Florida's Coral Reef Water Turbidity Data Compilation, Analysis and Decision Support: MICCI 28 Project - Phase 1

Final report

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Acronyms/Abbreviations

APHA	American Public Health Association			
ASTM	American Society for the Testing of Materials			
BNP	Biscayne National Park			
CDOM	Colored dissolved organic matter			
DEP	Department of Environmental Protection			
ECA	Environmental Conservation Area			
FIU	Florida International University			
FKNMS	Florida Keys National Marine Sanctuary			
FNU	Formazin nephelometric Units			
IR	infra-red			
ISO	International Organization for Standardization			
К	Kelvin			
LISST	proprietary name of Sequoia Scientific submersible particle size analyzer			
NOAA	National Oceanographic and Atmospheric Administration			
NTU	nephelometric turbidity units			
SEFCRI	Southeast Florida Coral Reef Initiative			
SOP	standard operating procedure			
SSC	Suspended Sediment Concentration			
TSS	Total Suspended Solids			
USACE	United States Army Corps of Engineers			
USEPA	United States Environmental Protection Program			

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1. **DESCRIPTION**

1.1 History

In 2000, the U.S. Coral Reef Task Force adopted a National Action Plan to conserve coral reefs which led to the formation of the Southeast Florida Coral Reef Initiative (SEFCRI). SEFCRI's primary mission is to develop local action strategies that preserve and protect the Kristin Jacobs Coral Reef Ecosystem Conservation Area (ECA). The ECA consists of the sovereign submerged lands and state waters offshore of Martin, Palm Beach, Broward, and Miami-Dade counties from the St. Lucie Inlet to the northern boundary of Biscayne National Park.

Members of the SEFCRI team identified the need to improve the methodology for measuring and monitoring turbidity and suspended sediment concentration (SSC) during dredging, beach nourishment and any coastal construction project that would require turbidity monitoring. This was an overarching objective designated for the Maritime Industry and Coastal Construction Impacts (MICCI) project number 28 (MICCI 28). The project was developed through conversations with the SEFCRI team, a subset of technical experts from the SEFCRI team called the Technical Advisory Committee, and members of Florida Department of Environmental Protection's (DEP) Division of Environmental Assessment and Restoration and Beaches, Inlets, and Ports Program. It was further determined that the initial phase (Phase 1) of the MICCI 28 project should conduct a data mining effort to locate all turbidity data sets in the ECA and surrounding areas along Florida's Coral Reef, and provide a review of new and existing turbidity, suspended sediment, and sedimentation monitoring methodologies.

1.2 Impacts of turbidity and mass concentration of suspended particulates

Suspended particulates in the water column have various effects in aquatic ecosystems (see Kirk [1994] for review). Sedimentation and light attenuation are aquatic processes greatly affected by the abundance, size, and morphology of suspended particulates. Sedimentation affects benthic communities and occurs when suspended particulates settle out of the water column and accumulate on the benthos and benthic organisms. Benthic organisms may become smothered if they cannot clear accumulated sediments from their surfaces. Corals are particularly negatively impacted by high rates of sedimentation (Rogers, 1990).

Light attenuation is the reduction of light intensity as light is transmitted through the water column. Benthic vegetation (e.g., seagrasses, benthic macro- and micro-algae) is limited to areas of sufficient light availability and is negatively impacted by increased

light attenuation. Light is attenuated in the water column by a combination of absorption and scattering of light waves by suspended particulates along with water-column chlorophyll (in phytoplankton), colored dissolved organic matter (CDOM), and by water molecules themselves (Kirk, 1994).

The density of suspended particulates in the water column can be expressed by measures of turbidity, SSC, or as total suspended solids (TSS) (see Sadar [2004] for review). Though these terms are often used interchangeably, they are defined and measured differently, and often are not correlated. Turbidity is an optical property and is measured with a nephelometer as the proportion of incident light from an internal light source that is scattered at right angles as it travels through a sample. The nephelometer relates that proportion to the scattering characteristics of a standard colloidal formazin suspension and reports turbidity levels in terms of nephelometric turbidity units (NTU). SSC and TSS, on the other hand, are gravimetric properties and are simply the dry weights of particulates collected from a known volume of water. SSC and TSS are often reported in mg dry weight/liter units. The difference between SSC and TSS is procedural. The SSC method captures nearly all particles in a sample while the TSS method misses dense particles (i.e., sand) that quickly settle in a sample and escape the sub-sampling that is specified in the TSS methodology. Because these terms are specifically defined based upon their operations, the use of these terms in this report is limited to their narrow definitions. When referring to measures produced by any or all of the gravimetric methods of suspended particle density in the water column, the term "mass concentration of suspended particulates" is used instead of the broader common use of the terms "TSS" and "SSC".

2. OBJECTIVES

The goals of this project were to identify and compile existing turbidity and mass concentration of suspended particulates data sets from Florida's Coral Reef (prioritizing data in the ECA), identify those data sets that meet DEP data collection and analysis requirements, identify temporal and spatial gaps in historical data, and perform a review of potentially useful methodologies for measuring turbidity and mass concentration of suspended particulates. The resulting compilation of data will be used in future analyses to provide an estimate of background turbidity and suspended sediment concentrations.

3. METHODS

3.1 Data sources and types

This project located and "mined" existing turbidity, mass concentration of suspended particulates, and similar data concerning water column suspended particle abundance from the study areas described below. The investigated sources of data include academic journal articles, "gray" literature and government reports, published and unpublished data sets produced by water quality monitoring programs, and turbidity compliance reports produced by dredging companies, and as required by DEP for beach nourishment, harbor maintenance and channel maintenance dredging projects. As only a few data sources were readily and easily available through internet searches, the data mining required contacting various government officials from Florida state and county agencies and other professional contacts via email, phone and video conference (e.g., Zoom) and inquiring about the location and availability of data. The contact information of the people useful in locating and providing data is listed in Table 1.

Agency	Contact	Email	References
Palm Beach County	Jena McNeal	JMcNeal@pbcgov.org	
Palm Beach County	Matt Mitchell	MMitchell@pbcgov.org	
Palm Beach County	Thomas Steinhoff	TSteinhoff@pbcgov.org	
Palm Beach County	Patrick Wille	PWille@pbcgov.org	
Martin County	Kathy Fitzpatrick	kfitzpat@martin.fl.us	
Martin County	Jessica Garland	jgarland@martin.fl.us	
Broward County	Ileana Suarez-	isuarezhale@broward.org	
	Hale		
Florida International	Henry Briceno	bricenoh@fiu.edu	
University			
University of Miami	Harold Wanless		Wanless et al. (1984)
DEP	Kristi Kerrigan	Kristi.Kerrigan@dep.state.fl.us	
DEP	Justin Nelson	Justin.M.Nelson@FloridaDEP.gov	
DEP	Allycia Shatters	Alycia.Shatters@dep.state.fl.us	
NOAA	Xaymara Serrano	xaymara.serrano@noaa.gov	

Table 1. Data source contact information.

Methodologies for measuring turbidity and mass concentration of suspended particulates were identified by a literature search using the Google Scholar search engine, listed Florida state analytical methods, and the websites of various nephelometer and water quality data sonde companies.

3.2 Data analysis

Temporal and spatial gaps were identified in the compiled data set for turbidity and mass concentration of suspended particulates by comparing summary statistics of the data categorized according to years, months, and regions defined by management zones (i.e., ECA, BNP, and FKNMS).

3.3 Study area and temporal scope

Data produced since 1972 was gathered from within the ECA in the offshore waters of Martin, Palm Beach, Broward, Miami-Dade, and Monroe counties. Data from coral habitat environments in BNP and FKNMS were also gathered (Figure 1).



Figure 1. Location map of study area. Source – Florida DEP, <u>https://floridadep.gov/rcp/coral/content/coral-eca-kristin-jacobs-coral-reef-ecosystem-conservation-area</u>.

4. **RESULTS**

4.1 Data sources

Data files with turbidity and/or mass concentration of suspended particulates measurements were obtained from 23 different programs, projects, or publications. Data from just 6 of these potential data sources are compiled in the combined data set. The data sources include data produced from individual grab samples and data collected by data sondes that measured continuously at fixed time intervals. The continuous data often had spatial and temporal gaps resulting from data removal due to instrument failure, periods of biofouling and spikes/anomalies during deployments. The 6 data sources included in the combined spreadsheet (Appendix A) and the corresponding original data file names are listed in Table 2 and described in further detail below. The data types, sampling locations, and time periods covered by the 6 data sources are listed in Table 3. The remaining data sources were weekly turbidity reports required by DEP from 17 individual beach nourishment, inlet, or harbor maintenance projects by dredging companies (n = 283 individual .pdf files). Data within the weekly dredging data reports were not included in the combined data set because the data-entry effort required to compile data from individual reports was time- and cost-prohibitive for this data compilation project's duration and budget. More details about the types of data within these reports and the potential value of turbidity data produced by dredging companies are provided below in Section 4.1.7.

Data source name	Source	File name
Coral ECA Water Quality	Watershed	ECAWQA_TSS-Turb_alldates.xlsx
Assessment	Information Network	
	(WIN)	
USACE and NOAA Trial Station	NOAA	trial station data_report_Dec 11 2020
		through Feb 5 2021.xlsx
Port Everglades Harbor Monitoring	USACE	Port Everglades compilation post
		dredging.xlsx
FKNMS Water Quality Monitoring	FIU	WQFloridaKeys&Shelf (uM) 1995-
Program		2021.xlsx
South Florida Estuaries Water	FIU	SouthFloridaEstuariesWQ_uM.xlsx
Quality Monitoring Programs		
Sources and circulation of turbidity	Wanless et al. (1984)	Wanless et al 1984 data.xlsx
in Biscayne Bay, Florida		

Table 2. Data sources and corresponding original file names included in the combined spreadsheet.

WIN Source:

https://prodenv.dep.state.fl.us/DearWin/public/welcomeGeneralPublic?calledBy=GENERALPUBLIC

Table 3. Data types, sampling locations, and time period covered of the data sources included in the combined spreadsheet.

Data source	Data types	Locations	Time period
Coral ECA Water Quality Assessment	Turbidity, mass concentration of suspended particulates	ECA	September 22 2016 to December 14 2021
USACE and NOAA trial station	Turbidity, mass concentration of suspended particulates	ECA	December 11 2020 to February 5 2021
Port Everglades Harbor Monitoring	Turbidity	ECA	December 4 2020 to April 7 2021
FKNMS Water Quality Monitoring Program	Turbidity	FKNMS	March 22 1995 to November 22 2021
South Florida Estuaries Water Quality Monitoring Programs	Turbidity	BNP, FKNMS	March 14 1991 to September 18 2008
Sources and circulation of turbidity in Biscayne Bay, Florida	Turbidity, mass concentration of suspended particulates	BNP	March 3 1982 to August 30 1983

4.1.1 Coral ECA Water Quality Assessment

In response to the need for more water quality data in the ECA, a joint NOAA-DEP water quality assessment program was established in the ECA. The Coral Reef Conservation Program currently manages this water quality sampling program. Monthly water quality monitoring of physical and nutrient water quality parameters was initiated in the ECA at 66 randomly selected reef sites, 24 fixed sites within 6 water treatment outfall locations, and at 36 fixed sites within the 9 inlet locations of the inlet contributing areas (Whitall et al. 2019). The 6 water treatment outfall locations are Boynton-Delray, Boca Raton, North Broward, Hollywood, North Miami-Dade, and Central Miami-Dade. The 9 inlet locations are Government Cut, Baker's Haulover, Port Everglades, Hillsboro, Boca Raton, South Lake Worth (Boynton Inlet), Lake Worth, Jupiter and St. Lucie inlets. Water quality monitoring started on September 22 2016 and is continuing. Approximately 10,000 turbidity and mass concentration of suspended particulates data points were collected from the initiation of the project through December 14 2021 are included in the present data compilation (Appendix A).

Surface (approximately 0.5 m below surface) and bottom samples (via Niskin bottle) were collected at reef and inlet sites. Only surface water was collected at the outfall sites. Mass concentration of suspended particulates was measured by Standard Method 2540D (APHA, 1999) (comparable to USEPA Method 160.1, USEPA, 1983). Turbidity was determined using a nephelometer via USEPA Method 180.1 (USEPA,

1993). Analyses were performed at a National Environmental Laboratory Accreditation Conference certified laboratory.

4.1.2 USACE and NOAA Trial Station

The USACE and NOAA Trial Station data file consists of temperature, salinity, underwater PAR and suspended solids measurements and was produced from sampling at a single site located near the middle reef north of the Port Everglades channel by a collaboration between the United States Army Corps of Engineers Engineer Research and Development Center and the National Oceanographic and Atmospheric Administration Atlantic Oceanographic and Meteorological Laboratory. The data were collected at five minute intervals using deployed sondes from December 11 2020 through February 5 2021. Turbidity was measured using an Aquatroll 600 data sonde that employs ISO method 7027 for nephelometric measurements. Suspended particle mass concentrations were calculated using measurements of particle volume concentrations produced by a Sequoia Scientific LISST submersible particle size analyzer that uses laser diffraction technology. Approximately 16,000 paired measurements of turbidity and suspended particle mass concentration were produced and compiled in the combined data set.

4.1.3 Port Everglades Harbor Monitoring

The Port Everglades Harbor Monitoring data was produced from a water quality monitoring program conducted by SOL Engineering Services and GHD Inc. for the USACE during Operation and Maintenance dredging for Port Everglades Harbor in Fort Lauderdale, Florida. Turbidity and mass concentration of suspended particulates were measured at fixed and varied locations during and after dredging operations. Only turbidity measurements produced after dredging operations (March 6 2021 to April 7 2021) from the fixed locations were compiled in the combined data set. Mass concentration of suspended particulates data were not obtained.

Turbidity was measured at 6 monitoring stations adjacent to the outer entrance channel of Port Everglades using an Aquatroll 600 data sonde that employed ISO method 7027 for nephelometric measurements. The data sondes were deployed at near surface (approximately 1 meter below the surface) and at near bottom (approximately 1 meter above the sediment surface) depths for continuous measurements at six-minute intervals. Approximately 50,000 turbidity measurements were produced by the Port Everglades Harbor water quality monitoring program and compiled in the combined data set.

4.1.4 FKNMS Water Quality Monitoring Program

The Florida Keys National Marine Sanctuary Water Quality Monitoring Program data was produced by FIU as part of the Water Quality Protection Program established by the USEPA. The program is continuing at the time of this report. Turbidity data included in the combined data set of this report's compilation was measured from water samples collected quarterly at 173 sites from March 22 1995 to November 22 2021 (27 years). The 173 sites are located within the following segment area polygons within the FKNMS: OFF, LK, MK, UK, MAR, BKS, and BKB (Figure 2). Most data are surface measurements (within 1 m of water surface) but many sites also have bottom (approximately 1 meter above the bottom) measurements. Turbidity was determined using a nephelometer via USEPA Method 180.1 (USEPA 1993). Approximately 14,000 turbidity measurements were produced by the FKNMS water quality monitoring program and compiled in the combined data set.



Figure 2. Location map of FIU water quality sampling sites and biogeochemical segment areas in South Florida's estuarine and coastal areas. Turbidity data from segments OFF, MAR, BKS, LK, BKB, MK, UK, MBS, CS, SCM, SCI, and SCO were included in the turbidity data compilation. Source – Briceño et al. (2013).

4.1.5 South Florida Estuaries Water Quality Monitoring Programs

The South Florida Estuaries Water Quality Monitoring Programs data were produced by FIU. Turbidity data included in the combined data set of this report's compilation were measured from water samples collected at approximate monthly intervals at 31 sites from March 14 1991 to September 8 2008 (17 years). The sites are located within the following South Florida biogeochemical segment area polygons: MBS, CS, SCM, SCI and SCO (Figure 2). The turbidity data are measurements of surface water samples collected within 1 m of water surface. Turbidity was determined using a nephelometer via USEPA Method 180.1 (USEPA, 1993). Approximately 4,000 turbidity measurements were produced by the South Florida Estuaries Water Quality Monitoring Programs and compiled in the combined data set.

4.1.6 Sources and circulation of turbidity in Biscayne Bay, Florida

The data compiled in the combined data set from the report "Sources and circulation of turbidity in Biscayne Bay, Florida" submitted to Dade County and Florida Sea Grant and authored by Wanless et al. (1984) consists of 184 mass concentration of suspended particulates measurements and 33 turbidity measurements produced from March 3 1982 to August 30 1983. These were produced from samples collected from near the water surface at 16 sites in Biscayne National Park. Samples were only taken on days when wind speeds were less than 12 kt (5 m/s) and at least 3 days after any major wind stress event. Turbidity was measured using an unspecified nephelometer. Mass concentration of suspended particulates was measured as dried particulates collected on pre-weighed 0.45 micron Nuclepore filters from measured sample water volumes. The Wanless et al. (1984) report contains additional data from North Biscayne Bay but those data were not included in the combined data set because the sample sites were located outside of the areas specified for compilation.

4.1.7 Weekly turbidity reports from dredging operations

DEP requires dredging companies to provide weekly dredging summary data reports as part of the permitting process for beach nourishment, channel and harbor dredging maintenance projects. The weekly reports require turbidity monitoring during all dredging and sediment placement activities. Turbidity is produced from instruments calibrated daily and sampling conducted in compliance with FT 1600 Field Measurement of Turbidity. Besides measurements produced from water sampled within turbidity plumes, turbidity is also measured at background sites located 500 meters upcurrent. The data from background sites may be useful in analyses to establish turbidity levels protective of biological resources. Permit requirements indicate that turbidity be measured at least 3 times daily, at least 2 hours apart. Sampling shall occur at surface (approximately one foot below the surface), mid-depth (for sites with depths greater than 6 feet), and bottom (approximately 6 feet above the bottom for sites with depths greater than 25 feet). Turbidity data is reported in NTU and included in tabular format in the weekly summary reports.

The format of the data in these weekly reports, though possibly valuable, is not standardized to permit easy extraction. In many cases, the data require manual re-typing into a spreadsheet because the submitted .pdf files are protected. There is potential value in the turbidity data produced by dredging companies during their operations if this data is made more easily accessible, possibly using a centralized data compilation process.

4.2 Review of potentially useful turbidity and mass concentration of suspended particulate methodologies

4.2.1 Turbidity methodologies

The DEP defines a standard operating procedure (SOP) for the field measurement of turbidity (FT1600) but does not define an SOP for mass concentration of suspended particulates. FT1600 specifies that turbidity measurements of individual water samples be produced using a nephelometer. Continuous measurements of turbidity by unattended deployed instrumentation (e.g., data sondes) are exceptions to DEP requirements, and therefore can be used for continuous measurement using a light source different from that specified. The true nephelometer measures the scattering of light caused by suspended solids in the water column and consists of a light source that is directed through a sample cell and a light detector positioned at 90° to the incident light. FT1600 specifies that the light source must have a tungsten-filament lamp operated at a color temperature of 2000 and 3000K (white light) and the detector with a spectral peak response between 400 to 600 nanometers wavelength.

The turbidity method as specified in FT1600 corresponds closely to USEPA method 180.1. There is a small difference in the specified color temperature of the white light source with the minimum light temperature specified at 2200K in USEPA method 180.1.

The International Organization for Standardization produces a quantitative method for the determination of turbidity described as International Standard ISO 7027-1 (ISO, 1999). This method is commonly used by data sonde manufacturers Nepand is a regulatory compliance method for drinking and wastewater applications in Europe. ISO 7027-1 is a nephelometric method that uses a light source in the near-infra-red (IR) range of 830 to 890 nanometers (nm) wavelength. The light source is most often a light emitting diode with light emission centered at 860 with a half peak height bandwidth of 30 nm. The advantage of using a near IR light source in place of a white light source is that interference caused by either the color of suspended particulates or of dissolved material (e.g., colored dissolved organic matter) is minimized. Turbidity measured in

colored water samples using nephelometric methods specifying a white light source (e.g., EPA Method 180.1) will be negatively biased and underestimate the actual turbidity level (Sadar, 2004). Brackish waters in estuaries and near-shore marine waters near inlets will often have significant CDOM concentrations that will interfere with white light source turbidity determination methods. It has been proposed and adopted by various manufacturers, that turbidity measurement produced in compliance with EPA Method 180.1 report turbidity in NTU units, while measurements produced in compliance with ISO 7027 report turbidity in Formazin Nephelometric Units (FNU). Nephelometer models and turbidity sensors that are ISO 7027 conformant include Lamotte Model 2020wi, Hanna Instruments HI88713, YSI ProDSS turbidity sensor, and In-Situ Aquatroll 600 turbidity sensor.

Sadar (2004) describes in great detail other turbidity methods that are modifications of these two standard methodologies. These less common methods may employ multiple forward, tangential, and backscatter detectors and laser light sources for specific applications. In order to reliably compare turbidity measurements produced from different monitoring programs it is important to know the instrumentation used, the methodology employed in the particular instruments, and the bias associated with the specific methodology (Sadar, 2004).

4.2.2 Mass concentration of suspended particulates methodologies

Historically, and most commonly, the mass concentration of suspended particulates in the water column was measured gravimetrically by filtering a known volume of a water sample onto a pre-weighed filter, drying the filter and residue, and calculating the dry weight by difference and dividing the dry residue mass by the sample volume. There are three standard methods used to quantify mass concentration of suspended particulates in natural water samples. These standard methods are EPA Method 160.2 "Residue, Non-Filterable (Gravimetric, Dried at 103 to 105°C)" (EPA TSS) (USEPA, 1999), Standard Method 2540 D. "Total Suspended Solids Dried at 103-105°C" (Standard Methods TSS) (APHA, 1999), and ASTM Method D3977-97B "Suspended Sediment Concentration" (ASTM, 1997). These methods are very similar but differ in how the chosen amount of water is, or is not, subsampled from the original sample. The use of these standard methodologies produces significantly different mass concentrations of suspended particulates (Guo, 2006).

EPA Method 160.2 specifies using a graduated cylinder to transfer a known sub-sample from a vigorously shaken sample to the filtering apparatus. Standard Method 2540 D specifies that a chosen sub-sample volume is transferred via pipet from a sample being stirred with a magnetic stir-bar to the filtering apparatus. ASTM Method D3977-97B does not sub-sample but requires the entire sample to be transferred to the filtering apparatus. Both EPA Method 160.2 and Standard Method 2540 D underestimate the mass concentration of suspended particulates when there are larger sand grains

suspended in the natural sample. The sub-sampling specified by EPA Method 160.2 often does not capture larger sand grains as these settle out from suspension immediately prior to sub-sampling. The sub-sampling specified by Standard Method 2540 D does not capture larger sand grains because they concentrate in the middle of the stirring vortex away from the point of pipet sub-sampling. ASTM Method D3977-97B (SSC) produces reliable measurements of the mass concentration of suspended particulates regardless of the amount of sand grains in a natural sample (Gray et al., 2000).

Despite the accuracy of the SSC methodology and the simplicity of gravimetric methods, this method and the other gravimetric methods for measuring the mass concentration of suspended particulates are labor intensive requiring a multiple step procedure and individual handling of each sample. Sample cost per measurement is therefore high and the number of measurements produced in a study may be limited by processing time and the number of filtering apparatus or drying ovens. These methods are not amenable for data collection by unattended instrument deployments.

The USACE and NOAA Trial Station mass concentration of suspended particulates data compiled for this report were produced from continuous data sonde measurements using a Sequoia Scientific LISST submersible particle size analyzer (https://www.sequoiasci.com/product/lisst-200x/) that uses laser diffraction technology to measure particle volume concentrations. The particle volume concentrations are converted to mass concentrations of suspended particulates by assuming a known mass density of the suspended particles present in natural waters. The efficiency of data collection using unattended deployment of continuously measuring data sondes and the ability to generate large amounts of data in short periods of time are surely huge advantages. The use of this technology in water quality monitoring appears to be relatively recent and little is known how well these measurements produced by laser diffraction correlate to the established gravimetric methods. The assumption that suspended natural particles are of similar density may also need verification.

4.3 Description of data and metadata

The compiled turbidity and mass concentration of suspended particulates data set is contained the Excel workbook (Appendix A) that consists of a metadata worksheet followed by 6 worksheets (one for each data source listed in Table 2). The 6 worksheets within the workbook are formatted identically with 15 columns. The data entries for each column are as follows:

- Column A original data file name
- Column B sample date
- Column C local time
- Column D latitude

- Column E longitude
- Column F sample depth
- Column G local site/sample identifier
- Column H site type
- Column I turbidity
- Column J TSS, or mass concentration of suspended particulates equivalent
- Column K turbidity method
- Column L TSS, or mass concentration of suspended particulates equivalent method
- Column M region
- Column O month

The identical formatting permits the worksheets to be easily combined into a single data matrix for analyses by statistical programs. The compiled data set contains 109,833 unique sampling events recorded from the ECA, BNP, and FKNMS. A total of 108,039 and 27,668 measurements of turbidity and mass concentration of suspended particulates, respectively, are provided in the compiled data set.

The numbers of turbidity measurements produced in the ECA, BNP, and FKNMS are 79,593; 4,115; and 24,331; respectively. Turbidity measurement values ranged from 0.00 to 52.00 NTU with a median value of 1.43 NTU in the ECA, from 0.00 to 22.35 NTU with a median value of 0.68 NTU in BNP, and from 0.00 to 85.59 NTU with a median value of 0.56 NTU in FKNMS (Table 4).

Turbidity (NTU) Summary Statistic	ECA	BNP	FKNMS
Data points (n)	79,593	4,115	24,331
Minimum	0.00	0.00	0.00
maximum	52.00	22.35	85.59
median	1.43	0.68	0.56

Table 4. Descriptive summary statistics for turbidity measurements produced in the ECA, BNP, and FKNMS.

The numbers of mass concentration of suspended particulates measurements produced in the ECA, BNP, and FKNMS are 27,484; 184; and 0; respectively. Turbidity measurement values ranged from 0.00 to 840 mg/L with a median value of 0.38 mg/L in the ECA, and from 0.08 to 6.72 mg/L with a median value of 1.83 mg/L in BNP (Table 5).

Table 5. Descriptive summary statistics for mass concentration of suspendedparticulates measurements produced in the ECA, BNP, and FKNMS.

Mass concentration of suspended particulates (mg/L) Summary Statistic	ECA	BNP	FKNMS
Data points (n)	27,484	184	0
minimum	0.00	0.08	NA
maximum	840	6.72	NA
median	0.38	1.83	NA

4.4 Temporal and spatial data distributions

Nearly 75% of the turbidity data and almost all of the mass concentration of suspended particulates data in the compiled data set are from sites in the ECA (Figure 3). This is remarkable because the data from the ECA only dates back to 2016 and data from BNP and the FKNMS monitoring programs originate 2 to 3 decades earlier (Table 3). Much of the data volume is due to data collection by data sondes deployed for the Port Everglades Harbor Monitoring project that collected a large amount of data at 6-minute intervals. Over a 1-month period in 2021, approximately 50,000 unique sampling events were recorded. The ECA Water Quality Assessment also contributed significantly to the data volume from the ECA with over 10,000 unique sampling events performed at 126 unique sites. The number of sites sampled within the ECA (126) approaches the greater number of unique sites within FKNMS (171) (Figure 3) where turbidity has been measured at various sites since 1995 as of the completion of this report.



Figure 3. Turbidity and mass concentration of suspended particulates data distributions according to regions and the relative proportions of the number of unique sampling sites within each region. The regions are defined by management areas and include the ECA, BNP, and FKNMS.

The temporal distribution of turbidity and mass concentration of suspended particulates data in the compiled data set is greatly skewed towards more recent data collections with nearly 75% of the turbidity data collected since 2016 and nearly 75% of the mass concentration of suspended particulates data collected from 2020 to 2021 (Figure 4).





The turbidity and mass concentration of suspended particulates data in the compiled data set represent water column suspended particle concentrations that occur throughout a yearly seasonal cycle with measurements produced from sampling events at all times of the year (Figure 5). The intra-annual temporal distribution of both the turbidity and mass concentration of suspended particulates data is skewed towards the winter and spring months (November to April) with approximately 75% of the totals (Figure 5).





As the ultimate aim of this data compilation is to provide background turbidity and mass concentration of suspended particulates data to use towards the creation of suspended particulate concentration standards that are protective of corals in the ECA, it is imperative that the provided background data encompass inter- and intra-annual time periods that capture the greatest proportion of natural variation of these parameters. Turbidity and mass concentration of suspended particulates data from the ECA only exist since 2016 and is greatly skewed towards recent collections in 2020 and 2021 (Figure 6).





Examination of intra-annual data distribution of turbidity and mass concentration of suspended particulates data produced from locations within the ECA reveals that

although data has been produced during all seasons and months, the data volumes are greatly skewed towards the half-year period between November and April (Figure 7).



Figure 7. Turbidity and mass concentration of suspended particulates data distributions within the ECA according to bi-monthly periods within a year.

5. Summary and Decision Support

A compiled data set consisting of 108,039 and 27,668 measurements of turbidity and mass concentration of suspended particulates, respectively, was produced. This includes 79,593 (turbidity) and 27,484 (mass concentration of suspended particulates) measurements from the ECA distributed across 6 years and produced during all months of the year, though data amounts are skewed towards winter and spring periods. Winter and spring periods may produce higher concentrations of suspended particles in the water column because of higher winds associated with these seasons. The number of unique sampling sites within the ECA approaches the number of sites sampled in BNP and FKNMS over much longer time periods, suggesting that the spatial distribution of data is sufficient to capture the spatial variation of turbidity and mass concentration of suspended particulates. The wide range of observed turbidities (0 to 52 NTU) and mass concentrations of suspended particulates (0 to 840 mg/L) in the ECA further suggest sufficient temporal and spatial coverage to capture a large range of naturally occurring turbidities and mass concentrations of suspended particulates.

The mini-review of potentially useful turbidity and mass concentration of suspended particulates methodologies suggests many areas for improvement of data measurement and acquisition. The current turbidity method detailed in FT1600 specifies using a nephelometer with a white light source. Measurements produced from these types of nephelometers are prone to interference and negative bias (lower turbidity measurements than actual turbidity) when the water column is colored. Adoption of International Standard ISO 7027-1, which specifies use of a near-IR light sources in

nephelometers to avoid interference due to color, is recommended to improve accuracy of turbidity measurement in natural waters.

The increased use of data sondes is also recommended to produce data efficiently and in greater amounts. The recent development and use of laser diffraction technology in data sondes to efficiently produce measurements of mass concentrations of suspended particulates is promising. Continued and expanded use of this technology within the ECA is recommended.

Field studies employing the older but established methodologies in conjunction with the newer technologies used in data sondes are also recommended to compare resulting measurements of turbidity and mass concentration of suspended particulates and evaluate the relationships and correlations between the different data types.

In conclusion, the compiled data set, descriptive data analyses, and review of potentially useful technologies are valuable towards establishing standards for turbidity and mass concentration of suspended particulates that are protective of coral reef ecosystems. Standards for both measures are recommended to protect both benthic animals and vegetation.

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APPENDIX A

To obtain a copy of the compiled data sets of turbidity and mass concentration of suspended particulates, please send a request to coral@floridadep.gov.