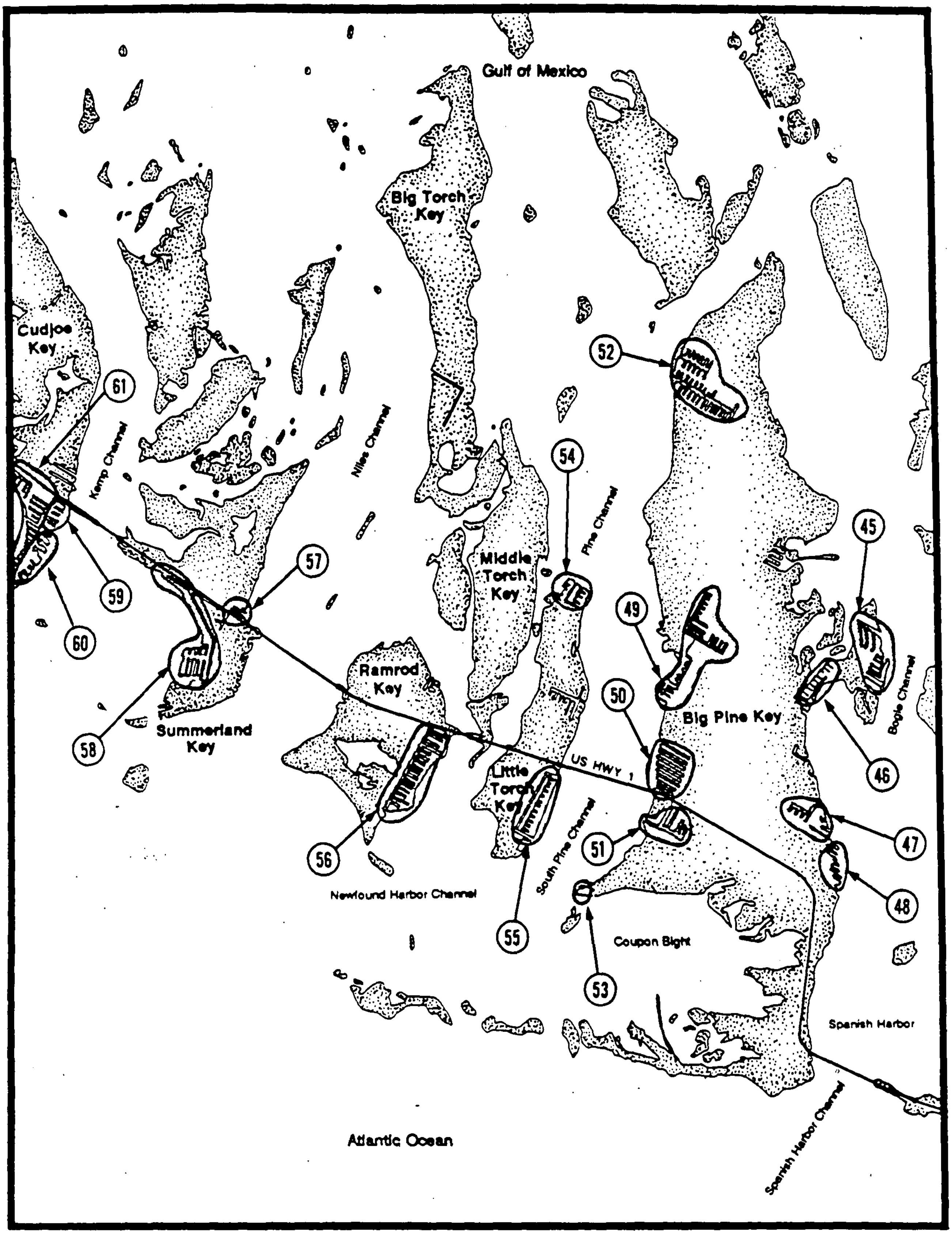

Figure 5-2-10. Locations of degraded and potentially degraded water quality in the Florida Keys National Marine Sanctuary (shaded areas). (continued)

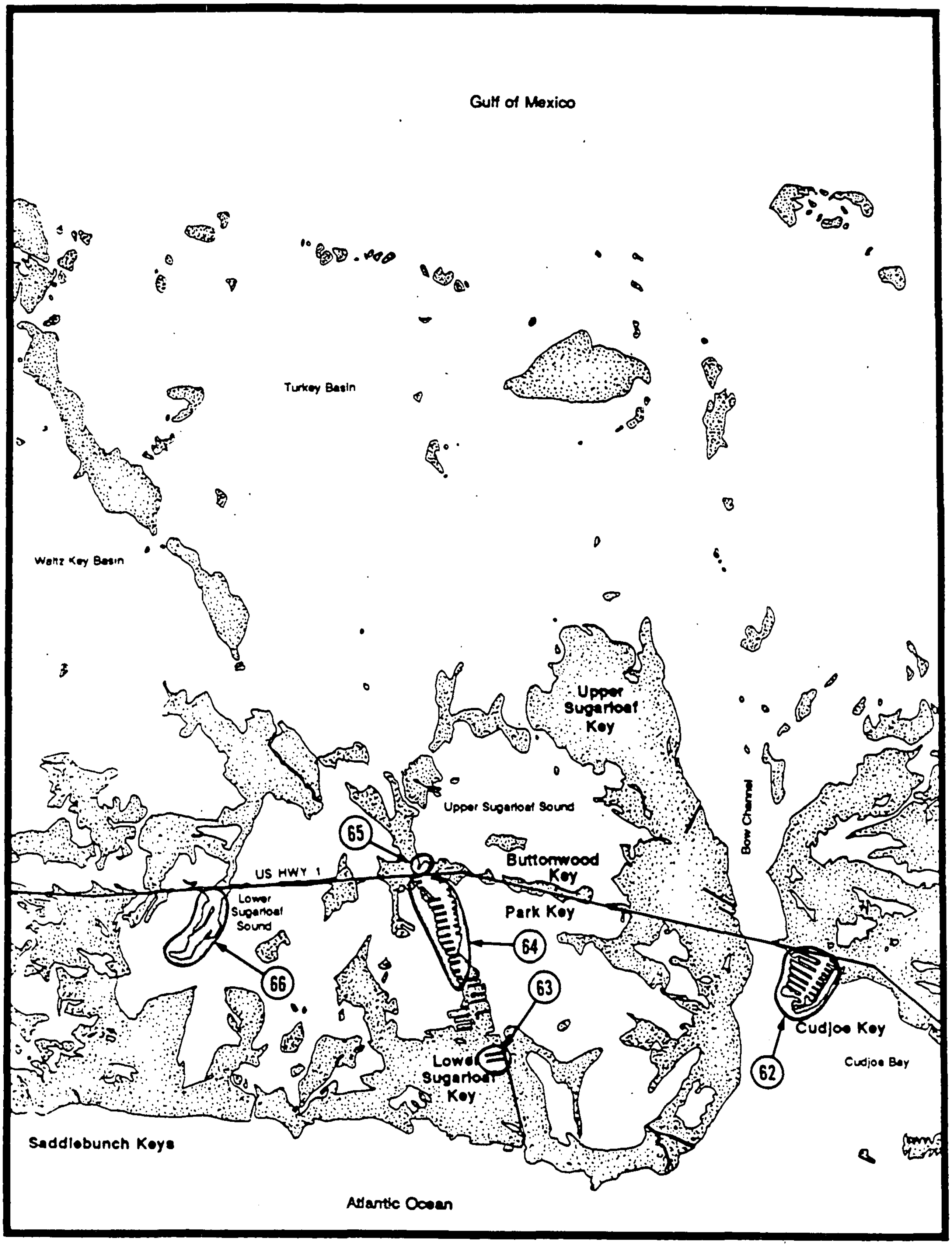

Figure 5-2-11. Locations of degraded and potentially degraded water quality in the Florida Keys National Marine Sanctuary (shaded areas). (continued)

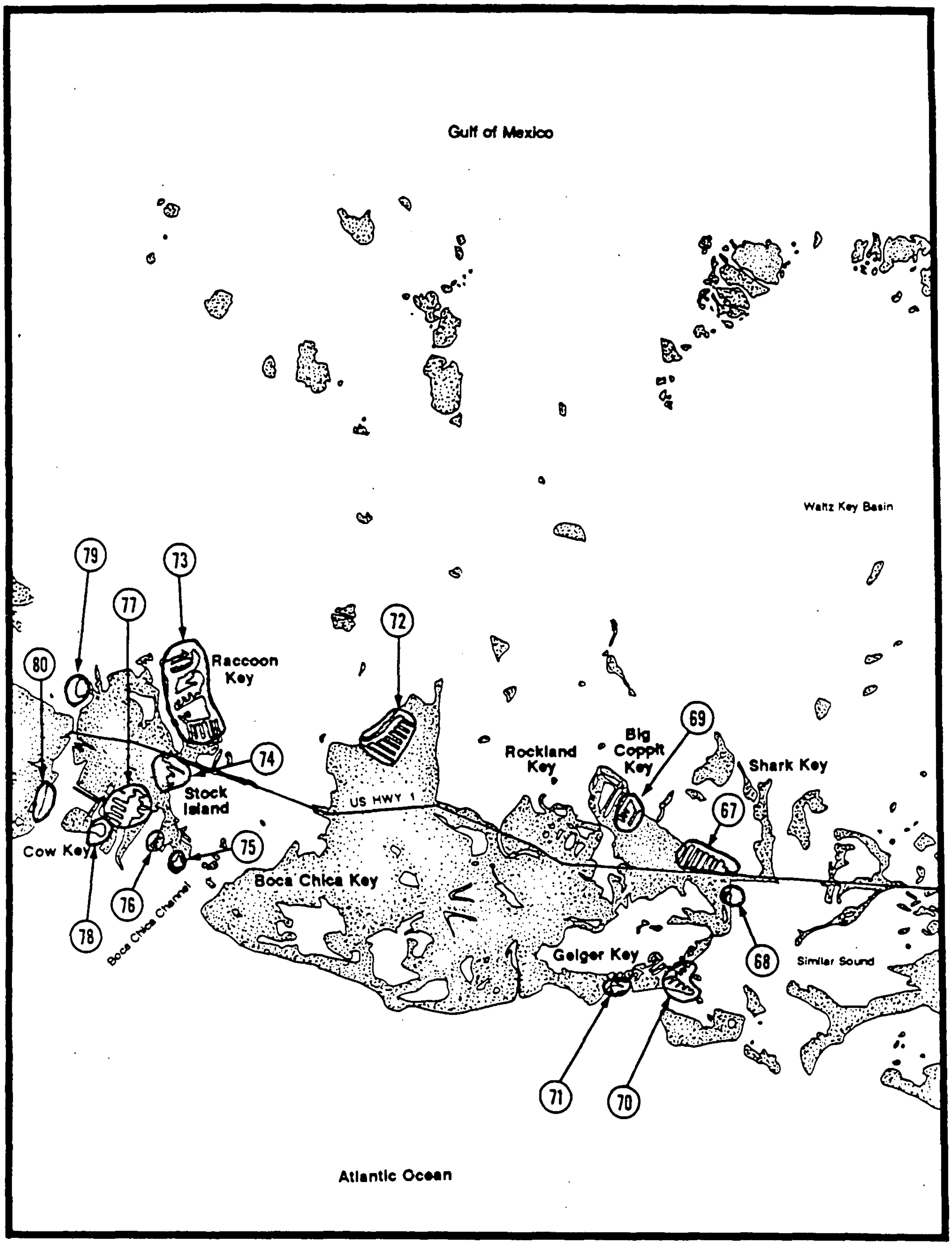

Figure 5-2-12. Locations of degraded and potentially degraded water quality in the Florida Keys National Marine Sanctuary (shaded areas). (continued)

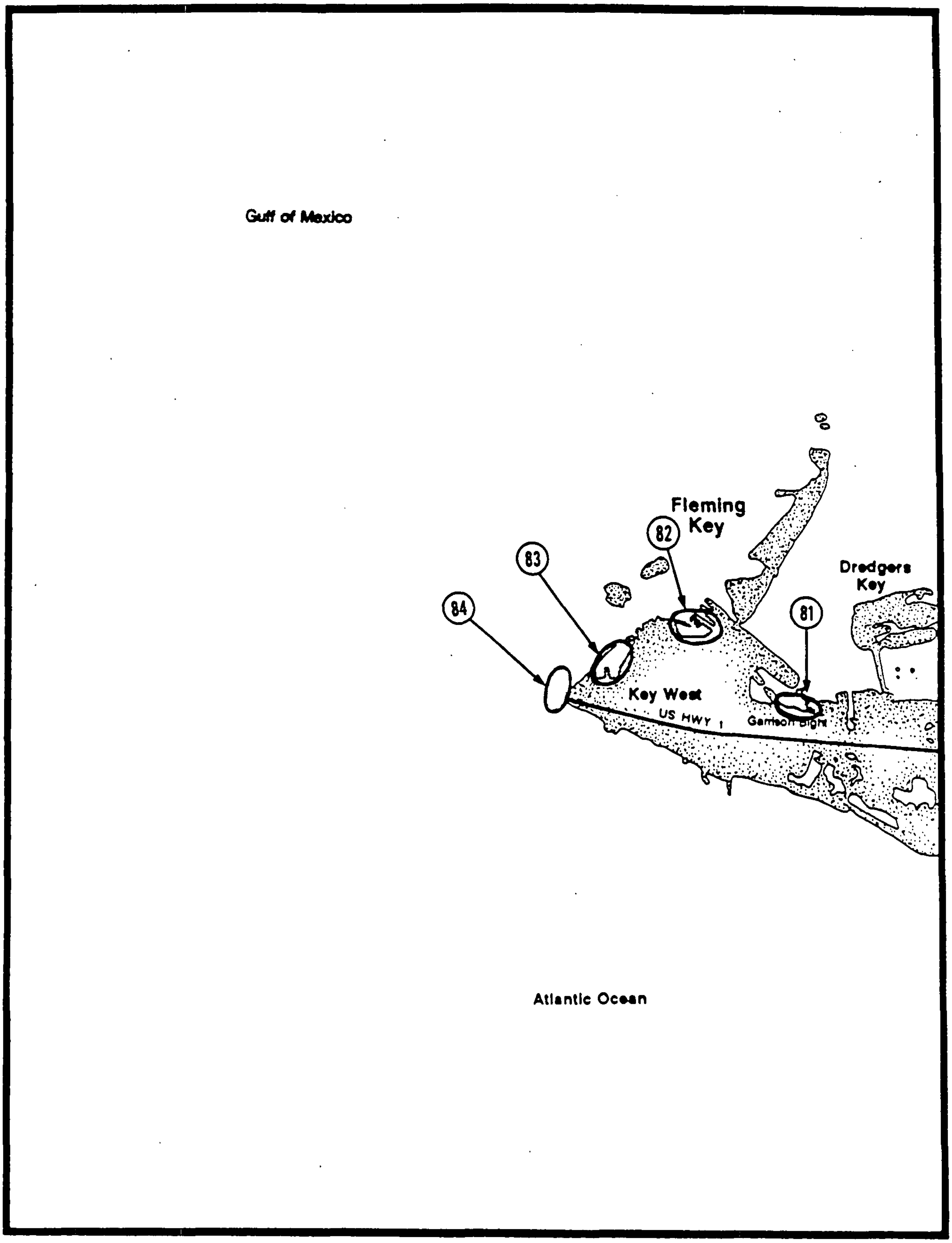

Figure 5-2-13. Locations of degraded and potentially degraded water quality in the Florida Keys National Marine Sanctuary (shaded areas). (continued)

5.0 STATEMENTS OF PROBLEMS

A key part of Phase I of the Water Quality Protection Program is the identification of water quality problem areas to be addressed during Phase II. A two-step approach was used to identify and obtain agreement among members of the scientific community on known, suspected, or potential water-quality problems affecting the natural resources of the Sanctuary. Initially, information gathered during the literature review was used to derive a series of statements describing potential water-quality related problems (presented in Section 5.1). These problem statements were then refined through discussions with EPA Region IV Coastal Programs staff and State of Florida environmental staff and delivered to workshop participants to provide focal points for discussions at technical workshops. The participants in each workshop were charged with coming to a consensus, where possible, on the problem statements developed for each workshop resource area. A matrix analysis of each workshop resource area (Appendix B) was the tool used to develop consensus on the problem statements. Specific descriptive terms were used to complete the matrix based on the discussions with the expert panels assembled for each workshop (Appendix B). Public comments were also heard during the course of each workshop. To assist EPA Region IV and the State of Florida to direct their limited resources, each expert panel was asked to rank the overall significance of the water-quality related problems at the end of each daily workshop. The consensuses developed at the workshops are summarized in Section 5.2 and presented in more detail in Appendix B.

5.1 PROBLEMS IDENTIFIED DURING THE LITERATURE REVIEW

The potential problems for water quality of nearshore and confined waters are presented below. Some changes in water quality associated with these potential problems include reduced dissolved oxygen (DO) concentrations, elevated chlorophyll *a* and nutrient concentrations, and elevated bacterial counts. Sediment contamination may also be associated with these problems. Each problem is evaluated in light of the reviewed studies to identify information gaps and stimulate discussions of these problems with regard to potential regulatory steps.

Water quality in confined waters is deteriorating and is potentially deteriorating in nearshore waters, and this degradation may be adversely affecting biota inhabiting nearshore areas. — Water quality in confined waters (such as canals that receive input from anthropogenic sources) appears to have deteriorated. The extent of this deterioration is unknown, other than in a few areas where data have been collected. If the quantity of the anthropogenic-source input increases with an increasing population and development of the Florida Keys, the water quality may reasonably be expected to continue to deteriorate. At present, the spatial extent of the problem is not well known, but it appears to be limited to areas of development. Nearshore water quality in areas that are well flushed does not appear to be presently degraded, except where anthropogenic pollutants are being released. The effect of continued development is not known. Studies directly relating changes in water quality to changes in the biota have not been performed within the FKNMS. It is reasonable to assume that degrading water quality will affect biota in the nearshore. The extent and degree of possible effects on the biota are unknown.

Septic leachate from on-site sewage disposal systems (OSDS) is degrading water quality in confined waters and may be degrading water quality in nearshore waters. — Septic leachate appears to have contributed to degrading water quality in canals that have housing developments with septic tanks and cesspools around them. Continued development without proper treatment of wastes may result in degradation beyond the immediate vicinity of affected canals. The contribution of this pollution source relative to other sources is also unknown and is likely site-specific.

Sewage discharges from live-aboard vessels are degrading water quality in nearshore and confined waters. — Degraded water quality has been demonstrated in some areas where live-aboard vessels congregate. Degraded water quality may also be a problem in unstudied areas. If the number of live-aboard vessels increases and untreated sewage continues to be discharged, the water quality may be degraded further. The contribution of this pollution source relative to other sources is unknown and is likely site-specific.

Decomposition of weed wrack and other windblown organic debris may be degrading water quality in canals. — Deposition of windblown debris in canals has been mentioned in several studies as a reason for reduced water quality relative to ambient conditions. This has not been well studied, and its contribution to degraded water quality relative to other sources is unknown. Its contribution would not be expected to increase with increasing population.

Discharges from sewage treatment/package plants into nearshore receiving waters may be degrading nearshore water quality. — Discharges from the Key Colony Beach outfall affected water quality in the vicinity of the outfall. Effects of discharges from the Key West Sewage Treatment Plant have not been studied. The degree of changes in water quality are likely related to the level of waste treatment. The contribution of the pollution source relative to other sources is unknown and is probably site-specific.

Stormwater runoff is degrading confined water quality and may be degrading nearshore water quality. — Stormwater runoff has been shown to degrade water quality in some canals. Runoff occurs throughout the Keys, and the effects on water quality at individual locations are probably related to the substrate over which the runoff flows prior to reaching the nearshore waters. Changes in land use will therefore affect the nature of the runoff. Deleterious effects of stormwater runoff on water quality are probably more prevalent in developed areas.

5.2 PROBLEMS IDENTIFIED AT THE NEARSHORE AND CONFINED WATERS ASSESSMENT WORKSHOP

This workshop was divided into three areas of interest, Confined Waters, Nearshore Waters, and Back Country Waters. The problems discussed in relation to ***confined waters*** were divided into two areas; eutrophication and human health. Under eutrophication, increased epiphyte growth, increased chlorophyll (i.e., phytoplankton), and change in benthic community structure were identified as problems. Under human health, the effects of fish and shellfish consumption on human health was discussed. Problems discussed in relation to ***nearshore waters*** were increased epiphyte growth and increased chlorophyll (i.e., phytoplankton). Problems discussed in relation to ***back country waters*** were increased epiphyte growth and increased chlorophyll (i.e., phytoplankton). The parameters for analysis and the matrices used for the discussion are presented in Appendix B.

The consensus of the workshop panel members was that water quality in some confined waters was degraded; however, there was not a unanimous consensus that water quality in nearshore and back country waters was degraded. Priority areas in need of more information were new methodologies for using managed aquatic systems for treatment, hot spots (areas of severe water quality degradation), nutrient loading, nutrient transport/hydrology, monitoring from a hydrological/biological standpoint (develop a systems monitoring program), back country waters, hydrology regarding well injection (has the ability to impact nearshore and offshore waters), and hydrological studies [intensive surveying needed, establish a liaison with the United States Geological Survey (USGS)]. Priority problem areas are the canal systems adjacent to inappropriate sewage treatment systems; secondary treatment should be mandated for such areas.

Confined Waters — Eutrophication

[*Note:* Confined waters are defined as canals, marinas, bays, and lagoons.]

Increased epiphyte growth is a widespread problem and the trend is worsening. — Epiphyte growth has been increasing over the last decade. This problem is water-quality related and the overall significance of the problem from a water-quality perspective is high. Parameters that significantly affect increased epiphyte growth are nutrients, turbidity, and anthropogenic BOD loadings. An increase in epiphyte growth is an indicator of a change in the community structure and amount. Poor flushing and the lack of circulation in the canals contributes to the poor water quality in the canals.

Increased chlorophyll is related to temperature and light, and is thought to be widespread, chronic, and worsening (anecdotal evidence). — This problem is water-quality related and the overall significance of the problem from a water-quality perspective is high. Parameters that significantly affect this problem are nutrients, turbidity, and anthropogenic BOD loadings. Increased chlorophyll is an indicator of the severity of the nutrient loading.

Change in the benthic community structure is a widespread problem and the trend is worsening. — The problem is water-quality related and the overall significance of the problem from a water-quality perspective is high. Parameters that significantly affect this problem are nutrients, turbidity, and anthropogenic BOD loadings. Decomposing seagrass wrack can lead to eutrophication.

Confined Waters — Human Health

Human health (fish and shellfish consumption) refers to problems associated with consuming fish/shellfish caught by an individual, not fish/shellfish purchased from a seafood market. No historical data exist regarding health problems from personally caught fish/shellfish.

More data are needed regarding the trend, severity, and certainty of the human health problem. — Toxics/pesticides, human-derived bacteria, turbidity, anthropogenic BOD loading, and viruses significantly affect the problem. Temperature, nutrients, and salinity affect the problem slightly to significantly depending on the species. It is possible but unlikely that the problem is water-quality related. The overall significance of this problem from a water-quality perspective is unknown. In areas with inappropriate sewage treatment systems, the potential exists for severe health problems.

Nearshore Waters

[*Note:* Nearshore waters are defined as those that extend from shore to Hawks Channel including the 18 ft depth contour.]

Increased epiphyte growth is widespread and worsening, and has been increasing over the last decade. — For increased epiphyte growth, severity is slight, certainty is possible, and overall significance of this problem from a water-quality perspective is slight. The problem is water-quality related. Parameters that significantly affect this problem are nutrients, turbidity, and anthropogenic BOD loadings.

Increased chlorophyll is thought to be widespread, chronic, and worsening. — Severity is slight, certainty is possible, and overall significance of this problem from a water-quality perspective is slight. Increased chlorophyll is related to temperature and light, and has been reported since 1973. The problem is water-quality related. Parameters that significantly affect this problem are nutrients, turbidity, and anthropogenic BOD loadings.

Back Country Waters

[*Note:* Back country waters are defined as nearshore Florida Bay waters within the 8 to 10 ft depth contour.]

Increased epiphyte growth is widespread and worsening, and has been increasing over the last decade (anecdotal evidence). — For increased epiphyte growth, the severity is slight, certainty is possible, and overall significance of this problem from a water-quality perspective is slight. The problem is water-quality related. Parameters that significantly affect this problem are nutrients, turbidity, and anthropogenic BOD loadings.

Increased chlorophyll is thought to be widespread, chronic, and worsening (anecdotal evidence). — Severity is slight, certainty is possible, and overall significance of this problem from a water-quality perspective is slight. Increased chlorophyll is related to rainfall, temperature, and light and has been reported since 1973. The problem is water-quality related. Parameters that significantly affect this problem are nutrients, turbidity, and anthropogenic BOD loadings. In addition, no historical data exist regarding the back country waters.

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SPILLS AND HAZARDOUS-MATERIALS ASSESSMENT
Task 6

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TASK 6: SPILLS AND HAZARDOUS-MATERIALS ASSESSMENT

1.0 INTRODUCTION

The purpose of this task report is to identify the sources and causes of toxic or hazardous-material spills within the Florida Keys National Marine Sanctuary (FKNMS). In this discussion, hazardous material is defined as any substance that may produce negative environmental impacts or human health problems if spilled or released into the environment. This definition is specifically selected to include all petroleum products. The causes and types of materials spilled are reviewed and the likelihood of future spills, as well as their potential for impacts on the Sanctuary, are assessed. Data reviewed for this report consist of the United States Coast Guard (USCG), National Response Center summary of reported spills 1987-1991, the National Oceanic and Atmospheric Administration (NOAA) Strategic Environmental Assessments Division copies of the USCG reported spill records 1970-1990, the Florida Department of Environmental Regulation (FDER), Ground Water Management System, and the FDER "Emergency Sampling Response" records.

The USCG reported spill records, the data set from which a large portion of any historical analysis must be derived, show a number of entry errors and discrepancies in the spill location and cause sections, particularly in earlier reports (1970s through the earlier 1980s). Many of these problems result from recording methods. Although standardization has improved with time, there are still significant typographical errors and spill location accuracy problems in the database. To be used in the most effective manner, extensive ground truthing and "cleaning" of the digitized database would be required (T. Goodspeed, NOAA Strategic Environmental Assessments Division, personal communication, 1991). NOAA's Strategic Environmental Assessments Division has generated draft maps of spill locations and quantity from these data files, but the maps are not suitable for publication without extensive review by field personnel and verification of the individual electronic data files (T. Goodspeed, NOAA Strategic Environmental Assessment Office, personal communication, 1991).

The quality of the spill records reported by the National Response Center improved dramatically over time with the period between 1985 and the present having the most complete spill records available. While the entire data suite has been reviewed, for the purposes of this text, only the records between 1985 and 1991 are discussed in detail. Electronic data sets, reduced from the USCG records showing spill types and geographic coordinates from 1973 through 1990, could be developed and provided to the Florida Department of Natural Resources (FDNR) for inclusion in the Sanctuary Geographic Information System (GIS), if such inclusion is justified in view of the ongoing NOAA spill-mapping effort.

2.0 HISTORICAL SPILL DATA AND SITES OF HAZARDOUS-MATERIAL CONTAMINATION

2.1 TERRESTRIAL

2.1.1 Spills

The FDER records indicate that, between January 1987 and June 1991, there were 26 environmental incidents (e.g., spills and groundings) within the Florida Keys. These were of a sufficient magnitude to initiate "Emergency Response Sampling." Of these incidents, 12 were spills of various substances at terrestrial locations. These spills were further categorized as follows.

- Six petroleum products spills: jet fuel, two spills; gasoline, three spills; diesel, one spill
- Three sewage spills: raw sewage, two spills; treated sewage, one spill
- Miscellaneous toxic substances: one case where potassium cyanide was abandoned but not actually spilled; 1 spill of infectious medical waste; one pesticide spill.

The National Response Center data files obtained from NOAA show that, between October 1984 through March of 1990, a total of 81 spills were reported at terrestrial locations within the Florida Keys. Fifty-seven of these spills were petroleum products, six were chemicals, and 18 were classified as other substances such as "soot and ash," "foam," garbage, etc. The spills resulted from

Structural failure (12 spills)
Natural seepage (12 spills)
Equipment failure (9 spills)
Intended discharges (5 spills)
Unintended discharges (3 spills)
Tanks spills (3 spills)
Not elsewhere classified (37 spills)

Geographically, the spills were concentrated in accordance with population centers. These were

Key West (26 spills)
Key Largo (18 spills)
Islamorada (7 spills)
Marathon (6 spills)
Tavernier (4 spills)
Big Pine (3 spills)
Other areas of the Keys (17 spills)

Petroleum products are the hazardous material most often spilled in the terrestrial areas within the Florida Keys. Structural failure and natural seepage were responsible for the largest percentage of the hazardous-materials spills occurring at specific facilities in the Florida Keys. New FDER regulations pertaining to storage tanks and underground facilities should reduce the risk of future spills from these facilities (see discussion below). Equipment failure and human error (intended and unintended discharges and tank spills) accounted for the remaining classified spills reported. Increased enforcement, more frequent equipment inspections, and tougher penalties will reduce but not eliminate spills in these categories.

The category "Not elsewhere classified" included an array of miscellaneous spill causes as well as spills detected after the fact and that occurred for unknown causes. These types of spills were typically isolated incidences, such as transportation accidents or deliberate dumping by unknown persons. Such spills can not be allotted to any specific problem or facility, and they are the most difficult to prevent or guard against.

2.1.2 Hazardous-Materials Generators

The Resource Conservation and Recovery Act (RCRA) was enacted to enable Federal, State, and local authorities to regulate handling of hazardous materials, especially those activities related to the handling, storage, treatment, disposal, and generation of hazardous substances. The Federal government has delegated to individual states, such as Florida, the authority to implement rulings and statutes listed under RCRA. Most states, such as Florida, have gone beyond the minimum guidelines set forth by RCRA in their attempt to deal more adequately and effectively with responsible parties involved with the use of hazardous materials.

RCRA technically defines hazardous materials as solids, liquids, or gases or combinations thereof, which may because of its quantity; concentration; or physical, chemical or infectious characteristics be harmful or toxic to human health. The Environmental Protection Agency (EPA) provides a concise definition, listing all exemptions and exclusions, as well as constituents considered to be hazardous materials in 40 CFR 261.

As part of Florida's enforcement program, the FDER has created numerous tracking systems/databases capable of storing a site's past and current activities, its level of compliance with State statutes, current environmental status, and other site-specific criteria.

A specific example is the FDER Groundwater Management System (GMS), which is a database system consisting of several subsections. A subsection of particular interest is the GMS 10 System (small quantity generators). This database or facility directory includes EPA and GMS operating permit numbers, site locations, operating status, and treatment processes.

To be registered as a "small quantity generator," no more than 1000 kg can be generated within a 1-month period. Full generator status is applicable to facilities that exceed 1000 kg/month or generate acutely hazardous waste in excess of 1 kg/month.

There are currently (FDER GMS 10, dated 8 August 1991) 44 registered hazardous-waste generator sites in the Florida Keys. Data quantifying the type of hazardous materials generated are not available. Only two sites were classified as small quantity generators. These two sites are the United States Naval Air Station at Boca Chica and the United States Naval Facility at Demolition Key. These sites were listed as facilities that transport, dispose, and store hazardous materials.

2.1.3 Contaminated Sites

Site contamination in the Florida Keys generally is the result of failure of an underground storage tank system that contains either petroleum products or materials listed under RCRA, Subtitle I. Under RCRA, Subtitle I, the Regulation of Underground Storage Tanks was enacted in 1984 as part of the Hazardous and Solid Waste Amendments (HSWA) to RCRA. An underground storage tank is one that stores "regulated substances" and has at least 10% of its total volume below the surface of the ground, including all piping network. Regulated substances are hazardous chemical products regulated under the Comprehensive Environmental Response, Compensation, and Liability Act (CERCLA). The regulation of petroleum products is covered by CERCLA. Regulated substances do not include RCRA hazardous wastes. EPA 40 CFR Parts 280 and 281 differentiate among substances regulated by CERCLA and RCRA.

The State of Florida, specifically the FDER, has been delegated authority by EPA through the development of internal programs that exceed or meet EPA Federal guidelines, specifically the criteria set in Florida Chapter 1-761, Florida Administrative Code (FAC), and Chapter 17-762,FAC. These are laws that deal with aboveground as well as underground storage-tank systems, respectively. These chapters deal exclusively with regulatory compliance, regulation, retrofitting to meet current "best available technology" criteria. In addition, Florida developed Chapter 17-770,FAC, which deals exclusively with the assessment and remediation of contaminated sites.

Of the 395 registered storage-tank systems sites in the Florida Keys, there are currently 64 sites that have reported a "notice of discharge" with the FDER. A notice of discharge is required under Section 17-761,FAC when a suspected underground storage-tank leak has contaminated the surrounding soils, surface waters immediately adjacent to, or groundwaters directly beneath a tank system.

A portion of these sites are a part of either the Florida "Early Detection Incentive Program" (the EDIP) or the more recently implemented "Abandoned Tank Restoration Program" (ATRP). These programs assist in the funding of assessing the areal extent of a sites contamination, as well as the remedial activities required to clean up contaminated sites. While the majority of sites contaminated are locations of major oil/gasoline companies, marinas, retail facilities, and privately held commercial businesses, the costs from assessment to remediation can easily exceed hundreds of thousands of dollars.

Although approximately 17% of the sites in the Florida Keys have experienced some sort of storage-tank failure, the immediate nearshore marine environment could be impacted by tank failure, but the timing, location, and magnitude cannot be predicted. As laws continue to improve the structural integrity of new underground storage tank systems, the impacts attributed to their inadequacies will significantly decrease. There will still be problems with older systems until these can be replaced.

2.2 MARINE

Between October 1985 and September 1991, there were 355 reported spills of hazardous materials in the waters of the present FKNMS. Of these spills, 319 (90%) were petroleum products, 29 were classified as other oils, and seven were classified as other materials.

The vast majority of these spills were detected after the fact, consequently their actual cause is not known. For those spills where causes were reported (84 of the 355), USCG data show the following.

Equipment failure (23 spills)
Intended discharge (15 spills)
Structural failure (13 spills)
Unintended discharge (12 spills)
Other (21 spills)

In 73 of the 355 spills, the type of vessel held responsible was identified. These data show the following.

Fishing boats (27 spills)
Freight barges (12 spills)
Recreational vessels — e.g., yachts (11 spills)
Passenger vessels (9 spills)
Public vessels — e.g., research vessels (4 spills)
Tug/tow boats (3 spills)
Unclassified vessels (3 spills)
Tank barges (2 spills)
Tank ships — e.g., tankers (2 spills)

Geographically, the 355 spills were reported as having taken place in the following areas.

Atlantic Coast — 0 to 3 nmi from shore (156 spills)
Gulf Coast — 0 to 3 nmi from shore (132 spills)
Inland, including canals and harbors (35 spills)
Atlantic contiguous — 3 to 12 nmi offshore (14 spills)
Gulf contiguous — 3 to 12 nmi offshore (9 spills)
Atlantic offshore — 12 to 200 nmi offshore (9 spills)

Petroleum products, primarily gas and diesel fuel, were the hazardous materials most often spilled into Sanctuary waters. In 98 of the 355 spill records, estimations of the quantity of material spilled are given. **Figure 6-1** illustrates the relative frequencies of petroleum spills in the 0-5, 6-50, 51-100, and 100+ gal ranges. The maximum spill for which a volume was given was 755 gal. Obviously, small spills (0-5 gal) make up the vast majority of reported petroleum spills from the FKNMS.

Applying percent by volume estimates (**Figure 6-1**) to the total 355 reported spills yields a range from 3852 to 17,785 gal of spilled petroleum products over the last six years. Based on these calculations, between 642 and 2964 gal of oil are spilled annually into the FKNMS. **Figure 6-2(a)** shows the total reported spills per year

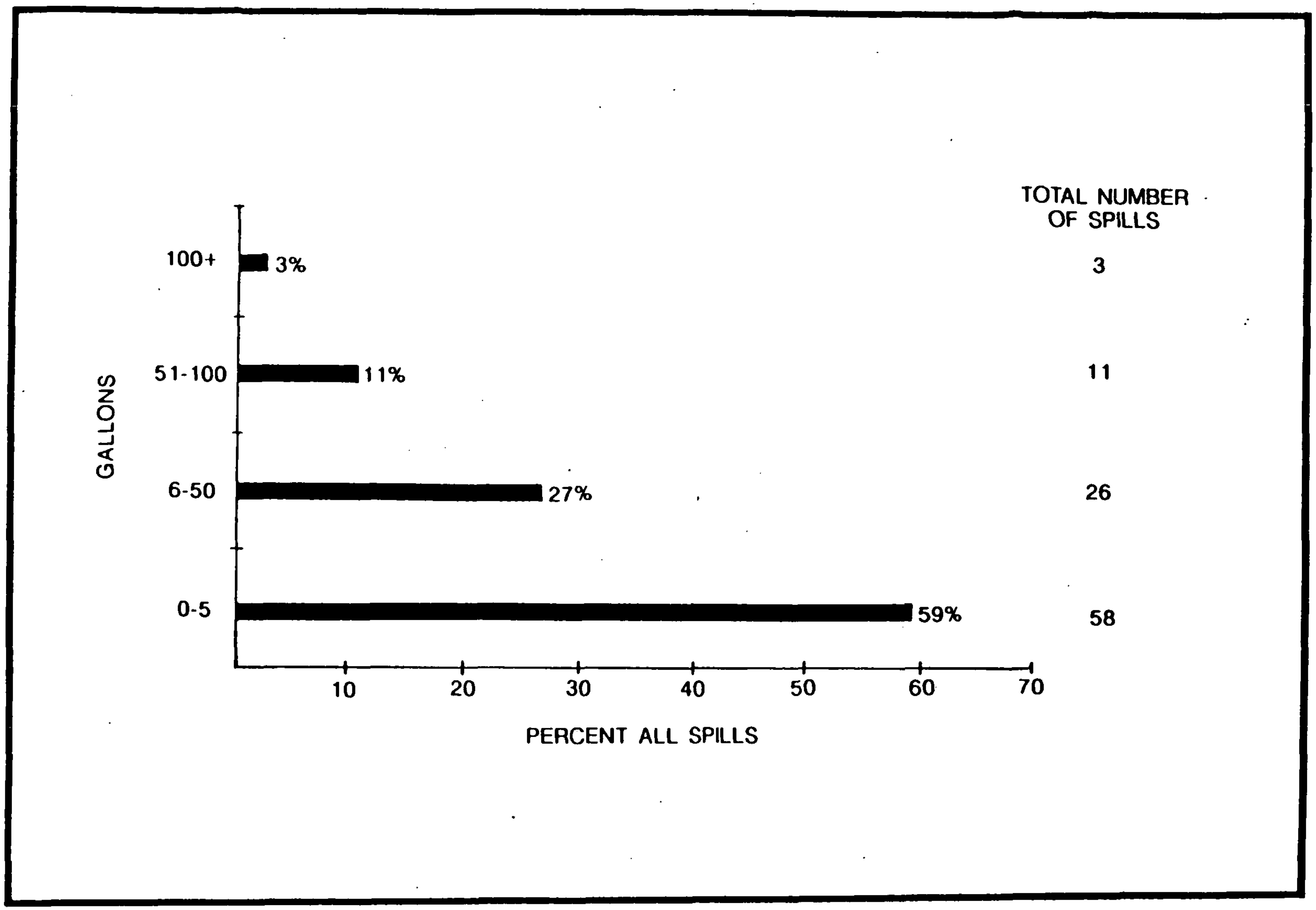

Figure 6-1. Percent by volume of reported petroleum spills in the Florida Keys National Marine Sanctuary (based on 98 of 355 spills reported from October 1985 through September 1991 for which volume estimates are available).

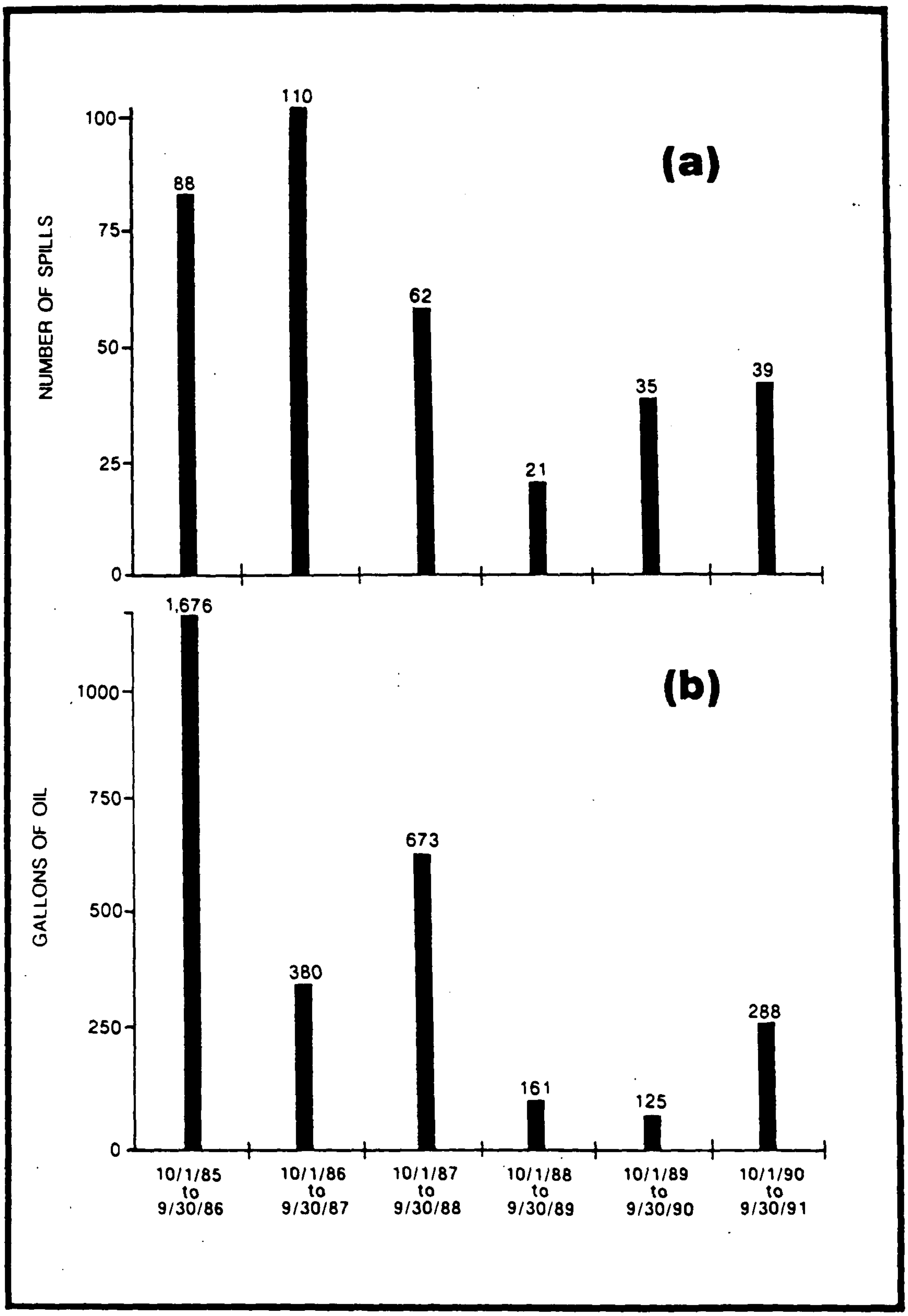

Figure 6-2. Total number of spills (a) and annual volume of oil spilled (from the 98 reported spills for which volume estimates are reported) (b) into the waters of the Florida Keys National Marine Sanctuary.

over the last six years in the FKNMS, and Figure 6-2(b) presents the annual volume of spilled oil from the 98 spills for which volume estimates are reported.

Annual reported volumes of spilled oil fluctuate far too much to reveal any trend. This is primarily because of the lack of consistent volume estimates accompanying the spill reports, and the fact that large oil spills, while occurring infrequently, distort the annual picture. No trends were seen in the seasonal data on oil spill frequency or volume.

The vast majority of spills happen in coastal or nearshore waters and they are rather small in terms of the quantities discharged. Structural or equipment failure accounted for 43% of the spills whose cause was reported. Human error accounted for 32%. Commercial boats accounted for 85% of the spills for where actual vessel type was reported, whereas recreational boats accounted for only 15%. Fishing boats, with 30% of the boat-specific reported spills, were the vessels that most often spilled oil within the Sanctuary.

It is important to remember that all of the oil spills discussed represent only those spills that were reported or came to the attention of the authorities. One can assume that a large number, probably the majority of small spills (0-5 gallons), are never reported. No data exist on the number of these small spills occurring annually in the FKNMS, but based on the amount of boating activity, such unreported spills may represent a significant source of petroleum within the Sanctuary.

3.0 POTENTIAL LOCATIONS AND RISK OF FUTURE SPILLS OR HAZARDOUS-WASTE CONTAMINATION WITHIN THE FLORIDA KEYS NATIONAL MARINE SANCTUARY

3.1 TERRESTRIAL

The causes of storage-tank system releases, which typically result in the discharge of a regulated or hazardous substance, can be attributed to many sources, which include, the following.

- Spillage of fuels because of overfilling a storage-tank system. Systems that lack overfill protection are susceptible to continued discharges that infiltrate and/or percolate downward into the soil and eventually the phreatic or groundwater interface.

- Structural failures because tanks are old and unprotected from direct contact with groundwaters. Unprotected tanks constructed of steel (which offer little resistance to the effects of rusting) degrade to the point where they become prone to leakage. The groundwater interface in the Florida Keys makes this type of failure a common source or cause of pollutants being released into the surrounding environment. Most underground storage tanks are set directly within the groundwater. Taking measures such as providing cathodic protection or using polymers or waterproof coatings on the exterior of an underground storage tank prior to placement help to retard corrosion. However, storage tanks, as part of a tank management program, should be inventoried monthly or "tightness"-tested annually to check the structural integrity of the storage tank system.

- Pipe joint and integral pipe fitting failure because of improper installation, corrosion, and degraded structural integrity. Sealants, epoxies, and similar pipe adhesives tend to decompose over extended periods, especially in the Florida Keys area, where the combination of solvents, gasoline additives, and persistent exposure to moisture accelerate decomposition.

- Poor human judgment, lack of training, indifference to impact on the environment and the consequences thereof are additional causes of spills. Training and education are very important to decrease spills from these causes.

Fortunately, Florida is currently putting into law a program requiring that newly installed underground storage tanks have "dual" containment lining systems to prevent the leakage of hazardous substances into the environment. Depending on the initial installation date, storage tank systems are subject to either removal or retrofitting to have as a minimum (1) leak detectors and (2) protection against overfill.

3.2 MARINE

Marine spills are presently not a major source of environmental impact within the FKNMS. The spills that do occur typically are small and confined to the surface of the Sanctuary waters. The marine communities and habitats comprising the critical environmental resources of the Sanctuary are relatively resistant to minor amounts of oil floating on the water surface. There is a potential for long-term, cumulative environmental effects resulting from frequent small oil spills. This potential is particularly acute in nearshore and confined waters, but the basic research available on such low level exposures to petroleum products for FKNMS-type habitats is so limited and equivocal that it is difficult to draw any firm conclusions that could be used to guide a management strategy.

Mangrove mortality resulting from heavy oiling from a major spill incident is attributed to the oil covering the gas exchange surfaces of the affected trees causing mechanical suffocation. While this is a logical assumption, there is no experimental evidence to confirm the theory. There are reports in the oil spill literature indicating delayed mortalities in oiled mangroves months or years after an oiling incident occurred (Getter *et al.* 1980). Based on these reports, it appears that persistent oil or its breakdown products impose a chronic, sublethal stress that taxes the metabolic resources of the trees. This chronic stress could be the direct result of an accumulation of toxic materials (e.g., aromatic petrogenic compounds) in the sediments, or an indirect response to the altered sediment chemistry (Marshall *et al.* 1990). To date no research has been conducted on the cumulative effects of low-grade chronic exposure of sublethal amounts of petroleum products to mangroves.

Since 1973, there have been two major tanker-related oil spills in or adjacent to the waters of what is now the FKNMS. Forty thousand gallons of oil were spilled on 18 July 1975. This slick actually oiled shorelines from Boca Chica to Little Pine Key, where it came ashore between 21 and 25 July 1975 (Chan 1976). Sixty-nine thousand gallons of oil were spilled into the Florida Current at a point northwest of Miami on 17 January 1980, but this spill moved northward and did not impact any U.S. shorelines.

The major risk to the FKNMS from marine spills is the risk of a catastrophic oil spill resulting from a tanker grounding or other major shipping accident. In 1989, the volume of oil transported through the Straits of Florida for Florida ports alone was 286.5 million barrels. This volume was carried in 5860 transits along the coast of Florida. Heavy tanker traffic off the Florida coast was estimated to transport over 12 billion gallons per year (Najafi *et al.* 1991). The South Florida Regional Planning Council has identified four "hazard areas" as having a greater potential for oil spills because of the presence of converging or crossing tanker traffic. One of these areas is 12 nmi south of the Dry Tortugas, where the traffic from the Gulf of Mexico converges to enter the Loop Current and travel northeast. The heavy tanker traffic utilizing the Loop Current increases the possibilities of groundings as well as collisions (Najafi *et al.* 1991). No catastrophic shipping accident has ever occurred in the area of the FKNMS, but the risk of such an accident remains. New Federal shipping regulations (*Federal Register* 55:19,418-19,419) have moved tanker traffic farther offshore from the Keys. Although this should reduce the risk of a *Valdez*-type accident impacting the Sanctuary, that kind of risk will always remain.

4.0 STATEMENTS OF PROBLEMS

A key part of Phase I of the Water Quality Protection Program is the identification of water quality problem areas to be addressed during Phase II. A two-step approach was used to identify and obtain agreement among members of the scientific community on known, suspected, or potential water-quality problems affecting the natural resources of the Sanctuary. Initially, information gathered during the literature review was used to derive a series of statements describing potential water-quality related problems (presented in Section 4.1). These problem statements were then refined through discussions with EPA Region IV Coastal Programs staff and State of Florida environmental staff and delivered to workshop participants to provide focal points for discussions at technical workshops. The participants in each workshop were charged with coming to a consensus, where possible, on the problem statements developed for each workshop resource area. A matrix analysis of each workshop resource area (Appendix B) was the tool used to develop consensus on the problem statements. Specific descriptive terms were used to complete the matrix based on the discussions with the expert panels assembled for each workshop (Appendix B). Public comments were also heard during the course of each workshop. To assist EPA Region IV and the State of Florida to direct their limited resources, each expert panel was asked to rank the overall significance of the water-quality related problems at the end of each daily workshop. The consensuses developed at the workshops are summarized in Section 4.2 and presented in more detail in Appendix B.

4.1 PROBLEMS IDENTIFIED DURING THE LITERATURE REVIEW

The following lists either known, suspected, or potential problems related to spilled material impacts on water quality in the FKNMS. However, to state a problem does not of itself mean or imply that the stated problem actually exists. There is a divergence of views on what actually constitutes real or potential problems for the FKNMS.

Chronic, relatively small petroleum and chemical spills may be adversely impacting the water quality of the FKNMS. — Illegal dumping, where oil or other chemicals are deliberately dumped into marine waters, and vessel spills could occur throughout the FKNMS, although the latter appear to be concentrated in nearshore areas. Terrestrial spills involving oil or chemicals may occur at terrestrial facilities or during the transport of such materials along any and all highways in the Florida Keys. Historically, spills at terrestrial facilities sometimes reached marine waters, particularly under the old spill containment requirements. Transport spills occurring on bridges may result in the material entering FKNMS waters. Data are sufficient to state that chronic, relatively small spills of primarily petroleum products occur frequently in the waters of the FKNMS. New regulations and stricter enforcement may reduce certain types of oil spills in the FKNMS, but overall the number of small spills each year is not expected to decrease substantially. Data are insufficient to predict the cumulative impact of these small spills on the overall water quality of the FKNMS. There are no quantitative data on the effect of this chronic hydrocarbon pollution in the waters of the FKNMS. The problem is water quality related and is possibly significant.

Catastrophic oil tanker spills are a risk to the FKNMS biological communities. — A catastrophic oil spill, resulting from the sinking or grounding of a tanker in or near the FKNMS, could affect the entire FKNMS. Tanker spills have been rare in the Florida Keys. Only one major spill has come ashore since the United States Coast Guard began keeping computerized spill records in 1973, and the impacts from that spill were minimal in marine waters. The data are insufficient to determine the real likelihood or risk of a catastrophic oil spill impacting the FKNMS at any specific time. The problem is not directly related to water quality, but is essentially a risk assessment problem. A catastrophic spill is potentially significant, but the extent of its effects is undetermined.

4.2 PROBLEMS IDENTIFIED AT THE SPILLS AND HAZARDOUS MATERIALS ASSESSMENT WORKSHOP

The ten problems discussed at this workshop were small vessel spills (marine), small facility spills (landbased), illegal dumping (marine and landbased), catastrophic tanker spills, tanker truck spills, effects of dispersant use, bioremediation, leachable toxics, boat scraping, and ruptured bulk tanks and pipelines. The parameters for analysis and the matrix used for the discussion are presented in Appendix B. For all of the following problems, there is little documentation or information generated in the Keys and this information is greatly needed.

Small vessel spills occur year-round, are widespread (nearshore and fueling areas), and the trend is worsening (with the qualification that there has been an increase in reporting). — Small vessel spills (marine) were defined as spills from a vessel with ≤5000 gallons of fuel and/or cargo. The major constituents of these spills are diesel fuel, gas, and bilge. The problem is severe locally and unknown overall. The adequacy of existing contingency plans is low. The water-quality effect is locally toxic and unknown overall. The authority exists for enforcement, but manpower is low and compliance is also low. The risk (likelihood of an event occurring) is high. The overall significance of this problem to the Water Quality Protection Program is high.

Small facility spills occur year-round and are widespread (in marinas and fueling areas) and the trend is worsening (with the qualification that there has been an increase in reporting). — Small facility spills (landbased) generally are unreported and include those spills from marinas, auto fueling facilities, small industrial facilities, and residents. Constituents of these spills are diesel fuel, gas, solvents, pesticides, used motor oil, and paint-related material. The problem is severe locally and unknown overall. Compliance, enforcement, and the adequacy of existing contingency plans are low. The water-quality effect is locally toxic and unknown overall. The risk (likelihood of an event occurring) is high. The overall significance of this problem to the Water Quality Protection Program is moderate.

Illegal dumping (marine and landbased) occurs year-round, is widespread, and the trend is worsening. — Illegal dumping (marine and landbased) for marine-based sources was defined as spills from a vessel with ≥5000 gallons of fuel and/or cargo and materials resulting from the pumping of bilges and cleaning of cargo holds. Constituents of these marine-based spills are petroleum products. The constituents of land-based spills are paint and solvents. The quality and quantity of these marine- and land-based substances are unknown. The problem is severe locally and unknown overall. The water-quality effect would be locally high and unknown overall. Compliance is very low and enforcement is improving. The risk (likelihood of an event occurring) is moderate. The overall significance of this problem to the Water Quality Protection Program is high.

Catastrophic tanker spills occur year-round (two have occurred in the last 16 years in the Keys) and the potential severity of a spill in the FKNMS is high. — Catastrophic tanker spills were defined as a spill of >10,000 gallons inshore and >100,000 gallons offshore whose major constituents are diesel fuel, blends of fuel, heavy fuels, hazardous materials, and crude. The likelihood of a catastrophic spill happening is decreasing. A sanctuary-specific contingency plan is needed and it should include what should be done with the cleanup waste. Compliance and enforcement are moderate to high and the risk (likelihood of the event occurring) is low. The water-quality effect is high if the spill reaches the FKNMS. The overall significance of this problem to the Water Quality Protection Program is high.

Tanker truck spills (including tractor trailers) occur year-round (two have occurred in the last 10 years in the Keys) and are usually isolated to highways. — The major constituents of this type of spill are gasoline, diesel fuel, and other hazardous materials. The severity of a spill is high locally and the likelihood of this type of spill occurring is decreasing. The adequacy of the existing contingency plans is good; however, response time is a problem. The water-quality effect would be severe locally because of the highly toxic compounds being spilled. Compliance and enforcement are moderate to high and the risk (likelihood of the event occurring) is moderate. The overall significance of this problem to the Water Quality Protection Program is moderate.

The effects of dispersant use would have a seasonal impact on habitats. — Currently in the Keys, dispersants are considered for every spill but have not been used. The adequacy of contingency plans is low and there is a need for more work on the plans. The risk of using dispersants is low; the water-quality effect would be variable. The overall significance of this problem to the Water Quality Protection Program is high. More information is needed regarding the effects of dispersant use on larvae. There are tradeoffs to consider when using dispersants. Research is needed regarding the toxicity of spilled oil versus the toxicity of the dispersed oil.

The use of bioremediation is not as constrained as dispersant use. — The potential water-quality effect of adding nutrients is low. The overall significance of this problem to the Water Quality Protection Program is unknown but unlikely. Interim guidelines are needed.

The leaching of toxics occurs year-round in isolated areas. — Leachable toxics were defined as substances originating from Comprehensive Environmental Response, Compensation, and Liability Act (CERCLA) and Resource Conservation and Recovery Act (RCRA) sites and underground storage tanks and include a variety of constituents such as heavy metals, polychlorinated biphenyls (PCB), insecticides, and pesticides. The problem is moderately severe and improving. Compliance/enforcement and contingency plans are site dependent and are low to high in adequacy. Risk is unknown. The water-quality effect is unknown but potentially significant. The overall significance of this problem to the Water Quality Protection Program is moderate.

The problem of hazardous materials resulting from boat scraping (metals) occurs year-round with seasonal peaks and is isolated to site-specific areas. — Trend, severity, and compliance/enforcement are unknown and the risk (likelihood of event occurring) is high. The water-quality effect of this problem is high. The overall significance of this problem to the Water Quality Protection Program is high.

The problem of hazardous materials resulting from ruptured bulk tanks and pipelines occurs year-round in isolated, site-specific areas. — These hazardous materials consist of jet fuel, diesel, and various other petroleum products. The severity of the problem is moderate to high. Contingency plan adequacy is moderate. Compliance/enforcement is moderate to high and risk (likelihood of event occurring) is high. The water-quality effect is probable. The overall significance of this problem to the Water Quality Protection Program is high.

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SUMMARY AND RECOMMENDATIONS

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SUMMARY AND RECOMMENDATIONS

1.0 POINT-SOURCE DISCHARGES

There were 13 active National Pollutant Discharge Elimination System (NPDES) permitted point-source dischargers within the Florida Keys National Marine Sanctuary (FKNMS) as of January 1992. There are an additional four facilities with permits that may have discontinued discharging or discharge only in the event of an emergency. Several of the active facilities are planning to eliminate their surface water discharge either by connecting to an existing facility or by discharging into the ground. Only one domestic wastewater facility [Key West Sewage Treatment Plant (STP)] is considered a major [5.82 million gallons per day (MGD)] discharger. The second largest domestic wastewater discharger (City of Key Colony Beach STP) discharges an average of 0.17 MGD. The remaining wastewater facilities that are actively discharging and for which data are available (7) have a total combined flow of 0.93 MGD. Two facilities are industrial dischargers and a third permit is for stormwater. Key West Utility, a power plant, uses seawater for cooling. The average daily discharge from this facility was 21.4 MGD for the first 8 months of 1991. The second facility is a desalinization unit at Ocean Reef Club. The average daily discharge from this facility was 0.39 MGD for the first 6 months of 1991. The facilities are not required to monitor nutrient levels in their discharges. However, the Key West STP has initiated monitoring of influent and effluent nutrients. The average effluent values for NH_3-N, NO_3-N, and PO_4-P for 1991 were 2.0, 1.8, and 2.49 mg/L, respectively.

The C-111 and Model Land canals discharge into the FKNMS at Barnes and Card Sounds, respectively. Both canals are operated by the South Florida Water Management District (SFWMD) for flood control. Flow data are available for both canals. Nutrient data are available only for C-111. Total phosphorus ranged from 0.004 to 0.015 mg/L and inorganic nitrogen from 0 to 0.45 mg/L for the period of 1985 to 1987.

2.0 NONPOINT-SOURCE DISCHARGES

There are 209 Florida Department of Environmental Regulation (FDER) permitted wastewater treatment facilities within the FKNMS. This includes municipal plants (2) and package plants. One hundred ninety-nine have a subsurface discharge method, with the majority having injection wells. The FDER regulates facilities that treat flows exceeding 5000 gallons per day (GPD) for domestic establishments, 3000 GPD for food-service establishments, and where sewage contains industrial, toxic, or hazardous chemical waste. Marathon, Islamorada, and Key Largo have significant concentrations of facilities. These discharges are not monitored for nutrients. However, data on biological oxygen demand and total suspended solids are available. The discharges are considered to have received secondary treatment.

Onsite disposal systems (OSDS) include septic tanks, cesspools, and aerobic systems. The exact number of OSDS in the Florida Keys is presently unknown. Monroe County's contractor [Wallace Roberts & Todd (WRT) team] is inventorying all permitted and unpermitted septic tanks and cesspools in unincorporated Monroe County as part of the development of the County's Comprehensive Plan. It is estimated that there are approximately 25,000 permitted septic tanks within the FKNMS. The treatment efficiency of OSDS in the Florida Keys has been questioned due to the geology of the Keys. No monitoring of flow or constituents is required.

There is a lack of effluent nutrient data for the FDER-permitted facilities and OSDS units in the Florida Keys although data from other areas are available. Additionally, there are very few studies that have investigated nutrient uptake by soils, movement of nutrients within the groundwater, and entry of these nutrients into the marine waters of the FKNMS. Monroe County, as part of their comprehensive plan, is proposing the development of a Sanitary Wastewater Master Plan by 1995 that may include data gathering in these areas.

Landfill sites and mosquito control spraying are additional potential nonpoint sources of pollutants to marine waters within the FKNMS. The amount of pollutants entering marine waters from these sources is unknown.

The SFWMD is responsible for permitting surface-water management in the Florida Keys. There have been approximately 50 permits issued by the SFWMD. Stormwater flow and its constituents have not been directly studied in the Florida Keys. There has not been a single study involving the sampling of flow constituents in the Keys. The SFWMD has depended on studies outside Florida to assess land use and runoff quality relationships. Treatment efficiencies for the Keys were also evaluated. Additional studies (Riviera Canal, Key West; upper Keys) have calculated stormwater loadings based on land use and literature data. Monroe County, as part of the development of the comprehensive plan, is preparing an updated land-use map. This is needed to evaluate pervious/impervious conditions for prediction of seepage versus runoff. Monroe County, as part of their comprehensive plan, is proposing the development of a Stormwater Management Plan by 1995.

Individuals who live aboard their boats continuously for a period of 2 months or more have been termed *live-aboards*. The largest number of live-aboards are found in marinas, but many are also anchored offshore. The discharge of raw sewage from the live-aboards is a potential problem in the FKNMS. There are over 180 marinas in the Florida Keys, but there are only nine sewage pumpout facilities.

Live-aboards may contribute to water quality degradation in marinas as well as other areas of concentration. The Florida Department of Natural Resources (FDNR) has initiated rule development to assist in regulating live-aboard vessels on sovereign submerged lands.

3.0 EXTERNAL SOURCES

Water quality in the FKNMS can be affected by sources of poor water quality located outside the Sanctuary boundaries. Areas adjacent to the FKNMS include Florida Bay, Biscayne Bay, and the Gulf of Mexico/Atlantic Ocean. Florida Bay has shown no indications of a prevalent anthropogenic problem with contaminants other than freshwater. The variance in freshwater input from the Everglades area has affected salinity within the Bay. The effect of these changes in salinity on the FKNMS has not been documented. The effect of natural variations in temperature, turbidity, and other parameters within Florida Bay on the FKNMS are also relatively undocumented, although these same variations are probably also occurring in the FKNMS waters. A relatively extensive water quality sampling program has been conducted in Biscayne Bay. This program indicates that the water quality in south Biscayne Bay is relatively good and that it is likely that no significant degradation of FKNMS waters is directly occurring through exchange with Biscayne Bay. The effect of the waters of the Gulf of Mexico/Atlantic Ocean on the waters of the FKNMS through upwelling and entrainment of relatively nearby (e.g., Virginia Key sewage outfall) or distant (e.g., Mississippi River) discharges is very difficult to determine. This difficulty is based, in part, on the great natural variability of the physical oceanographic system and the level of entrainment and delivery to the FKNMS waters.

4.0 EXISTING WATER QUALITY

There is a lack of data to evaluate the existing water quality in the FKNMS. The water quality data are insufficient in terms of long-term studies to evaluate temporal changes. The offshore FKNMS waters do not appear to be degraded, based on the available scientific data though some anecdotal observations suggest degradation has occurred. Degraded water quality has been detected in many artificial waterways and canals. This degradation is in the form of measured increases in nutrients and depressed dissolved oxygen. These areas and others with documented water quality problems have poor water exchange with nearshore/offshore waters. This poor flushing combined with increased organic enrichment has led to the poor water quality. The boundaries between confined, nearshore, and offshore waters are difficult to define as the boundaries are relatively arbitrary. The effects of poor water quality in confined waters on nearshore and offshore waters is dependent on the level of degradation of the water quality and the delivery (mixing rates) of the water to nearshore waters. However, this poor water quality of confined waters should be considered a major problem due to the effect on the biotic resources within those waters and the potential effects of continued degradation on the biotic resources of the nearshore and offshore waters.

5.0 FUTURE WATER QUALITY (YEAR 2010)

The future water quality in FKNMS waters depends on both the natural and anthropogenic pollutant loadings that occur. The temporal and spatial variability of the loadings will also significantly affect the water quality. The factors that will probably most effect the anthropogenic loadings will be population growth, spatial distribution of the increase and land use, required treatment efficiencies of wastes from the existing and increased population, and selected disposal mechanisms of the wastes.

Many of these factors will be determined through the Monroe County Comprehensive Plan or the proposed Sanitary Wastewater and Stormwater Master Plans, and City of Key West Comprehensive Plan. The issue of population growth in the County has been addressed through measures of carrying capacity based on the ability to evacuate residents in the event of a hurricane threat.

Based on the limited water quality and biotic resource (Tasks 3 and 4) data, it appears that organic/nutrient loading may represent a serious long-term threat to the FKNMS. There may be other potential threats (e.g., metals in marina basins and insecticide usage), but a comprehensive water-quality monitoring program is needed to evaluate these possibilities.

Additionally, the relative significance of the different sources contributing to the organic/nutrient loading needs to be determined. This will also involve a determination of the delivery mechanisms. Stormwater runoff, groundwater discharge, rainfall, decomposition of concentrations of *Sargassum* and seagrass, and upwelling are some of the mechanisms that introduce nutrients into the Sanctuary. The location of the point of introduction is critical to determining the potential impact on water quality and biotic resources.

The existing data and/or data to be collected may suggest adoption of effluent standards to reduce nutrient inflow. Presently, there are no standards that apply to either surface water or wastewater discharge in the Keys. The Monroe County and City of Key West Comprehensive Plans discuss possible nutrient removal limits.

The ability to determine existing nutrient loadings is severely constrained due to a lack of data from the Florida Keys on measured loadings to the groundwater, transport of groundwater nutrients to marine waters, measured constituents in stormwater, and quantity of stormwater discharge to marine waters via groundwater and overflow.

6.0 CORAL COMMUNITIES

The high latitude coral reefs of the FKNMS extend from Cape Florida to the Dry Tortugas. Included are an estimated 19,420 ha of reef and 110,635 ha of low-relief hard bottom. Three types of reef habitats occur from the shoreline to 13 km offshore at depths ranging from <1 to 41 m. Hard-bottom areas, which occur close to shore, are exposed rocky substrates colonized by algae, stony corals, and a variety of other sessile invertebrates. The corals found here are small and are not actively building reef structures. Patch reefs typically occur offshore Hawk Channel, but inside the bank reefs occur at depths up to 9 m. The reef framework is formed primarily by massive star and brain corals *(Diploria, Montastrea)*, filled in with algae, sponges, octocorals, and bryozoans. Bank reefs, positioned parallel to shore, exist seaward of Hawk Channel and the patch reefs. Most bank reefs occur in the upper and lower Keys where island mass shelters the reefs from the waters of Florida Bay. Bank reef structure is complex, generally characterized by a spur-and-groove system oriented perpendicular to the shoreline or depth contours.

Reef-dwelling corals include hydrozoan corals, octocorals, and scleractinian corals. The primary hydrozoan coral found in the FKNMS is the limestone-bearing fire coral, *Millepora*. Octocorals, sea whips or sea fans, are usually the most common coral within the FKNMS, one species occurring at reported densities of up to 73 colonies per square meter. Scleractinian, or stony, corals are major contributors to reef structure. Life spans of stony corals range from a few to hundreds of years.

Significant changes in the coral communities of the FKNMS have been documented in recent years. Included are increases in coral abundance at Carysfort Reef because of fragmentation and subsequent regeneration of large colonies of *Acropora* and losses of coral cover at Looe Key and Key Largo. Other coral community components, octocorals and sponges, have decreased in abundance at Fiesta Key. Changes such as these may reflect alterations in the vitality of coral communities in the FKNMS attributable to either natural or anthropogenic factors.

There is a general consensus among researchers that the coral communities in the FKNMS are undergoing stress from both natural and anthropogenic factors. The problems associated with such stress appear to be severe, but there are not sufficient data from most localities in the Keys to document their extent. Furthermore, it is not always easy to extrapolate from studies of other reef systems because corals in the Keys live at the climatic threshold for coral reefs which may magnify the effects of relatively small environmental changes.

At the technical workshops, coral disease, zooxanthellae expulsion (bleaching), lack of coral recruitment, impaired colony growth rates, a decline in coral abundance, and blooms of *Lyngbya* were seen as significant problems. Many of these reef-associated "problems" are thought to be related to natural water quality parameters. Two, coral disease and coral bleaching, occur in the Keys as well as world-wide. Both may be affected by temperature and/or salinity. Temperature may also have an effect on several of the other problems mentioned. Though temperature stress is not usually anthropogenic, the draining of much of south Florida may have affected the thermal buffer that may have protected Florida Bay from cold fronts. Changes in several coral community parameters have been perceived as problems potentially attributable to water quality. The impacts of anthropogenic factors — e.g., nutrients, toxics/pesticides,and turbidity — are less clear. Nutrient levels affect blooms of *Lyngbya* or other algae, and turbidity affects coral growth rates and abundance. However, the impacts of the other water quality parameters on coral reefs in the Keys are unknown.

7.0 SUBMERGED AND EMERGENT VEGETATION

The FKNMS presently encloses an estimated 565,094 ha of seagrass beds and 22,560 ha of mangroves. Macroscopic algae also contribute significantly to submerged vegetation communities within the Sanctuary. Dredging and land filling associated with development in the Keys have significantly affected these plant communities. Significant storms and hurricanes may affect submerged and emergent vegetation.

Seagrasses — Submerged vascular plant communities within the FKNMS consist mainly of the perennial seagrass species *Thalassia testudinum* (turtle grass), *Syringodium filiforme* (manatee grass), and *Halodule wrightii* (shoal grass). These form large, complex biological habitats persisting from year to year in the same general locations. Such seagrass beds are possibly the most productive of the biological communities occurring within the FKNMS and produce about 95% of the submerged vegetative biomass in the FKNMS. Annual species, *Halophila decipiens* (paddle grass) and *H. engelmannii* (star grass) are minor contributors to seagrass biomass. Because they are able to survive at reduced light levels, these species may occur in relatively deep water.

Most documented losses of seagrasses have been attributed to the general development of the watershed and coastline that influence the beds. Most often the reduction of the quantity and quality of light that reaches the seagrasses is cited as the reason for the destruction of seagrass beds. Two water quality parameters responsible for increases in light attenuation are increases in suspended sediments in the water (turbidity) and anthropogenic nutrient input that may cause phytoplankton blooms and increased growth of epiphytes on seagrasses. These two factors may also affect the growth rates of individual plants, decreased geographical extent of seagrass beds, and decreased seagrass recruitment. Also having relatively important impacts on seagrass beds are temperature, salinity, and dissolved oxygen (DO) levels. Seagrass-related problems are most serious in "hot spots" — areas of severe water quality degradation.

Macroalgae — Many species of benthic macroscopic algae are important members of submerged vegetation habitats within the FKNMS. Notable are calcareous taxa such as *Halimeda,* that become disarticulated upon death and thereby contribute significantly to the buildup of carbonate sediments and a transient species, *Laurencia.* The latter, along with clumps of other taxa may provide environments for colonization by small invertebrates. These drift algal mats may stimulate settlement of postlarval spiny lobsters, *Panulirus.*

Priority problems identified for macroalgae communities were increased epiphyte growth and anthropogenic nutrient loading. Problems discussed at the technical workshops were thought to be acute in hot spots, but may occur at various degrees in other areas. Increased epiphyte growth, increased macroalgal growth rates, and decreased community diversity are affected to some degree by anthropogenic changes in nutrients, turbidity, or DO.

Mangroves—Once spanning the length of the Keys, mangrove forests have been reduced in extent by coastal development. Significant stands of forest remain, notably in the Marquesas, Rodriquez Key, and John Pennekamp Coral Reef State Park. *Rhizophora mangle* (red mangrove), *Laguncularia racemosa* (white mangrove), and *Avicennia germinans* (black mangrove) are the three species of mangroves that may be found among the six types of mangrove forests occurring in the FKNMS — overwash, fringe, riverine, basin, hammock, and scrub or dwarf. The main anthropogenic threats to mangrove swamps are diking, impounding, flooding, and outright destruction by dredging and filling activities.

Major concerns are preserving the geographical extent of mangroves and the functional value of the mangrove habitat. Both concerns are probably related to water quality; salinity, turbidity, nutrients, and DO affect the former, and anthropogenic DO, nutrients, and toxics/pesticides affect the latter. Decreased productivity of individual trees is a water quality problem of unknown significance.

Changes in the patterns of historic freshwater flow to Florida Bay have impacted animal and plant communities in the Bay in different ways. Reduced flow, and concomitant increased salinity, has allowed expansion of some mangrove communities. However, technical workshop participants felt that increased salinities are responsible for damaging coral reefs in the Bay. This increased salinity in the Bay may also be responsible for the shift in the community dominant from *Halodule wrightii* to *Thalassia testudinum.*

8.0 NEARSHORE AND CONFINED WATERS

Technical material that was derived from the interviews and literature review of nearshore and confined waters is summarized in Sections 4.0 and 5.0 above. The following discussion is derived from the technical workshops held in Miami, Florida. During the technical workshops *confined waters* were defined as canals, marinas, bays, and lagoons; *nearshore waters* as those extending from shore to Hawk Channel, including the 18 ft depth contour; and *back country waters* as nearshore Florida Bay waters within the 8 to 10 ft depth contour. Water quality of these areas is controlled by a variety of natural and anthropogenic factors. The decomposition of weed wrack and other organic debris, blown by winds into canals, may significantly lower DO levels especially in areas having poor water exchange. Nearshore water composition may be determined by upwelling and other exchange with offshore water. The introduction of nutrients from the atmosphere could affect the quality of these waters.

Anthropogenically-derived effects on biological communities may result from increased nutrient loads caused by sewage discharge from the previously described point and nonpoint sources (Sections 4.0 and 5.0). These increased nutrient loads may stimulate phytoplankton growth and subsequently lead to reduced DO levels. Sewage discharges may cause an increase in fecal coliform bacteria concentrations. It has been suggested that nutrients may build up in the groundwater during the winter dry season and are flushed into marine waters during the summer wet season. Increased nutrient loads also contribute significantly to increased growth of epiphytes, a problem that has been increasing over the past 10 years. Problems associated with increased nutrient loads appear to be more severe in confined waters than in nearshore or back country waters. In the latter two areas, epiphyte and phytoplankton growth increases are slight.

Concern was expressed at the workshops over human health risks associated with the consumption of personally caught seafood from confined waters. No data exist regarding the potential problem in the Keys.

9.0 SPILLS AND HAZARDOUS-MATERIALS ASSESSMENT

Terrestrial — FDER records for the Florida Keys showed 12 terrestrial spills between January 1987 and June 1991. These included spills of petroleum products (six), sewage (three), and miscellaneous toxic substances (three). National Response Center data files showed a total of 81 terrestrial spills between October 1984 and March 1990. These spills involved petroleum products (57), chemicals (6), and other substances (18). The principal causes of the spills were structural failures, natural seepage, and equipment failure. New FDER regulations pertaining to storage tanks and underground facilities along with more frequent inspections and increased enforcement should reduce spills. There are numerous hazardous-material generators and contaminated sites located within the Florida Keys.

The potential problem areas for the Sanctuary in terms of upland spills and contamination are the existing sites where the groundwater is known to be contaminated and the sites where the underground storage tank facilities have not yet been brought up to the current standard for containment and isolation of spills or contamination. These facilities are scheduled to be brought into compliance by the year 2010. The transport of petroleum products and other chemicals has the potential to introduce hazardous materials into Sanctuary waters. The rupture of pipelines used for the movement of petroleum products, such as jet fuel, or tanker truck spills are the most likely mechanisms for such spills. Contingency plans for these types of spills are moderately adequate. Terrestrial spills, unless they spill directly into marine waters, will most likely not significantly contaminate marine waters. Leaching of toxic materials from Comprehensive Environmental Response, Compensation, and Liability Act (CERCLA) and Resource Conservation and Recovery Act (RCRA) sites and underground storage tanks is moderately severe, but improving.

Marine — There were 355 reported spills of hazardous materials in the waters of the FKNMS between October 1985 and September 1991. Approximately 90% of these spills involved petroleum products. Most spills (76%) were detected after the fact, so no cause could be identified. Volume was estimated for 98 of the reported spills, all of which involved petroleum products. Most of these 98 reported spills were less than 5 gal. Most of the spills for which volume was estimated occurred in coastal or nearshore waters as a result of structural or equipment failure and human error.

The most significant sources for marine spills of hazardous material within Sanctuary waters are oil spills from small, locally operated, commercial vessels, primarily fishing and transport vessels. While every effort should be made to reduce and eliminate these spills through inspection and enforcement, at their present levels these spills do not appear to pose an immediate threat to the biological resources of the Sanctuary. However, the overall significance of this problem to the Water Quality Protection Program was judged to be high by the workshop participants. The likelihood of the introduction of metals into Sanctuary waters from boat scraping is high and, although the trend and severity are unknown, such introduction represents a significant problem for the Water Quality Protection Program.

The lowest risk to the FKNMS is from a large marine petroleum spill. Tanker spills have occurred in the area of the Florida Keys in 1975 and 1980. Tank vessels and vessels greater than 50 m long (except public vessels) are prohibited from operating in an area ('Area to be Avoided' — *Federal Register* 55:19,418-19,419) designated to protect the FKNMS. Mineral and hydrocarbon leasing, exploration, development, and production activities are also prohibited in the FKNMS.

Dispersants are considered for use in each significant spill of oil or other petroleum product into Sanctuary waters. The risk of using dispersants is low although more information on the effects of dispersants on larvae is needed. The toxicity of spilled versus dispersed oil needs to be studied. The introduction of nutrients by bioremediation efforts is not likely to have an impact on water quality.

10.0 EFFECTS OF WATER QUALITY PARAMETERS

The effects of seven water quality parameters — nutrients, turbidity, temperature, salinity, toxics/pesticides, bacteria/viruses, and DO — on the living resources of the FKNMS were evaluated by participants at the technical workshops. The evaluations are summarized in **Figure 7-1** for problems deemed significant by workshop participants. From this figure, one can determine whether or not enough information is available to determine the relative impact of a parameter on living resources and, if there are enough data, what that relative impact is. For example, nutrients and turbidity impact seagrasses, macroalgae, mangroves, and confined waters. They also impact some coral resources, but for the most part, their impact on corals is unknown. Conversely, the impacts of toxics/pesticides and bacteria/viruses on living resources in the FKNMS are largely unknown.

11.0 RECOMMENDATIONS

There is a lack of data documenting a decline in water quality in the offshore and nearshore waters of the FKNMS. There is also no documentation that the general declines in coral communities within the FKNMS are linked to water quality. Data are also not sufficient to definitively state that seagrass bed deterioration is or is not occurring in the FKNMS. However, it is well documented that deteriorating water quality will lead to declines in seagrass beds and coral communities if it is sufficiently severe. This fact, coupled with documented water quality problems in confined waters of the FKNMS, strongly suggests that the development of a Water Quality Protection Plan for the FKNMS is critical to the long-term survival of the biotic resources within the FKNMS. Increasing or continuing the current level of organic inputs could lead to further declines in the water quality of confined waters that could eventually effect the more nearshore waters and their biotic communities. The following recommendations are made relative to the development of the Water Quality Protection Plan.

Monitoring Program

- Develop a monitoring plan to characterize the nutrient inputs to the groundwater.
- Develop a monitoring plan to characterize the constituents within stormwater in the Florida Keys based on land use. Determine what percentage of stormwater results in overland flow to marine coastal waters.

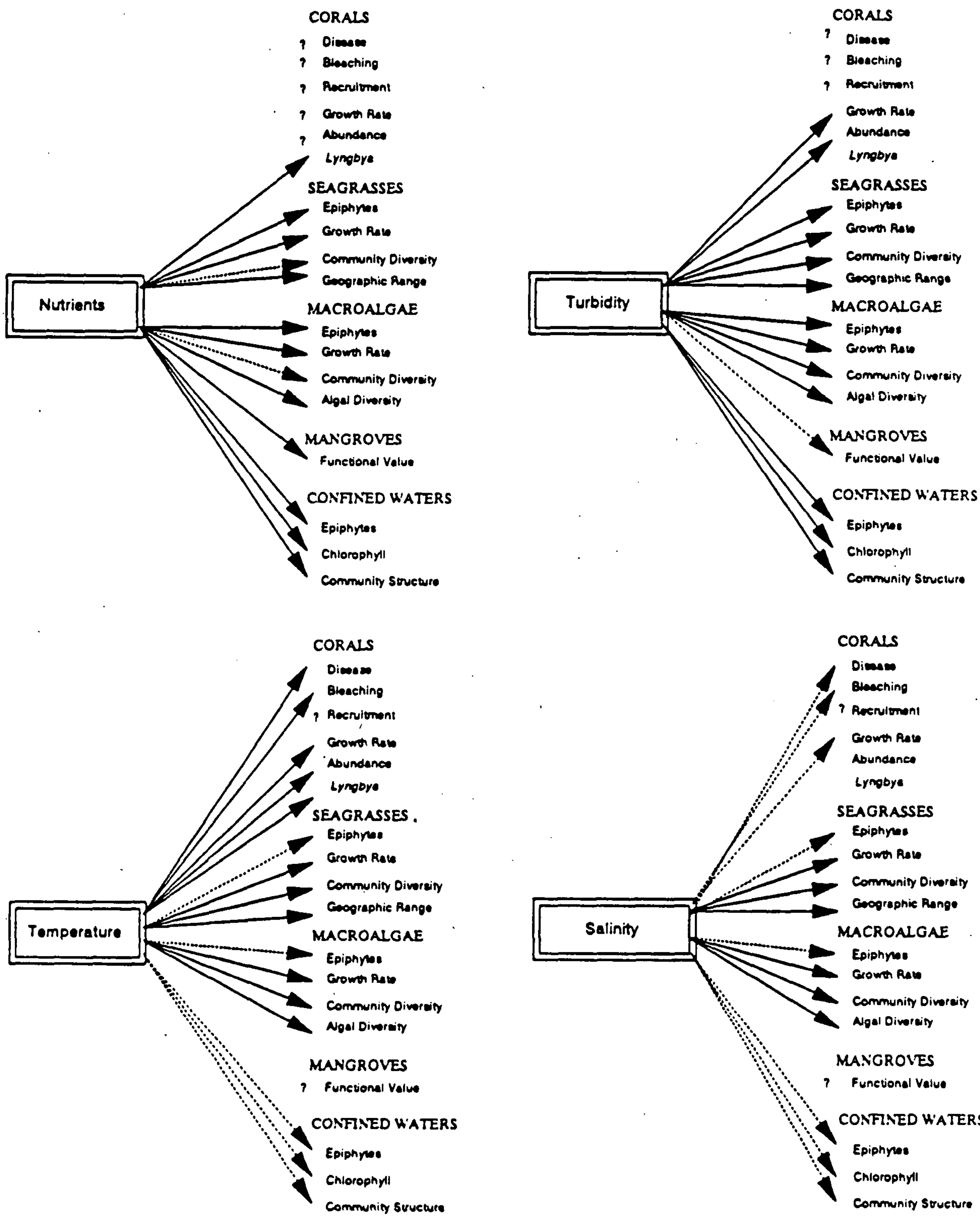

Figure 7-1. Effects of water-quality parameters on significant environmental problems in the Florida Keys National Marine Sanctuary. Solid arrow denotes a significant effect; dashed arrow denotes a possible effect; ? denotes an unknown effect; and no symbol denotes no effect.

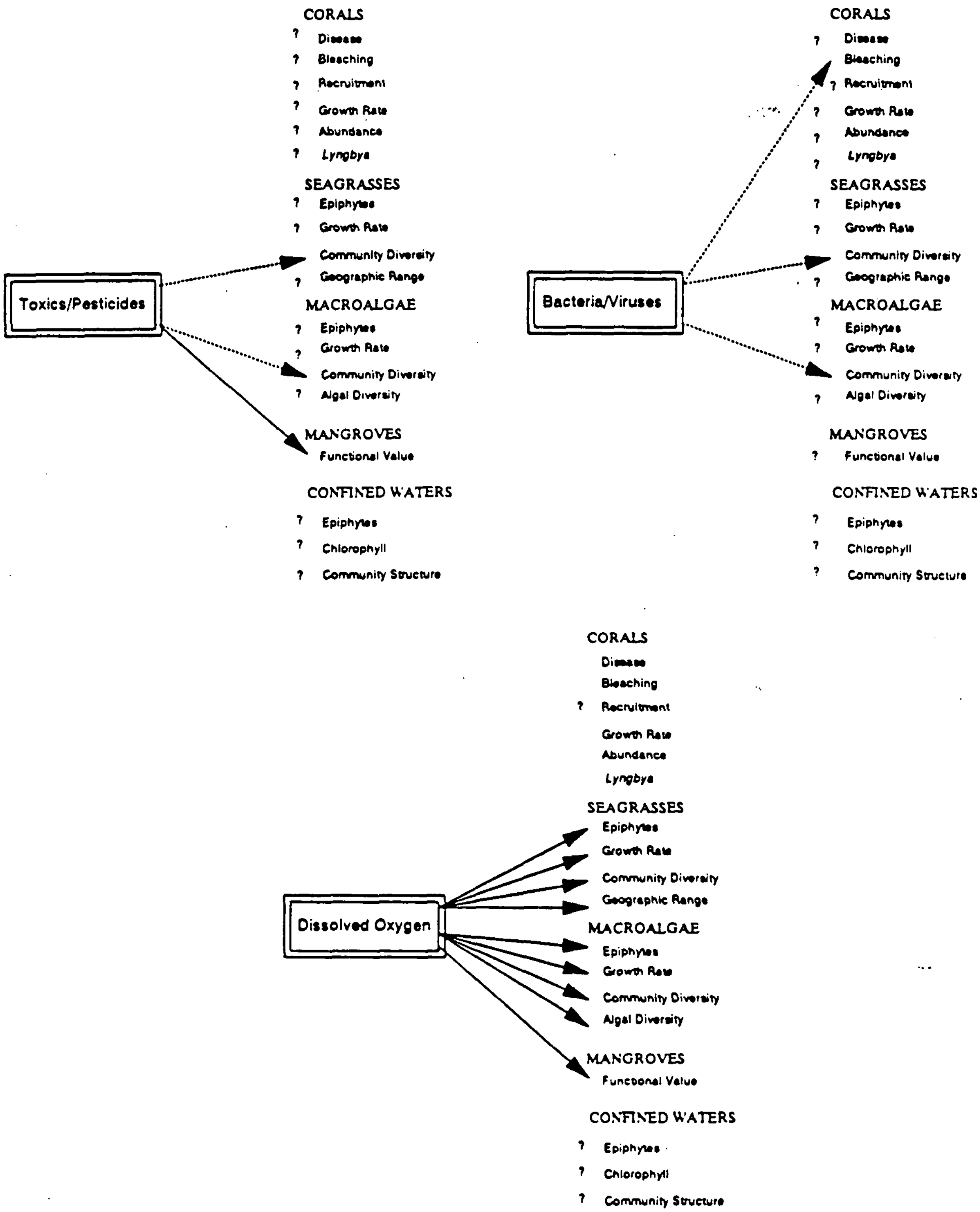

Figure 7-1. Effects of water-quality parameters on significant environmental problems in the Florida Keys National Marine Sanctuary. Solid arrow denotes a significant effect; dashed arrow denotes a possible effect; ? denotes an unknown effect; and no symbol denotes no effect. (continued)

- Develop for confined, nearshore, and offshore waters a water-quality monitoring program that incorporates water, sediment, and biotic parameters.

Research Program

- Develop a research plan to collect data and model the transportation of groundwater nutrients to marine coastal waters.

- Develop a research plan to collect data on "natural" nutrient regeneration due to the decomposition of floating *Sargassum* and seagrass within confined water bodies.

- Evaluate the relative contributions of point-source discharges, groundwater input, stormwater overland flow, natural decomposition of organic matter, and other mechanisms (e.g., rainfall) to nutrient input and the potential of further declines in water quality within the confined waters of the FKNMS.

- Develop a research plan to evaluate the effects of toxic chemicals and pesticides on living resources, especially corals.

General

- Select representative areas of confined waters that are experiencing poor water quality and develop potential engineering solutions with cost estimates. The solutions must have application to all of the Florida Keys.

- Coordinate all of the tasks with other government entities with jurisdiction in the Florida Keys. Particular coordination should be maintained with Monroe County's development of proposed Sanitary Wastewater and Stormwater Master Plans as well as the National Oceanic and Atmospheric Administration (NOAA) plans for research initiatives.

Phase II of the Water Quality Protection Program for the FKNMS was initiated in April 1992. During Phase II, the problems identified in Phase I will be used to evaluate and recommend priority corrective actions, strategies, and schedules for implementation to be incorporated into the Program. Management, institutional, agency, and engineering options as well as funding sources will be addressed in Phase II. The Phase I problem statements will also be considered in the design and establishment of a comprehensive monitoring program and research plan. The Water Quality Protection Program will recommend priority corrective actions and compliance schedules addressing point and nonpoint 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.

FINAL

FLORIDA KEYS NATIONAL MARINE SANCTUARY
WATER QUALITY PROTECTION PROGRAM
WORKSHOPS SUMMARY

U.S. ENVIRONMENTAL PROTECTION AGENCY
Office of Wetlands, Oceans, and Watersheds

Contract No. 68-C8-0105
Work Assignment 3-225

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FLORIDA KEYS NATIONAL MARINE SANCTUARY WATER QUALITY PROTECTION PROGRAM WORKSHOPS SUMMARY

The Environmental Protection Agency (EPA) and the State of Florida have been directed to develop a Water Quality Protection Program for the Florida Keys National Marine Sanctuary (FKNMS). The purpose of this Water Quality Protection Program is to recommend priority corrective action and compliance schedules addressing point and nonpoint sources of pollution. The first phase of this program involved a compilation and synthesis of available scientific and technical information on water-quality related parameters in the Florida Keys. The result of this effort was a Phase I Technical Assessment Report which related the water quality parameters to Florida Keys resources and identified pressing problems needing priority attention. This Phase I Technical Assessment Report was made available for review to a selected list of scientific technical experts currently conducting studies and investigations on the resources of the Florida Keys. The report was also furnished to (1) the National Oceanic and Atmospheric Administration (NOAA) Advisory Committee that was established to oversee the development of the Comprehensive Management Plan for the FKNMS, (2) the FKNMS Steering Committee that was established by EPA Region IV and the State of Florida to oversee the development of the Water Quality Protection Program, and (3) the public, environmental groups, and user groups within the Florida Keys.

On February 4 through 7, 1992, as part of Phase I of the program, four workshops were held in Miami Springs, Florida; the Coral Community Assessment, Submerged and Emergent Aquatic Vegetation Assessment, Nearshore and Confined Waters Assessment, and Spills and Hazardous Material Assessment Workshops. These workshops were the first of a series of three consensus-building activities directed by EPA Region IV and the State of Florida. The other two activities included presenting the results of the Phase I Technical Assessment Report and the workshops to the NOAA Advisory Committee, the FKNMS Steering Committee, and the public attending these committee meetings.

The panel members for each workshop are listed in Appendix A. Each workshop was charged with coming to a consensus, where possible, on the problem statements described in the Technical Assessment Report for each of the workshop resource areas. These problem statements were refined through discussions with EPA Region IV Coastal Programs staff and State of Florida environmental staff. The tool used to develop consensus on the problem statements involved a matrix analysis of each workshop resource area (Appendix B). The matrix was designed with problem statement key words across the horizontal axis and parameters for analysis down the vertical axis. Specific descriptive terms were used to complete the matrix based on the discussions with the expert panels assembled for each workshop resource area (Appendix C). Public and expert panel member comments on the discussions, matrices prepared for each workshop resource area, and the Phase I Technical Assessment Report were accepted during the course of each workshop. In order to assist EPA Region IV and the State of Florida to direct their limited resources, each expert panel was asked to rank the overall significance of the water-quality related problems at the end of each daily workshop.

The following is a summary of the major comments, recommendations, and priorities for EPA and the State to consider when developing the Water Quality Protection Program.

CORAL COMMUNITY ASSESSMENT WORKSHOP

Technical Panel: Dr. Phillip Dustan (College of Charleston, SC), Dr. Walter Jaap (Department of Natural Resources (DNR), FL), Dr. Pamela Hallock-Muller (University of South Florida, FL), Dr. James Porter (University of Georgia, GA), Dr. Laurie Richardson (Florida International University, FL), Dr. Eugene Shinn (United States Geological Survey (USGS), FL), and Dr. Alina Szmant (Rosenstiel School of Marine and Atmospheric Science, FL).

Problems/Issues discussed at this workshop were (1) Coral Disease, (2) Bleaching, (3) Problematic Algal Growth, (4) *Lyngbya* Growth, (5) Lack of Recruitment, (6) Growth Rate (Individual), (7) Decline in Coral Abundance, and (8) Decline in Species Diversity (see Appendix B). The parameters for analysis were **temporal consideration** (Is the problem related to season, has it been happening recently or in the past, and are there data?), **spatial consideration** (What is the geographical range of the problem?), **trend** (Is the problem worsening, same, better, or unknown?), **severity** (How severe is the problem?), **certainty** (How certain are we that there is a problem?), **water quality related?** (Is this problem related to water quality?), **water quality parameters** (Do the parameters have an affect on the problem?), and **overall significance** (What is the significance of the problem from a water-quality perspective?).

Generally, the panel members agreed that there is a lack of data regarding all of the above problems. More research and data are needed to determine how the water quality parameters affect each of the problems discussed.

(1) *Coral disease* is widespread with patchy occurrences, and its severity is increasing in the Keys. The panel members agreed that the cause of coral disease is possibly water-quality related. Temperature (significantly) and salinity (slightly) affect coral disease. Parameters that require more investigation regarding their effects on this problem are nutrients, turbidity, toxics/pesticides, bacteria, and viruses. The overall significance of the problem from a water-quality perspective is high. Additional comments were that more data are needed to determine the cause of coral diseases (epidemiology) and that there is a need to determine whether there is a global influence on coral disease.

(2) *Coral bleaching* is species-dependent and known to occur in the Keys. The trend for bleaching events is known to be increasing, but the events vary in their severity. The panel members agreed that this problem is water-quality related; temperature significantly affects bleaching of coral communities and salinity is also thought to be a contributor to the bleaching. The effects of nutrients, turbidity, and toxics/pesticides on the bleaching of coral communities are unknown; more data are needed. The overall significance of this problem from a water-quality perspective is high.

(3) Temporally, *problematic algal growth* is known to occur in localized "hot spots" and this trend is increasing. The panel members agreed that the potential exists for problematic algal growth to be water-quality related, however it is not yet a problem. Temperature and nutrients significantly affect this problem; however, the effects of toxics/pesticides and bacteria on problematic algal growth are unknown. The overall significance of this problem from a water-quality perspective is moderate.

(4) The panel members felt that *Lyngbya growth* deserved its own discussion because the recent (fall 1988 bloom) and rapid increase in *Lyngbya* occurrence could potentially occur to other species within the algal community. Occurrence of the *Lyngbya* bloom is localized, spreading, and increasing. The panel members agreed that the severity of this problem is high in the Keys and that this problem is definitely

water-quality related. Temperature and nutrients significantly affect *Lyngbya* growth; the effects of toxics/pesticides and bacteria are unknown. The overall significance of this problem from a water-quality perspective is high.

(5) The panel members agreed that the discussion regarding the problem of *lack of coral recruitment* should be an offshore discussion only. Recruitment is species-dependent and driven by the reproductive cycle of the organism. Areas exhibiting a lack of recruitment are patchy in the Keys. The trend of this problem is unknown, however, the severity of the problem is high in the Keys. The panel members agreed that it is possible that this problem is water-quality related. All of the water-quality parameters discussed have an unknown effect on the problem; more research is needed. The overall significance of this problem from a water-quality perspective is high.

(6) Cases of impaired *growth rates of individual corals* are known and isolated. The trend of this problem is variable and the severity is localized in the Keys. The panel members agreed that this problem is known to be water-quality related; temperature and turbidity significantly affect individual growth rates. It is unknown if nutrients, toxics/pesticides, bacteria, and viruses affect individual growth rates. The overall significance of this problem from a water-quality perspective is high. Additionally, it was commented that physical damage to corals is a concern and that coral diseases are known to affect growth rates.

(7) The *decline in coral abundance* is known to be a seasonal, long-term problem (geographically). The severity of the decline is high and the rate of the decline over time is unknown; there is a lack of data. The panel members agreed that it is probable, in the historical sense, that this problem is water-quality related. Water-quality parameters that significantly affect this problem are temperature and turbidity. Salinity has been an historically significant problem; however, it is currently insignificant. The effects of nutrients, toxics/pesticides, bacteria, and viruses are unknown and more data are needed. The overall significance of this problem from a water-quality perspective is high and the panel members agreed that more research and data are needed. An additional comment made was that cyanobacteria diseases are known to affect coral abundance.

(8) Temporally, the *decline in species diversity* (species other than coral) is extremely variable (from hours to years) and widespread for the width of the Keys. Species diversity is worsening particularly for commercially harvested species, although the panel members agreed that the available data relate to harvested species and few data exist for other species. It is probable that the decline in species diversity is water-quality related for the nearshore breeding species and possibly water-quality related for offshore breeding species. Temperature significantly contributes to the decline while the effects of nutrients on this problem are slight to moderate. Salinity is a slight contributor to this problem, and toxics/pesticides are a slight contributor offshore. It is unknown if turbidity, bacteria, viruses, and dissolved oxygen (DO) affect the problem; more data are needed. The overall significance of the problem from a water-quality perspective is unknown.

Review of Overall Significance by the Panel Members

Coral disease and problematic algal growth are the problems most directly related to water quality, therefore they should also have a high priority in the Water Quality Protection Program. In addition, the decline in biodiversity was rated as unknown by the panel members, and they felt that the lack of information indicates that additional work needs to be done regarding this problem.

Additional Comments from the Panel Members and Workshop Attendees

- EPA nutrient test standards are too insensitive to provide meaningful data.
- All of the topics discussed at the workshop are global in nature. EPA must take advantage of the international network of information; information sharing is crucial.
- Data from all research areas in the Keys must be compared to understand the whole ecosystem and its patterns.
- It must be realized that human impact to the Keys environment is superimposed on the natural cycles of the environment.
- More information is needed on recruitment cycles, algal blooms, indicator organisms, soft corals, and nutrient inputs to areas of the FKNMS.
- Long-term, spatial-scale studies are needed in the Keys.
- Fish and invertebrates were omitted from the report and workshop topics.
- Bioerosion of the coral reefs needs research.
- There is a need for a high quality laboratory in the Florida Keys for archiving data relevant to the Keys.
- EPA should develop site-specific, water-quality standards for the entire Keys; the Keys cannot be considered as one area.

SUBMERGED AND EMERGENT AQUATIC VEGETATION ASSESSMENT WORKSHOP

Technical Panel: Dr. Bill Kruczynski (EPA, FL), Dr. Kathleen Sullivan (The Nature Conservancy, FL), Dr. John Ogden (Florida Institute of Oceanography, FL), Dr. Jay Zieman (University of Virginia, VA), Dr. Brian Lapointe (Harbor Branch Oceanographic Institute (HBOI), FL), Dr. Jim Fourqurean (Continental Shelf Associates, Inc., FL), and Mr. Paul Carlson (DNR, FL).

Problems/Issues discussed at this workshop were divided into four areas — Seagrasses, Macroalgae, Mangroves/Buttonwoods, and Freshwater Influence (see Appendix B). Problems regarding Seagrass Communities were (1) Increased Epiphyte Growth, (2) Seagrass Historic Growth Rates (Individual), (3) Declines in Community Diversity (other than seagrass communities), (4) Decreased Geographical Extent, (5) Decreased Recruitment of Seagrasses, and (6) Hypoxia. Problems regarding Macroalgae Communities were (1) Increased Epiphyte Growth, (2) Macroalgae Historic Growth Rates (Individual), (3) Decreased Community Diversity (other than seagrass communities), (4) Hypoxia, and (5) Diversity of Algae. Problems regarding Mangrove/Buttonwood Communities were (1) Decreased Tree Productivity (individual), (2) Decreased Geographical Extent, and (3) Functional Value of Habitat. Problems regarding Freshwater Influence were (1) Decreased Productivity, (2) Decreased Geographical Extent, and (3) Functional Value of the Habitat.

The parameters for analysis were **temporal consideration** (Is the problem related to season, has it been happening recently or in the past, and are there data?), **spatial consideration** (What is the geographical range of the problem?), **trend** (Is the problem worsening, same, better, or unknown?), **severity** (How severe is the problem?), **certainty** (How certain are we that there is a problem?), **water quality related?** (Is this problem related to water quality?), **water quality parameters** (Do the parameters have an affect on the problem?), and **overall significance** (What is the significance of the problem from a water-quality perspective?).

Seagrasses

For this discussion, the panel members qualified several of the water-quality parameters on the matrix. Nutrients was changed to **anthropogenic nutrients**, bacteria and viruses were combined into **diseases**, and DO was changed to **anthropogenic DO** (DO caused by external sources).

(1) The problem of *increased epiphyte growth* on seagrasses is known to occur primarily in hot spots throughout the Keys and the trend is worsening. The panel members agreed that this problem is definitely water-quality related in the hot spots and possibly water-quality related elsewhere; more data are needed. Turbidity, and anthropogenic nutrients and DO significantly affect increased epiphyte growth in seagrass communities. The overall significance of this problem from a water-quality perspective is high.

(2) *Seagrass historic growth rates (individual)* have decreased recently and the reductions are known to occur in hot spots associated with human activity throughout the Keys. They are unknown yet suspected to occur elsewhere. The panel members agreed that this problem is water-quality related in the hot spots and possibly water-quality related elsewhere; more data are needed. Temperature, salinity, anthropogenic nutrients and DO, and turbidity significantly affect growth rates of seagrasses. The overall significance of this problem from a water-quality perspective is high in the hot spots and slight elsewhere in the Keys.

(3) The problem, *declines in community diversity*, was considered regarding anthropogenic changes. Areas of declines in community diversity are isolated to hot spots and the trend is worsening; declines are unknown elsewhere. The panel members agreed that this problem is water-quality related in the hot spots and probably water-quality related elsewhere; more data are needed. Temperature, salinity, and anthropogenic DO significantly affect community diversity. The overall significance of this problem from a water-quality perspective is high in the hot spots and possible but unknown elsewhere in the Keys. Overfishing effects were highlighted as having an impact on community diversity.

(4) *Decreased geographical extent* (i.e., anthropogenic losses) is known to be isolated to hot spots and this trend is worsening. Outside the hot spot areas, changes are taking place naturally; human effects here are slight. Temperature, anthropogenic nutrients and DO, salinity, and turbidity significantly affect this problem. The overall significance of this problem from a water-quality perspective is high in the hot spots and slight elsewhere.

(5) There is a general lack of data and information regarding *decreased recruitment of seagrasses*. This problem is isolated to hot spots and is worsening. Because of the lack of data, no accurate assessment could be made. The panel members agreed that the problem is possibly water-quality related. Parameters thought to have a significant affect on the problem are temperature, salinity, turbidity, and anthropogenic DO. The overall significance of this problem from a water-quality perspective is unknown.

(6) The problem of *hypoxia* depends on circulation patterns, flushing of an area, and climate effects and influence (drought, wet). The panel members agreed that hypoxia is definitely water-quality related and usually occurs in hot spots where it has the potential to be severe. Temperature and anthropogenic nutrients and DO significantly affect the problem. The overall significance of the problem from a water-quality perspective could not be determined because it depends on circulation.

The only anthropogenic effect on Florida Bay is the reduction of the historic and sporadic freshwater flow by canals such as the C-111 canal. The natural system in Florida Bay (50 years ago) would be better for more species of fish and vegetation than the present-day environment. Currently, extremely saline waters from Florida Bay are believed to be causing reef damage (coral die-off). The panel members commented that this freshwater flow to Florida Bay needs to be restored and that EPA should determine the extent of the previous coral community. The Florida Bay water quality issue must be included in the management of the FKNMS.

Additional Comments from the Panel Members and Workshop Attendees

- Calcareous epiphytes are an indicator of good water quality.
- Hypoxia covaries with epiphyte growth.
- Nutrient loading needs investigation.
- A strong relationship exists between anthropogenic nutrients and turbidity.

Macroalgae

For this discussion macroalgae was defined as all soft and hard-bottom macroalgae. Again, the panel members qualified several of the water-quality parameters on the matrix. Nutrients was changed to **anthropogenic nutrients**, bacteria and viruses were combined into **diseases**, and DO was changed to **anthropogenic DO** (DO caused by external sources).

(1) The problem of *increased epiphyte growth* on macroalgae is known to occur primarily in hot spots throughout the Keys and the trend is worsening. The panel members agreed that this problem is definitely water-quality related in the hot spots and possibly water-quality related elsewhere; more data are needed. Turbidity and anthropogenic nutrients and DO significantly affect increased epiphyte growth in macroalgae communities. The overall significance of this problem from a water-quality perspective is high.

(2) Macroalgae compete with seagrasses for area. *Macroalgae historic growth rates (individual)* have increased over the last decade, are known to occur in hot spots throughout the Keys, and are widespread elsewhere. The panel members agreed that this problem is water-quality related in the hot spots and possibly water-quality related elsewhere. Temperature, turbidity, salinity, and anthropogenic nutrients and DO significantly affect growth rates of macroalgae. The overall significance of this problem from a water-quality perspective is high in the hot spots and slight elsewhere in the Keys. More data are needed regarding this problem.

(3) The problem, *declines in community diversity*, was considered regarding anthropogenic changes. Areas of decreased community diversity are isolated to anthropogenic hot spots and the trend is worsening. Declines were unknown elsewhere; more data are needed. The panel members agreed that this problem is water-quality related in the hot spots and probably water-quality related elsewhere. Temperature, salinity, and anthropogenic DO significantly affect community diversity. The overall significance of this problem from a water-quality perspective is high in the hot spots and possible but unknown elsewhere in the Keys. Overfishing effects were highlighted as having an impact on community diversity.

(4) The problem of *hypoxia* depends on circulation patterns, flushing of an area, climate effects and influence (drought, wet). The panel members agreed that hypoxia is definitely water-quality related and usually occurs in hot spots where it has the potential to be severe. Temperature and anthropogenic nutrients and DO significantly affect the problem. The overall significance of this problem from a water-quality perspective could not be determined because it depends on circulation.

(5) *Diversity of the algae* has decreased within the last decade. This problem is worsening in and is isolated to hot spots, and is widespread elsewhere. The panel members agreed that this problem is water-quality related. Temperature, anthropogenic nutrients and DO, salinity, and turbidity significantly affect the problem. The overall significance of the problem from a water-quality perspective is high. Overfishing and grazing were highlighted as having an impact on this problem.

Additional Comments from the Panel Members and Workshop Attendees

- Positive algal growth for the wrong reason is a problem.

Mangroves/Buttonwoods

For the Mangroves/Buttonwoods problems, three parameters were added for analysis: **climatic effects** (What are the climatic effects of the problem?), **dredge and fill** (What are the effects of dredge and fill on the community?), and **other** (Are there other effects?).

(1) The extent, trend, and severity of *decreased tree productivity (individual)* are unknown. The panel members agreed that this problem is water-quality related and that temperature, salinity, turbidity and anthropogenic nutrients and DO significantly affect tree productivity. The overall significance of this problem from a water-quality perspective is unknown. A consequence of decreased tree productivity is increased flood sensitivity. Dredge and fill operations can cause changes in the community, and other effects that should be considered are impoundment effects.

(2) The severity of the problem, *decreased geographical extent*, is high. Decreased geographical extent is widespread and the continuing decline is characterized by large losses of mangroves and buttonwoods. The panel members agreed that this problem is probably related to water quality. Parameters that have a significant effect on the problem are salinity, turbidity, and anthropogenic nutrients and DO. The overall significance of this problem from a water-quality perspective is slight; however, the panel members agreed that this problem is a highly significant one.

(3) The *functional value of the habitat* is affected by seasonal and episodic flooding. The trend of this problem is unknown but thought to be declining. The panel members agreed that this problem is probably related to water quality. Anthropogenic nutrients and toxics/pesticides significantly affect this problem. The overall significance of the problem from a water-quality perspective is high. One additional comment made was that fragmentation is a critical component of the problem.

Freshwater Influence

For the Freshwater Influence problems, three parameters were added for analysis: **climatic effects** (What are the climatic effects of the problem?), **dredge and fill** (What are the effects of dredge and fill on community?), and **other** (Are there any other effects?).

(1) The spatial consideration, trend, severity, and certainty of the problem as they relate to *decreased productivity* are unknown; however, the panel members agreed that the problem is probably related to water quality. Temperature highs and lows, anthropogenic nutrients, and salinity significantly affect productivity; toxics/pesticides possibly affect productivity. The overall significance of the problem from a water-quality perspective is moderate to high. A climatic effect associated with decreased productivity is the lowering of the water table.

(2) The problem of *decreased geographical extent* is continuing; losses have been high and the severity of the problem is high. The panel members agreed that the problem is definitely water-quality related and impacted by nutrient additions and septic system runoff. The overall significance of how water quality affects this problem is high. Dredge and fill operations cause a direct loss of habitat due to development activities. Septic tanks and cesspools also contribute to the problem.

(3) The *functional value of the habitat* continues to worsen and the problem is widespread in the Keys. The panel members agreed that this problem is water-quality related (in part) and that anthropogenic nutrients, salinity, turbidity, and toxics/pesticides significantly affect the problem. The overall significance of the problem from a water-quality perspective is high. Fragmentation was listed as a critical component of the problem.

Review of Overall Significance by the Panel Members

Priority problems in the seagrass and macroalgae communities are epiphyte growth and anthropogenic nutrient loading; control measures are needed. Priority concerns in the mangrove/buttonwood communities are preserving geographical extent and the functional value of the habitat. For freshwater influence, the priority concern is preserving the geographical extent so that there is no further loss of mangrove/buttonwoods and coastal wetlands.

Additional Comments from the Panel Members and Workshop Attendees

- *Thalassia* communities are the most sensitive communities; they cannot be recolonized.
- It should be recognized that a portion of Florida Bay is located in the FKNMS.
- There is a need to restore the historic freshwater flow to Florida Bay; spiking (allowing the Bay to become all freshwater) should occur for a period of days every few months.
- A historical description of the FKNMS area should be developed; find out what communities existed and how much the area has changed.
- Sewage is impacting the nearshore waters of the Keys.
- Hot spots are likely to increase as long as nutrient loading increases.
- Standardized marina siting criteria are needed; seagrasses should be taken into account.
- The public should be educated about the problem of prop dredging.
- Mangroves were underrepresented in the report.
- Each point source may be operating under a valid permit within an overall regulatory strategy, however the cumulative impacts of all point sources should be investigated and considered.

NEARSHORE AND CONFINED WATERS ASSESSMENT WORKSHOP

Technical Panel: Mr. R.J. Helbling (Department of Environmental Regulation (DER), FL), Dr. Ron Jones (Florida International University, FL), Dr. Brian Lapointe (HBOI, FL), Dr. Alina Szmant (Rosenstiel School of Atmospheric Science, FL), Dr. Ned Smith (HBOI, FL), Dr. Steve Miller (NOAA National Undersea Research Center, FL), Mr. Del Hicks (EPA, GA), and Dr. Jim Fourqurean (Continental Shelf Associates, Inc., FL).

This workshop was divided into three areas of interest, Confined Waters, Nearshore Waters, and Back Country Waters (see Appendix B). Problems/Issues discussed in relation to Confined Waters were divided into two areas; eutrophication and human health. Under eutrophication, (1) Increased Epiphyte Growth, (2) Increased Chlorophyll (i.e., phytoplankton), and (3) Change in Benthic Community Structure were discussed. Under human health, (1) Human Health (Fish and Shellfish Consumption) was discussed. Problems discussed in relation to Nearshore Waters were (1) Increased Epiphyte Growth and (2) Increased Chlorophyll (i.e., phytoplankton). Problems discussed in relation to Back Country Waters were (1) Increased Epiphyte Growth and (2) Increased Chlorophyll (i.e., phytoplankton).

The parameters for analysis were **temporal consideration** (Is the problem related to season, has it been happening recently or in the past, and is there data?), **spatial consideration** (What is the geographical range of the problem?), **trend** (Is the problem worsening, same, better, or unknown?), **severity** (How severe is the problem?), **certainty** (How certain are we that there is a problem?), **water quality related?** (Is this problem related to water quality?), **water quality parameters** (Do the parameters have an effect on the problem?), and **overall significance** (What is the significance of the problem from a water-quality perspective?).

Confined Waters — Eutrophication

Confined waters are defined as canals, marinas, bays, and lagoons. The panel members made changes to two water-quality parameters. Bacteria was changed to **human-derived bacteria** and DO was changed to **anthropogenic biological oxygen demand (BOD) loadings.**

(1) *Increased epiphyte growth* is a problem that is widespread and the trend is worsening. Epiphyte growth has been increasing over the last decade. The panel members agreed that the problem is water-quality related and that the overall significance of the problem from a water-quality perspective is high. Parameters that significantly affect this problem are nutrients, turbidity, and anthropogenic BOD loadings. An increase in epiphyte growth is an indicator of a change in the community structure and amount. Poor flushing and the lack of circulation into the canals contributes to the poor water quality in the canals.

(2) *Increased chlorophyll* is related to temperature and light, and has been reported since 1973. The problem is thought to be widespread, chronic, and worsening (anecdotal evidence). The panel members agreed that the problem is water-quality related and that the overall significance of the problem from a water-quality perspective is high. Parameters that significantly affect this problem are nutrients, turbidity, and anthropogenic BOD loadings. Increased chlorophyll is an indicator of the severity of the nutrients.

(3) *Change in the benthic community structure* is a problem that is widespread and the trend is worsening. The panel members agreed that the problem is water-quality related and that the overall significance of

the problem from a water-quality perspective is high. Parameters that significantly affect this problem are nutrients, turbidity, and anthropogenic BOD loadings. An additional comment was that recycling seagrass wrack can lead to eutrophication.

The panel members identified the endpoints of eutrophication as

- Loss of biodiversity
- Hypoxia
- Increasing hydrogen sulfide
- Increased epiphyte growth
- Decreased benthic producers
- Decreased light transparency (increased turbidity)
- Change in biogeochemical processes
- Increased chlorophyll
- Decreased circulation (secondary process)
- Increased macroalgae
- Decreased seagrasses
- Increased odor (esthetics)
- Decreased nursery functions

Confined Waters — Human Health

Human health (fish and shellfish consumption) refers to problems associated with consuming fish/shellfish caught by an individual, not fish/shellfish purchased from a seafood market. No historical data exist regarding health problems from personally caught fish/shellfish. More data are needed regarding the trend, severity, and certainty of the problem. Toxics/pesticides, human-derived bacteria, and viruses significantly affect the problem. Temperature, nutrients, and salinity affect the problem slightly to significantly depending on the species. The panel members agreed that it was possible but unlikely that the problem is water-quality related. The overall significance of this problem from a water-quality perspective is unknown. In areas with inappropriate sewage treatment systems, the potential exists for severe health problems.

Nearshore Waters

Nearshore waters are defined as those that extend from shore to Hawks Channel including the 18 ft depth contour. The panel members made changes to two water-quality parameters. Bacteria was changed to **human-derived bacteria** and DO was changed to **anthropogenic BOD loadings.**

(1) For *increased epiphyte growth*, the panel members agreed that severity was slight, certainty was possible, and overall significance of this problem from a water-quality perspective was slight. Increased epiphyte growth is a problem that is widespread and worsening, and has been increasing over the last decade. The panel members agreed that the problem is water-quality related. Parameters that significantly affect this problem are nutrients, turbidity, and anthropogenic BOD loadings.

(2) For *increased chlorophyll*, the panel members agreed that severity was slight, certainty was possible, and overall significance of this problem from a water-quality perspective was slight. Increased chlorophyll is related to temperature and light, and has been reported since 1973. The problem is thought

to be widespread, chronic, and worsening (anecdotal evidence). The panel members agreed that the problem is water-quality related. Parameters that significantly affect this problem are nutrients, turbidity, and anthropogenic BOD loadings.

Back Country Waters

Back country waters are defined as nearshore Florida Bay waters within the 8 to 10 ft depth contour. The panel members made changes to two water-quality parameters. Bacteria was changed to **human-derived bacteria** and DO was changed to **anthropogenic BOD loadings.**

(1) For *increased epiphyte growth*, the panel members agreed that severity was slight, certainty was possible, and overall significance of this problem from a water-quality perspective was slight. Increased epiphyte growth is a problem that is widespread and worsening, and has been increasing over the last decade. The panel members agreed that the problem is water-quality related. Parameters that significantly affect this problem are nutrients, turbidity, and anthropogenic BOD loadings.

(2) For *increased chlorophyll*, the panel members agreed that severity was slight, certainty was possible, and overall significance of this problem from a water-quality perspective was slight. Increased chlorophyll is related to rainfall, temperature, and light and has been reported since 1973. The problem is thought to be widespread, chronic, and worsening (anecdotal evidence). The panel members agreed that the problem is water-quality related. Parameters that significantly affect this problem are nutrients, turbidity, and anthropogenic BOD loadings. In addition, no historical data exist regarding the back country waters; all information in this matrix column is anecdotal or from personal observations.

Review of Overall Significance by the Panel Members

The consensus of the panel members was that water quality in some confined waters was degraded; however, there was not a unanimous consensus that water quality in nearshore and back country waters was degraded. Priority areas in need of more information were new methodologies for using managed aquatic systems for treatment, hot spots, nutrient loading, nutrient transport/hydrology, monitoring from a hydrological/biological standpoint (develop a systems monitoring program), back country waters, hydrology regarding well injection (has the ability to impact nearshore and offshore waters), and hydrological studies (intensive surveying needed, establish a liaison with the USGS). Priority problem areas are the canal systems adjacent to inappropriate sewage treatment systems. Secondary treatment should be mandated for such areas.

Additional Comments from the Panel Members and Workshop Attendees

- Anecdotal evidence should be weighed very carefully; some is valuable.
- Need to address impacts of water quality on marine fisheries.
- Pesticide spraying in Monroe County should be banned.
- Pesticide problem is unknown; needs investigation.

Hot Spot Criteria

The panel members discussed what criteria they would use to determine a hot spot. The following is a list of the criteria identified.

- Documented fish kills (could be natural)
- Documented anaerobic conditions (could be natural)
- Potential discharge sources/sources of contamination
- High chlorophyll
- High macroalgal epiphytes
- Population density and type of sewage treatment
- Poorly flushed areas
- Anecdotal/observational evidence of change
- Documented water-quality violations
- Evidence of high anthropogenic inputs
- Type of land and water use

Some of the above criteria will occur before others. Almost all of these criteria are not indicators of a problem, necessarily. If a condition is observed, it should be investigated to determine if it is a natural occurrence or not.

Consensus by the Panel Members on Known and Suspected Hot Spots

Upper Keys (north to south) — Known Hot Spots
Phase 1 Ocean Reef, Carysfort Camp Ground, Alabama Jacks, Card Sound Road, C-111, Point Laurel, Lake Surprise, Sexton Cove, Cross Key Waterways, Largo Sound/Shores, Port Largo, Campbell's Marina, Indian Waterways, Venetian Shores, Lower Matecumbe Key, and all marinas.

Middle Keys (north to south) — Suspected Hot Spots
City of Layton, Fiesta Campground, Duck Key, Grassy Key, and Coco Plum Subdivision/Fat Deer Key.

Middle Keys (north to south) — Known Hot Spots
All marinas, Key Colony beach, Sierra Estates, 90th Street Canal, Winner Docks (Boot Key Harbor), City Fish Seafood Processing Plant, Marathon, and Faro Blanco Marina.

Lower Keys (north to south) — Suspected Hot Spots
Loggerhead Key and Raccoon Key (monkey droppings).

Lower Keys (north to south) — Known Hot Spots
Big Pine Key dead end canal systems (septic tanks), Dr. Arm, Orchid Park Subdivision, Key Haven Subdivision (undersized treatment system), Keys Community College, Key West Sewage Plant Outfall, Stock Island Power Plant Discharge, two Navy outfalls, City of Key West Secondary Plant Discharge (nearshore outfall), Boca Chica Naval Air Station Discharge, and canals (need advanced treatment for septic tanks and cesspools).

SPILLS AND HAZARDOUS MATERIALS ASSESSMENT WORKSHOP

Technical Panel: Mr. Eric Evans (Coastal Tug and Barge, FL), Dr. Ken Haddad (DNR, FL), Lt. Donna Kuebler (United States Coast Guard (USCG), FL), Mr. Greg Lee (DER, FL), Dr. Anita Wooldridge (Marine Spill Response Corporation, FL), Mr. William Hunt (United States Navy, FL), and Ms. Debbie Prebble (DNR, FL).

Problems/Issues discussed at this workshop were (1) Small Vessel Spills (Marine), (2) Small Facility Spills (Landbased), (3) Illegal Dumping Marine-Landbased, (4) Catastrophic Tanker Spills, (5) Tanker Truck Spills, (6) Effects of Dispersant Use, (7) Bioremediation, (8) Leachable Toxics, (9) Boat Scraping, and (10) Ruptured Bulk Tanks and Pipelines (see attached matrix).

The parameters for analysis were **temporal consideration** (Is the problem related to season, has it been happening recently or in the past, and are there data?), **spatial consideration** (What is the geographical range of the problem?), **trend** (Is the problem worsening, same, better, or unknown?), **severity** (What is the seriousness when the event occurs?), **contingency plans** (Are contingency plans in place?, Has there been a great deal of work on contingency plans?, Are contingency plans adequate?), **water quality effect?** (i.e., biotoxicity, physical damage, bioaccumulation), and **overall significance** (How significant is the problem to the Water Quality Protection Program? *Note:* this is different from the previous workshops). The panel members added three parameters, **compliance/enforcement** (evaluation of these capabilities), **major constituents** (of a spill), and **risk** (likelihood of event occurring).

For all of the following problems, the panel members agreed that there is little documentation or information generated in the Keys and that this information is greatly needed.

(1) *Small vessel spills (marine)* were defined as spills from a vessel with ≤5000 gallons of fuel and/or cargo. The major constituents of these spills are diesel fuel, gas, and bilge. Small vessel spills occur year-round, are widespread (nearshore and fueling areas), and the trend is worsening (with the qualification that there has been an increase in reporting). The problem is severe locally and unknown overall. The adequacy of existing contingency plans was identified as low. The water-quality effect would be locally toxic and unknown overall. The authority exists for enforcement, but manpower is low and compliance is also low. The risk (likelihood of an event occurring) is high. The panel members agreed that the overall significance of this problem to the Water Quality Protection Program is high.

(2) *Small facility spills (landbased)* generally are unreported and include those spills from marinas, auto fueling facilities, small industrial facilities, and residents. Constituents of these spills are diesel fuel, gas, solvents, pesticides, used motor oil, and paint-related material. This problem occurs year-round and is widespread (in marinas and fueling areas) and the trend is worsening (with the qualification that there has been an increase in reporting). The problem is severe locally and unknown overall. The adequacy of existing contingency plans was identified as low. The water-quality effect would be locally toxic and unknown overall. Compliance and enforcement were reported as low by the panel members. The risk (likelihood of an event occurring) is high. The panel members agreed that the overall significance of this problem to the Water Quality Protection Program is moderate.

(3) *Illegal dumping (marine-landbased)* for marine-based sources was defined as spills from a vessel with ≥5000 gallons of fuel and/or cargo and materials resulting from the pumping of bilges and cleaning of cargo holds. Constituents of these marine-based spills are petroleum products. The constituents of land-

based spills are paint and solvents. The quality and quantity of these marine- and land-based substances are unknown. This problem occurs year-round, is widespread, and the trend is worsening. The problem is severe locally and unknown overall. The water-quality effect would be locally high and unknown overall. Compliance was determined to be very low and enforcement is improving. The risk (likelihood of an event occurring) is moderate. The panel members agreed that the overall significance of this problem to the Water Quality Protection Program is high.

(4) *Catastrophic tanker spills* were defined as a spill of > 10,000 gallons inshore and > 100,000 gallons offshore whose major constituents are diesel fuel, blends of fuel, heavy fuels, hazardous materials, and crude. These spills occur year-round (two have occurred in the last 16 years in the Keys) and the potential severity of a spill in the FKNMS is high. The likelihood of a catastrophic spill happening is decreasing. The panel members agreed that a sanctuary-specific contingency plan is needed and that it should include what should be done with the cleanup waste. Compliance and enforcement are moderate to high and the risk (likelihood of the event occurring) is low. The water-quality effect would be high if the spill reaches the FKNMS. The panel members agreed that the overall significance of this problem to the Water Quality Protection Program is high.

(5) *Tanker truck spills* (including tractor trailers) occur year-round (two have occurred in the last 10 years in the Keys) and are usually isolated to highways. The major constituents of this type of spill are gasoline, diesel fuel, and other hazardous materials. The severity of a spill is high locally and the likelihood of this type of spill occurring is decreasing. The adequacy of the existing contingency plans were determined to be good; however, response time is a problem. The water-quality effect would be severe locally because of the highly toxic compounds being spilled. Compliance and enforcement are moderate to high and the risk (likelihood of the event occurring) is moderate. The panel members agreed that the overall significance of this problem to the Water Quality Protection Program is moderate.

(6) The *effects of dispersant use* would have a seasonal impact on habitats. At this time in the Keys, dispersants are considered for every spill but have not been used. The adequacy of contingency plans is low and there is a need for more work on the plans. The risk of using dispersants is low; the water-quality effect would be variable. The panel members agreed that the overall significance of this problem to the Water Quality Protection Program is high. More information is needed regarding the effects of dispersant use on larvae. There are tradeoffs to consider when using dispersants. Research is needed regarding the toxicity of spilled oil versus the toxicity of the dispersed oil.

(7) The use of *bioremediation* is not as constrained as dispersant use. The potential water-quality effect of adding nutrients is low. The panel members agreed that the overall significance of this problem to the Water Quality Protection Program is unknown but unlikely. Interim guidelines are needed.

(8) *Leachable toxics* were defined as substances originating from Comprehensive Environmental Response, Compensation, and Liability Act (CERCLA) and Resource Conservation and Recovery Act (RCRA) sites and underground storage tanks and include a variety of constituents such as heavy metals, PCBs, insecticides, and pesticides. Leaching occurs year-round in isolated areas. The problem is moderately severe and improving. Compliance/enforcement and contingency plans are site dependent and are low to high in adequacy. Risk is unknown. The water-quality effect is unknown but potentially significant. The panel members agreed that the overall significance of this problem to the Water Quality Protection Program is moderate.

(9) Hazardous materials resulting from *boat scraping* consist of metals. This problem occurs year-round with seasonal peaks and is isolated to site-specific areas. Trend, severity, and compliance/enforcement are unknown and the risk (likelihood of event occurring) is high. The water-quality effect of this problem is high. The panel members agreed that the overall significance of this problem to the Water Quality Protection Program is high.

(10) Hazardous materials resulting from *ruptured bulk tanks and pipelines* consist of jet fuel, diesel, and various other petroleum products. This problem occurs year-round in isolated, site-specific areas. The severity of the problem is moderate to high. Contingency plan adequacy was determined to be moderate. Compliance/enforcement is moderate to high and risk (likelihood of event occurring) is high. The water-quality effect is probable. The panel members agreed that the overall significance of this problem to the Water Quality Protection Program is high.

Review of Overall Significance by the Panel Members

The panel members agreed that their ratings for risk and severity should be used to determine the relative significance of each problem to the Water Quality Protection Program. If the severity is high and the risk is high, then some action needs to be taken. If the severity is unknown and the risk is high, more research is needed (refer to matrices in Appendix B).

Additional Comments from the Panel Members and Workshop Attendees

- More preplanning strategies with major agencies for spill response (must include resource managers) are needed.
- Contingency plans are effective in targeting available resources; however, more resources are needed.
- Existing contingency plans are inadequate; they are not designed to take into consideration the goals of the FKNMS (that the spill does not reach the FKNMS).
- Technology is not at the same level as the contingency plans.
- Existing contingency plans do not provide for a no damage scenario.
- The USCG is requiring area plans in addition to general contingency plans; however, the areas are too large. Areas must be decreased in size and the plans must target each ecosystem in the area individually.
- Contingency plans must be resource-specific and prioritized because decisions at the time of a spill must be made quickly.
- Resource managers in the Keys are responsible for a specific area of the Keys; they should be conferred with regarding contingency plan development.
- There is no spill equipment in the FKNMS; shallow-water spill cleanup equipment is needed (deep-water spill cleanup equipment is not adequate for the area).

CONCLUSIONS

Two themes emerged from the four workshops.

- Generally, the panel members agreed that there is an overwhelming lack of data regarding all of the resource areas and associated problem areas. More monitoring data and research are needed to determine how the water quality parameters affect each of the resource areas and related problems.

- The problem statements presented in the Phase I Technical Assessment Report and discussed at the workshops are problems that anecdotal studies have shown to be important for the well-being of the Florida Keys. All of the problems are important but the key problems prioritized at the end of each workshop are the problems that should be addressed first to efficiently use the limited resources of the Federal and State governments.

The lack of data highlights the need for a clear and concise water-quality monitoring plan that will produce data that can be compared in a status and trend manner. Many of the current studies have been conducted over different temporal and spatial periods using differing sampling and analytical techniques. Quality assurance and quality control procedures have been applied to differing degrees as well. These points indicate that a monitoring plan which provides a baseline for follow-on investigations and research studies is definitively needed in order to describe problems beyond the current effort and help focus long-range problem solving management plans.

APPENDIX A

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APPENDIX A

ACRONYMS

ADF	average daily flow
ATRP	Abandoned Tank Restoration Program
BAT	Best Available Technologies
BOD	biochemical/biological oxygen demand
CDERM	(Metro-Dade) County Department of Environmental Resources Management
CERCLA	Comprehensive Environmental Response, Compensation, and Liability Act
CIMAS	Cooperative Institute for Marine and Atmospheric Studies (University of Miami)
CWA	Clean Water Act
DO	dissolved oxygen
DOA	Department of Agriculture
DOD	Department of Defense
DOI	Department of the Interior
EDIP	Early Detection Incentive Program
EPA	Environmental Protection Agency
FAC	Florida Administrative Code
FDCA	Florida Department of Community Affairs
FDER	Florida Department of Environmental Regulation
FDHRS	Florida Department of Health and Rehabilitative Services
FDNR	Florida Department of Natural Resources
FDPC	Florida Department of Pollution Control

FIO	Florida Institute of Oceanography
FKNMS	Florida Keys National Marine Sanctuary
FP&L	Florida Power & Light
FWS	U.S. Fish and Wildlife Service
GIS	Geographic Information System
GMS	Groundwater Management System
GPAD	gallons per acre per day
GPCD	gallons per capita per day
GPD	gallons per day
HDPE	high-density polyethylene
HSWA	Hazardous and Solid Waste Amendments
LPC	limiting permissible concentration
MGD	million gallons per day
MHP	mobile home park
MSD	municipal services district
MSDS	Material Safety Data Sheets
NAS	Naval Air Station
NOAA	National Oceanic and Atmospheric Administration
NPDES	National Pollutant Discharge Elimination System
NTU	nephelometric turbidity unit
NWR	National Wildlife Refuge
ORC	Objections, Recommendations and Comment (Report)

OSDS	on-site sewage disposal system
PAE	phthalate acid ester
PCB	polychlorinated biphenyls
PCU	platinum-cobalt color unit
ppt	parts per thousand
pptr	parts per trillion
RCRA	The Resource Conservation and Recovery Act
RV	recreational vehicle
SFWMD	South Florida Water Management District
STP	sewage treatment plant
TBT	tributyltin
TP	trailer park
TPD	tons per day
TSS	total suspended solids
USACE	United States Army Corps of Engineers
USCG	United States Coast Guard
USGS	United States Geological Survey
USDA	United States Drug Administration
USNAS	United States Naval Air Station
WMD	Water Management District
WMI	Waste Management, Inc.
WRT	Wallace Roberts & Todd

APPENDIX B

Coral Commu[illegible]ssessment — Task 3

	PROBLEMS/ISSUES							
	Coral Disease	**Bleaching**	**Problematic Algal Growth**	**Lack of Recruitment***	**Growth Rate (Individual)**	**Decline in Coral Abundance**	**Decline in Species Diversity**	***Lyngbya* Growth**
Temporal Consideration Seasonal—Historical	Summer, 1970s	Summer, Fall. 1911	Summer, Fall.	Driven by reproduction cycle. Species dependent. No historical data.	Seasonal differences. Species dependent (significant).	Seasonal. Long-term problem (geologically).	Extremely variable (hours to years)	Fall 1988 bloom. Summer, Fall
Spatial Consideration	Widespread	Variable	Localized*	Patchy	Isolated	Variable	Widespread (width of Keys)	Localized and spreading
Trend	Widespread	Increasing	Increasing	Unknown	Variable	Decline? No data. Change in rate unknown.	Worsening*	Worsening
Severity	Increasing, patchy	Variable—species dependent	Moderate "+"	High	Localized	High	Moderate (overwhelming lack of data)	High
Certainty	Known	Known	Known	Suspected	Known	Known	Unknown Known*	Known
Water Quality Related?	Possible	Yes	Potential exists. Possible—not yet a problem.	Possible	Known	Probable in the historical sense.	Probable (for nearshore breeding species) Possible (offshore)	Yes
WATER QUALITY PARAMETERS								
Temperature	Significant	Significant	Significant	Unknown	Significant	Highly Significant	Significant	Significant
Nutrients	Unknown	Unknown	Significant	Unknown	Unknown	Unknown. Need data.	Slight—Moderate	Significant
Salinity	Slight	Contributor	No	Unknown	Slight	Historically significant. Currently insignificant.	Slight	No
Turbidity	Unknown—need work	Unknown	No	Unknown	Significant	Significant	Unknown	No
Toxics/Pesticides	Unknown—need work	Unknown	Unknown	Unknown	Unknown	Unknown	Slight (offshore)	Unknown
Bacteria	Unknown	Slight—secondary	Unknown	Unknown	Unknown	Unknown	Unknown	Unknown
Viruses	Unknown	Slight—secondary	NA	Unknown	Unknown	Unknown	Unknown	NA
Dissolved Oxygen	No	NA	NA	Unknown	NA	NA	Unknown	NA
Overall Significance	High	High	Moderate	High	High	High	Unknown	High
Additional Comments	Need to determine the cause (epidemiology). Global influence?		*Hot spots (e.g., *Lyngbya*) Herbivore effects.	*Offshore discussion only. Increase in algae abundance reduces selective coral recolonization. Competitors, grazers, predators.	Physical damage to coral. Coral diseases are known to affect growth rates.	Need more data. Cyanobacteria diseases are known to affect this problem.	*Particularly harvested species (for aquariums, etc.).	

	PROBLEMS/ISSUES						
	SEAGRASSES						
		Increased Epiphyte Growth	Seagrass Historic Growth Rate (Individual)	Declines in Community Diversity**	Decreased Geographical Extent	Decreased Recruitment of Seagrasses	Hypoxia
Temporal Consideration (Seasonal - Historical)		Summer (best time to monitor) Recent*	Seasonal * Decreasing recently.	Anthropogenic Hot Spots	Hot Spot losses. Historical—natural gains and losses.	Seasonal	Summer, Fall. Historically—unknown.
Spatial Consideration		Widespread* Unknown	In Hot Spots** Unknown elsewhere.	Isolated*	Isolated*	Isolated*	Depends on circulation.
Trend		Worsening, Increasing	Worsening* Unknown elsewhere.	Worsening* Unknown	Worsening* Same—other areas	Lack of data Worsening*	Unknown
Severity		High* Moderate—Unknown elsewhere.	High* Slight elsewhere.	High* Unknown	High*	Lack of data	Potentially high
Certainty		Known* (for nutrients)	Suspected* Possible elsewhere.	Suspected* Possible	Known*	Unknown	Known
Water Quality Related?		Possible Certain*	Certain* Possible elsewhere.	Certain* Probable	Certain	Possible	Definitely
WATER QUALITY PARAMETERS	Temperature	Moderate	Significant	Significant	Significant	Significant	Significant
	Anthropogenic Nutrients	Significant	Significant	Moderate	Significant	Unknown	Significant
	Salinity	Slight	Significant	Significant	Significant	Significant	Possible
	Turbidity	Significant	Significant	Moderate—Significant	Significant	Significant (as it relates to light)	Possible
	Toxics/Pesticides	Unknown	Unknown	Moderate—Significant	Unknown but unlikely	Unknown but unlikely	Unknown but unlikely
	Disease	Unlikely but unknown	Unlikely but unknown	Moderate	Unknown but unlikely	Unknown but unlikely	Unknown but unlikely
	Hypoxia	In Hot Spots	Hot Spots	Hot Spots	Hot Spots	Hot Spots	Hot Spots
	Anthropogenic Dissolved Oxygen	Significant*	Significant	Significant	Significant	Significant	Significant
Overall Significance		High	High* Slight elsewhere.	High* Possible but unknown overall.	High* Slight overall	Unknown	Depends on circulation.
Additional Comments		*Hot Spots Lack of data. Widespread species variation. Strong relationship between temperature and nutrients. Above are observations.	*Hot Spots **Associated with human activity. Need data. Variable. Strong relationship between temperature and nutrients. Hot Spot influence.	*Hot Spots **Other than seagrass. Overfishing effects. Strong relationship between temperature and nutrients. Loss of habitat.	*Hot Spots Human effects slight to nil. Changes taking place naturally. Natural fluctuations.	*Hot Spots Lack of data and information.	Circulation, flushing, climate effects and influence (drought, wet).

Submerged and Emergent Aquatic Vegetation Assessment — Task 4 (continued)

		PROBLEMS/ISSUES				
		MAGROALGAE				
		Increased Epiphyte Growth	Macroalgae Historic Growth Rates	Declines in Community Diversity**	Hypoxia	Diversity of Algae
Temporal Consideration (Seasonal - Historical)		Summer Recent*	Seasonal* Increased over last decade.	Anthropogenic Hot Spots	Summer, Fall. Historically—unknown.	Diversity has decreased within last decade.
Spatial Consideration		Widespread* Unknown	More widespread	Isolated*	Depends on circulation	Isolated* More widespread
Trend		Worsening, Increasing	Worsening* Unknown	Worsening* Unknown	Unknown	?
Severity		High* Moderate—Unknown	High* Slight	High* Unknown	Potentially high	?
Certainty		Known* (for nutrients)	Known	Suspected* Possible	Known	Known
Water Quality Related?		Possible Certain*	Certain* Possible	Certain* Probable	Definitely	Known
WATER QUALITY PARAMETERS	Temperature	Moderate	Significant	Significant	Significant	Significant
	Anthropogenic Nutrients	Significant	Significant	Moderate	Significant	Significant
	Salinity	Slight	Significant	Significant	Possible	Significant
	Turbidity	Significant	Significant	Moderate—Significant	Possible	Significant
	Toxics/Pesticides	Unknown	Unknown	Moderate—Significant	Unlikely but unknown	Unknown
	Disease	Unknown but unlikely	Unknown but unlikely	Moderate	Unknown but unlikely	Unknown
	Hypoxia	Hot Spots	Hot Spots	Hot Spots	Hot Spots	?
	Anthropogenic Dissolved Oxygen	Significant*	Significant	Significant	Significant	Significant
Overall Significance		High	High* Otherwise slight	High* Possible but unknown.	Depends on circulation.	High
Additional Comments		*Hot Spots Lack of data Widespread species variation Strong relationship between temperature and nutrients. Above are observations.	*Hot Spots Competes with seagrasses. Lack of data. Strong relationship between temperature and nutrients. Above are observations.	*Hot Spots **Other than macroalgae. Overfishing effects. Strong relationship between temperature and nutrients. Loss of habitat.	Circulation, flushing, climate effects and influence (drought, wet).	*Hot Spots Overfishing. Grazing.

Submerged and Emergent Aquatic Vegetation Assessment — Task 4 (continued)

	PROBLEMS/ISSUES					
	MANGROVES/BUTTONWOODS			FRESHWATER INFLUENCE .		
	Decreased Tree Productivity (Individual)	**Decreased Geographical Extent**	**Functional Value of the Habitat**	**Decreased Productivity**	**Decreased Geographical Extent**	**Functional Value of the Habitat**
Temporal Consideration (Seasonal - Historical)	Seasonal Historically—unknown.	Not seasonal Historically—NA	Seasonal and episodic flooding	Seasonal Historically—unknown.	Historically—known.	Seasonal (wet/dry) Historic losses
Spatial Consideration	Unknown	Widespread. Decreasing historically.	Slight	Unknown	Losses high Important legally	Widespread
Trend	Unknown	Large losses, declining	Unknown, declining	Unknown	Decreasing	Loss continues
Severity	Unknown	High	Moderate	Unknown	High	High
Certainty	Unknown	Known	Suspected	Unknown	Known	Known
Water Quality Related?	Possible	Possible	Probable	Probable	Yes. Nutrient additives. Septic system runoff.	Yes (in part)
WATER QUALITY PARAMETERS						
Temperature	Significant	Slight	Possible	High/Low Significant	None	Slight—None
Anthropogenic Nutrients	Significant	Significant	Significant	Significant	Significant	Significan
Salinity	Significant	Significant	Likely	Significant	Significant	Significant
Turbidity	Significant	Significant	Likely	None	Possible	Significant
Toxics/Pesticides	Possible	Possible	Significant	Possible	Possible	Significant
Bacteria	None	None	Unknown but unlikely	None	None	Possible
Viruses	None	None	Unknown but unlikely	None	None	Possible
Anthropogenic Dissolved Oxygen	Significant	Significant	Significant	Unknown	Unknown	Probable—Significant
Overall Significance	Unknown	Slight	High	Moderate—High	High	High
Climatic Effects	Flood sensitive	—	—	Lowering of the water table	—	Fragmentation
Dredge and Fill	Changes in community type.	—	—	—	Direct loss of habitat due to development. Dredging.	—
Other	Impoundment effects.	Inverse to water quality. Highly significant as a problem.	Fragmentation is critical component.	—	Human activity: cesspool problem and septic tanks.	—
Additional Comments	—	—	—	—	—	—

Confined Waters Assessment — Task 5

		PROBLEMS/ISSUES			
		EUTROPHICATION			Human Health (Fish and Shellfish Consumption)
		Increased Epiphyte Growth	Increased Chlorophyll	Change in Benthic Community Structure	
Temporal Consideration (Seasonal — Historical)		Seasonal (summer) Increased over last decade	Seasonal (severe spikes with rain events) 1973-1974	Seasonal	Seasonal No historical data
Spatial Consideration		Widespread	Widespread Chronic	Widespread	Potentially widespread
Trend		Worsening	Worsening (anecdotal evidence)	Worsening	Unknown (need to look at data).
Severity		High	High	High	Unknown
Certainty		Known	Known	Known	Unknown
Water Quality Related?		Certain	Certain	Certain	Possible but unknown
WATER QUALITY PARAMETERS	Temperature	Slight—Moderate	Slight—Moderate	Slight—Moderate	Slight—Significant*
	Nutrients	Significant	Significant	Significant	Slight—Significant*
	Salinity	Slight	Slight	Slight	Slight—Significant*
	Turbidity	Significant	Significant	Significant	Significant
	Toxics/Pesticides	Unknown	Potentially important. Unknown	Unknown	Significant
	Human-Derived Bacteria	Unknown but unlikely	Unknown but unlikely	Unknown but unlikely	Significant
	Viruses	Unknown but unlikely	Unknown but unlikely	Unknown but unlikely	Significant
	Anthropogenic BOD Loadings	Significant	Significant	Significant	Significant
Overall Significance		High	High	High	Potential for problems. Unknown
Additional Comments		Significant affect on hypoxia. Succession—increased nutrients. Dealt mostly with canals. Indicator of change in community structure and amount. Circulation and prevention of funneling of organic material into canals.	Related to rain, temp, light and other variables. Indicator of severity of nutrients. Discussion is regarding phytoplankton (no information on zooplankton or ichthyoplankton).	Recycling seagrass wrack can lead to eutrophication.	*Species specific. Because no adequate sewage treatment, potential exists for severe health problems.

Nearshore and Back Country Waters Assessment — Task 5 (continued)

		PROBLEMS/ISSUES			
		NEARSHORE		BACK COUNTRY	
		Increased Epiphyte Growth	Increased Chlorophyll	Increased Epiphyte Growth*	Increased Chlorophyll*
Temporal Consideration (Seasonal - Historical)		Seasonal (Summer) Increased over last decade	Seasonal (severe spikes with rain events)	Seasonal (Summer) Increased over last decade	Seasonal (severe spikes with rain events)
Spatial Consideration		Widespread	Widespread Chronic	Widespread	Widespread Chronic
Trend		Worsening	Worsening	Worsening	Worsening
Severity		Slight	Slight	Slight	Slight
Certainty		Possible	Possible	Possible	Possible
Water Quality Related?		Certain	Certain	Certain	Certain
WATER QUALITY PARAMETERS	Temperature	Slight—Moderate	Slight—Moderate	Slight—Moderate	Slight—Moderate
	Nutrients	Significant	Significant	Significant	Significant
	Salinity	Slight	Slight	Slight	Slight
	Turbidity	Significant	Significant	Significant	Significant
	Toxics/Pesticides	Unknown	Unknown	Unknown	Unknown
	Human—Derived Bacteria	Unknown but unlikely	Unknown but unlikely	Unknown but unlikely	Unknown but unlikely
	Viruses	Unknown but unlikely	Unknown but unlikely	Unknown but unlikely	Unknown but unlikely
	Anthropogenic BOD Loadings	Significant	Significant	Significant	Significant
Overall Significance		Slight	Slight	Slight	Slight
Additional Comments		Significant effect on hypoxia. Indicator of change in community structure and amount. Sewage spills.	Related to rain, temperature, light, and other variables. Indicator of severity of nutrients. Discussion is regarding phytoplankton (no information on zooplankton or ichthyoplankton).	*All anecdotal evidence (no data). Significant effect on hypoxia. Indicator of change in community structure and amount.	*All anecdotal evidence (no data). Related to rain, temp, light and other variables. Indicator of severity of nutrients. Discussion is regarding phytoplankton (no information on zooplankton or ichthyoplankton).

Spills and Hazardous-Materials Assessment — Task 6

	PROBLEMS/ISSUES				
	Small Vessel Spills (Marine)*	Small Facility Spills (Landbased)*	Illegal Dumping Marine-Landbased*	Catastrophic Tanker Spills*	Tanker Truck Spills*
Temporal Consideration Seasonal-Historical	Year-round Past/Current	Year-round (marinas, auto fueling facilities) Past/Current	Year-round Past/current	Year-round 2 in last 16 years.	Year-round 2 in last 10 years
Spatial Consideration	Widespread Nearshore, fueling	Widespread (Marinas, fueling facilities)	Widespread	Isolated—offshore (link to climate conditions)	Isolated—highway.
Trend	(More reported) Worsening	(More reported) Worsening	Worsening	Improving—better (likelihood is decreasing)	Better
Severity	Severe—locally Overall—unknown	Severe—locally Overall—unknown	Local—High Overall—unknown	High in FKNMS	Locally severe
Contingency Plans	Low—low "-"	Low "+"	NA. Coast Guard and State response high.	Sanctuary-specific. A contingency plan is needed.	Good. Response time a problem.
Water Quality Effect[a]	Local—toxic Overall—unknown	Local—toxic Overall—unknown	Local—High Overall—unknown	High, if spill reaches FKNMS	Severe locally. Highly toxic compounds.
Overall Significance	High	Moderate	Overall—High	High	Moderate
Compliance/ Enforcement	Low authority exists, not enough manpower	Low	Compliance—very low Enforcement—improving with Coast Guard, State manpower declining	Moderate—High	Moderate—High
Major Constituents	Diesel, gas, bilge	Diesel, solvents, gas, pesticides, used oil, paint-related material	Marine—petroleum products Land—paint solvents	Diesel, blends of fuel, heavy fuels, hazardous materials, crude.	Diesel, gas, hazardous material.
Risk	High	High	Moderate	Low	Moderate
Additional Comments	*≤5000 gal fuel or cargo. A lot of spills are unreported. Need more information. Aircraft downings—source.	Many spills unreported. Runoff from boat yards and paint scraping. Need more information (Keys-related).	*>5000 gal fuel/cargo, large vessels. Quality and quantity of substances unknown. Need more information (Keys-related).	*Major spill >10,000 gal inland >100,000 gal offshore. Usually occurs outside FKNMS but may reach it. Need information (Keys-related).	*Includes tractor trailers. Need more information (Keys-related).

[a]Biotoxicity, physical damage, bioaccumulation, other.

Spills and Hazardous-Materials Assessment — Task 6 (continued)

	PROBLEMS AND ISSUES				
	Effects of Dispersant Use	Bioremediation	Leachable Toxics (CERCLA + RCRA Sites, Underground Storage Tanks)	Boat Scraping	Ruptured Bulk Tanks and Pipelines
Temporal Consideration Seasonal-Historical	Seasonal impact to habitats	NA	Year-round Past	Year-round with seasonal peaks. Past/Current	Year-round
Spatial Consideration	Isolated-offshore	NA	Isolated	Isolated Site-specific	Isolated Site-specific
Trend	Better understanding	NA	Better	Unknown	Better
Severity	Better offshore. Slight—tradeoffs	NA	Moderate	Unknown	Moderate—High
Contingency Plans	Low. Needs work	NA	Site-dependent Low—High	NA	Moderate
Water Quality Effect[a]	Tradeoffs Various effects	Potential effect of adding nutrients is low	Unknown, but significant	High	Probable
Overall Significance	High	Unknown but unlikely	Need information on heavy metal impacts	High	High
Compliance/ Enforcement	NA	NA	Low-High Site dependent	Unknown	Moderate—High
Major Constituents	Proprietary Constituents (9527)	NA	Variety of heavy metals, PCBs, insecticides and pesticides	Metals	Jet fuel, diesel, various petroleum products
Risk	Risk of using it is low.	NA	Unknown	High	Moderate
Additional Comments	Larval effects. Tradeoffs. Need information. Need preapproval to use. Need to stockpile dispersants. Planes available.	Interim guidelines. Use not as time constrained as with dispersants.	Need information on heavy metal impacts on nearshore waters. Runoff from boat yards/boat paint scraping.		

[a]Biotoxicity, physical damage, bioaccumulation, other.

APPENDIX C

DESCRIPTIVE TERMS FOR MATRIX ANALYSIS

Temporal Consideration

Seasonal

- Winter, Spring, Summer, Fall-Duration

Historical

- Recent, Past (Years), - Duration

Spacial Consideration

- Widespread, moderate, isolated, unknown - specific

Trend

- Worsening, Same, Better, Unknown

Severity

- High, Moderate, Slight, Unknown

Certainty

- Known, Suspected, Possible, Unknown

Water Quality Related?

- Probable, Possible, Unlikely, Unknown

Temperature, Nutrients, Salinity, Turbidity, Toxics/Pesticides, Bacteria, Viruses, Dissolved Oxygen

- Significant, Moderate, Slight, Unknown

Overall Significance

- High, Moderate, Slight, Unknown

Contingency Plans

- High, Medium, Low, Adequacy

Compliance/Enforcement

- High, Medium, Low, Adequacy