Project Report (FWRI Grant #5446):

Florida’s Coral Reef Water Quality Data Compilation, Analysis and Decision Support

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Project Dates:

Year 1: January 11th - June 4th, 2021

I. Background

This project was motivated by the need to easily understand water quality patterns at different spatial and temporal scales, and to ultimately assess the effect of efforts to improve water quality locally. The need to aggregate and visualize data from different observing programs, and an analysis of water quality hotspots and data gaps, was identified among the management goals of the Florida Keys National Marine Sanctuary (FKNMS) and as a priority within the sanctuary's Water Quality Protection Program (WQPP), co-chaired by the US Environmental Protection Agency (EPA) and the Florida Department of Environmental Protection (DEP). We proposed addressing these needs by aggregating various historical and current water quality data sets, analyzing spatial and temporal trends, and evaluating compatibility between monitoring protocols to establish a foundation from which existing monitoring programs can be adapted to better inform regulatory frameworks.

Under Tasks 1 and 2, we proposed compiling, collating, and mapping water quality data for the south Florida coral reef ecosystem, and to subsequently construct a water quality data comparison matrix to compare parameters and protocols across all sampling programs. In addition to a report and the comparison matrix, we proposed two presentations to managers and water quality experts to discuss the purpose, tasks, and outcomes of the project.

Under Tasks 3 and 4, we proposed analyzing the suite of water quality data to identify spatial and temporal hotspots and changing patterns. Additionally, we proposed integrating remote sensing visualization of water quality with the field water quality measurements to assess the role of watershed processes on coastal water quality. We proposed integrating these products into an interactive story map.

II. Effectiveness and Compatibility of Existing Monitoring Programs

We initially identified over 80 potential water quality monitoring programs throughout South Florida by approaching partners within our professional network, examining past research permits within the FKNMS that mentioned water quality parameters, and systematically searching the WIN/STORET and SEACAR databases. We removed programs that did not conduct sufficient sampling (10 years minimum within the FKNMS and 5 years minimum north of the FKNMS to Martin County); that were substantially beyond the geographic extent of the area of interest (the Florida Reef Tract from Monroe to Martin County); and that did not sample most of the parameters of interest (chlorophyll-a, temperature, salinity, nitrate+nitrite (NOx), soluble reactive phosphorus (PO4), silica (Si), turbidity, total nitrogen (TN), and total phosphorus (TP)). We attempted to combine data from 19 programs that met our initial criteria, but quickly found issues with naming conventions, metadata records, units, and other issues, discussed in Section IV "Opportunities for Improvement", that required further narrowing based on an internal QA/QC process.

Ultimately, we identified four compatible programs for the purpose of examining hotspots and trends, and constructing a program matrix, based on our initial criteria and an internal QA/QC process: 1) the South Florida Ecosystem Restoration Cruises (Walton Smith), 2) The Southeast Environmental Research Center Water Quality Monitoring Network (SERC), 3) the Miami-Dade County Department of Environmental Resources Management Water Quality Monitoring Program (DERM), and 4) the Broward County Water Quality Monitoring Program. The program matrix containing the sampling frequency, the parameters analyzed, length of time-series, and methodologies used for each parameter is listed in Appendix A.

III. Hotspots and Trends

To identify "hotspots" and trends where water quality may be worsening over time (e.g., where turbidity is "increasing" over time), time series were extracted from each sampling location and assessed using a seasonal Mann-Kendall test following the methods in Millette et al. 2019. The Mann-Kendall test estimates the Theil-Sen slope, or the rate of change of a parameter over the period that data were collected.

To ease interpretation, we categorized the Theil-Sen slope, or rate of change, as generally increasing or decreasing for each parameter of interest (turbidity, total nitrogen, NOX, silicate, phosphorous, and chlorophyll-a) and each program in the linked story map:

https://storymaps.arcgis.com/stories/52a114b2d89d4e60ac3fd75d713d90f7

Generally, changes in water quality trends over time differed between inshore and offshore areas across several parameters and monitoring programs. For the most part, there were greater trends and changes in water quality calculated for nearshore stations/regions versus offshore. This held true both near the Florida Peninsula and near the Florida Keys. However, the waters connecting these two regions on the southwest Florida shelf, had smaller changes in water quality.

Using 18 years (2003-2020) of ocean color satellite data from the Moderate Resolution Imaging Spectroradiometer (MODIS-Aqua) sensor, a gridded set of monthly satellite images covering the Florida Keys was created using four MODIS-Aqua satellite products related to water quality: chlorophyll-a concentration (an estimate of phytoplankton biomass), the diffuse attenuation coefficient at 490nm ($K_d(490)$ - a proxy for water clarity), light absorption by colored dissolved organic matter (CDOM) at 443nm ($a_{CDOM}(443)$ - an estimate of blue light absorption by CDOM), and reflectance at 667nm ($R_{rs}(667)$ - a proxy for suspended sediments).

Chlorophyll-a, $K_d(490)$, and $a_{CDOM}(443)$ estimate water color in the blue and green and often covary, which is not surprising because their algorithms are based on similar wavebands. The fourth parameter, reflectance in the red or $R_{rs}(667)$, indicates the presence of suspended sediments in the surface. These images should be viewed with the caveat that satellite retrievals of ocean color products are influenced by light reflected from the sea floor in shallow areas like the Florida Keys, leading to overestimates of parameters such as chlorophyll-a concentration. Shallow water effects can be mitigated by looking at patterns over time as opposed to absolute magnitudes and accounting for seasonality during the Mann-Kendall analysis.

Satellite-based Maps of Theil-Sen's slope for each parameter are presented in Figures 1-4. Based on these maps, hotspots were observed in two main areas, the Lower Keys and Biscayne Bay. Positive values (warm colors) of Theil-Sen's slope indicate a positive trend in values for a particular parameter (a worsening of water quality) at that location during the period of record (2003-2020) and negative values (cool colors) indicate a negative trend (an improvement in water quality) for that parameter during the period of record. Green is neutral and indicates the lack of a trend in the data over time.

Millette, N.C., Kelble, C., Linhoss, A., Ashby, S., and L. Visser. 2019. Using Spatial Variability in the Rate of Change of Chlorophyll a to Improve Water Quality Management in a Subtropical Oligotrophic Estuary. Estuaries and Coasts 42:1492-1803.

i. Lower Keys

Satellite-based maps of chlorophyll-a concentration, water clarity ($K_d(490)$) and dissolved organic matter ($a_{CDOM}(443)$) show similar patterns in Theil-Sen's slope (Figure 1) in the Lower Keys. Chlorophyll-a, $K_d(490)$, and $a_{CDOM}(443)$ all increased over time near Key West and Big Pine Key. Two primary areas in the lower Keys were identified as "hotspots" based on values of Theil-Sen's slope: areas directly north and west of Key West, and areas east of Big Pine Key (Figure 1). The three satellite products listed above show positive trends at these two locations, suggesting the water has become more highly colored by phytoplankton and CDOM over time, while a decrease over time is observed in the suspended sediment proxy ($R_{rs}(667)$) indicates that sedimentation improved in those areas over time.

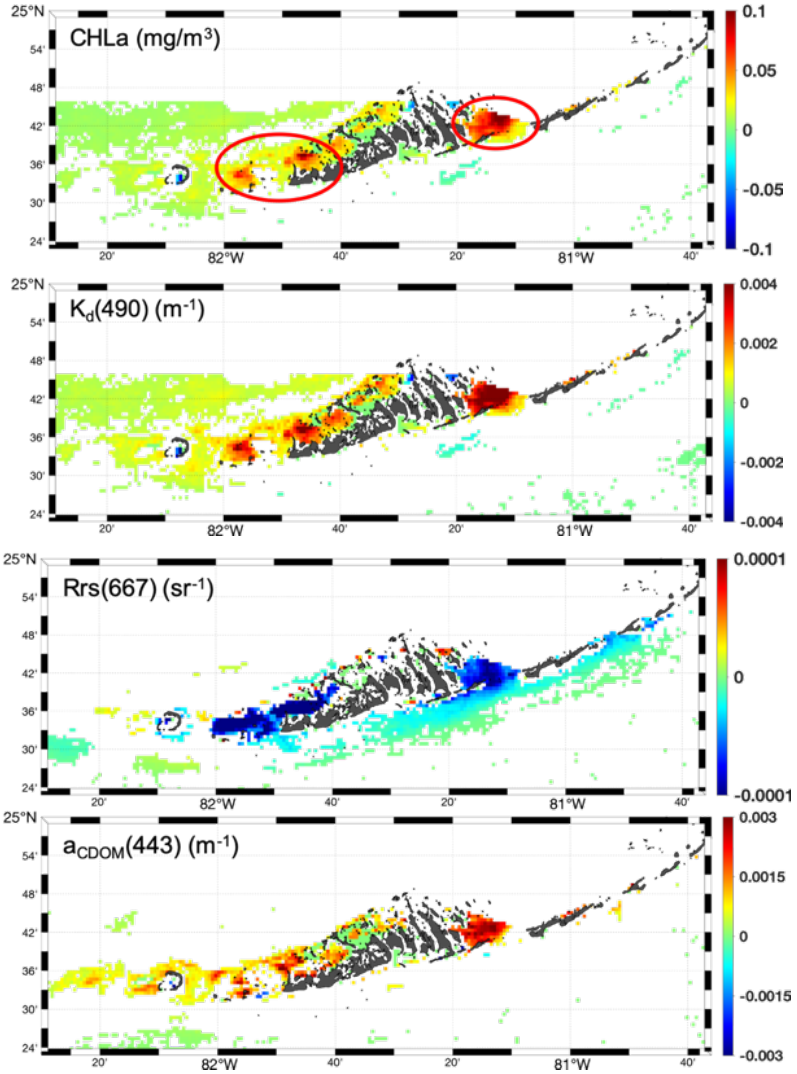

Figure 1. From top: Satellite-based Theil-Sen's slope maps showing trends of chlorophyll-a concentration (top), diffuse attenuation coefficient at 490nm (2nd from top), remote sensing reflectance at 667nm (2nd from bottom) and light absorption by colored dissolved organic matter (bottom) in the lower Keys between 2003 and 2020. The location of hotspots visible in all products are denoted in red in the top map. Warm colors indicate a positive trend, cool colors indicate a negative trend, and green indicates no trend over time.

ii. Upper Keys and Biscayne Bay

Biscayne Bay is quite variable in terms of Theil-Sen's slope in all parameters (Figure 2). a_{CDOM} does show spatial variability in the bay, but patterns are difficult to discern due to a lack of pixels showing a significant trend. In Biscayne Bay, K_d(490) and chlorophyll-a show largely the same trends with positive slope values in the middle and southern sections of the bay and a sharp band of pixels with negative slopes along the coastline at the southwestern edge of the bay. The Rrs(667) sediment proxy shows largely opposite trends, with positive slopes along the western side and negative slopes across the mouth of the bay, indicating areas where sedimentation may have improved over time.

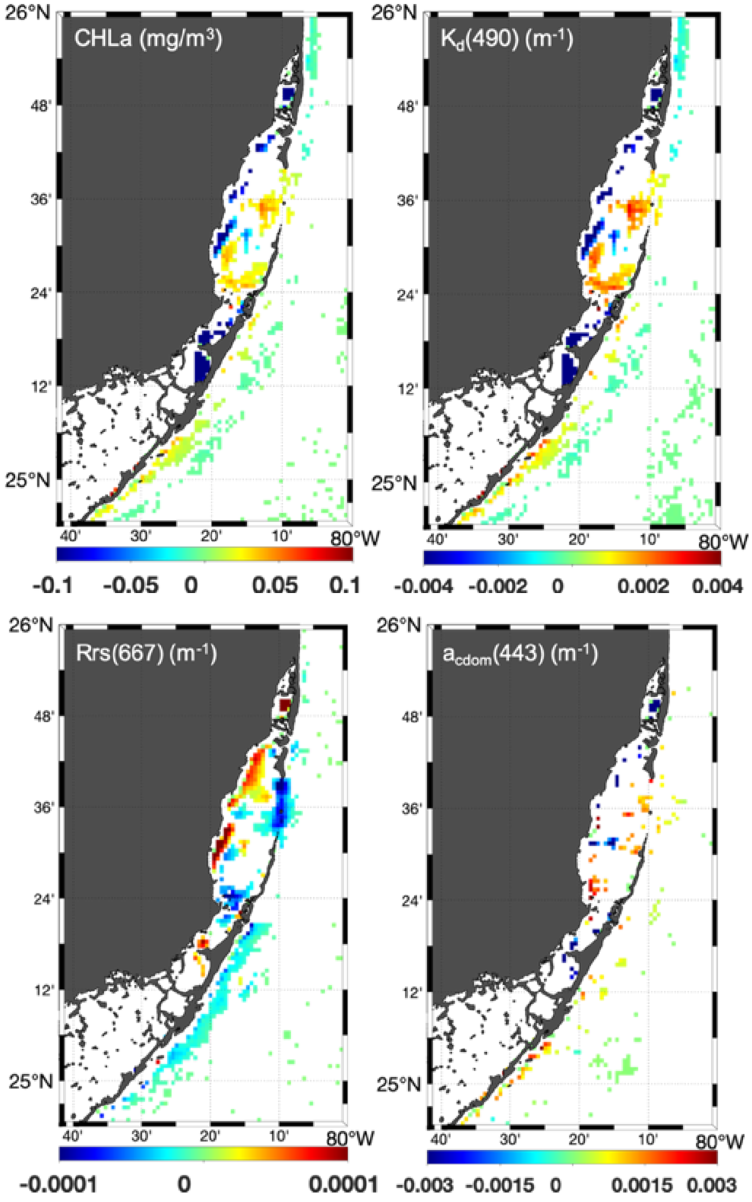

Figure 2. From top: Satellite-based Theil-Sen's slope maps showing trends of chlorophyll-a concentration (top left), diffuse attenuation coefficient at 490nm (top right), remote sensing reflectance at 667nm (bottom left) and light absorption by colored dissolved organic matter (bottom right) in the upper Keys and Biscayne Bay between 2003 and 2020. Warm colors indicate a positive trend, cool colors indicate a negative trend, and green indicates no trend over time.

iii. Time series

Some of the trends observed in the satellite imagery in the Lower Keys and Biscayne Bay agree with those seen in the SERC and DERM, as demonstrated in the linked story map. Furthermore, when we compare chlorophyll-a time series from the Walton Smith cruises to satellite derived estimates at the same coordinates, complementary trends emerge despite the increased variability from in situ observations. Monthly chlorophyll-a and a_{CDOM} at 443nm time series extracted from two locations in the lower Keys (Figure 3) exhibit both interannual variability as well as a pronounced seasonal cycle, which is accounted for in the Mann-Kendall analysis. Spatio-temporal variability in water quality parameters is quite high in the Florida Keys. In general, chlorophyll-a concentrations are higher in winter months, particularly offshore of the reef tract. Closer to shore, patterns are less clear due to influences from land.

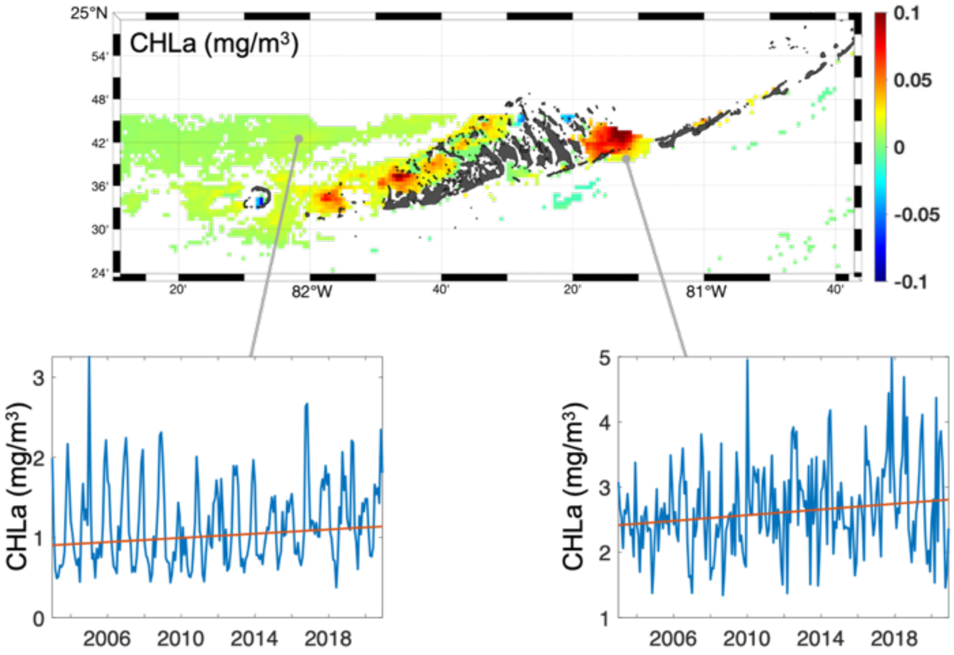

Figure 3. Satellite-based Theil-Sen's slope maps of chlorophyll-a concentration and example time series plots at two locations in the lower Keys. Time series extracted from the end of each gray line are plotted in blue. A representation of the trend line based on Theil-Sen's slope is given in red.

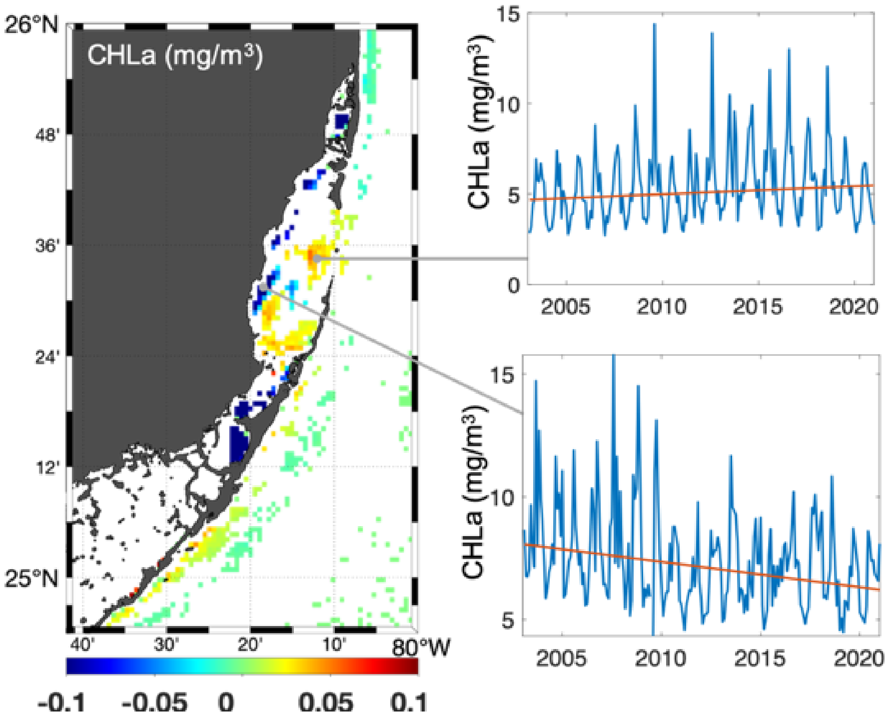

Figure 4. Satellite-based Theil-Sen's slope maps of chlorophyll-a concentration and example time series plots at two locations in Biscayne Bay. Time series extracted from the end of each gray line are plotted in blue. A representation of the trend line based on Theil-Sen's slope is given in red.

IV. Opportunities for Improvement

We could not combine several datasets simply because of the time required to reformat different databases for the purposes of bringing data into a common framework.

Specifically,

- Databases use different naming conventions for basic information, and it greatly increases the time required to effectively work with similar datasets. The most common information that differed between monitoring programs, in terms of formatting, was site coordinates, sampling dates, program names, units, and nutrient names.
    - Solution: Agree to common naming conventions among existing programs, and/or create code that automatically renames datasets to a common framework moving forward.

- Station names between, and within, monitoring programs can be inconsistent and/or illogical.
    - Solution: Use unique names with a reference key and easily accessible metadata. For example, "year sampled" should not be in the station name.

- Stations are rarely sampled at the exact same location in repeated visits, but still need to be considered discrete locations for subsequent analyses.
    - Solution: Provide coordinates as the average of site coordinates or define a local fixed coordinate to represent the general sampling site in subsequent years.

- The time frame(s) of interest can differentially weight trends in subsequent analyses, and monitoring programs do not always overlap in temporal sampling frequency.
    - Solution: Time periods of interest need to be clearly defined by management questions to compare and contrast regional water quality trends more accurately.

- Some programs sample year-round and others only sample in the summer. For example, the EPA's Environmental Monitoring and Assessment Program (EMAP) was an ideal candidate for subsequent hotspot analyses but could not be aggregated because sampling only occurred in the summer.
    - Solution: Hotspot analyses and other pattern recognition techniques require quarterly sampling at minimum and more frequent sampling is preferred.

V. Next Steps for Data Compatibility and Long-Term Integration

We presented two on-line PowerPoint presentations to separate stakeholder groups and will present a new presentation on June 16, 2021. On April 15th, 2021 and April 2nd, 2021, we presented project objectives and progress to the FKNMS Water Quality Protection Program and to the Southeast Florida Coral Reef Initiative. At the end of both presentations, we asked participants 1) if we would have missed any substantial water quality monitoring programs in South Florida due to our selection process, and 2) if there was a community preference for a long-term database solution to combine programmatic sampling data. Additionally, we sent all participants (Appendix C) a follow-up solicitation email to provide another opportunity to answer our questions. We received some valuable input regarding potential programs we may have missed in our selection process, but importantly, we did not receive a single opinion regarding a preference for a long-term database solution.

If the water quality sampling community in South Florida has no preference for a database solution, as indicated, one option could utilize the existing capabilities of state agencies. The Florida Fish and Wildlife Conservation Commission (FWC) reformats the SERC Water Quality Monitoring Network data for the purpose of uploading data to WIN and has done so since 1995. Additionally, FWC has the programmatic experience of bringing in disparate datasets to create the Unified Reef Map using a common framework. However, FWC's mission is to broadly manage fish and wildlife resources while other agencies are more directly involved with water quality programs (i.e., the Department of Environmental Protection). Thus, we propose a more targeted effort moving forward that brings together state agencies and federal partners to identify a long-term cooperative solution.

In FY21/22, we intend to build from this initial effort in several ways. Specifically, we intend to:

1) Incorporate programmatic monitoring data that sampled some, but not all the initial parameters of interest to identify additional spatio-temporal hotspots;
2) Conduct a detailed gap analysis, compare the variability between water quality time series from different programs, and present findings to a monitoring workshop; and
3) Construct geostatistical models to determine the appropriate spatial resolution for aggregating different water quality parameters.

APPENDIX A: Water Quality Program Matrix and Methods

Dataset	**Institution(s)**	**Contact Person**	**URL for project**	**Spatial Distribution**	**Temporal Frequency**
South Florida Ecosystem Restoration Cruises (Walton Smith)	NOAA AOML, University of Miami-CIMAS	Alexandra Fine, alexandra.fine@noaa.gov	https://www.aoml.noaa.gov/ocd/ocdweb/wsmith/wsmith_introduction.html	Key Biscayne to Dry Tortugas, W. FL Shelf and FL Bay	Bimonthly
SERC South Florida Estuaries Water Quality	Florida International University (FIU)	Henry O. Briceño, bricenoh@fiu.edu	http://serc.fiu.edu/wqmnetwork/SFWMD-CD/Pages/DataDL.htm	Northern North Bay to Dry Tortugas, W. FL shelf and FL Bay	Monthly
DERM	Miami-Dade County's Department of Environmental Resources Management (DERM)	Omar Abdelrahman, Omar.Abdelrahman@miamidade.gov, Yin Chen (lab manager) Yin.Chen@miamidade.gov	https://www.miamidade.gov/environment/surface-water-quality.asp	Biscayne Bay	Monthly
Broward County Water Quality Monitoring Program	Broward County Environmental Lab	Patricia Holowecky, pholowecky@broward.org	https://www.broward.org/NaturalResources/Lab/AboutUs/Pages/canalwaterquality.aspx	Broward County	Quarterly

Dataset	**Length of Time Series**	**Instruments Used**	**Parameters Analyzed**
South Florida Ecosystem Restoration Cruises (Walton Smith)	1998 to Present	SEAL AA3 Autoanalyzer, Turner TD-700 Fluorometer, Shimadzu	SSS, SST, NH4, NOX, NO2, NO3, PO4, Si, Chl-a, TDN, TDP
SERC South Florida Estuaries Water Quality	1988 to Present	Rapid flow analyzer Alpkem modelRFA300, Shimadzu, Gilford Fluoro IV Spectrofluorometer, ANTEK 7000N Nitrogen Analyzer	SSS, SST, NOX, NO3, NO2, NH4, TN, DIN, TON, TP, SRP, APA, Chl-a, TOC, SiO2, Turbidity, pH, Kd
DERM	2005 to Present	SEAL Analytical AA3 Autoanalyzer, Lachat QC 8500	Chl-a, TPO4, TKN, Entero, Ecoli, TP, NH3, NOX, Turbidity
Broward County Water Quality Monitoring Program	2006 to Present	SEAL Analytical AA500, SEAL Analytical AA3 Autoanalyzer	NOX, NH4, TN, TP, Chl-a, TKN, TON, DO, pH, SPC, Salinity, Cooper, Entero bacteria

Dataset	**Chl-a**	**NOX**	**NH4**	**Si**	**TDN**	**TDP**	**TN**	**TP**	**PO4**	**DIN**	**TON**
South Florida Ecosystem Restoration Cruises (Walton Smith)	Shoaf and Lium, 1976	Zhang, 2000	Zhang et al. 1997	Zhang and Berberian, 2000	X	X	N/A	N/A	Zhang et al. 2000	N/A	N/A
SERC South Florida Estuaries Water Quality	Strickland and Parsons, 1972	Alpkem Corporation, 1986	Alpkem Corporation, 1989	X	N/A	N/A	Frankovich and Jones, 1998	X	Alpkem Corporation, 1987	X	X
DERM	EPA 445.0	EPA 353.2	EPA 350.1	N/A	N/A	N/A	EPA 351.4	EPA 365.1	EPA 365.1	N/A	N/A
Broward County Water Quality Monitoring Program	EPA 445.0	EPA 353.2	EPA 350.1	N/A	N/A	N/A	EPA 353.2 + EPA 351.2	EPA 365.4	N/A	N/A	EPA 351.2-EPA 350.1

X indicates the parameter is measured by the program, but we do not have specific details on the methodology.

N/A indicates the parameter is not measured by the program.

Dataset	**TKN**	**APA**	**pH**	**Kd**	**DO**	**Turbidity**	**Entero/Ecoli**	**EDCs**	**NELAC Certified**
South Florida Ecosystem Restoration Cruises (Walton Smith)	N/A	N/A	N/A	N/A	EXO Handheld	N/A	N/A	N/A	NO
SERC South Florida Estuaries Water Quality	N/A	X	X	X	N/A	HF Scientific model DRT-15C turbidimeter	N/A	N/A	YES
DERM	EPA 351.2	N/A	N/A	N/A	N/A	N/A	X	N/A	YES
Broward County Water Quality Monitoring Program	EPA 351.2	N/A	YSI ProDSS	N/A	YSI ProDSS	X	X	N/A	YES

X indicates the parameter is measured by the program, but we do not have specific details on the methodology.

N/A indicates the parameter is not measured by the program.

I. Program Name: South Florida Ecosystem Restoration Cruises (Walton Smith)

Methods:

Samples are collected using CTD. Nutrient samples are filtered at sea using 0.45 micron nylon syringe filters and stored in the freezer until analysis. Nutrient analysis for NO2, NO3, NOX, PO4, Si and NH4 on a SEAL AA3 Nutrient Autoanalyzer following Zhang methods. Chlorophyll-a samples are filtered through vacuum filtration using 25 mm GF/F filters and stored in -80° freezer until analysis. Chlorophyll-a analysis follows methods described in Shoaf and Lium, 1976.

Notes and References:

Not historically NELAC Certified, but in process now.

II. Program Name: Southeast Environmental Research Center Water Quality Monitoring Network (SERC)

Methods:

Duplicate, unfiltered water samples are collected and kept at ambient temperature in the dark during transport. Samples are filtered by hand through 25mm GF/F glass fiber filters into sample rinsed 60 ml HDPE bottles, which were capped and immediately placed on ice in the dark for transport. The wet filters, used for chlorophyll-a analysis were placed in 1.8ml plastic centrifuge tubes to which 1.5 ml of 90% acetone was added (Strickland and Parsons, 1972), then capped and put into a dark bottle on ice for transport. Unfiltered water samples were analyzed for total nitrogen (TN), total phosphorus (TP), total organic carbon (TOC), alkalinephosphatase activity (APA), and turbidity. TN was measured using an ANTEK 7000N Nitrogen Analyzer using O2 as carrier gas instead of argon to promote complete recovery of the nitrogen in the water samples (Frankovich and Jones, 1998). TOC was measured by direct injection onto hot platinum catalyst in a Shimadzu TOC-5000 after first acidifying to pH < 2 and purging with CO2-free air (MDL = 0.06 mg l□1). Turbidity was measured using an HF Scientific model DRT-15C turbidimeter and reported in NTU. Filtrates were analyzed for nitrate + nitrite (NOX), nitrite (NO2), ammonium (NH4), and soluble reactive phosphorus (SRP), on a four channel autoanalyzer (Alpkem modelRFA300) by flow injection analysis. The nutrient analysis followed the procedure suggested by Alpkem Corporation. NOX was determined by the quantitative reduction of NO3 to NO2 using an activated Cd column. Filters for chl-a content(lgl□1) were allowed to extract for a minimum of 2 days at 20 °C before analysis. Extracts were analyzed using a Gilford Fluoro IV Spectrofluorometer (excitation = 435 nm, emission = 667 nm) and compared to a standard curve of pure chl-a (Sigma).

Notes and References:

Also listed as Florida Keys Water Quality Monitoring Project. Data were provided by the SERC-FIU Water Quality Monitoring Network which is supported by SFWMD/SERC Cooperative Agreement #4600000352 as well as EPA Agreement #X7-96410603-3.

III. Program Name: Miami-Dade County Department of Environmental Resources Management Water Quality Monitoring Program (DERM)

Methods:

Orthophosphate: Collect orthophosphate unfiltered and unpreserved. Holding time is 48 hours per EPA 365.1. They do not heat the molybdate - reaction occurs at room temperature to reduce interference with Si, which they don't currently measure. Nutrients: collected in a separate bottle, pre-washed, with sulfuric acid. Samples are collected and preserved in the field and left on ice unfiltered for a max of 28 days. No preservative for NH4 samples. Samples stored in fridge < 6 deg C (not frozen). Use SEAL AA3 Autoanalyzer or Lachat QC 8500 with flow injection method. Chlorophyll-a: samples collected in pre-washed amber bottles. 1 L filtration within 24 h of sample collection. After filtration, filters are frozen in -20 C freezer for up to 21 days. Filters are macerated in the dark. 13 mL is extracted. Use narrow band fluorometer.

Notes and References:

Lab was NELAC-certified in 2005.

IV. Program Name: Broward County Water Quality Monitoring Program

Methods:

Gas chromatography and mass spectrometry, absorption and emission spectroscopy, all following EPA and FDEP regulations. All samples are processed unfrozen. NOX, NH4, TKN and TP samples are acidified to pH <2 with sulfuric acid. Orthophosphate samples are unacidified and filtered within 15 minutes. Hold time is 48 hours for unacidified samples and 28 days for acidified samples.

Notes and References:

Entero sampling started in 2017. Lab also analyzes copper (from antifouling paint) and algal blooms (cyano blue-green algae). In addition to the Broward County Ambient Water Quality Dashboard, the long-term hosting of this data can be found in WIN- Watershed information network using the WAVES data extract menu, query organization ID: 21FLBROW and project ID PROJ-001. Coordinates available on ESRI online (https://bcgis.maps.arcgis.com/apps/opsdashboard/index.html#/b98ad6a3c9534bed96ac12762a988a9d)

APPENDIX B: Literature Cited in Program Matrix

ALPKEM Corporation (1986). RFA methodology for nitrate and nitrite nitrogen. A303-S170. ALPKEN Corporation, Clackamas, Oregon, p. 11.

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Strickland, J.D.H. and Parsons, T.R. (1972). A Practical Handbook of Seawater Analysis. 2nd Edition, Fisheries Research Board of Canada Bulletin, No. 167, Fisheries Research Board of Canada, 310.

U.S. Environmental Protection Agency (1983). Methods for the chemical analysis of water and wastes. U.S. Government Printing Office, Method number 353.2.

U.S. Environmental Protection Agency (1993). “Method 350.1: Determination of Nitrate-Nitrite Nitrogen by Automated Colorimetry,” Revision 2.0.

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Zhang, J.-Z., Ortner, P. B., Fischer, C. J., and Moore, L. D. (1997). Determination of Ammonia in Estuarine and Coastal Waters by Gas Segmented Continuous Flow Colorimetric Analysis. EPA Method 349.0. National Exposure Research Laboratory Office of Research and Development. Cincinnati, OH: U.S. Environmental Protection Agency.

APPENDIX C: List of Contacted Stakeholders

Name	Affiliation	Email
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