4.0 CHARACTERIZATION AND CLASSIFICATION OF RESIDENTIAL CANALS RELATING TO WATER QUALITY

4.1 INTRODUCTION

The impact of residential canals on the ecology of the Florida Keys environs can best be appreciated by understanding what the environment was like prior to canal construction. South Florida's geological processes represent a unique carbonate sedimentary environment. The geological history and range of sedimentary processes are unlike most other coastal and island environments (see review by Chiappone 1996; Hoffmeister 1974). Two features of the Florida Keys challenged humans through history: 1) the islands were separated by creeks and channels that needed to be crossed, and 2) the islands were low-lying with large areas of emergent coastal wetlands (e.g. mangroves) surrounded by shallow waters. Early in the 20th century, both problems were addressed by the construction of a railroad and massive dredging projects to create harbors and waterways (see review by Lott et al.1996). Shorelines were primarily altered to improve access by ships and barges. Canal construction was an engineering solution to the limited natural harbors and waterways of the Florida Keys as well as a need to generate fill to raise the land for development.

Dredging was a relatively easy solution in the soft carbonate rock of the Keys, but the carbonate geology of the Keys makes these islands especially vulnerable to ecological perturbations (see Mee 1988, LaPointe and Clarke, 1992). Dredging of residential canals and marinas represents a massive landscape-scale change to the coastal ecology of the Florida Keys in both alteration of natural coastal processes, and the introduction of high flux rates for both organic matter and inorganic nutrients to canal and nearshore waters (**Figure 4-1**). The natural process of recycling matter and energy in the coastal ecology was removed when coastal wetlands and other natural communities were removed. In addition, development added new sources of nutrients in the form of sewage, fertilizers and exotic plants along canals. In addition, canals served as a sink for sea-based loading from dead seagrass flotsam. The design and construction of individual canal systems is **one** contributing factor to nearshore environmental degradation in the Florida Keys. Therefore, understanding how canal design contributes to nutrient-loading can help identify mitigation options

Figure 4-1: Photograph of dredging finger canals in the Florida Keys

Islands are, by their nature, only pieces of a larger whole. Tropical islands integrate ecological processes such as nutrient flux across the land-water interface. Fluxes of nutrients from land to sea, and vice versa, are in critical balance. The relationship between biological production (ecosystem function) and diversity has become a central focus of environmental science, and must be fundamentally linked to nutrient cycles (see review by Loreau et al, 2001). Canals can be viewed as a major source of disrupting natural nutrient fluxes in the coastal environment, and a causal agent in nearshore eutrophication. Coastal eutrophication has been linked to decline in the health of corals, and changes in the marine environment in Florida as well as the wider Caribbean for decades (Littler et al 1992, Dustan and Hallas 1987, Law and Redalje 1982, LaPointe et al. 1994)

Nearshore water quality is naturally variable, and supports the biological diversity in shallow-water marine communities, like coral reefs. Tropical marine environments are resilient to some intermediate level of perturbation (Connell 1978). Hurricanes and large tropical storms provide an important disturbance regime for meso-scale sediment or detritus transport on and off of the Keys. Human disturbances can amplify the natural range of water quality variables, and in time, produce profound ecological shifts and changes (See Marzalek 1987; Griggs 1995; Griggs and Dollar 1990; Maragoes et al 1985). Island systems are resilient to some threshold of disturbance, but that threshold has potentially been exceeded on most islands in the Florida Keys and the wider Caribbean by anthropogenic activities.

There are three central reasons to be concerned about water quality degradation in the canals.

1.) Poor water quality poses a human health hazard. The direct and indirect seepage of wastewater into canal systems is now known to support human pathogens previously thought not able to survive in marine waters.
2.) Poor water quality poses an ecological threat to nearshore marine environments of the Florida Keys, now protected as Outstanding Florida Waters, and the Florida Keys National Marine Sanctuary, and
3.) Poor water quality poses an aesthetic problem with fish kills, bad smells and accumulation of rotting algae or seagrass. Poor water quality makes living along a canal less desirable.

What are some of the symptoms of water quality degradation in canals? Water quality in residential canals begins to degrade with two processes:

1.) Lack of circulation or restricted circulation with nearshore waters, and
2.) Chronic or acute build-up of organic material or inorganic nutrients, primarily from land sources.

Inputs into the canals come from organic materials (such as leaves, grass clippings, fertilizers), seepage from septic tanks/cesspits, stormwater runoff and soil erosion. Everything that is on (or in) the ground in the Florida Keys has the potential to end up in the canals. Water quality degradation is noticed by the residents and general public by certain symptoms, and can be generally described as:

- Darkening of the water, with inability to see the bottom
- Foul smell of the water, especially during the summer or after a storm
- Periodic fish kills, especially during the summer or when storms cause water column turn-over,

- Lack of marine life in the canal, except in the top meter of the water column, and
- Algal scum or algal blooms inside the canal

Some water quality degradation includes the seasonal buildup of seagrasses and algae blown into the canal, particularly canals in the Lower Keys facing north into Florida Bay.

Changes in coastal environments are readily identified and documented, but rarely linked to a specific and single activity. The development impacts on nearshore marine habitats only amplify the barriers to successful reproduction, recruitment and growth of coastal species, including corals and fishes. Canal systems are now a permanent part of the Keys landscape, thus a better understanding of how the canals function along various types of coastal environments and on different islands (keys) is critical to examining remediation and treatment options. The characterization of canals addresses the issues of nutrient loading and circulation along high energy (exposed) to low energy (protected) shorelines.

4.2 OVERVIEW OF BASIS OF CHARACTERIZATION OF RESIDENTIAL CANALS CLASSIFICATION

The water quality in canals will be worse than nearshore water due to the physical attributes and construction of the canals. Residential canals can degrade nearshore water quality for the following reasons:

- The canal and associated development destroys coastal wetlands and coastal vegetation that are critical to protecting nearshore water from pollutants and sediment
- Canals can be deeper than adjacent natural nearshore waters, and thus serve as a sink or trap for accumulated organic matter from plants, animal waste or detritus, and
- Canals receive groundwater seepage, and thus can easily be contaminated by residential sewage disposal systems.

The loss of coastal vegetation communities, particularly mangroves, combined with the disruption of the freshwater lens and ground water flow leads to increased organic matter and nutrients added to the nearshore waters. The size, location and design of the canal all contribute to the degree to which nutrient loading occurs. Canals were organized in a hierarchical fashion to capture the canal physical attributes most likely to impact water quality.

There are two main processes that affect the ways that canals are likely to experience water degradation: pollutant loading and amount of flushing or circulation. High pollutant loading and limited circulation leads to high water quality degradation. The hierarchy encompasses physical attributes that characterize the extent and severity of both of these processes.

The hierarchy was organized with the highest level (Level I) based on size and shape. The larger the canal, the greater is the potential for water quality degradation in surrounding waters. In general the larger the size of the canal the poorer will be the circulation. The second level of the hierarchy deals with wind and wave energy of the adjacent shoreline, and orientation of the canals. Level II attempts to capture the potential for natural circulation in the specific location of the canal. Level III looks at the specific construction of the canal. Canals built on filled wetlands are likely to have poorer water quality than canals built by dredging uplands. Areas surrounding

canals constructed of fill will not retain nutrients and will allow a greater pollutant loading to the canal waters. Additional attributes that are incorporated as modifiers include number of mouths, number of convolutions and type of canal outfall (eg. spoil, channel, shallow nearshore). Level IV looks at the degree of development which would influence the amount of pollutant loadings into a canal.

There are certainly exceptions to the hierarchy, but the hierarchy is designed to set priorities and identify water quality degradation in the absence of time-consuming and expensive water sampling programs.

4.3 DETAILED DESCRIPTION OF CANAL CLASSIFICATION

LEVEL I. SIZE AND SHAPE OF RESIDENTIAL CANALS

Size is considered to be the most easily identified and important attribute influencing natural flushing and therefore potential for water quality degradation. The size of the canal is evaluated by ***AREA*.** Area was calculated by the digitized outline of the canal, and is a proxy measurement for the total volume of water incorporated in the canal. Volume is also presented in the GIS attribute table, but the majority of canal depths were not known, thus were estimated as the average permitted canal depth. Since depth is generally the smallest dimension in the volume calculations, it is omitted for this initial sorting. It is sufficient to say that canal depth is critical to its function and design, and more detailed depth and sediment characteristics of the canals are needed in the development of treatment options for individual canals.

UNITS of area are presented in English units such as feet, miles and acres, with the metric units (e.g. meters, kilometers and hectares). Area of the canal is a critical parameter and the units of acres and hectares are given as a proxy for canal size (volume). The average permitted depth of the residential canal systems is 15 feet (4.6 meters), but actual depths vary greatly from canal to canal, and depths can change over time with accumulated sediments, thus area remains a more reliable proxy for canal size until a better depth dataset is developed from ground surveys. **For reference, a (1) hectare canal area is 2.47 acres, and this represents about 2,200 cubic meters of water (just over half million US gallons).** Residential canals are characterized at the highest level of the hierarchy based on area and maximum length.

Table 4-1: Summary of Residential Canal Area Statistics.

Number of canals	**481**
Mean area in acres	**3.21**
Mean area in hectares	**1.30**
Standard Deviation	**2.88**
Maximum area in hectares	**20.42**
Minimum area in hectares	**0.044**

The mean canal size is 3.21 acres (1.30 hectares), but a few very large canals skew this number. The median size of a canal is only 1.3 acres (0.53 hectares). Most canals are very small with a single mouth.

The **MAXIMUM LENGTH** characterizes the SHAPE of canals; maximum length, in meters, is the distance from the mouth to the farthest point in the canal. Canals can be long and narrow, finger-like in shape or more compact and basin-shaped. Maximum length can be used as a general indication of circulation in the canal; the longer the distance of the canal, the less circulation is likely to occur. Individual canals may have mitigating factors such as culverts that enhance circulation, but this classification begins with the simple canal configuration.

TABLE 4-2: SUMMARY OF RESIDENTIAL CANAL LENGTH STATISTICS

Number of canals	**481**
Mean length in feet	**1,218**
Mean length in meters	**375**
Standard Deviation	**371**
Maximum length (meters)	**3229**
Minimum length (meters)	**48.5**

The mean canal length is 1,218 feet (375 meters), and canal lengths are more widely distributed than areas. There are many canals that tend to be narrow, and finger-shaped; thus prone to water quality degradation.

The combination of SIZE and SHAPE allows the characterization of canals into 2 basic categories. The ratio of AREA to LENGTH can provide a general index of a canal as "finger-shaped" vs. "basin-shaped". Some basic assumptions are made about the general water quality performance of these two types of canals:

- **"Finger-shaped" canals will have the potential for greater nutrient loading** from the shoreline, and will tend to have more shoreline per unit volume than "basin-shaped canals"
- **"Finger-shaped" canals will likely have poorer circulation** from both the restrictions of the waterway, and the limited wind-driven circulation that may occur in a more open body of water (e.g. basin).

Figure 4-2: Examples of "finger-shapped" (Rock Harbor 77) vs. "basin-shaped" canals (Rock Harbor 71)

Figure 4-2 illustrates examples of "finger-shapped" vs. "basin-shaped" canals. The area to length ratios of the canals can be used to characterize the shape of canals. Long, narrow finger canals have a low area to length ratio, and are sensitive to both poor circulation and land-based loading of nutrients. These "finger'shaped" canals will have a poorer water quality performance compared to a comparably sized "basin-shaped" canal.

Graphs of area to length (**Figures 4-3 a, b and c)** illustrate the distribution of canals by shape. Most canals are very small, and clustered near the origin. There are only 10 out of 481 canals that are "Jumbo" in size, that is a canal greater than in area 10 hectares or 24.7 acres (100,000 square meters).

JUMBO Canals

- Basin-shaped are wide canals at Ocean Reef (#2, 7), or Lower Matecumbe (#185), Port Largo Canal system (#55)
- Finger-shaped are Big Pine Key (#388, #382), Key West (#612); kilometer or more to mouth, relatively small areas to length ratio

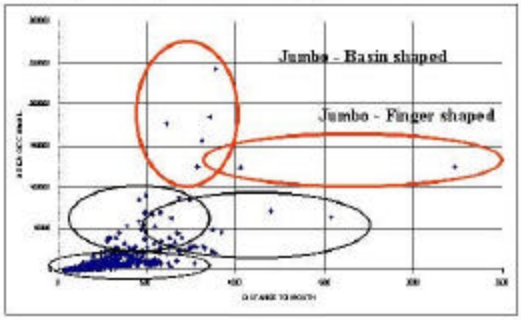


Figure 4-3a: Graph illustrating area to length distribution in the Keys canals (**Jumbo**)

LARGE Canals

- Basin-shaped: Sombrero Key (#293), Plantation (#158, #157), Boca Chica (#572),
- Finger-shaped: Sugar Loaf (#465), Marathon (#235, 234), Very long, narrow canals, usually dredge construction.

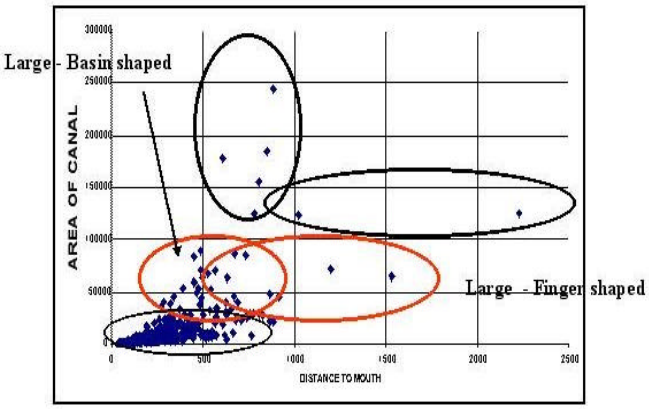


Figure 4-3b: Graphs illustrating area to length distribution in the Keys canals (**Large**)

MEDIUM & SMALL CANALS

- Most canals less than 2 hectares in size, less than 200 meters in length.
- Most are "fill" construction, built on coastal wetlands.

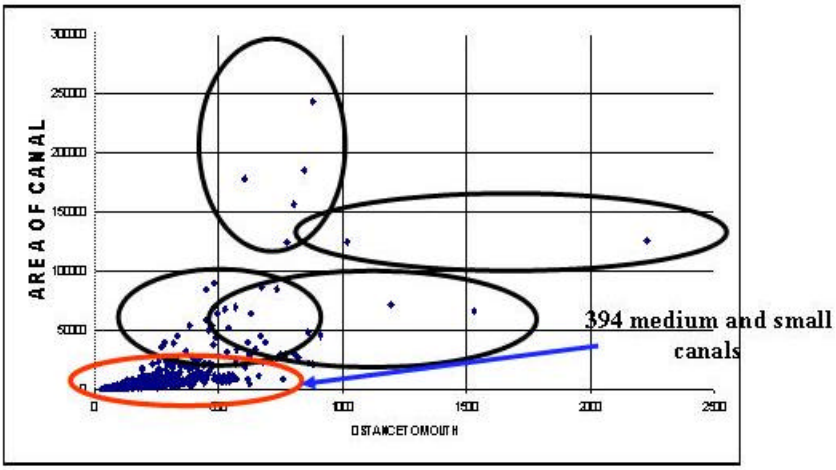


Figure 4-3c: Graphs illustrating area to length distribution in the Keys canals (Medium and Small)

TABLE 4-3: CHARACTERISTICS OF SIZE CATEGORIES OF CANALS
UNITS GIVEN IN HECTARES AND METERS

SIZE Category	Number of canals	Mean Area (hectares +/- standard deviation	Mean Length (meters +/- standard deviation)	Range of RATIO Area/Length
A. Jumbo – over 10 Hectares	**10**	**14.4 +/- 3.6**	**1892 +/- 808**	**4.0 to 15.6**
B. Large – less than 10 to over 2 hectares	**76**	**3.5 +/- 1.7**	**781 +/- 312**	**1.6 to 32.3**
C. Medium – 2 hectares to 0.6 hectares	**135**	**1.1 +/- 0.3**	**411 +/- 178**	**0.3 to 21**
D. Small – less than 0.6 hectares	**260**	**0.3 +/- 0.1**	**176 +/- 94**	**0.7 to 5.4**

LEVEL II: WAVE AND WIND ENERGY REGIME

A classification of "high", "medium" or "low" was developed relating to the wind and wave energy adjacent at the mouth of the canal system. The energy regime incorporates the orientation of the mouth of the canal, the adjacent body of water, depth and exposure to prevailing winds or storm events. The energy regime is an attempt to capture the likelihood of wind-driven flotsam or water masses to move into or out of the canal. The input of turbid water and organic material (e.g. seagrass) can impact the water quality of the canal system. Canal mouths opening to high energy shorelines are the most prone to high seaward organic loadings.

High energy shorelines have high wave and wind conditions. This shoreline may be a rocky shore and subjected to winds from both prevailing winds (SE) or from storm/frontal systems (NW to NE). The canal opening is exposed to open water with a long fetch, and frequently receives flotsam.

Residents of the Florida Keys have long reported the problem with flotsam entering canals, with the accumulating seaweed decaying and fouling the waterway (**Figure 4-4**). This has been the largest single water quality complaint from residents of particular canal systems, and has lead to innovative devices called "weed gates" or "bubble gates" to prevent wind-driven flotsam from entering the canal system. One of the predominant problematic conditions is when canal openings along Florida Bay face to the north-northwest-northeast (between 270 and 30 degrees) and are affected by storm/frontal systems. Flotsam may be a problem in many other conditions and is variable seasonally and different for ocean vs. bay side.

Under normal conditions, without dredged canals, this flotsam would have accumulated on the shoreline and would have been an important component of the land-sea nutrient dynamics. Seasonal accumulation of dead seagrass along the shoreline would have provided a food source for wading birds, and a long-term source of nutrients to coastal plant communities. In canal systems, this organic material accumulates in the canals, decomposes, and then sinks. The high BOD (Biochemical Oxygen Demand) of this organic material (algae and seagrass) causes many enclosed water bodies to develop anoxic layers, and increased sedimentation rates in the canal channel. Aesthetically, residents complain of the foul smell, unpleasing site of vegetation accumulation, and loss of clarity in the canal system. The problem of weed accumulation is specific to NE to NW facing canals along open, high-energy shorelines of the middle and lower Keys. This *seaward-input* of organic material is a separate water quality issue from land-based sources of pollutants, and can be mitigated by the maintenance of weed gates, and active flotsam removal.

TABLE 4-4 DEFINITIONS OF SHORELINE ENERGY CATEGORIES

HIGH	MEDIUM	LOW
Definition: High wave and wind conditions prevail on shoreline of canal opening. This shoreline may be rocky shore and subjected to winds from both prevailing winds (SE) or from storm/ frontal systems (NW to NE). The canal opening is exposed to open water with a long fetch, and frequently receives flotsam.	Definition: Moderate wave and wind conditions prevail on the shoreline of the canal opening. Shoreline may be a combination of rocky shore and mangrove shorelines. Canal opening may under certain wind conditions (frontal systems) be filled with flotsam.	Definition: Low wind and wave conditions prevail on the shoreline. Shoreline is/was mangrove shoreline or wetland, and canal opening very rarely accumulates flotsam by wind or wave action. The opening of the canal is highly protected by a channel or small embayment
Characteristics: • Canal likely to be dredged from high-energy shoreline. • High wind-driven exchange of water in the canal system. • Canal would tend to "trap" or fill with flotsam like dead seagrass and algae on a regular basis.	Characteristics: • Moderate energy shoreline likely to be or have been mangrove dominated • Medium wind-driven exchange of water in canal system only with extreme weather conditions • Canal can fill with flotsam only occasionally	Characteristics: • Low energy shoreline outside the canal system • Little wind-driven exchange of water between canal and adjacent marine environment. • Little to no flotsam accumulates in the canal system
Example: 150 Lower Matecumbe	Example: 280 Little Torch Key	Example: 74 Rock Harbor

Examples of each type of shoreline are shown in **Figures 4-5** through **4-7**. **Figure 4-5** shows an example of a HIGH energy shoreline for a canal (Lower Matecumbe 150). Canals opening onto a high energy shoreline are likely to accumulate seagrasses and seaweed. The accumulated flotsam can severely degrade canal water quality and requires manual removal or installation of a weed gate or bubble curtain.

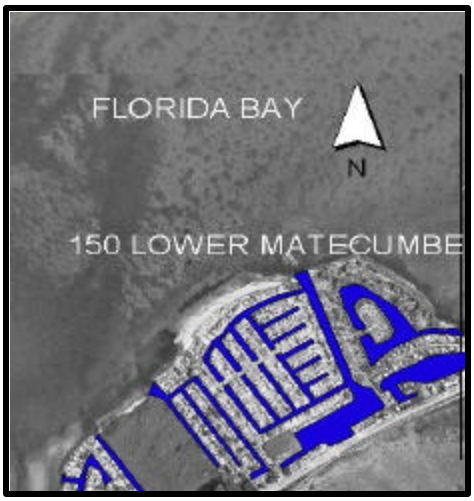


Figure 4-5: Example of a HIGH Energy Shoreline (Lower Matecumbe 150)

Figure 4-6 shows and an example of a MEDIUM energy shoreline for a canal (Little Torch Key (280). Canals opening onto a medium energy shoreline are likely to accumulate seagrasses and seaweed.on a chronic basis, but in smaller quantities. The accumulated flotsam adds to chronic water quality degradation

Figure 4-6: Example of a MEDIUM Energy Shoreline (Little Torch Key (280) with Pine Channel adjacent to the mouth

Figure 4-7 presents an example of a LOW energy shoreline (Rock Harbor 74). Canals opening onto a protected mangrove creek or small embayment are not likely to accumulate seagrasses and seaweed. These canals have less natural circulation, and receive organic material and nutrient loadings that are primarily from land-based sources.

Figure 4-7: Example of a LOW Energy Shoreline (Rock Harbor 74)

LEVEL III: CANAL CONTRUCTION

There are several attributes that relate to canal construction. These include the original natural shoreline conditions and lithology that influences the fill materials and construction methodology, the number of convolutions, the number of mouths, and the nature of the outfall.

Canal Construction

The term "**residential canals**" refers to man-made waterways that intrude into the natural shoreline. The natural shoreline in the Florida Keys was either seagrass meadows, mangrove wetlands, or low-relief rocky shores (classification of coastal wetland and deepwater habitats is described in Cowardin et al 1979). The construction of canals included both dredging out the water way from upland areas as well as the filling of coastal wetlands (mangroves). The construction of the canal system may impact circulation and nutrient retention; the assumption being that canals constructed of fill will not retain nutrients and will have a greater potential for water quality degradation.

Old charts and aerial photographs were used to determine whether a particular canal system was mostly upland rock dredged or mangrove filled. Many canal systems are a combination of the two (dredge and fill development). The classification was based primarily on the construction of the seaward half of the canal system, particularly near the mouth or opening of the canals.

Big Pine Key Canals 297, 298, 299 and 300 (provide an example of straight finger canals that were dredged out of limestone into the upland pineland communities of Big Pine Key (**Figure 4-8**). The lots required very little if any additional fill. Key Largo Canal 57, adjacent to Pennekamp Coral Reef State Park, represents a canal lot that was developed by the filling of mangrove wetlands. The fill generated from the canals was used to raise the elevation of adjacent lots for development. Homes along these canals are required to be constructed on stilts for flood protection.

Figure 4-8: Dredged canals on Big Pine Key (Big Pine 297, 298, 299, and 300)

Figure 4-9: Filled canals on Key Largo (Key Largo 57)

Dredged canals that penetrate the upland areas of the Keys are often cut into carbonate rock, have hard limestone perimeters, and do not require bulk-heading (**Figure 4-10**). Dredging through these areas can damage freshwater lenses (ground water) and impact island hydrology. Fill canal systems that are created on the soft sediments of coastal wetlands often require retaining walls (bulk-heads) to maintain the canal and prevent shoreline erosion. Canal shorelines often must be maintained to prevent the collapse of the canal wall, and filling of the canal itself (**Figure 4-11).** Undeveloped canals can also be colonized by invasive exotic plants such as the Australian pine (Casaurina spp.) (**Figure 4-12**).

Figure 4-10: Photo of canal with limestone walls (Adams waterway)

Figure 4-11: Canals with "bulk-heading" along the perimeter of the canal (Key Largo 43, 45 and 47)

Figure 4-12: Filled canal – undeveloped

Number of Convolutions

The number of convolutions or turns in the canals can greatly influence the flushing of the canal. The number of convolutions was scored by counting the number of 90 degree turns in the canals, giving each a score of "1". If there was a 45 degree turn, it was scored a 0.5. The greater the number of convolutions in the canals, the poorer the water quality performance of the waterway is likely to be. This canal system (Key Largo 60) has 11 convolutions.

Figure 4-13: Illustration of Port Largo showing how the convolution numbers were calculated for the data base

Canal Mouths and Outfall:

Residential canals were attributed by the number of mouths or openings in a single canal. The more openings in a canal, the greater the circulation within the canal system is likely to be. The mouth of the canal can open into three different "conditions" of adjacent water. The depth of the mouth sill, and its configuration can hinder or facilitate turnover within the canal. "Canal Outfall" describes the conditions of the adjacent waters, and are described as follows:

TABLE 4-5 DEFINITION OF CANAL OUTFALLS

Dredged	This outfall classification has adjacent waters that are highly modified with dredged navigation channels, basins or fill islands. Marine environments likely to be highly disturbed. An example would be areas north of Key West where shorelines are filled, Salt Pond Keys are filled for development, and navigation channels constructed. This also includes the dredging along the shoreline, as seen along the western shore of Big Pine Key, to facilitate moving of watercraft to deeper water channels. Also includes canal systems that open into marinas or dredged basins.
Channel	The adjacent marine environment is a natural channel or tidal creek, usually between two islands, or a natural mangrove creek within an island-mangrove complex. These channels provide some amount of tidal flow and circulation.
Shallow Nearshore Environments	Canal opens to more or less natural shoreline with nearshore very shallow marine habitats – including hard bottom and seagrass areas. No obvious alterations to the seabed in the areas outside of the canal mouth. Often the access to these canals can be restricted during very low tides, and in the absence of a dredged channel, propeller scaring can be seen on the seabed.

LEVEL IV: DEVELOPMENT

Level IV includes a variety of factors relating to pollutant loading into a canal system. The degree of development was assumed to correlate with the potential degree of inputs including septage, storm water runoff and other human influences that might degrade water quality. The degree of development was based on visual observation of the percentage of the shoreline that was developed using the 1998 aerial map. The assumption is that the greater the housing density in the canals, the poorer the water quality performance of the waterway is likely to be. Water quality degradation is also impacted by the amount and type of vegetation adjacent to the canal systems. All other factors being equal, a canal system populated by numerous small homes with pea-rock yards is likely to have much poorer water quality that a canal with few homes vegetated with native plants.

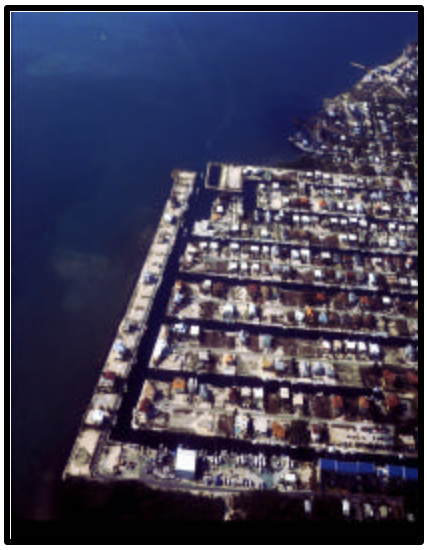


FIGURE 4-14: Example of highly developed canal (Port Largo, Key Largo 60)

Exotic invasive plant species such as the Australian pine can also contribute to water quality degradation by restricting the growth of other shrubs, eroding the shoreline and dropping leaf litter into the canals.

4.4 HIERARCHY OF THE CLASSIFICATION OF THE FLORIDA KEYS

A classification hierarchy was developed to assist in organizing all of the canal attributes. The levels are not based strictly upon importance. Level I, size and shape, is the most influential to the water quality degradation. However, other attributes are also important, some more than others in certain canals and different combinations. The canal classification hierarchy is shown below.

LEVEL I: SIZE AND SHAPE
LEVEL II: WAVE AND WIND ENERGY REGIME/ CANAL ORIENTATION
LEVEL III: CANAL CONTRUCTION
LEVEL IV: DEVELOPMENT

TABLE 4-6 HIERARCHY OF THE CANAL CLASSIFICATION OF THE FLORIDA KEYS

LEVEL I	**SIZE**		
	I.A	JUMBO	
	I.B	LARGO	
	I.C	MEDIUM	
	I.D	SMALL	
LEVEL II	**ENERGY**		
	II.A	HIGH	
	II.B	MEDIUM	
	II.C	LOW	
LEVEL III	**CONSTRUCTION**		
	III.A	DREDGE	
	III.B	FILL	
		MODIFIERS	SINGLE MOUTH MULTIPLE MOUTHS NUMBER OF CONVOLUTIONS CANAL OUTFALL - SPOIL - CHANNEL - SHALLOW NEARSHORE - PLUGGED
LEVEL IV	**DEVELOPMENT**	% DEVELOPED as interpreted from aerial photos	
	IV. A	Low < 30%	
	IV.B	Medium 30-70%	
	IV.C	High > 70%	

The GIS Attribute Table includes the classification assigned to each canal. A hard copy of the Attribute Table is included in **Appendix B.4** and also included in the 100% GIS on the attached CD ROM.

4.5 CANAL WATER QUALITY DESIGNATION

The canal hierarchy was created to capture the design characteristics of the canals most likely to impact water quality. The hierarchy is organized with the highest level (Level I) based on size and shape. The larger the canal, the greater is the potential for water quality degradation. The assumption is that large, finger-shaped canals are inherently more prone to water quality degradation than small basin-shaped canals. Level II of the hierarchy deals with wave and wind energy of the adjacent shoreline, and orientation of the canals. A canal along a high or medium energy shoreline, with an adjacent channel would likely have better circulation and turnover of water than a canal created in an enclosed embayment. Level II attempts to capture the potential for natural circulation in the specific location of the canal. Exceptions to this relate to canals that

have a natural orientation that allow high inputs of seaward loading into the canals. These canals are separated out by use of the modifier of canal mouth orientation.

Level III looks at the canal construction. Canals built on wetlands that were filled are assumed to have poorer water quality than canals that were built by dredging rock uplands. This assumption is based upon fill having a higher percolation rate with resultant greater leaching of pollutants into the canal than in natural rock areas. Additional modifiers that relate to canal construction that affect water quality are the number of mouths and number of convolutions of the canal. Canals with multiple mouths that are straight canals will have better water quality than canals with fewer mouths and a high number of convolutions. The outfall environment at the canal mouth is important. Canals that open into a tidally-flushed channel are likely to experience better water quality than a canal that opens into an enclosed bay.

Level IV looks at specifics of pollutant loading in the canals based upon the degree of development which includes sewage treatment inputs as well as storm water runoff and other human influences that might degrade water quality. Higher density housing will, in general, have poorer water quality.

Based upon the classification system and the potential for water quality degradation, a water quality classification or designation was applied to each canal. The anticipated water quality designations were: “POOR”, “FAIR” and “GOOD”. This water quality designation recognizes that for most canals, water quality will never be comparable to nearshore waters of the Florida Keys. Sections 4.5 and 4.6 define the comparison of the canal water quality to the nearshore waters and compares the classification prediction of water quality to actual water quality collected in canals across the Keys.

4.6 ANALYSIS OF CANAL CLASSIFICATION AND AVAILABLE WATER QUALITY DATA

Section 2 of this report described the extensive compilation effort undertaken to determine the available water quality data collected in Keys canals. A summary of the available water quality data grouped by canal classification is presented below.

Certain assumptions are made in the canal classification scheme. The largest canals built on porous fill along low-energy shorelines with high housing density would be expected to have the worst canal water quality. Within a given size category, high energy, rock dredged canals would be expected to have the best potential for good water quality performance. Low energy, fill canals would be expected to have the worst water quality performance. These assumptions were tested against an inventory of available water quality data.

TABLE 4-7: ASSUMPTIONS ON THE EXPECTED WATER QUALITY OF CANALS BASED ON SIZE AND CONSTRUCTION

	LEVEL III. A Dredged Rock	LEVEL III. B – Filled Mangroves
LEVEL II A-HIGH	***BEST water quality in the size group***	
LEVEL II B – MEDIUM		
LEVEL II C - Low		***WORST water quality in the size group***

NOTE: In the hierarchy, there are never any "Low energy, dredged canals". This is because low energy shorelines tend to promote the accumulation of sediment, and typically support mangroves, mudflats or low-energy beaches. Rocky shore environments are restricted to high to moderate energy shorelines. A summary of the distribution of canals by the classification is presented with an indication of the number of water quality studies available. Ideally, we would like to have long-term water quality information from a large number of canals in each size category. The water quality data should reflect tidal, seasonal and even interannual variability in important parameters such as temperature, salinity, dissolved oxygen, turbidity, chlorophyll a, and inorganic nutrients.

TABLE 4-8A: LEVEL IA: JUMBO CANALS (10 CANALS TOTAL)

A total of three canals have Bay Watch stations, and a good temporal series of water quality measurement

	LEVEL III. A Dredge	LEVEL III. B – Fill
LEVEL II A-HIGH	1	1
LEVEL II B –MEDIUM	1 (with WQ data)	6 (2 with WQ data)
LEVEL II C – Low	0	1

TABLE 4-8B LEVEL IB: LARGE CANALS (76 CANALS TOTAL)

A total of ten canals have Bay Watch stations, and a good temporal series of water quality measurement

	LEVEL III. A Dredge	LEVEL III. B - Fill
LEVEL II A-HIGH	1	11 (1 with WQ data)
LEVEL II B –MEDIUM	9	31 (8 with WQ data)
LEVEL II C – Low	0	24 (1 with WQ data)

TABLE 4-8C: LEVEL IC: MEDIUM CANALS (135 CANALS TOTAL)

A total of twelve canals have Bay Watch stations, and a good temporal series of water quality measurement

	LEVEL III. A Dredge	LEVEL III. B - Fill
LEVEL II A-HIGH	1	8 (1 with WQ data)
LEVEL II B –MEDIUM	26	58 (10 with WQ data)
LEVEL II C – Low	0	42 (1 with WQ data)

TABLE 4-8D: LEVEL ID: SMALL CANALS (259 CANALS TOTAL)

A total of six canals have Bay Watch stations, and a good temporal series of water quality measurement

	LEVEL III. A Dredge	LEVEL III. B - Fill
LEVEL II A-HIGH	4	9
LEVEL II B –MEDIUM	58 (1 with WQ data)	102 (5 with WQ data)
LEVEL II C – Low	0	86

Small canals are the most under-sampled group, with the least amount of water quality sampling information for the number of canal systems. Since small canals are the most numerous, and are most likely to have affordable mitigation and treatment options, small canals should be targeted for more water quality monitoring. Small canals are not likely in larger developments or neighborhoods, and thus are not likely to have the residents that both request or participate in programs such as Bay Watch.

The water quality designation assigned to each canal developed from the classification system is shown in the Attribute Table in **Appendix B.4** and included in the 100% GIS Database.

There are certainly exceptions to the classification and water quality designations, but the hierarchy is designed to help set priorities and identify water quality degradation in the absence of time-consuming and expensive sampling programs. The general classification of the residential canals can be matched with appropriate and cost-effective treatments to mitigate the water quality impacts of development in the Florida Keys. **Table 4-9** illustrates two extremes in the classification hierarchy.

TABLE 4-9 EXAMPLES OF CANAL CLASSIFICATION HIERARCHY

	Example of POOR WATER QUALITY PERFORMANCE	Example of GOOD WATER QUALITY PERFORMANCE
Example Canal	PORT LARGO (60 KEY LARGO)	305 SUGAR LOAF KEY
LEVEL 1: SIZE	A. Jumbo canal, 12.4 hectares in area, finger-shaped	D. Small canal, 0.067 hectares in size, single finger, very small, only 52 meters in length
LEVEL 2: ENERGY	Medium energy – mouth facing south-southeast, shallow sill, opens to very shallow nearshore areas, Offshore is Hawk Channel	High energy rock shoreline, canal empties into Bow Channel, opens to shallow nearshore areas but with tidal channel
LEVEL 3: CONSTRUCTION/ OUTFALL	Built on filled mangrove wetlands, canal system with seawalls, one mouth, and a high number of convolutions. Outfall is a shallow, soft bottom seagrass area that is low in energy.	Dredge construction in rock uplands, little fill on adjacent lots, straight canal. Nearshore outfall area is well flushed, and a combination of hardbottom and seagrass.
LEVEL 4: DEVELOPMENT	High development	Low development
WATER QUALITY COMMENTS	This canal poses a particular water quality problem with a combination of residential and commercial development, little vegetated landscape, and high density build-out.	This canal is very small, open to a channel, and likely has a high flushing rate. Lots are vegetated, and few houses along the canal. Not prone to seagrass and weed accumulation. This canal should maintain reasonable water quality performance.

An example of a canal that the classification predicts will have poor water quality is Port Largo (Key Largo 60) (**Figures 4-15 a and b**). Large canals are likely to have restricted circulation and high loading of organic material and inorganic nutrients. This canal is large (30.63 acres; 12.4 hectares), built on filled wetlands, with many convolutions and a single mouth. There is no vegetation buffer along the perimeter of the canal.

Figure 4-15: Example of a canal with POOR Water Quality (Key Largo 60**)**
a) Aerial Photo b) Photograph

An example of a canal that the classification predicts will have good water quality is Sugarloaf 305 (**Figures 4-16**). Very small canals are less likely to have water quality problems. This is a very small (0.16 acres; 0.067 hectares) straight canal, adjacent to a natural channel. This very small canal likely receives natural flushing.

Figure 4-16: Example of a canal with potentially GOOD water quality (304 Sugarloaf).

4.7 EVALUATION OF EXISTING WATER QUALITY DATA IN CANALS

4.7.1 Evaluation Methodology

From a scientific perspective, water quality will be defined by comparing water quality parameters in canals to adjacent nearshore waters. Natural waters have patterns of variability in key parameters such as temperatures, salinity, dissolved oxygen and turbidity. As water quality degrades, these patterns are changed, often to include more extreme values under particular conditions of tides, season or storm events. Degrading water quality is indicated generally by the following changes in parameters:

1.) Strong stratification within the canal, particularly the presence of an "anoxic" or low oxygen zone near the bottom.

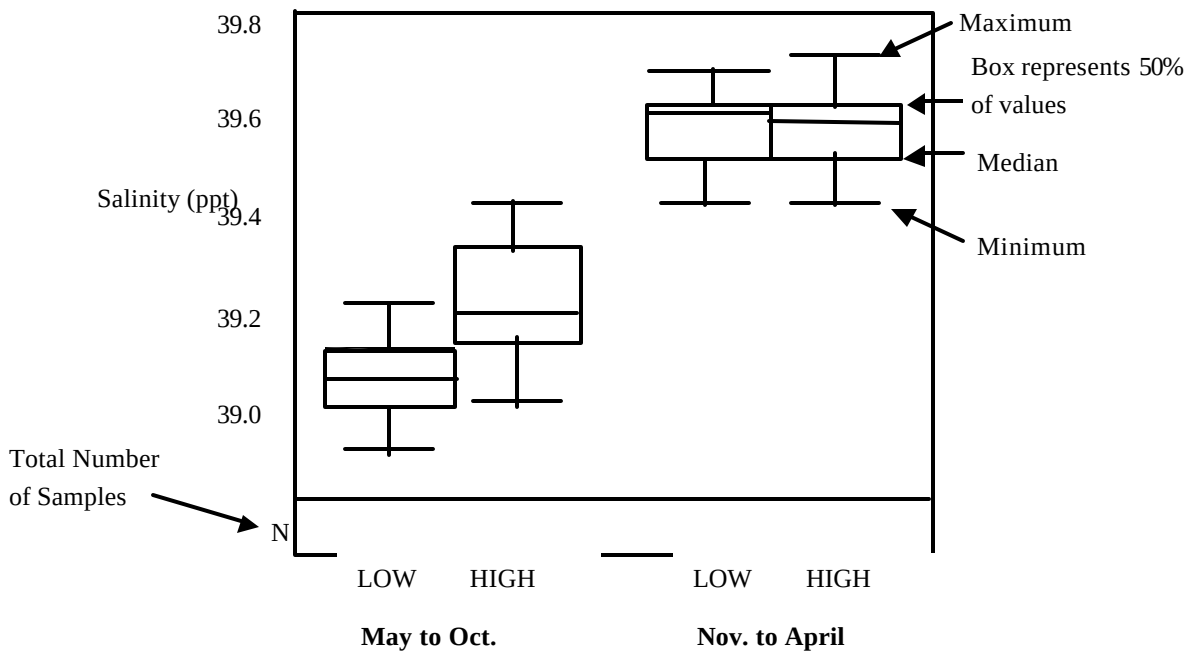
2.) Very high temperatures and very low temperatures within the canal that indicate a limited movement of the water (with pronounced diurnal heating and cooling of the water).

3.) A strong stratification of salinity within the canal, indicating fresh water run-off on the surface, and denser, hypersaline water at the bottom of the canal.

4.) High nutrient content in the water or in the sediment indicating an accumulation of nutrients (eutrophication) within the canal. This phenomenon is often associated with "soupy" looking water, algal blooms, and lack of seagrasses growing on the canal bottom.

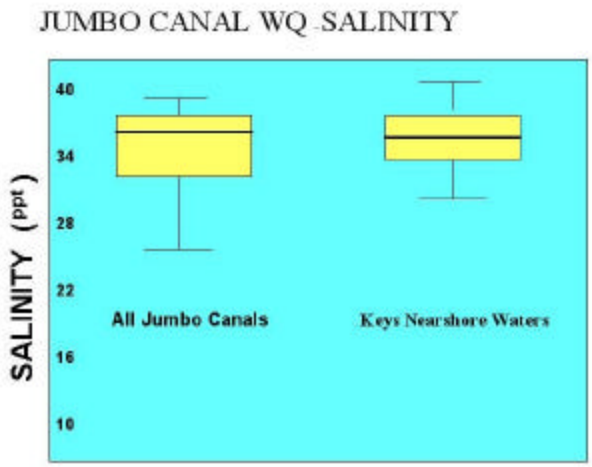
Because natural environments do vary, it is difficult, if not impossible, to characterize a canal water quality status by a single sampling in space or time. Water Quality Performance for residential canals can be compared by creating box plots to visually show the seasonal and tidal variability for certain water quality parameters. The box plots can indicate two aspects of water quality: the central tendency of a parameter, and the range of variability of these parameters. For example, the following box plot shown in **Figure 4-17** illustrates the difference in salinity between seasons and tides for one canal system (55 Key Largo) in the Florida Keys. Salinity is slightly higher in the winter (drier months) than in the summer. There appears to be good circulation in this small canal with tidal mixing and change in salinity values between high and low tides.

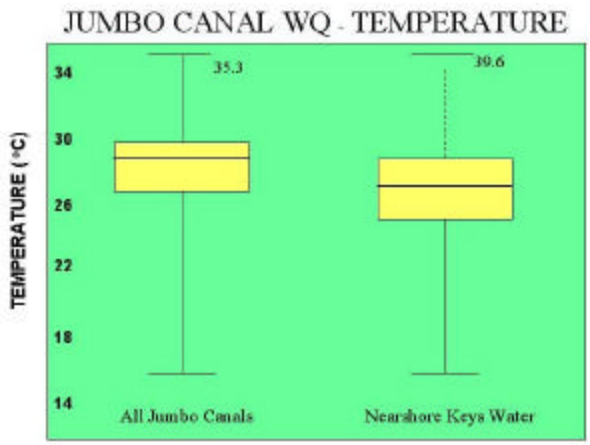
FIGURE 4-17 BOX PLOT OF KEY LARGO 55 CANAL

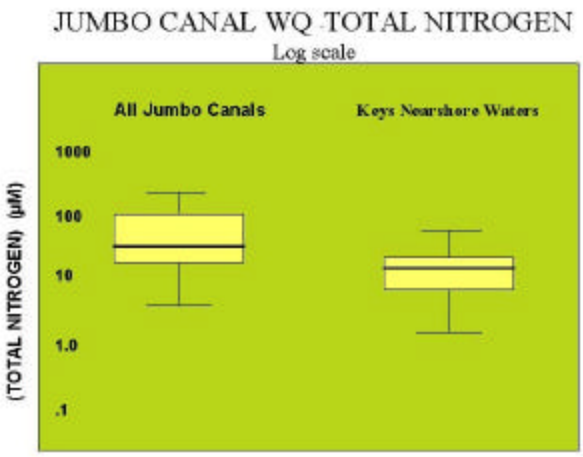


Box plots are used in the Florida Keys National Marine Sanctuary Water Quality Monitoring Program to characterize "clusters" of water quality sampling stations for similarity in water quality parameters. There are less tidal differences in the winter than in the summer. Salinity values appear consistent with salinity values for nearshore Keys waters. Box plots present a more complete picture of water quality performance within a canal, and may be most important with the application of treatment technologies to measure success or improvements in water quality. The box plots assist in understanding the natural variability of the water quality data, and allow evaluation of the changes in water quality due to anthropogenic activity. The limits of the box denote 50% of the values. The "whiskers" indicate 3 standard deviations from the mean. Values greater than 3 standard deviations from the mean are considered outliers. Enough water quality sampling events are needed to cover the tidal cycle, and address seasonal change. The sampling design of the original "Bay Watch" program was ideal as two water samples were collected weekly (one high tide and one low tide during the day) over a period of several years.

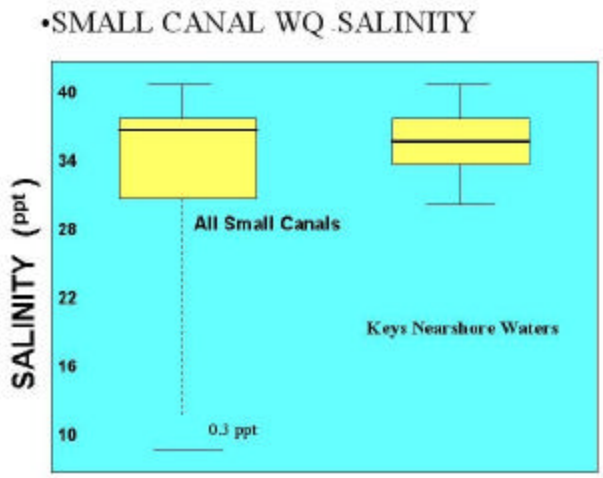
In residential canals, the variability of water quality parameters tends to be greater than in adjacent natural waters. The box plots readily show this greater variability. Box plots can also be utilized to compare water quality performance in different canals from each of the size groups in the classification: small, medium, large and jumbo (**Figures 4-18** and **4-19**). The assumptions made on water quality performance is that unless there is strong circulation through the canal systems (e.g. 164 Duck Key), the larger canals will have poorer water quality than smaller canals, as indicated by a central tendency of parameters to be different in the canals from nearshore keys water.

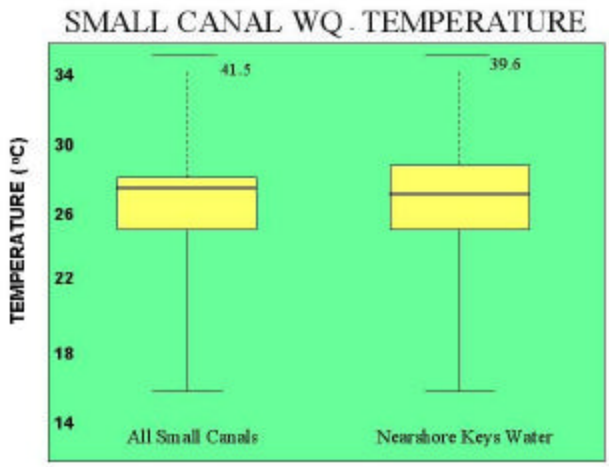


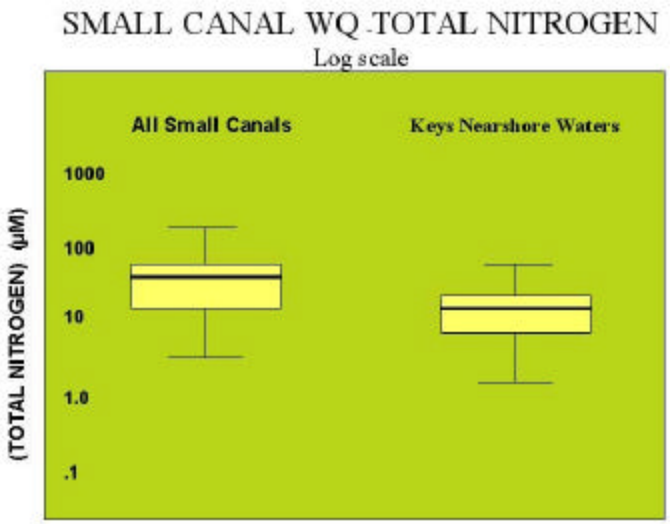




Figures 4-18a, b, and c: Box Plots of Water Quality Parameters for Jumbo Size Canal Classification







Figures 4-19a, b, and c: Box Plots of Water Quality Parameters for Small Size Canal Classification

In terms of variability, some parameters will not vary in canal systems. Natural waters create a dynamic ecological system by seasonal, tidal and diurnal variability. The question to investigate is not whether variability exists, but whether variability within the canal systems is similar to variability in nearshore waters.

Water quality summaries for canal data required creating a data summary then a summary plot for each parameter. **Table 4-10** presents a sample of the water quality station summary data. The following steps were used:

1. Consolidate all the data from one canal system (could be several water quality sampling stations) into a single spreadsheet.
2. Annotate each data point as to season and tide (Baywatch stations are taken at high and low tides already).
3. Sort by season (Group months as May to October, November to April). Seasons are set on the two months with the greatest annual temperature range, May and October. The average date of the first cold front to pass through South Florida is 20 October, and late May is the end of the dry season, start of summer afternoon thunderstorm pattern in the weather).
4. Sort by season, then tides to get FOUR groups of data points:
    a. May to October – High tide
    b. May to October – Low tide
    c. November to April – High tide
    d. November to April – Low tide
5. Calculate summary statistics for each of the four groups:
    a. Mean and median
    b. Standard Deviation
    c. Maximum
    d. Minimum
6. From inspection of these statistics, determine if the datasets include any outliers or spurious data points (values more than 3 standard deviations from the mean); find the value of "whiskers" in boxplot.
7. Determine the range of 50% of the values (limits of "box")
8. Plug in values to Box plot template for each parameter,
9. Evaluate variation in parameters compared to Florida Keys nearshore water. Is the box plot for the canal data higher or lower? Is the box and whiskers larger (greater variability) or smaller (less variability) compared to plots for nearshore waters?

TABLE 4-10 SAMPLE OF WATER QUALITY STATION SUMMARY DATA

Station	**256 Marathon (Flamingo Island)**
Duration of sampling	06/02/94 to 02/05/01
Seasonal	Yes
Tidal	Yes
Diurnal	No
Number of data points	324
Parameters used	Temperature, Salinity, Nutrients (total N and P), Chlorophyll a

Table 4-11 presents example ranges (maximum and minimum) for salinity, temperature, dissolved oxygen, turbidity, total nitrogen, total phosphorus, and chlorophyll-a concentration for surface nearshore waters in the Florida Keys. The most comprehensive water quality database for comparison to residential canal water quality is the Florida Keys Water Quality Protection Program in the Florida Keys National Marine Sanctuary (see Jones and Boyer, 2001 for FY2001 Annual report). This is a large, Keys-wide water quality monitoring program for 154 stations monitored quarterly. The data are analyzed by "clusters", and the stations closest to the canal opening were chosen, as well as the channels (Cluster 5: Nearshore Keys waters) as comparison values to canal water quality data. Water quality designations for the canals ranging from good to poor were denoted based upon this comparison. **Table 4-12** describes the water quality designations. A summary of all compiled near-shore Keys water quality data (refer to **Table 2-1**) is presented in the following discussion on water quality performance in canals.

TABLE 4-11 EXAMPLE RANGES OF WATER QUALITY PARAMETERS IN NEARSHORE WATERS IN THE FLORIDA KEYS

PARAMETER	RANGE (MIN - MAX)	MEDIAN VALUE	SEASONAL VALUES	REFERENCE
Salinity (ppt)	35.6-42.5		Higher during summer	Lapointe and Clark (1990)
	28.0-38.0		Higher during summer	Skinner and Corcoran
	34.5-37.9		Higher during summer	Springer and McErlean
	29.5 – 40.0	36.3		Cluster 5, Jones and
Temperature (^{o}C)	21.8-33.5		Higher during summer	Lapointe and Clark
	19.0-32.0		Higher during summer	Mathieson and Dawes
	< 16		Passage of cold front	Roberts et al. (1983)
	16.6-33.3		Higher during summer	Skinner and Corcoran (1987)
	15.1-39.6	27.9	Larger inter-annual variability	Cluster 5, Jones and Boyer (2001)
Dissolved oxygen (mg/l)	3.65-7.03		Higher during winter	Lapointe and Clark (1990)
Turbidity (NTU)	0.15-20.25		Higher during winter	Lapointe and Clark (1990)
				Cluster 5, Jones and Boyer (2001)
Total Nitrogen (µM)	2.21-10.36		Higher during summer	Lapointe and Clark (1990)
	21.29-55.00		Not consistent	Lapointe et al. (1994)
	12.50-37.50		Summer range	Szmant (1991)
	1.78 – 85.88	13.25		Cluster 5, Jones and Boyer

PARAMETER	RANGE (MIN - MAX)	MEDIAN VALUE	SEASONAL VALUES	REFERENCE
Total Phosphorous (µM)	0.12-4.09		Not consistent	Lapointe and Clark (1990)
	0.02 - 0.62	0.20	Variable and patchy in nearshore waters	Cluster 5, Jones and Boyer (2001)
Chlorophyll-a (µg/l)	0.06-15.51		Higher during summer	Lapointe and Clark (1990)
	0 – 1.79	0.23	Variability in methods between researchers	Cluster 5, Jones and Boyer (2001)

TABLE 4-12 WATER QUALITY DESIGNATIONS AND DESCRIPTIONS OF WATER QUALITY PARAMETERS

CATEGORY	DESCRIPTION
POOR	Water quality parameters measured over seasons, storm and tidal fluctuations are different from nearshore waters of the Florida Keys. This includes - Lower minimums, and high maximums of temperature - Lower minimum and high maximums of chlorophyll a - Higher median and maximum values of turbidity, Total Nitrogen and Total Phosphorus - Low Dissolved Oxygen, especially at the bottom of canals.
FAIR	Water quality parameters measured over seasons, storm and tidal fluctuations is SLIGHTLY different from nearshore waters of the Florida Keys. This can mean that at particular times of the year, water quality may have - Lower minimums, and high maximums of temperature - Lower minimum and high maximums of chlorophyll a - Higher median and maximum values of turbidity, Total Nitrogen and Total Phosphorus - Low Dissolved Oxygen, especially at the bottom of canals - These conditions do not persist year round
GOOD	Water quality parameters measured over seasons, storm and tidal fluctuations is NOT significantly different from nearshore waters of the Florida Keys. This includes - Similar minimums and maximums of temperature - Similar minimum and maximum of chlorophyll a - Similar median and maximum values of turbidity, Total Nitrogen and Total Phosphorus - Similar Dissolved Oxygen, and no stratification of water column in the canal.

4.7.2 WATER QUALITY SUMMARY FOR ALL CANALS

A summary of the available water quality data for all seasons and tidal cycles is presented in **Table 4-13**. Data from similar methodologies are combined for comparison to Keys nearshore water quality parameters. Italics values are notably different from baseline values. This analysis is important but limited for several reasons:

- the sampling effort for canal water quality data is uneven between canal size groups, and very limited for the jumbo and large size canals

- the summary values for these water quality parameters do not give a complete picture of water quality degradation, such as extreme values that can be reached after storm events in a given canal system, and
- most values are for surface waters in the canal, which may experience a higher degree of circulation, thus the quality of "trapped" bottom waters and sediments in the canals are not indicated in this dataset.

There is a real information gap in long-term water quality collected from residential canal systems in a stratified random design to capture size, construction and development characteristics across the Keys.

TABLE 4-13 SUMMARY OF WATER QUALITY FOR ALL CANALS IN THE FLORIDA KEYS

CATEGORY	WATER QUALITY DESIGNATION	WATER QUALITY PARAMETER	MEDIAN	MAX	MIN
JUMBO Very limited sampling, especially in winter	POOR	Temperature (^oC)	29.6	35.3	16
		Salinity (ppt)	36.65	37.2	26
		Total Nitrogen (µM)	**26.8**	**263.3**	**8.8**
		Total Phosphrus (µM)	0.36	2.7	0.1
		Chlorophyll a (µg/l)	0.54	15.22	0
LARGE Better representation of POOR water quality	POOR	Temperature (^oC)	**29.9**	**41.5**	**15.0**
		Salinity (ppt)	**35.2**	**50.3**	**8.8**
		Total Nitrogen (µM)	**31.6**	**184.65**	**8.33**
		Total Phosphrus (µM)	**0.39**	**10.09**	**0**
		Chlorophyll a (µg/l)	**0.49**	**23.09**	**0**
MEDIUM	FAIR	Temperature (^oC)	26.5	38.5	14
		Salinity (ppt)	**36.7**	**59.1**	**12.2**
		Total Nitrogen (µM)	**29.39**	**145.78**	**0.33**
		Total Phosphrus (µM)	**0.32**	**44.39**	**0**
		Chlorophyll a (µg/l)	0.38	19	0
SMALL	FAIR TO GOOD	Temperature (^oC)	26.8	41.5	15
		Salinity (ppt)	**37.3**	**46.4**	**0.3**
		Total Nitrogen (µM)	**32.39**	**149.32**	**7.72**
		Total Phosphrus (µM)	**0.34**	**4.75**	**0.06**
		Chlorophyll a (µg/l)	0.43	4.79	0
Cluster "B" Keys Nearshore Waters 2001- FKNMS Water Quality Monitoring	BASELINE	Temperature (^oC)	27.5	39.6	15.1
		Salinity (ppt)	36.3	40	29.5
		Total Nitrogen (µM)	13.25	85.88	1.78
		Total Phosphrus (µM)	0.20	0.62	0.02
		Chlorophyll a (µg/l)	0.23	1.79	0

Note: Values that are statistically different from the nearshore water baseline are shown in BOLD. Refer to the Water Quality Summaries in the attached CD ROM for details of the statistical analyses.

Please note that the sampling in LARGE canals provides a better representation of "Poor" water quality, as sampling was very limited in JUMBO canals. Also, no canal will perform like natural nearshore waters; even the small canals have elevated inorganic nutrient levels.

From the summary table, "POOR" water quality is then defined by:

- extremes in both temperature and salinity beyond the range found in nearshore waters, and,
- at least an order of magnitude higher values in inorganic nutrients and chlorophyll a.

In canals with "POOR" water quality, there is a chronic degradation with low circulation and buildup of both organic material and inorganic nutrients. The dark color of the water (high suspended material) contributes to the extreme heating of the water in the summer months.

Residential canals are very vulnerable to acute discharge and spill events. Much of the water quality sampling carried out by the Bay Watch program targeted water quality degradation events and likely captured some of the "worst-case" conditions in the canal. There is as yet no comprehensive water quality-sampling program in the canals that would give a more accurate look at year-to-year variability of water quality parameters.

The 100% GIS included in the attached CD ROM contains a shape file locating the canal water quality monitoring stations and a link to the water quality summaries. The summary of the water quality associated with each canal is based upon the closest available sampling point(s), as well as all other canals in the same classification group. The canal water quality summary contains the same information as presented in **Table 4-13**. The canal data are compared to the nearshore data (based on the statistical clustering of sampling stations in the Florida Keys National Marine Sanctuary Water Quality Monitoring Program (See Jones and Boyce, 2002), to assist in evaluating the water quality designation. The water quality designations derived for each canal are included in the GIS Attribute Table in the GIS Database included on the CD ROM and in hard copy as **Appendix B.4**. Excel spreadsheets containing the water quality data are also included on the CD ROM. Creation of box plots for each canal data set was beyond the scope of this project, but is suggested for future water quality evaluations. Box plots would be especially useful to evaluate the water quality changes that might occur with application of treatment technologies.