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Water Quality Monitoring Project for Demonstration of Canal Remediation Methods: Florida Keys

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A. Introduction

Several important results have been realized from FIU's regional monitoring project. First is the documentation of elevated nutrient concentrations (DIN, TP and SiO2) in waters close to shore along the Keys, and corresponding responses from the system, such as higher phytoplankton biomass (CHLA), turbidity and light attenuation (Kd), as well as lower oxygenation (DO) and lower salinities of the water column. These changes, associated to human impact, have become more obvious in a new series of ten stations (# 500 to #509) located very close to shore, near canal mouths and sampled since November 2011 (SHORE; Fig 4). These waters are part of the so called Halo Zone, a belt following the shoreline which extends up to 500 meters offshore, and whose water quality characteristics are closely related to those in canals and affected by quick movement of infiltrated runoff and wastewaters (septic tanks), tides and high water tables

Many canals do not meet the State's minimum water quality criteria and are a potential source of nutrients and other contaminants to near shore waters designated as Outstanding Florida Waters. Hence, the Monroe County BOCC has approved moving forward with a series of canal restoration demonstration projects whose results will be used to further define restoration costs and for information in future grant applications to state and federal sources.

The Monroe County, the WQPP Steering Committee and the Canal Subcommittee have selected ten (10) canals out of twenty (20) pre-selected sites, for demonstration of restoration technologies (See Summary in Table 4). The main objective of this demonstration is to obtain realistic data and costs for future restoration planning and grant application purposes (AMEC 2012). Those technologies under consideration target two fundamental problems, poor circulation (stagnation) and accumulation of organic matter. Both, poor circulation and accumulation of organic debris, besides run-off and seepage from septic tanks, are major contributors to water quality degradation in the Florida Keys (Kruczynski, 1999), especially to the degradation of canal waters.

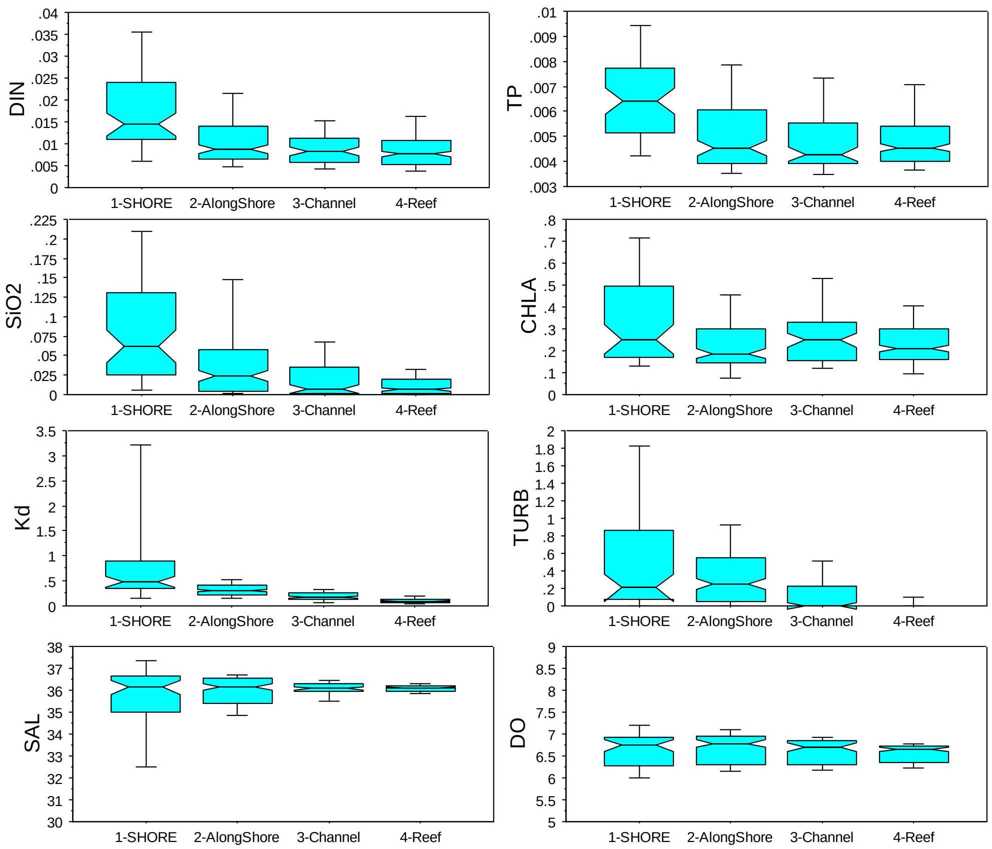

Figure 4. *Nutrient and response changes along transect from shore sites (~100 m) to reef-track*

TABLE 4. Selected Canal Demonstration Projects Monroe County and Village of Islamorada. (Modified after AMEC 2013)

Weed Barrier			**Organic Removal**	**Weed Barrier & Organic Removal**	**Pumping**	**Culvert Installation**		**Backfilling**
#137 Plantation Key Treasure Harbor	#148 Lower Matecumbe Key Mate-Lido Beach	#287 Big Pine Hollerich Subdivision	#290 Big Pine Between Ave I & J	#266 Big Pine. Dr Arm Subdivision	#278 Big Pine. Eden Pines Colony Subdivision	#277 Big Pine. Tropical Bay Subdivision	#459 Geiger. Boca Chica Ocean Shores Subdivision	#29 Key Largo Sexton Cove Estates Subdivision
							#472 Geiger. Geiger Mobile Homes Subdivision	
#132 Plantation Key	**#147 Matecumbe K**	**#293 Big Pine**			**#282 Big Pine**		**#458 Geiger**	**# 28 Key Largo**

Control canals highlighted in yellow

B- Proposed Remediation Technologies

The potential restoration technologies proposed for canal restoration demonstration are as follows:

- Reductions in weed wrack loading (using bubble curtains, weed gates or other methods)
- Enhanced circulation (using culverts, pumps, or other means) to reduce hydraulic residence times and eliminate areas of water column stagnation
- Removal of accumulated organic sediments, in areas where the sediments are contributing to the development of phytoplankton blooms, bottom-water hypoxia and excessive hydrogen sulfide production; and
- Backfilling to reduce canal depth, in areas where excessive depth is contributing to poor circulation, bottom-water hypoxia, and other canal management issues.

C- Selected Management goals

The Canal Subcommittee identified the following goals in their April 27, 2012 meeting, considered in the *Monroe County Canal Master Plan Phase 1, Summary Report* (AMEC Environments and Structure; June 2012). First, Restore and maintain water quality conditions in canal systems to levels that are consistent with the State's current water quality criteria for Class III waters; second, install cost-effective barriers to prevent or substantially reduce weed wrack inputs from nearshore waters to avoid eutrophication and/or hypoxia; third, to reduce or prevent the incidence of anoxia, problematic sulfide levels and sediment toxicity in canals; fourth, protect aquatic and benthic canal habitats that currently support native flora and fauna; and fifth, create and maintain a constituency of informed, involved citizens who understand the environmental and economic issues involved in managing manmade canal systems

D- Monitoring Objectives

The general objective of water quality monitoring for the demonstration canals is to measure the status and trends of water quality parameters to evaluate progress toward achieving and maintaining water quality standards and protecting/restoring the living marine resources of the Sanctuary, and to objectively compare diverse restoration methodologies used in the demonstration. The major tasks for this project include: logistical planning, field measurements, water sampling, laboratory analysis, data management, data analysis, interpretation and reporting, and participation in science and management meetings related to remediation and water quality of the Florida Keys canals

Specific objectives are as follows:

- To provide data needed to make unbiased, statistically rigorous statements about the status and temporal trends of water quality parameters in the remediated canals
- To inform management actions and policy development processes for improved water quality in the Sanctuary.

E- Conceptual Guidelines to Canal Monitoring

Monitoring is defined as the continued observation of the selected canal waters to determine spatial and temporal variability in water quality. Monitoring involves systematic, long-term data collection and analysis to measure the status of water quality and to detect changes over time. Detecting and quantifying such changes at each specific canal, subjected to a specific remediation methodology (Table 5), can focus research on quantifying and qualifying those changes to evaluate the success of corrective ACTIONS (Table 5). As shown in Table 5, each ACTION (Reduce Weed Wrack, Culvert Installation, Removal of Organic Sediments and Backfilling) is expected to lead to the achievement of some desired GOALS established as landmarks by the Canal Subcommittee. Reaching or approaching these GOALS entail important CONSEQUENCES in the canal conditions responding to CHANGES occurring in the water column, and if such changes were to occur, we can detect and quantify them using our analytical toolkit and INDEXES or indicators environmental conditions (Doren et al 2009).

Let us use the Reduction of Weed Wrack as example of ACTION in Table 5 to lay down the scientific rationale behind the proposed monitoring strategy. If in fact this ACTION leads towards the desired GOALS (Reduce Organic Matter Load) foreseen by the Canal Sub-Committee, it is because some changes with hypothesized CONSEQUENCES occurred in the canal system. That is, dissolved and particulate organic matter (DOM & POM) and nutrient concentrations must decline, while the decomposer bacteria community, which thrives on organic matter, changed in abundance and/or structure.

These transformations would be manifested as a series of EXPECTED CHANGES in the water column as follows: phosphorous, nitrogen, carbon and silica species in water would decline limiting potential biota productivity. This, in turn, would lead to lower concentrations of phytoplankton biomass (CHLa) and lower rates of biological oxygen consumption or demand (BOD). These would immediately cascade into higher dissolved oxygen (DO) concentrations and higher DO % saturations in the water column, as well as changes in the previously stratified water column. New types and assemblages of bacteria adapted to this new set of conditions in the water column would result. Then, if those changes were to occur, we have a wide gamut of tools (INDEXES) to detect and quantify such changes, among them, nutrient concentrations (N, P, C and SiO_2), biological oxygen demand (BOD), chlorophyll a (CHLa) concentration and sources determined with Pulse-Amplitude-Modulation (PAM) analyzer (differentiates pigments produced by phytoplankton components, such as diatoms, cyanobacteria and dinoflagellates).

Additionally, concentration of dissolved organic matter (DOM) and its types may be determined by Parallel Factor Analysis (Parafac) to separate DOM into terrestrial humic-like, microbial-derived humic-like, and protein-like components; and, if deemed appropriate, the source of fecal colliforms present in the water column may be discriminated with Quantitative Polymerase Chain Reaction (qPCR) assays for microbial source tracking of fecal contamination from bird, dog, or human sources. Finally a simple way to determine water column conditions and stratification is by using sondes to capture a series of CTD casts of continuous water quality profiles. Similar detailed analysis was performed for the rest of proposed ACTIONS as shown in Table 5, to finally consolidate the Conceptual Monitoring Design as presented in Figure 5.

F- Characterization of Water quality in the Demonstration Canals

The proposed monitoring experiment has been conceptually conceived as a Before–and-After Control-Impact Design with multiple sites (BACI experiment; Green, 1979; Smith, 2002). This design (Table 5) entails the collection of data prior to the remediation activity (ACTION) in several sites within the canal to compare with data after remediation. The impact areas (remediated canals) are paired and compared to another canal (non-remediated canal), which is referred to as the control canal. Selected canals for remediation and the proposed control canals are presented in Table 4. The BACI experiment allows the application of methods where the data are treated as independent samples and are compared using diverse statistics. Physical-chemical properties of the water column will be measured, and selected water samples will be collected and analyzed following previous experience characterizing and monitoring canal WQ in Little Venice, Marathon (Briceño and Boyer 2009)

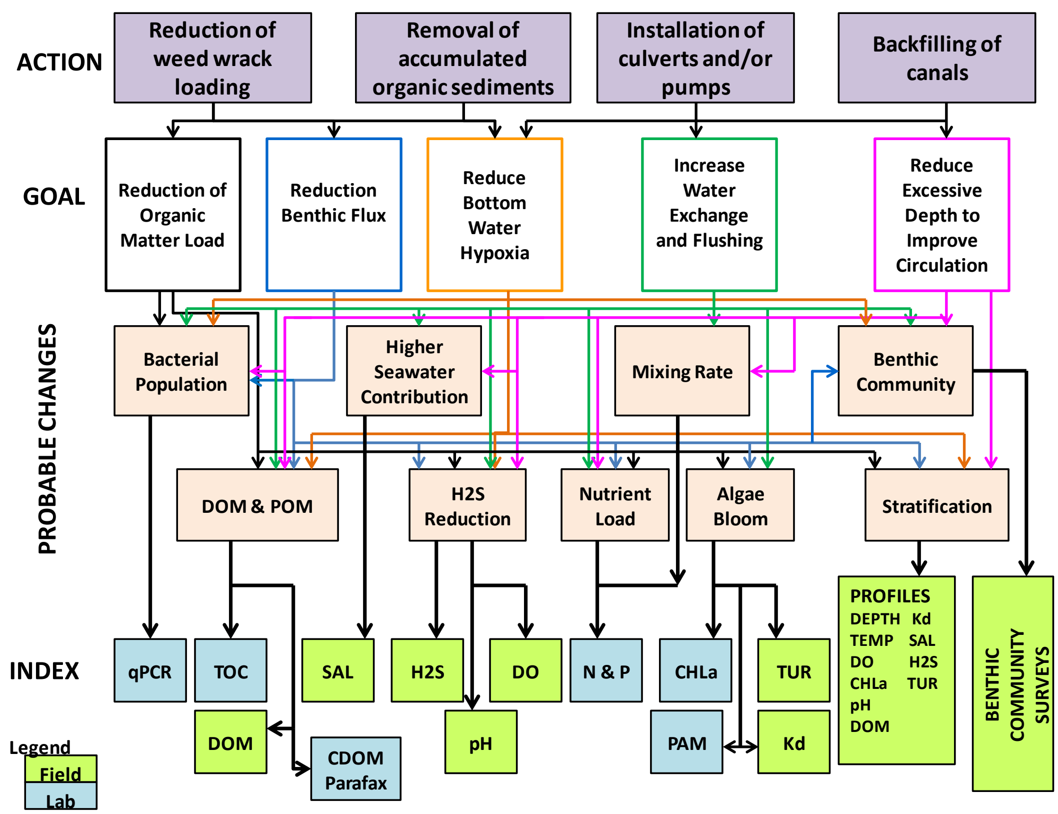

Figure 5. Conceptual Monitoring Design

Table 5. Conceptual model guidelines

ACTION	GOAL	CONSEQUENCES	EXPECTED CHANGE	INDEX TOOLKIT
Reduce Weed Wrack Loading	Reduce Organic Matter Load	DOM, POM and Nutrients decline. Decomposer Bacteria change	P declines N declines BOD declines CHLa declines DO increases DOM changes Stratification Bacteria type	P N BOD, TOC CHLa; Phyto-PAN DO & %DO sat DOM; Parafac CTD cast profiles qPCR

ACTION	GOAL	CONSEQUENCES	EXPECTED CHANGE	INDEX TOOLKIT
Installation of culverts	Reduce flushing time. Increase water circulation	Mixing increases Stratification declines Nutrient load declines Benthic community changes	P declines N declines BOD declines CHLa declines DO increases DOM changes Stratification Bacteria type Turbidity declines Salinity changes	Kd P N BOD, TOC CHLa; Phyto-PAN DO & %DO sat DOM; Parafax CTD cast profiles qPCR

ACTION	GOAL	CONSEQUENCES	EXPECTED CHANGE	INDEX TOOLKIT
Organic Sediment Removal	Reduce benthic flux & hypoxia Reduce chemical stratification	DOM and POM reduction Oxygen demands (organic /chemical) decline Hydrogen sulfide declines	P declines N declines BOD declines CHLa declines DO increases DOM changes H2S generation Stratification Bacteria type Turbidity declines Salinity changes	Kd P N BOD, TOC CHLa; Phyto-PAN DO & %DO sat DOM; Parafax CTD cast profiles qPCR H2S pH

ACTION	GOAL	CONSEQUENCES	EXPECTED CHANGE	INDEX TOOLKIT
Backfilling	Reduce excessive depth to improve circulation and reduce hypoxia	Stratification declines Oxygenation improves Hydrogen sulfide reduced	Light penetration P declines N declines BOD declines CHLa declines DO increases DOM changes H2S generation Stratification Bacteria type Turbidity declines Salinity changes	Kd P N BOD, TOC CHLa; Phyto-PAN DO & %DO sat DOM; Parafax CTD cast profiles qPCR H2S pH Redox

Table 6. Calendar of Monitoring Planned Activities for the BACI experiment. Summary of activities to be performed in BACI experiment designed for demonstration of restoration techniques. Remediation (Control) canals in green (yellow). Tabulated values indicate the number of Profiles, Diel cycles and water samples planned for monitoring each canal

	Canal#	**#028**	**#029**	**#132**	**#137**	**#148**	**#147**	**#266**	**#277**	**#278**	**282**	**#287**	**#290**	**#293**	**#458**	**#459**	**#472**	Totals
Activity	**Stations**	**2**	**1**	**1**	**2**	**2**	**1**	**2**	**2**	**2**	**1**	**2**	**2**	**1**	**1**	**2**	**2**	**26**
BEFORE 1	Profiles	3	3	3	4	3	2	3	3	4	3	3	3	3	2	2	2	**46**
(1 month)	Diel	2	2	2	2	2	2	2	2	2	2	2	2	2	2	2	2	**32**
	Enterococci	2	2	2	2	2	2	2	2	2	2	2	2	2	2	2	2	**32**
	FIU WQ	4	2	2	4	4	2	4	4	4	2	4	4	2	2	4	4	**52**
R	**E**	**M**	**E**	**D**	**I**	**A**	**T**	**I**	**O**	**N**								
6 month																		
AFTER 1	Profiles	3	3	3	4	3	2	3	3	4	3	3	3	3	2	2	2	**46**
(1 month)	Diel	2	2	2	2	2	2	2	2	2	2	2	2	2	2	2	2	**32**
	Enterococci	2	2	2	2	2	2	2	2	2	2	2	2	2	2	2	2	**32**
	FIU WQ	4	2	2	4	4	2	4	4	4	2	4	4	2	2	4	4	**52**
3 month																		
AFTER 2	Profiles	3	3	3	4	3	2	3	3	4	3	3	3	3	2	2	2	**46**
(1 month)	Diel	2	2	2	2	2	2	2	2	2	2	2	2	2	2	2	2	**32**
	Enterococci	2	2	2	2	2	2	2	2	2	2	2	2	2	2	2	2	**32**
	FIU WQ	2	2	2	4	2	2	2	4	4	2	2	2	2	2	2	4	**40**
3 month																		
AFTER 3	Profiles	3	3	3	4	3	2	3	3	4	3	3	3	3	2	2	2	**46**
(1 month)	Diel	2	2	2	2	2	2	2	2	2	2	2	2	2	2	2	2	**32**
	Enterococci	2	2	2	2	2	2	2	2	2	2	2	2	2	2	2	2	**32**
	FIU WQ	2	2	2	4	2	2	2	4	4	2	2	2	2	2	2	4	**40**
2 month																		
AFTER 4	Profiles	3	3	3	4	3	2	3	3	4	3	3	3	3	2	2	2	**46**
(1 month)	Diel	2	2	2	2	2	2	2	2	2	2	2	2	2	2	2	2	**32**
	Enterococci	2	2	2	2	2	2	2	2	2	2	2	2	2	2	2	2	**32**
	FDEP WQ	2	2	2	4	2	2	2	4	4	2	2	2	2	2	2	4	**40**
2 month	**REPORT**																	
AFTER 5	Profiles	3	3	3	4	3	2	3	3	4	3	3	3	3	2	2	2	**46**
(1 month)	Diel	2	2	2	2	2	2	2	2	2	2	2	2	2	2	2	2	**32**
	Bacteria	2	2	2	2	2	2	2	2	2	2	2	2	2	2	2	2	**32**
	FIU WQ	2	2	2	4	2	2	2	4	4	2	2	2	2	2	2	4	**40**
2 month																		
AFTER 6	Profiles	3	3	3	4	3	2	3	3	4	3	3	3	3	2	2	2	**46**
(1 month)	Diel	2	2	2	2	2	2	2	2	2	2	2	2	2	2	2	2	**32**
	Enterococci	2	2	2	2	2	2	2	2	2	2	2	2	2	2	2	2	**32**
	FDEP WQ	2	2	2	4	2	2	2	4	4	2	2	2	2	2	2	4	**40**
2 month																		
AFTER 7	Profiles	3	3	3	4	3	2	3	3	4	3	3	3	3	2	2	2	**46**
(1 month)	Diel	2	2	2	2	2	2	2	2	2	2	2	2	2	2	2	2	**32**
	Enterococci	2	2	2	2	2	2	2	2	2	2	2	2	2	2	2	2	**32**
	FIU WQ	2	2	2	4	2	2	2	4	4	2	2	2	2	2	2	4	**40**
2 month																		
AFTER 8	Profiles	3	3	3	4	3	2	3	3	4	3	3	3	3	2	2	2	**46**
(1 month)	Diel	2	2	2	2	2	2	2	2	2	2	2	2	2	2	2	2	**32**
	Enterococci	2	2	2	2	2	2	2	2	2	2	2	2	2	2	2	2	**32**
	FDEP WQ	2	2	2	4	2	2	2	4	4	2	2	2	2	2	2	4	**40**
2 month	**FINAL REPORT**																	

G- Characterization of Water quality in the Demonstration Canals

We will characterize the systems before (BEFORE) any action is taken using three data-gathering techniques from the toolkit, vertical profiles, continuous 24-hour recording (diel) of physical-chemical properties (Fig. 6), and water sampling and analysis for nutrients and bacteria (Enterococcus) at selected stations. We will deploy multi-sensor, water quality monitoring instruments (SeaBird CTD and YSI) to measure physicochemical parameter profiles at least at the head, middle and mouth of the canal throughout the water column in an effort to generate a depth profile of each parameter. The physicochemical parameters to be measured include depth (m), salinity (PSU), specific conductivity, temperature (°C), dissolved oxygen (DO in mg l^{-1}), %DO Saturation, PAR (μE m^{-2} s^{-1}), pH, turbidity and in situ chromophoric dissolved organic matter (CDOM) fluorescence. The light extinction coefficient (k_d in m^{-1}) will be calculated as a log function from PAR measurements through the water column.

The occurrence of values lower than those established by the Rule 62-302.533 of the Florida Administrative Code for Dissolved Oxygen has been the cause of impairment of most canal waters in the Florida Keys. According to this Rule for Class III predominantly marine waters, and Class III-Limited predominantly marine waters …"*Minimum DO saturation levels shall be as follows: ….The daily average percent DO saturation shall not be below 42 percent saturation in more than 10 percent of the values; and "a full day of diel data shall consist of 24 hours of measurements collected at a regular time interval of no longer than one hour*."

Additionally, according to this same Rule, "*…pH. Shall not vary more than one unit above or below natural background of predominantly fresh waters and coastal waters as defined in paragraph 62-302.520(3)(b), F.A.C. or more than two-tenths unit above or below natural background of open waters as defined in paragraph 62-302.520(3)(f), F.A.C., provided that the pH is not lowered to less than 6 units in predominantly fresh waters, or less than 6.5 units in predominantly marine waters."* Hence, to monitor compliance with the Rule, two YSI sondes (surface and bottom) will be displayed to collect data (DO, %DO Saturation, Turbidity, Specific Conductivity, Salinity, Temperature and pH) every 15 minutes for the 24-hour diel experiments. Water samples will be collected from surface (1 ft) and bottom (1 ft above canal bottom) of the water column using Niskin bottles. Water samples will be analyzed for total nitrogen (TN), total phosphorus (TP), and Dissolved Inorganic Nitrogen (DIN) using standard laboratory methods described above. Finally, upon recommendation from FDEP and EPA consent, Enterococcus content will be assessed with ENTEROLERT® for surface and bottom waters at one station per canal. Water quality monitoring program for Canals adhered to existing rules and regulations governing QA and QC procedures as described in EPA guidance documents, given that FIU-SERC Nutrient Laboratory maintains NELAP certification.

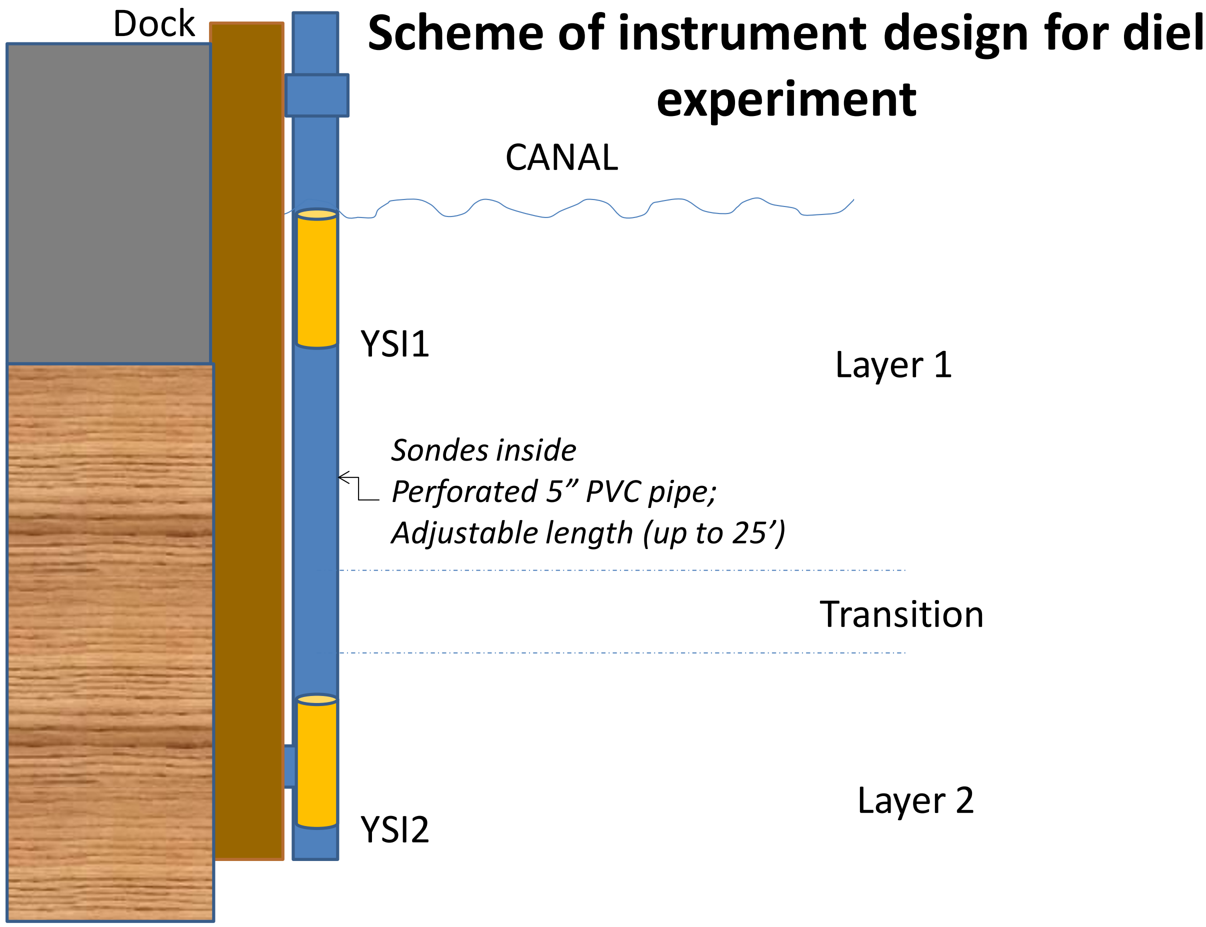

Figure 6: Location of YSI sondes for capturing physical-chemical properties of water column in Florida Keys canals. YSI are inside PVC pipe clamped to wooden piling

H- Monitoring Water quality in the AFTER Phase

Monitoring during the AFTER Phase will begin six months after Remediation. Water samples and Diel data will be captured Quarterly for surface and bottom depths at selected stations in each canal (remediated and control. Table 6). SeaBird-YSI casts will be measured at the selected stations of each remediated canal and its paired control canal.

I- Assessing WQ recovery

We will use diverse methods to evaluate changes in biogeochemical water quality after remediation:

1. Comparing before and after (B&A) data from SeaBird-YSI profiles.

2. Comparing B&A data from YSI Diel quarterly experiments

3. Comparing B&A number of %DO Saturation and pH exceedences

4. Comparing B&A mean nutrient concentrations.

5. Developing a Score-Card system to express the evolution of water quality parameters along the monitoring period.

Methodologies 1 to 4 will compare the sites with themselves to track absolute changes in the selected index, and with control canal sites to correct for changes unrelated to remediation. Neither one of these methodologies is able to filter-out differentially induced variations such as eventual anthropogenic impacts (i.e. boat discharges, lawn irrigation, etc.) which may occur as confounding effect in any of the paired canals. In summary, the proposed monitoring program for 10 remediated canals and 6 control canals would have results as shown in Table 7

Table 7: Summary of proposed tests and measurements to be performed during Canal monitoring

	SUMMARY				
	WQ Samples	**DIEL**	**PROFILES**	**Enterococci**	**DO**
Number	**384**	**288**	**414**	**288**	**41886**
Determinations	**1152**	**248832**	**3726**	**288**	**41886**

J- Management

The principal investigator has established a QA Program for water quality monitoring to ensure that the data generated are accurate and representative of actual conditions, and that the degree of certainty of the data can be established. The principal investigator will consult with the EPA Region IV QA/QC Officer on any issues involving QA/QC matters. The principal investigator will develop and maintain protocols and procedures under a data management program for water quality monitoring to ensure that the data generated are accessible to potential users in a timely manner. All original and ancillary data produced under this project will be generated, processed, stored, and archived in a manner that provides detailed documentation of the procedures used at all stages of data collection, reduction, processing, analysis, and storage. All data will housed and available for downloading in Excel format at FIU/SERC Water Quality Monitoring Network website http://serc.fiu.edu/wqmnetwork/. All data from this project will be added to this website on a quarterly basis.

K- Environmental Impacts

Aside from normal boating activities, no environmental impacts will result from this project. Water sampling will not affect the water column or benthic communities in any significant manner. No anchoring during sampling will be necessary and PVC pipe containing YSI sondes (Fig 3) will not reach the canal bottom. Likewise, sonde casts will not reach the canal bottom either.

L- Results/Outputs and Deliverables

Quarterly Progress Reports

Upon completion of the data gathering and analysis of samples from each quarterly survey, the PI will submit a data and narrative report documenting the results of each quarterly survey. The data report will include the raw data and statistical summaries in hard copy and electronic format. The PI will evaluate the data in accordance with the data quality objectives developed in the Work/Quality Assurance Project Plan.

Annual Report

After completion of analysis of data from every year of activities, the PI will produce statistical summaries of the data collected at each water quality monitoring station to be incorporated in an annual report. The data will be analyzed using appropriate statistical tests of significance to meet the specific objectives of the monitoring program. The statistical analysis and presentation will include, at minimum:

- Statistical characterization (e.g., means, standard deviations, and ranges of water quality parameters) for each site.
- Significant differences among paired remediated-control canals and remediation methodology
- Graphical and/or statistical analysis of relationships between water quality parameters and water depth

The draft annual report should summarize the objectives, methods, and results of water quality monitoring. The report should interpret the results in relation to the objectives of the canal monitoring program. The draft annual report will be reviewed by EPA, FDEP, and the Canal Sub-Committee and returned with comments. The PI will address the comments and submit the final annual report with revisions.

Deliverable Items and Schedule

Quarterly reports will be submitted to EPA Region 4 within 90 days of end of quarter. Annual reports will be submitted to EPA Region 4 within 6 months of end of collection.

M- FDEP Water Quality analysis

The Florida Department of Environmental Protection (FDEP) will perform some water quality analysis for nutrients during the second and third years of the project. These analyses would complement the plan described above, with additional nutrient analysis for samples to be collected by FIU in 2016 and 2017 following FDEP SOP. This set of samples will be analyzed for TN, TP and DIN.

N- Final Considerations

A precise assessment of the work to be performed is difficult given the unpredictable delays and expected asynchrony in the implementation of remediation measures. As a reference this monitoring program would include the collection of 384 water samples; performing 288 diel cycle test with measurements every 10 min; measuring along 414 physical-chemical profiles (casts); 288 Enterococcus tests, for a total of 1,152 nutrient determinations (TN, TP, DIN); 248,832 measurements during diel cycles; 3,726 measurements of physical-chemical parameters in profiles; 288 Enterococci determinations; and a total of 41,886 DO determinations (Table 2).

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