Florida’s Coral Reef Water Quality Data Compilation, Analysis, and Decision Support Year 6

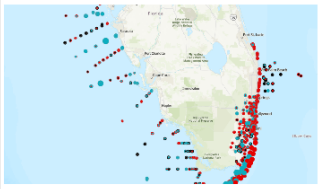
Florida's Coral Reef Unified Water Quality Monitoring Data Compilation

Unified Water Quality Monitoring Data for Florida's Coral Reef

Welcome to the resource page for "Florida's Coral Reef Unified Water Quality Monitoring Data Compilation" created by the Florida Fish and Wildlife Conservation Commission, University of South Florida, and Florida Department of Environmental Protection. Funded by DEP, this project has developed a unified water quality monitoring database for nutrient and turbidity data and an inventory of temperature, salinity, DO, and pH, as well as an inventory of biological and ecological monitoring programs in the region. Our work is feeding into the Florida’s Coral Reef Coordination Team’s plan to develop a Unified Water Quality Monitoring Framework to look at how Everglades Restoration affects Florida's Coral Reef.

Current Data

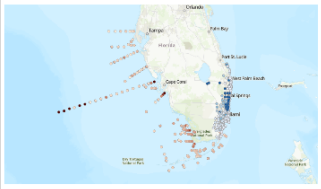
Water quality data was aggregated from 8 providers: NOAA Atlantic Oceanographic and Meteorological Laboratory, Florida International University Southeast Environmental Research Center, Miami-Dade County Department of Environmental Resource Management, Florida Department of Environmental Protection (DEP), Broward County, City of Miami Beach, DEP Biscayne Bay Aquatic Preserves, and Palm Beach County.



Water Quality Slope Map 2025-26

2025 - 2026 data that summarizes the Theil-Sen slope (calculated as rate of change over a period of time) for water quality analytes in South Florida coastal waters.

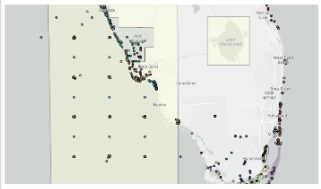
Open App



2025 Unified Water Quality Monitoring Data

2025 and 2026 aggregated water quality data for water quality analytes in South Florida coastal waters including nitrogen, phosphorus, and water clarity.

Open App



Biological Ecological Monitoring Inventory

Inventory of biological and ecological coastal monitoring programs in southeastern and southwestern Florida. Sources include SEACAR, NOAA, and FWC GeoData.

Open App

FLORIDA'S CORAL REEF

Florida's Coral Reef Water Quality Data Compilation, Analysis, and Decision Support Year 6

Final Report

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Management Summary
The water quality data compilation, analysis, and decision support project was tasked with creating a single unified water quality monitoring dataset for Florida's Coral Reef. Initially, the project comprehensively reviewed available water quality data and programs, compiled comparable datasets, and constructed inclusion criteria to support data interoperability. In year 6, the water quality team collaborated with the SEACAR team to develop an automated workflow in SEACAR following previously developed criteria and QA/QC processes to export the aggregated water quality dataset quarterly. After verifying the first SEACAR export in March 2026, the data were used to update the trend analysis, maps, and visualization tools with data through 2025. The team was involved with Florida's Coral Reef Coordination Team (FCRCT), Florida's Coral Reef Resilience Program Water Quality Team, and Florida Keys National Marine Sanctuary Water Quality Protection Program meetings to support reef-wide water quality monitoring efforts and research. Two inventories of abiotic parameters and biological and ecological monitoring programs were maintained and updated to include additional programs, along with updated contact information, names and newly added monitoring sites on the web maps. These inventories addressed priority actions for the FCRCT and included interactive web maps for users to visualize the spatial patterns of these monitoring programs. The team developed a modular trend analysis tool that includes a step-by-step tutorial and accompanying R scripts for conducting both general and seasonal trend analyses on water quality data. Finally, the team examined patterns of precipitation, river discharge, and water quality that link events such as water releases and rainfall events to river discharge patterns and salinity conditions in Florida Bay to water quality conditions on the reefs.

Executive Summary

Florida's Coral Reef (FCR) has been facing a range of anthropogenic and biophysical stressors over the last several decades that have led to widespread declines in coral cover. Water quality is a key concern for FCR, which is affected by pollution, land-use change, weather events, and water diversions. However, FCR stretches 350 miles with diverse localized and regional pressures that cause significant regional variation in water quality. Efforts to monitor water quality on FCR are made up of a series of discrete regional field sampling programs, continuous sampling with autonomous instruments, and remotely-sensed and satellite-derived analyses. Thus, it is challenging to combine these disparate sources of water quality data to create a comprehensive picture of historical and current water quality trends across FCR. The water quality monitoring data aggregation and analysis project addressed this challenge by developing a unified water quality database ranging from Martin County in the northeast to the Dry Tortugas in the southwest of FCR. During year 6 of this project, the water quality team updated and improved the water quality database made up of 8 programs meeting the compatibility criteria, conducted inventory and methods analyses for 'abiotic' water quality and biological and ecological monitoring programs, contributed to statewide water quality management teams, collaborated with existing databases to automate data aggregation, and investigated fine-scale patterns of water quality from pulse events. Additionally, all maps are now available in one place on the Water Quality ArcGIS Online Hub.

The most significant development in year 6 was the collaboration with the Statewide Ecosystem Assessment of Coastal and Aquatic Resources (SEACAR) team to automate updates to the Unified Water Quality Monitoring Database and to host the dataset on the SEACAR Data Discovery Interface. The Unified Water Quality Monitoring Dataset will now be updated quarterly on its dedicated SEACAR program page, providing users with consistent access to the most current water quality data. The water quality team worked with the SEACAR team to develop a workflow that ensures data submissions from multiple monitoring partners are standardized, integrated, and quality-checked. The first quarterly export from SEACAR in March 2026 was used to update the unified water quality database and update trend analyses, web maps, and visualization tools to incorporate the 2025 data.

The team supported and contributed to the Florida's Coral Reef Coordination Team (FCRCT) and Florida Coral Reef Resilience Program (FCRRP) Water Quality team throughout the year. To address priority actions, the team updated the inventory of water quality monitoring on FCR and the inventories and methods analyses for programs monitoring abiotic parameters, including temperature, salinity, pH, and dissolved oxygen and biological and ecological monitoring programs developed in Year 5. Inventories were revised using feedback from water quality teams and updated with monitoring locations for programs that add new sampling sites. Both inventories have interactive web maps where survey locations can be filtered by parameter, method, and other relevant categories. Additionally, managers identified a need to quickly analyze water quality trends. Therefore, the team developed a modular script and tutorial to help managers and researchers quickly run analyses using data from their specific programs of interest. The tool provides guidance for adapting the analysis workflow to other datasets or locations. Finally, using the team conducted a fine-scale analysis of water quality trends based on water quality parameters along with in situ observations of abiotic factors such as precipitation,

river discharge, and salinity. The water quality and in situ abiotic data is complemented by satellite remote sensing data which provides synoptic views of the study area.

Table of Contents

1. BACKGROUND/INTRODUCTION

Water quality in marine ecosystems can be negatively affected by a number of local-scale factors including discharges of nutrients from human sources, resuspension events from winds, tides, or currents, or from watershed disturbances due to deforestation and other land-use and land-cover change, nutrient pollution, and water diversions. On larger scales, climate change, sea level rise, changing ocean chemistry, species range expansions, soil transport, and erosion can exacerbate these issues. However, few field studies can frequently collect data in dense geographic grids or consider land and adjacent marine systems as part of a continuum within an ecosystem. Often, data from disparate sources (e.g., in situ and satellite derived data) are required to identify patterns in the water quality, especially across wide geographic bounds in South Florida ecosystems that include Biscayne Bay, Florida Bay, the Florida Keys National Marine Sanctuary (FKNMS), and Florida's Coral Reef (FCR). These patterns are affected by the diverse hydrography, geography, and human impacts that can propagate from local to landscape scales.

For the past six years, research scientists from the Florida Fish and Wildlife Conservation Commission and the University of South Florida have comprehensively reviewed the wide array of water quality data collected in southern Florida, compiled comparable datasets, visualized trends in water quality data, and constructed a set of criteria for standards between monitoring programs that would allow for increased interoperability. These efforts resulted in the development of a unified water quality monitoring (UWQ) dataset of nutrient and water clarity data from eight monitoring programs. The UWQ dataset continues to be updated and improved, and communication tools such as interactive web maps, trend analyses, and visualization tools are produced with each update.

The breadth of information in the UWQ provides an opportunity for the research team to support managers and practitioners who wish to incorporate regional water quality information into their decision-making processes. The Florida's Coral Reef Coordination Team (FCRCT), a multi-agency team created to "regionally integrate and coordinate management and restoration-related activities to conserve and restore Florida's Coral Reef", has been supported by the WQ research team with technical support by providing datasets, indicators, and map layers. The FCRCT developed the Unified Water Quality Monitoring Framework to guide a monitoring network to answer questions about the impacts of Everglades restoration efforts on FCR and effects of water quality on coral reef health. The research team contributed to the first two priority actions within this framework which address inventories of existing water quality and biological and ecological monitoring programs and provide input to additional priority actions.

We proposed the continued improvement of the UWQ, providing technical support to the FCRCT to aid in the assessment of water quality trends and helping complete priority actions for the Unified Water Quality Monitoring Framework, and using the WQ datasets to identify patterns of water quality changes across the reef. During the 6th year of this project, we worked with the Statewide Ecosystem Assessment of Coastal and Aquatic Resources (SEACAR) team to automate updates to the Unified Water Quality Monitoring Database and to host the dataset on the SEACAR Data Discovery Interface. With the automated exports, we updated the existing unified water quality monitoring database, parameter analyses, and web maps with new data and programs. We also informed and provided open-ended technical support at the FCRCT and Florida Coral Reef Resilience Program (FCRRP) Water Quality team meetings to assist with interpretation of existing data products including GIS layers, data visualization tools, and data

analyses. In addition, we updated the abiotic and biological/ecological inventories created in Year 4 and 5 using stakeholder feedback and information on new monitoring locations. We developed a modular trend analysis tool including a step-by-step tutorial to help managers and researchers more easily extract general and seasonal trend analyses from water quality data. Finally, we identified patterns of water quality within the reef ecosystems that could be linked to terrestrial events and activities. Using the UWQ, satellite observations, river discharge data, and in-situ monitoring data, we linked regional terrestrial precipitation patterns to water quality on FCR and associated ecosystems.

2. METHODS

2.1 Collaboration with SEACAR to update the unified water quality dataset and associated data products

Staff reviewed water quality monitoring programs to determine if previously included programs continued to meet inclusion criteria and if previously excluded programs now meet the same inclusion criteria. The five inclusion criteria were 1) sampled within South Florida 2) sampled at least four water quality parameters of interest 3) contained unique sampling data 4) active sampling and 5) have at least 5 years of continuous data. The water quality parameters of interest include Chlorophyll-a, nitrate (NO3), nitrite (NO2), nitrate + nitrite (NOx), ammonia (NH4), soluble reactive phosphorus (PO4), turbidity, total Kjeldahl nitrogen (TKN), total nitrogen (TN), and total phosphorus (TP). These monitoring program partners were: NOAA Atlantic Oceanographic and Meteorological Laboratory (AOML), FIU Southeast Environmental Research Center (SERC), Miami-Dade County Department of Environmental Resource Management (DERM), Florida Department of Environmental Protection (FDEP), Broward County (BC), City of Miami Beach (MB), FDEP Biscayne Bay Aquatic Preserves (BBAP), and Palm Beach County (PBC).

Staff coordinated with the SEACAR team to standardize the complete datasets for all eight monitoring program partners. As part of this process, staff provided historic water quality data dating back to 1970, along with a crosswalk aligning analyte names to SEACAR's standard vocabulary to support integration of the Unified Water Quality Monitoring Database into SEACAR (Table 1). The crosswalk document specifically mapped each of the 8 programs, several of which were not yet part of SEACAR, to the SEACAR metadata and QA/QC standards. Staff also developed data integration procedures to generate a standardized data export, which required pivoting tables, reformatting dates, and combining multiple worksheets to merge the datasets effectively. Using these procedures, the SEACAR team produced a single standardized export table incorporating both historical and current data. This integrated dataset was hosted on the Florida's Coral Reef Unified Water Quality Monitoring program page and will be updated quarterly with newly submitted data. Staff also updated the 'Florida's Coral Reef Unified Water Quality Monitoring Database' SEACAR program page with new ArcGIS online web maps and products and uploaded excel files with the biological and ecological monitoring, and abiotic inventories.

Staff provided QA/QC to compare the standardized export table from SEACAR to the unified database assembled through 2024, that was created using prior standardized methods. For each of the 8 data providers, comparisons were run between datasets retrieved from the Florida SEACAR Data Discovery web interface. Both standardized data in the WIN format and raw data

uploaded to SEACAR by each provider were compared to the year 4 version of the unified database, which was updated with data through the end of 2023. Comparisons were made to assess any differences in sampled parameters (analytes), trends, sampling locations, location IDs, sample size, and datetime range for each data provider. The QA/QC comparison was compiled into a report using R and Quarto.

The SEACAR-comparison report was published separately from the pre-2024 data ingestion methods. The new report includes calculation of seasonal Mann-Kendal slopes for each parameter at each sampling site. The structure of the previous data ingestion site was reproduced to create reports for each program and provider. Additional reports were created to focus on the depths of reported data and changes in the rate of change products from SEACAR and the previous data ingestion methods. Drilldown reports were created to allow closer inspection of a single parameter within a site and program; the selection is randomized at each generation of the website. New data visualizations were added to enable data exploration and confirmation of data quality expectations.

Additionally, usage examples of the SEACAR data product were added to the report website demonstrating spatial mapping of parameter rate of change, distribution of parameter values, and a scalable hexagon aggregated spatial map of values. Additional details of the work completed are available in the supplementary document linked in the 'FWRI WQ Project Links 2026.pdf' document.

Table 1. List of data providers with their Watershed Information Network (WIN) organization and project IDs, SEACAR names and IDs, and duration of data collected.

Program	WIN Organization ID	WIN Project ID	SEACAR name	SEACAR ID	Date Duration
FIU SERC	21FLFWC	WQMP	Florida Keys National Marine Sanctuary Water Quality Monitoring Project; SERC Water Quality Monitoring Network	297; 509	6/27/1989-9/15/2025
BBAP	21FLBBAP	JTDIEOFF	North Biscayne Bay Seagrass Loss Water Quality Program; Biscayne Bay Aquatic Preserves Continuous Water Quality Monitoring	5026; 5077	2/4/2019-9/17/2025
DERM	21FLDADE	BBWQ	Miami-Dade County DERM Benthic Habitat Monitoring Program	4018	10/18/1993-12/4/2025
DEP-ECA	21FLCRCP	FRTWQA	Southeast Florida Water Quality Assessment Survey	5033	9/20/2017-6/12/2025

Palm Beach County	21FLPBCH	ERMWQ	Palm Beach County Water Quality Program	10012	3/18/2002-12/03/2025
Broward County	21FLBROW	PROJ-001	Broward County Water Quality Monitoring	10013	1/26/1999-5/29/2025
AOML	N/A	N/A	Atlantic Oceanographic and Meteorological Laboratory (AOML) South Florida Program Shipboard Survey	3	12/1/2014- 8/16/2025
Miami Beach	N/A	N/A	City of Miami Beach Water Monitoring	4058	8/16/2016-12/28/2025

Staff then conducted trend analyses on the processed SEACAR export dataset using scripts developed in previous years and updated this project year. 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 for each analyte 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 (Chlorophyll-a, nitrate (NO3), nitrite (NO2), nitrate + nitrite (NOx), ammonia (NH4), soluble reactive phosphorus (PO4), silica (Si), turbidity, total Kjeldhal nitrogen (TKN), total nitrogen (TN), and total phosphorus (TP)), at each monitoring site.

The dataset will be updated quarterly in SEACAR, and the export will be used to generate subsequent trend analyses. Staff will then update web maps, mapping applications, and data visualization tools. To streamline this process, the team developed a script that automates the processing of SEACAR data, and trend-analysis outputs, generating an updated ArcGIS Online layer. A link to the code for the data ingestion, merging, quality control and Sen's slope calculations can be found in the associated 'FWRI WQ Project Links 2026.pdf' document.

2.2 Open-ended technical advisory support for FCRCT and water quality meetings

Staff were asked to attend and provide open-ended technical support for the Florida's Coral Reef Coordination Team meetings during 2025-2026. Staff were on hand to present overviews and results of the water quality aggregation project and contribute to answering questions identified in the Unified Monitoring Framework for Florida's Coral Reef. Staff also attended Florida's Coral Reef Resilience Program Water Quality Team meetings to collaborate with water quality monitoring managers across FCR and contribute to the actions to meet the priorities of the FCRCT. Staff attended additional regional water quality meetings such as the FKNMS Water Quality Protection Program (WQPP).

Staff developed an online questionnaire to gather feedback on the biological and ecological monitoring program inventories, as well as the abiotic monitoring program inventories created during Years 4 and 5. The questionnaire was distributed to FCRCT and FCRRP Water Quality members and additional stakeholders from the broader Florida Coastal Everglades restoration community. It included questions about potentially missing programs, errors or gaps in existing inventory information, missing monitoring sites, and any issues or needed improvements related to web map functionality. All feedback received was reviewed and incorporated into updates of the inventories and associated web maps.

Staff updated the web maps for the biological and ecological monitoring program inventory with sites of monitoring programs that use annually updated random sampling methods. The web maps will be updated regularly as new monitoring locations are made available.

Progress on both the abiotic and biological/ecological inventories is ongoing. The team will continue to update these inventories as new programs meet the inclusion criteria and as additional monitoring locations are identified. Staff will also maintain the accompanying metadata and web maps to ensure the information remains accurate, current, and useful for stakeholders.

2.3 Updates to the abiotic factor and biological and ecological monitoring inventories

The data layer showing locations of programs that use random sampling locations for biological and ecological monitoring was updated to reflect changes in the Disturbance Response Monitoring (DRM) program and the Harmful Algal Bloom program. The Queen Conch research team at FWRI requested that specific location points for their monitoring program be generalized, so the team converted the location points to a simple coverage polygon. The team also plans to incorporate Fisheries Independent Monitoring data and data from the Reef Environmental Education Foundation's Volunteer Fish Survey Project into future updates of the web map, as well as any programs with monitoring locations that vary annually or according to their respective sampling intervals.

The results of the questionnaire shared with members of the FCRCT, and other stakeholders were incorporated into the inventories. For the abiotic inventory, the discrete monitoring programs were updated to include additional parameters for the Southeast Water Quality Assessment Survey in Kristin Jacobs Coral Aquatic Preserve and for the Biscayne Bay Aquatic Preserve Continuous Water Quality Monitoring. The Indian River Lagoon Observatory Network was added to the abiotic inventory. Additional abiotic monitoring sites, the locations of the Sofar buoys were added in the FKNMS on the web map. Smaller updates to the inventories included correcting contact information, sampling frequency, and collection years for the Palm Beach County Environmental Resource Management abiotic water quality sampling as well as the Integrated Biscayne Bay Ecological Assessment and Monitoring Project in the Biological/Ecological inventory. The team has also updated mapping symbology to improve visualization for users. The questionnaire will remain open so the team can continue gathering feedback and improving the inventories. The project team will also keep updating it to include new programs that meet the inclusion criteria, while continuing to maintain accurate and consistent metadata for each program. The web maps with sampling locations will also be updated accordingly.

2.4 Fine scale analysis of water quality to identify historical pulse events and responses to Everglades restoration and development of modular analysis tools

Using the unified water quality monitoring database, the WQ team conducted broad-scale analyses of regional water quality across Florida's Coral Reef. Additionally, the breadth and depth of the water quality database provide opportunities to conduct finer-scale analyses of water quality. The research team complemented the unified water quality database with other datasets, including satellite observations, river discharge data, and in-situ measurements of abiotic factors, particularly salinity and precipitation. This comprehensive dataset was used to identify the general patterns of precipitation over South Florida, how those spatial and temporal precipitation patterns relate to patterns in river discharge, and if those patterns manifest with measurable changes in water quality.

The team developed a modular trend analysis tool to aid users with limited coding experience to easily perform general and seasonal trends analyses from water quality data. This trend analysis tool includes two well-annotated R scripts for the analyses and an accompanying markdown document that walks users through each step of the script with examples, maps, and figures. Following the markdown, the tutorial brings in DEP Kristen Jacobs Aquatic Preserve (KJCAP) water quality data downloaded from SEACAR Data Discovery to ensure compatibility and transforms the data into the format required for analysis. The tutorial performs the seasonal Mann-Kendall test on the full dataset for Chlorophyll-a, Total Kjeldahl Nitrogen, and Total Suspended Solids at each site with 5 or more years of data. The seasonal Mann-Kendall test accounts for seasonal variation in the data and provides the slope of the trend at each site with the significance of the trend. Summary statistics for each site, including minimum, maximum, mean, and the coefficient of variation, are appended to the results. The tutorial also provides a workflow for separating trends between wet and dry seasons for each analyte. The script creates plots displaying the trend lines per analyte for all sites and split out by county to better visualize the trends. The script also creates static maps that show trends per analyte at each site along with the strength, significance, and direction for the annual and seasonal (wet and dry) analyses.

Along with the tutorial, two R scripts were provided. The first script allows users to input water quality data downloaded from SEACAR and run the full annual and seasonal analyses on all analytes present with the dataset, as long as it meets the minimum of 5 years of data. This would prevent the user from having to filter or wrangle the data before running the script. The second script also runs the full analysis but allows the user to set specific configurations depending on needs. The configurations include specifying a site or an analyte they are interested in analyzing. The R scripts generate the results as .csv files and accompanying figures and are written into the user's specified folder of choice. The research team met with DEP staff to complete a walkthrough of the script and markdown tutorial and incorporated their feedback into the final products. A recording of the walkthrough, along with the markdown tutorial and associated R scripts, can be found in the associated 'FWRI WQ Project Links 2026.pdf' document.

3. RESULTS

3.1 Collaboration with SEACAR to update the unified water quality dataset and associated data products

The exported data from SEACAR, accessed through the Florida's Coral Reef Unified Water Quality Monitoring Database program page, was used to generate trend analyses. The project team filtered the export to include only samples collected in 2025, then compiled, collated, and mapped water quality data for the South Florida coral reef ecosystem by merging sampling results from multiple monitoring partners. The export for each analyte includes all available data from all partners, and the 2025 dataset was used to produce new web maps. In addition, program pages were created in the SEACAR Data Discovery portal for both the Palm Beach County Water Quality Program and Broward County Water Quality Monitoring. This project now includes 8 actively sampling monitoring programs- four more than in the first year of the project.

SEACAR standardized each monitoring partner's updated data, including historical data, that is no longer hosted on WIN, but included in the Unified Water Quality Monitoring Database. Analyte naming conventions in the database have been aligned with SEACAR standards, which are available on the SEACAR page. Future work will involve collaborating with SEACAR to develop new program pages and incorporate any additional programs that staff determine meet the criteria for inclusion in the unified water quality database.

The results of the 2025 update to the unified water quality database and trend analysis are available in publicly available web maps and are incorporated into the data visualization tool that was developed in year 4 of the project. Following feedback received from interested parties, the team developed an ArcGIS Hub that organizes the existing data visualization products the team has developed into one platform. This includes the current and historical data and trend web maps for the Unified Water Quality Monitoring database, both the Abiotic monitoring and Biological and Ecological monitoring inventories and data matrices. The unified database can be found on the SEACAR program page as a comma-separated text file.

To develop the workflow to create an automated export in SEACAR of the Unified Water Quality database, the research team collaborated with the SEACAR team. The custom-tailored database export required information mapping the 8 programs to sources in SEACAR and matching our QA/QC process to the automated backend process in SEACAR. Further, following the initial export of UWQ dataset from SEACAR, the water quality team compared the export to the most 2024 update of the dataset. There were no systematic issues or significant differences between the two datasets requiring changes to the automated workflow. Notably, the enhanced QA/QC process improved the dataset by identifying additional interoperable parameters between programs.

A new web report was created which focuses on the SEACAR data export which will be the preferred data aggregation going forward. These reports focus on a comparison of SEACAR data to the previous compilation data product. Creation of the parameter rate of change data product using a seasonal Mann-Kendal slope calculation was produced using the SEACAR data product. The structure of the previous data ingestion site was reproduced to create reports for each program and provider. Additional reports were created to focus on the depths of reported data and changes in the rate of change products from SEACAR and the previous data ingestion methods. Drilldown reports were created to allow closer inspection of a single parameter at a site

for a program, which is randomized at each generation of the website. Data usage examples were added to the website demonstrating spatial mapping of parameter rate of change, distribution of parameter values, and a scalable hexagon aggregated spatial map of values (Figure 1). Overall, the following features were added to the ingestion report website:

- An analyte co-occurrence matrix (Figure 2) was added to each program report for easy assessment of which analytes can be cross-examined.
- An assessment of depth ranges for each program was added to the Program listing, allowing easy assessment of which programs are missing depth data. The distribution of reporting depths from each program was added to the web report visualizations.
- Documentation was improved to address common questions which arose during discussions with SEACAR personnel.
- Assessment of analyte naming alignment and programs reporting non-standard analytes was added.
- Conversion of Degree-Minute-Second coordinates to Decimal Degrees for relevant programs.
- A check for duplicate rows was added to each program report.
- A tidy-wide format export was added to the list of data products.
- An assessment of missing units was added to each program report along with visualizations of unit distributions for each analyte.
- A detailed comparison of missing values between this ingestion and the SEACAR data was created.
- Additional columns were added to align with SEACAR standards.
- The display of several figures and tables improved.

Some issues previously identified in the data ingestion pipeline were also resolved. These include:

- Two-digit years in source data are now correctly parsed.
- Total Organic Nitrogen is no longer combined with Total Kjeldahl Nitrogen
- Rows with missing units are no longer dropped.
- Rows with missing coordinates are no longer dropped.
- Dates from STORET providers are now correctly parsed.
- Dates from excel files are now correctly parsed.
- Chlorophyll corrected and uncorrected for pheophytin were separated.

In the process of reproducing the quarto-powered web report to create the new SEACAR web report, the batched parameter quarto markdown template paradigm was generalized into a template that can be used to easily create similar batched-template web reports. The resulting template was published as a GitHub template along with detailed usage documentation. Data loading was also refactored to handle the increased volume of data. Previously, all data was loaded into memory on application startup. To support larger volumes of data the application now loads only metadata associated with each station on startup and loads the station's data upon selection. Using this paradigm, the application can now scale to include much more data. Filtering of displayed sites by parameters available was also added to the tool.

The methods for QA/QC, the reports for data ingestion and comparison, data visualizations, and quarto markdown template are published on a website that can be found in the associated 'FWRI WQ Project Links 2026.pdf' document. The website also includes all R scripts to reproduce analyses and QA/QC procedures.

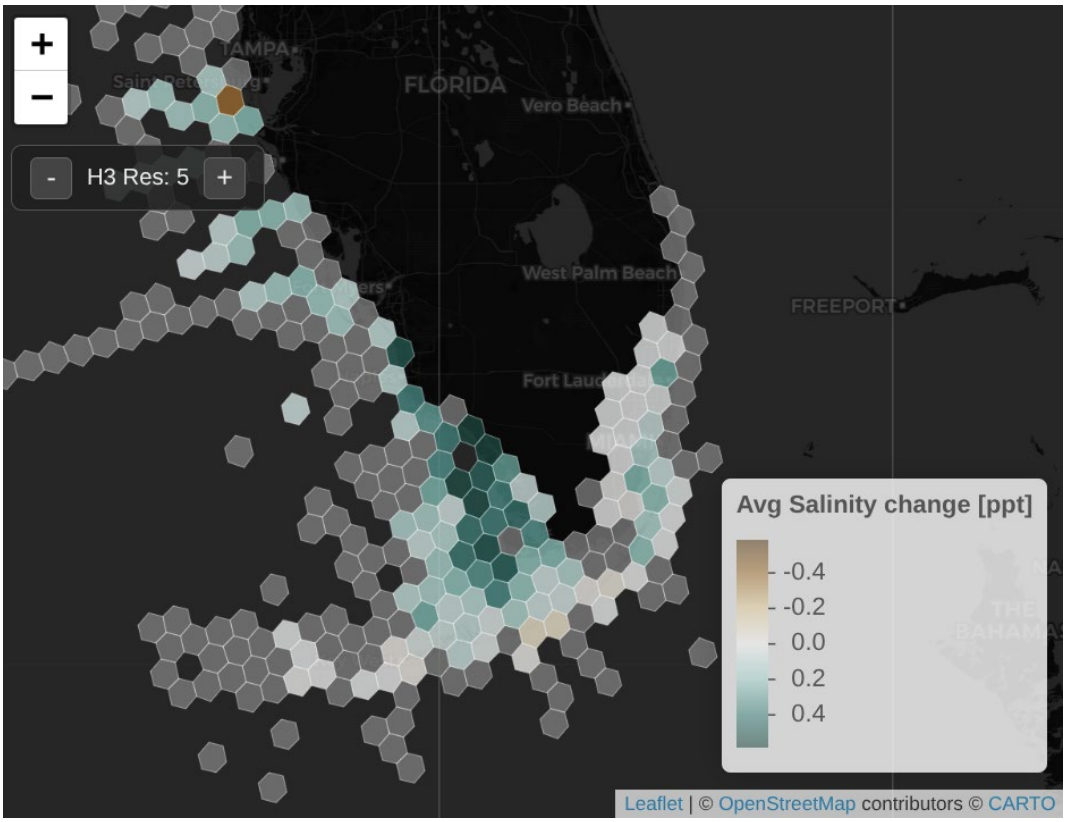

Figure 1. Usage example creating an interactive map showing average values for each H3 hexagon at multiple resolutions.

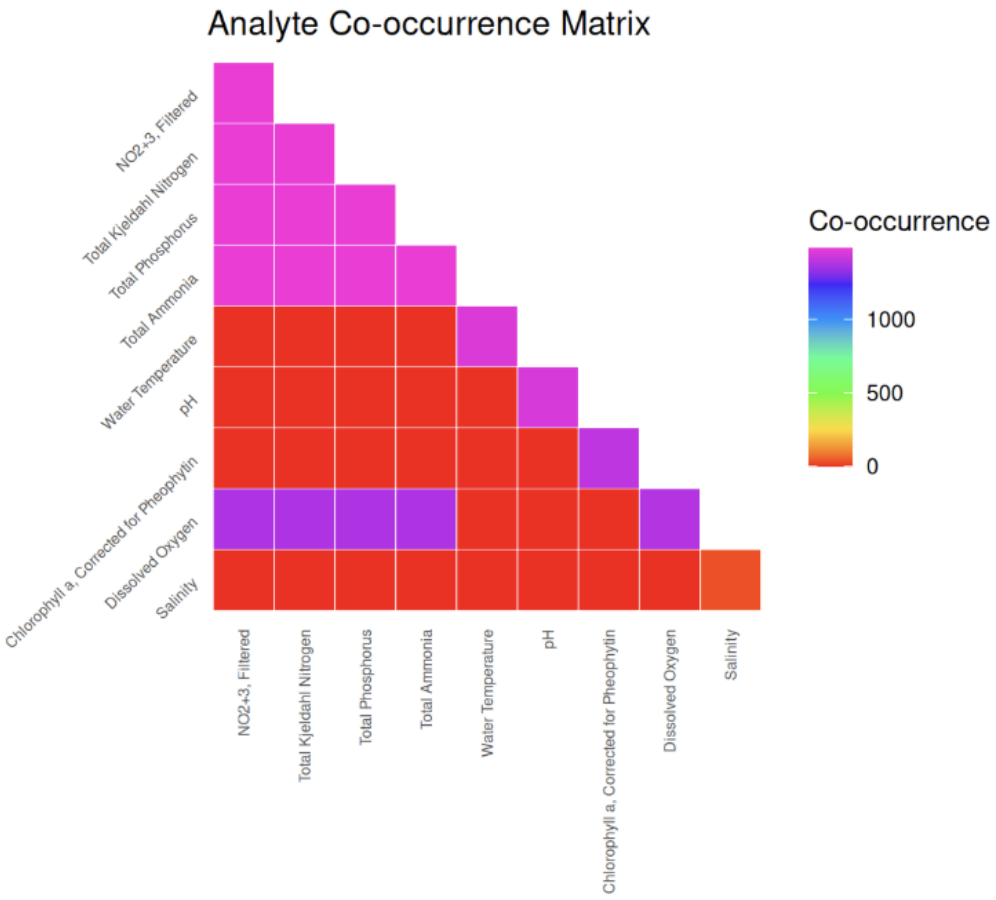

Figure 2. Example analyte co-occurrence matrix showing the number of rows with co-occurring parameters.

3.2 Open-ended technical advisory support for FCRCT and water quality meetings

Staff attended 21 meetings of the FCRCT, FCRRP, and additional relevant water quality programs (Table 2). The team presented this project to the FCRCT, FCRRP, and FKNMS Water Quality Protection Program Steering Committee meeting.

Table 2. List of water quality meetings attended during the reporting period.

Meeting	Date	Attendees
FCRCT	6/27/2025	Jade Lee, Dan Otis, Tylar Murray
FCRRP WQ Team	7/18/2025	Christina Mallica
FCRRP WQ Team	8/22/2025	Jade Lee, Christina Mallica
FCRRP WQ Team	9/26/2025	Jade Lee, Christina Mallica
FKNMS WQPP	10/8-10/9/2025	Postponed
FCRCT	10/10/2025	Postponed
FCRRP WQ Team	10/17/2025	David Kochan, Christina Mallica
Florida Keys Marine Science Conference	10/27-10/30/2025	Jade Lee, Christina Mallica, David Kochan
FCRRP WQ Team	11/21/2025	Jade Lee, Christina Mallica, David Kochan
FKNMS WQPP	12/17/2025	David Kochan
FCRRP WQ Team	12/19/2025	Christina Mallica, David Kochan
FCRRP WQ Team	1/16/2026	Jade Lee, Christina Mallica
FCRRP WQ Team	2/20/2026	Jade Lee, Christina Mallica
FCRCT	2/20/2026	Jade Lee, Christina Mallica, Dan Otis, Tylar Murray
FKNMS WQPP	3/4-3/5/2026	David Kochan (Presentation)
FCRRP WQ Team	3/20/2026	Jade Lee, Christina Mallica, David Kochan
FCRCT	4/11/2026	David Kochan
FCRRP WQ Team	4/17/2026	Christina Mallica, David Kochan
FCRRP Technical Workshop	4/21-4/23/2026	David Kochan
FCRRP WQ Team	5/15/2026	Christina Mallica, David Kochan
FCCRP WQ Team	6/26/2026	Jade Lee (Presentation)

The research team developed an ArcGIS Hub (Fig. 3) site to host all ArcGIS mapping products and monitoring inventories, ensuring that databases remain up-to-date and easily accessible to users. The Hub site provides links to the inventory matrices, which include contact

information for each monitoring program, the parameters sampled and their sampling frequencies, the start dates of monitoring, and the methods used for sample collection. The site also provides links to current web maps displaying data and slope trends from the Unified Water Quality Monitoring Database, as well as web maps showing the sampling locations for the abiotic and biological/ecological inventories. All web maps are interactive, and filters can be used to find monitoring locations meeting specific criteria. The inventory web maps are not intended to display the data collected by each program; instead, they illustrate the geographic distribution of sampling locations. Data from previous years of this project can also be found in the Hub, as well as links to products produced during previous years of the project.

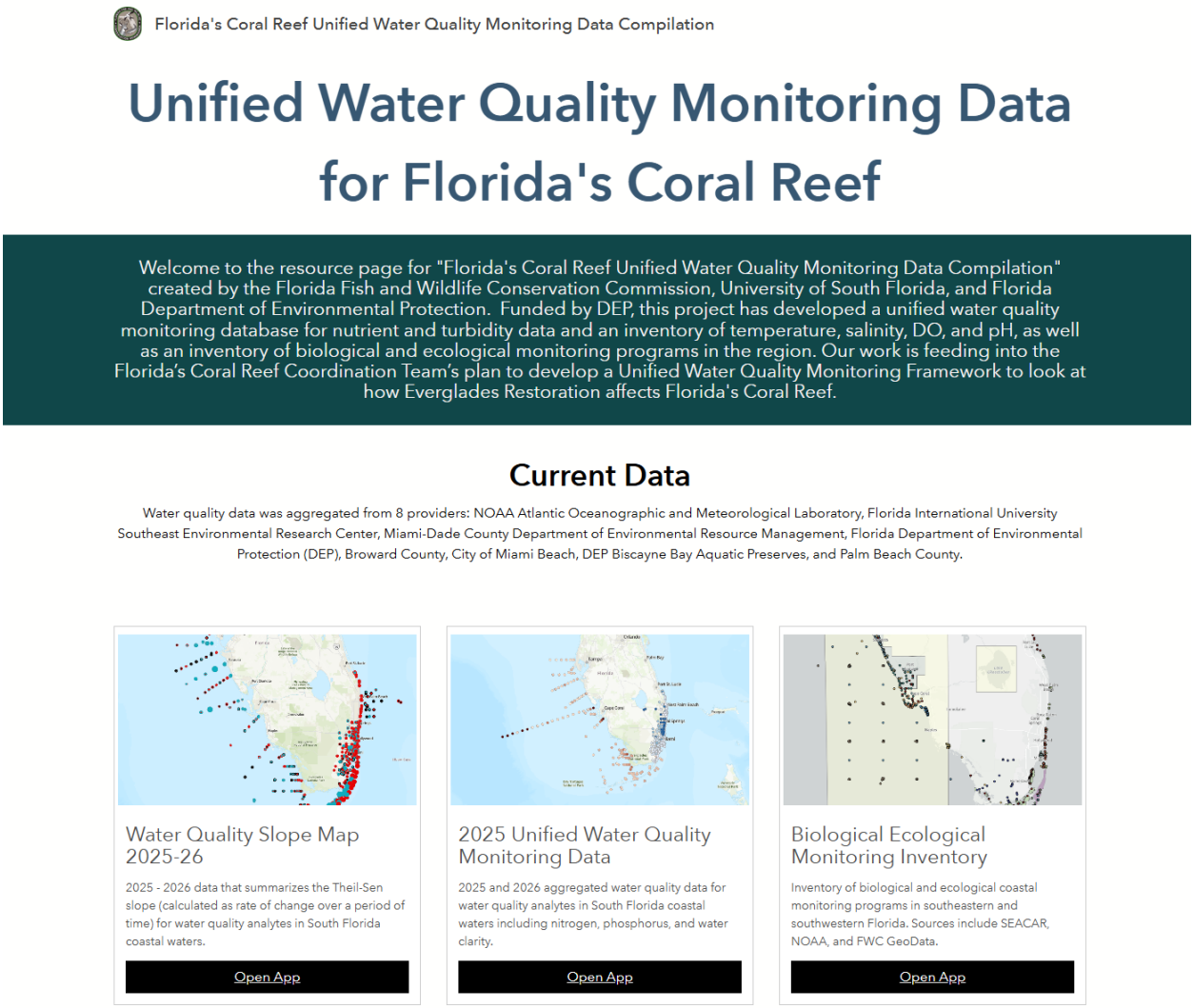

Figure 3. Screenshot of the ArcGIS Hub for the Unified Water Quality Monitoring Dataset.

3.3 Updates to the abiotic factor and biological and ecological monitoring inventories

The layer showing locations of programs that use random sampling locations for biological and ecological monitoring was updated to reflect updates in the Disturbance Response Monitoring program and the Harmful Algal Bloom program. The Queen Conch research team at

FWRI requested that specific location points for their monitoring program be generalized, so the team converted the location points to a simple coverage polygon. The team also plans to incorporate Fisheries Independent Monitoring data and data from the Reef Environmental Education Foundation's Volunteer Fish Survey Project into future updates of the web map, as well as any programs with monitoring locations that vary annually or according to their respective sampling intervals.

The results of the questionnaire shared with members of the FCRCT, and other stakeholders were incorporated into the inventories. For the abiotic inventory, the discrete monitoring programs were updated to include additional parameters for the Southeast Water Quality Assessment Survey in Kristin Jacobs Coral Aquatic Preserve and for the Biscayne Bay Aquatic Preserve Continuous Water Quality Monitoring. The Indian River Lagoon Observatory Network was added to the abiotic inventory. Additional abiotic monitoring sites, the locations of the Sofar buoys were added in the Florida Keys National Marine Sanctuary on the web map. Smaller updates to the inventories include correcting contact information, sampling frequency, and collection years for the Palm Beach County Environmental Resource Management abiotic water quality sampling as well as the Integrated Biscayne Bay Ecological Assessment and Monitoring Project in the Biological/Ecological inventory. The team has also updated mapping symbology to improve visualization for users. The questionnaire will remain open so the team can continue gathering feedback and improving the inventories. The project team will also keep updating it to include new programs that meet the inclusion criteria, while continuing to maintain accurate and consistent metadata for each program. The web maps with monitoring locations will also be updated accordingly.

3.4 Fine scale analysis of water quality to identify historical pulse events and responses to Everglades restoration and development of modular analysis tools

Full results from the fine-scale analysis can be found in the report, which is available as a PDF document and is linked in the associated 'FWRI WQ Project Links 2026.pdf' document. Precipitation is not consistent in space and time over the Florida peninsula. By parsing the study area into four subregions, the team was able to identify differences between subregions, particularly in terms of variability, number of wet days and maximum recorded values (Table 3 in the full report). The use of individual rain gauges to assess precipitation would not be able to resolve these differences. Finer-scale analyses are possible using the NASA IMERG satellite-based precipitation product and are recommended, particularly for subregion 1 (the coastal southeast Florida region). Precipitation is not consistent in space and time over the Florida peninsula. By parsing the study area into four subregions, the team was able to identify differences between subregions, particularly in terms of variability, number of wet days and maximum recorded values (Table 3 in the full report). The use of individual rain gauges to assess precipitation would not be able to resolve these differences. Finer-scale analyses are possible using the NASA IMERG satellite-based precipitation product and are recommended, particularly for subregion 1 (the coastal southeast Florida region).

River discharge along the east coast of Florida from St. Lucie River to Biscayne Bay is not coherent over time between river gauges due to the influence of water releases from Lake Okeechobee into the St. Lucie Canal. River discharge within other subregions of the study area was generally consistent among gauge locations. However, river discharge is not necessarily consistent between subregions.

Salinity in Florida Bay is affected to a large degree by freshwater inputs and the inner bay experiences overall lower salinity levels compared to the mid- and outer-bay regions. Freshening events due to high levels of river discharge tend to start in the inner bay and spread into the outer bay and onto FCR.

4. DISCUSSION AND MANAGEMENT RECOMMENDATIONS

This project was motivated by the need to easily understand water quality patterns at different spatial and temporal scales along Florida's Coral Reef, 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, trends, and data gaps, were 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).

In year 6, the research team continued to address this overall need to understand the patterns of water quality and monitoring programs across the FCR. The most significant upgrade to the Unified Water Quality dataset was the automation of updates through a workflow and exports from the SEACAR database. The collaboration with SEACAR included developing a crosswalk guide between the previously manual updates with data from the 8 programs and the SEACAR data, a rigorous QA/QC for the data ingestion, and a comparison of the SEACAR export with the existing dataset. There were no systematic differences between the UWQ dataset and the SEACAR export, and the enhanced QA/QC process improved the interoperability of the parameters across programs. There will now be quarterly updates to the UWQ dataset that are available through the Data Discovery Portal on the Florida's Coral Reef Unified Water Quality Database SEACAR page. The collaboration with SEACAR addressed feedback from the research and management community in two ways: the dataset is updated more frequently allowing for more rapid analysis of data and the dataset is available in a public and easily accessible location. The research team also created an ArcGIS Hub, which is linked on SEACAR, to house each of the maps and visualizations in a single location. The ArcGIS Hub is intended to provide both a quick overview of water quality monitoring and an opportunity to dig deeper into local and regional trends.

Because of the team's experience working with water quality across the FCR, the team has been working closely with the FCRCT in a technical advisory role. The FCRCT's mission to understand how Everglades restoration affects water quality on the FCR was outlined in the Unified Water Quality Monitoring Framework, and the research team contributed to addressing multiple priority actions. The team maintained the abiotic inventory and methods analysis, which when combined with the unified water quality database, completed the requirements for priority action 1, an inventory of water quality monitoring across the FCR. The team addressed priority action 2 by completing an inventory and methods analysis of biological and ecological monitoring programs. Both actions are critical to understand the state of monitoring on the FCR and will help guide the future recommendations, funding, and actions when investigating the effects of water quality on the FCR and associated ecosystems. The inventories and methods analyses were updated with feedback and presented to the FCRCT, who formally accepted their inclusion to address the priority actions.

Water quality monitoring over FCR would benefit from more instrumented records collected near the reefs. Quarterly or even monthly discrete sampling may lack the temporal frequency to capture events where water quality on FCR becomes degraded. These sampling programs should be maintained at a minimum and expanded if possible. Further, the set of temperature and salinity buoys in Florida Bay allows for the creation of surface maps and near real-time monitoring of temperature and salinity conditions in the bay. This is a very valuable resource that should be maintained. While not over the reefs themselves, these moorings provide valuable insight into conditions inside the bay which may impact FCR. Finally, the connection between Florida Bay and FCR is not well characterized. The link between the two regimes should be extensively studied to assess what environmental conditions may lead to water from Florida Bay reaching the FCR. Modeling studies coupled with increased sampling (both discrete and instrumented or continuous) will lead to a much better understanding of this important link.

Throughout year 6, the research team has continued to find a need for accessible and interoperable water quality data in the region, and collaboration and outreach are critical to support research and management on the FCR. Ultimately, the database, maps, and visualization products are meant to provide a simple and user-friendly way to access these data coming from disparate sources, so understanding the needs of users like scientists, managers, and the public is crucial. Multiple researchers from universities in Southeast Florida have used the database in coral reef research projects, and their insight into the usability of the database has allowed the team to improve access and metadata. The team will continue to incorporate feedback into the database and products with special consideration to find historical programs that may provide valuable insight into longer-term trends. Much of the feedback leading into this year's project was to make the dataset more readily available and incorporate provider monitoring data more rapidly. The collaboration with SEACAR resulted in automated quarterly updates that are located on the publicly available Data Discovery interface, allowing researchers and managers to access updated data on demand. The development of the Water Quality ArcGIS Hub further provides access to the maps, analyses, and visualization products produced with the UWQ dataset.

Further, outreach efforts have identified a need to coordinate and integrate with a broader group of stakeholders when planning longer-term and larger-scale monitoring efforts. Coral restoration is a critical component of FCR management and conservation, and there are several efforts like the FWRI-led Coral Reef Decision Support System (CRDSS) that aim to support restoration activities. The CRDSS provides a platform where users can access relevant data layers to make decisions based for restoration site selection. Adding water quality data in ways that are relevant for coral restoration would allow users to improve site selection based on local conditions and trends. Integrating the UWQ and water quality research into the broader FCR and South Florida ecosystem communities is critical for the management and conservation of Florida's Coral Reef.