Southeast Water Level Network Workshop Report

June 2023

The Southeast Water Level Workshop was hosted by the Southeast Coastal Ocean Observing Regional Association and NOAA's Center for Operational Oceanographic Products and Services to address water level needs within the Southeast. This document provides an overview of the current water level operators, sensor technology, data products, station and data management best practices, and key gaps in water level observations. The gap assessment provides critical information for the SECOORA Regional Coastal Ocean Observing System Plan.

SECOORA
SOUTHEAST
COASTAL OCEAN OBSERVING
REGIONAL ASSOCIATION

In-Situ

NOAA
TIDES & CURRENTS

IOOS
Integrated Ocean Observing System

Hohonu

Table of Contents

Acknowledgements

This workshop was hosted by the Southeast Coastal Ocean Observing Regional Association (SECOORA) and NOAA's Center for Operational Oceanographic Products and Services (NOAA CO-OPS).

Funding for the workshop was provided by NOAA's Integrated Ocean Observing System through award number NA21NOS0120097.

Thank you to the workshop sponsors, Hohonu and In Situ. Your contributions were vital to the success of the Southeast Water Level Workshop.

Thank you to the following workshop report writers and editors:

- Katie Urbanski, Contractor with Ocean Associates, Inc. supporting NOAA CO-OPS
- David Wolcott, NOAA CO-OPS
- Laura Rear McLaughlin, NOAA CO-OPS, now at NOAA NWS
- Virginia Dentler, NOAA CO-OPS
- Greg Dusek, NOAA CO-OPS
- Jennifer Dorton, SECOORA
- Doug Marcy, NOAA OCM
- Athena Clark, USGS

Thank you to the 60+ attendees who participated in this workshop. Your thoughtful comments and questions highlighted the need for water level training and sensor installations throughout the Southeast.

Acronym List

AOOS	Alaska Ocean Observing System
ASBPA	American Shore & Beach Preservation Association
CORMS	Continuous Operational Real-Time Monitoring System
CORS Network	Continuously Operating Reference Station
CO-OPS	NOAA’s Center for Operational Oceanographic Products and Services
FLDEP	Florida Department of Environmental Protection
IOOS	NOAA’s Integrated Ocean Observing System
NCDOT	North Carolina Department of Transportation
NCDPS	North Carolina Department of Public Safety
NGS	NOAA’s National Geodetic Survey
NOS	NOAA’s National Ocean Service
NWLON	National Water Level Observation Network
NWS	NOAA’s National Weather Service
OCM	NOAA’s Office of Coastal Management
QARTOD	Quality Control and Assurance of Real-Time Oceanographic Data
SECOORA	Southeast Coastal Ocean Observing Regional Association
USACE	US Army Corps of Engineers
USGS	United States Geological Survey

Water Level Workshop: Introduction

Coastal areas around the country are plagued by flooding events (e.g., storm surge, King Tides, high tide flooding) which lead to public inconveniences such as road closures. These events are becoming increasingly common as sea levels rise.[1] The 2014 NOAA Technical Memorandum, A Network Gaps Analysis for the National Water Level Observation Network, documented major spatial gaps in national water level measurements from North Carolina to the west coast of Florida. At present, many of the southeastern states do not have the density of water level data required to fully understand variations in water level at the appropriate spatial and temporal scales required for decision making (e.g., emergency management, habitat/environmental management, agriculture).

Due to the number of requests for water level data received by both NOAA's Center for Operational Oceanographic Products and Services (CO-OPS) and the Southeast Coastal Ocean Observing Regional Association (SECOORA), the two organizations worked together to host the Southeast Water Level Workshop. This workshop was based on a similar event hosted in 2015 by NOAA and the Alaska Ocean Observing System (AOOS), a NOAA Integrated Ocean Observing System (IOOS) Regional Association, to meet with Alaskan stakeholders and learn about their water level monitoring needs. Based on this meeting, AOOS developed a plan to augment the CO-OPS National Water Level Observation Network (NWLON) and almost doubled the number of sensors in Alaska. They also developed Alaska Water Level Watch, a website that documents water level needs and provides access for stakeholders to contribute data and view data on a water level portal. Similarly, the Southeast Water Level Workshop was held to identify water level station needs, data applications, and products and services that will help inform stakeholders about water level and flooding concerns in the Southeast.

The Southeast Water Level Workshop was hosted June 15-17, 2023, in Jacksonville, FL with over 60 representatives from 11 federal and state agencies, four private companies, and nine academic institutions. The workshop purpose was to:

- understand the variety of water level sensors in use;
- identify water level station locations, programs, and uses in the Southeast;
- document priority locations for additional sensors;
- learn about specific online data and stakeholder tools; and,
- document training needs

The meeting agenda and presentations are available for download on the following webpage: https://secoora.org/workshop-water-levels-in-the-southeast/

[1] Sweet, William, Dusek, Gregory P., Marcy, Douglas C., Carbin, Gregory W., Marra, John. 2019. 2018 State of U.S. High Tide Flooding with a 2019 Outlook. National Ocean Service Center for Operational Oceanographic Products and Services (U.S.); NOAA technical report NOS CO-OPS 090. doi: https://doi.org/10.25923/rbv9-th19

Workshop Overview

The Southeast Water Level Workshop featured presentations and discussions focused on water level sensor installations, technology use cases, and data access. Session leads throughout the workshop included:

- Gary Thompson, North Carolina Department of Public Safety (NCDPS)
- Rudy Konou and Kevin Meers, Florida Department of Environmental Protection (FLDEP) Division of State Lands, Surveying and Mapping Division
- Nicole Elko, Russ Clark, and Charlton Galvarino representing SECOORA
- Athena Clark, US Department of Interior, United States Geological Survey (USGS)
- Laura Rear McLaughlin, David Wolcott, James Spore, Laura Fiorentino, Nathan Holcomb, NOAA CO-OPS
- Doug Marcy, NOAA Office of Coastal Management (OCM)

Panel and lightning talks allowed meeting participants to learn about similarities and differences in federal, state, and Non-governmental Organization (NGO) approaches to water level data collection. Breakout sessions allowed participants to engage with technical experts to review the various types of water level sensors and learn about the tools and products for processing or displaying data. The workshop ended with attendees identifying priority locations for installing new water level sensors in Florida, Georgia, South Carolina, and North Carolina. This document provides a summary of the sessions and the major takeaways that resulted from discussions throughout the week.

Water Level Programs in the Southeast

Gary Thompson, NCDPS, North Carolina Flood Inundation Mapping and Alert Network (FIMAN)

The NC Flood Inundation Mapping and Alert Network (FIMAN) provides near real-time water level and flood mapping information for the entire state of North Carolina. Water level data is used for federal, state, and local emergency management support, and communicating flood risks with the media and the public. FIMAN started in 2000 and there is now a network of 700 gauges across the state. NCDPS owns and operates 221 of the gauges and other federal, state, and municipal agencies operate the others. The majority of NCDPS water level gauges are radar and ultrasonic, with a few in situ pressure transducers. However, they are gradually moving away from this type of sensor.

All water level data are available on the FIMAN website (https://fiman.nc.gov/) and mobile app. While all gauges provide water level data, many stations (especially those in the mountains) also provide rain gauge data. The FIMAN gauges primarily use GOES satellite communication on the coast, VHF in the mountains, and cellular in the Piedmont region. Users of the FIMAN website can set up alerts to be notified when water levels reach their identified threshold for a specific water level gauge.

To help reduce downtime, NCDPS has established a local gauge maintenance policy where local governments can install a water level gauge and have it incorporated into the FIMAN network. Once incorporated, NCDPS will assume the maintenance on the gauge into the future. There is also an Adopt-a-Gauge program where local residents or town or city staff will monitor gauge sites for vandalism or maintenance/hardware issues.

NCDPS partners with NCDOT on Bridge Watch. This collaboration collates data from the FIMAN network and other sources to be used for decision making (e.g. bridge closures, road closures, flooding alerts) during emergencies and extreme events (e.g. hurricanes). NCDPS also partners with the NC Department of Environmental Quality on Dam Watch. This partnership focuses on rivers with dams to identify flooding events that could impact dam integrity and downstream flooding. Both Bridge Watch and Dam Watch are only available for authorized government business purposes and are not public facing sites. Finally, NCDPS is working with NOAA CO-OPS to incorporate six FIMAN gauges in coastal NC into the CO-OPS water level network (see more below).

Rudy Konou, FLDEP Division of State Lands, Surveying and Mapping Division
Established by Florida Statute 177.29, the Tide Gauge Program provides continual maintenance of tide station and benchmark networks for the state of Florida. In 1975, the Coastal Mapping Act codified the Mean High Water (MHW) determination process to preserve Florida sovereign lands, which included the installation of water level gauges along Florida coastal waterways. FLDEP worked closely with NOAA's National Ocean Service (NOS) to develop uniform standards and procedures to establish Mean High Water and Mean Low Water elevations to preserve local tidal datums and to interpolate between tide stations. Under this program, FLDEP also coordinates with public and private agencies and the federal government to make tidal surveys and maps of coastal areas.

There are currently 85 active water level stations installed, seven of which are long-term stations (defined as those where data records exist for more than 10 years). FLDEP installs Aquatrak acoustic water level sensors and YSI radar water level sensors. Each water level station has 5 benchmarks that are leveled annually, except Apalachicola where GPS leveling is used. All elevations are reported in NAVD88. The major challenge to operating water level sensors is hurricanes, which can cause damage to the sensor and even loss of bench marks. FLDEP-Stevens.com houses the data collected by the network of gauges and makes it publicly available at the following link: https://stevens-connect.com/public/fldep.

Nicole Elko, American Shore & Beach Preservation Association (ASBPA)
SECOORA Water Level Network
The SECOORA Water Level Network is composed of four funded project teams distributed throughout the southeast states of North Carolina, South Carolina, Georgia, and Florida. These members include ASBPA in partnership with Hohonu, Georgia Tech, Florida International University, and Coastal Carolina University in partnership with Florida Atlantic University. SECOORA and project team members are working to install lower cost water level sensors in approximately 150-200 locations in the Southeast to address coastal flooding for communities.

SECOORA team members partner with stakeholders and decision makers to meet local water level data needs. In south Florida, the group has installed both Maxbotix ultrasonic water level sensors and in situ pressure sensors. The sensors gather 6-minute water level samples and are surveyed to NAVD88 per NOAA sampling and surveying standards. The data are quality controlled based on NOAA IOOS Quality Assurance/Quality Control for Real-Time Oceanographic Data (QARTOD) standards and are available at the following link: https://wl.secoora.org

SECOORA has seen high demand for water level data. The teams are balancing the needs for water level data with the accuracy that communities require since this impacts sensor choice and costs. Finally, while there are many lower cost sensors on the market, costs related to vertical elevation surveys, operations and maintenance, and data telemetry need to be taken into consideration when developing a water level network.

Athena Clark, US Geological Survey (USGS) Storm Team Leader

As the science arm of the US. Department of the Interior, the USGS provides an array of earth, water, biological, and mapping data and expertise in support of decision-making on environmental, resource, and public safety issues. The USGS is structured across5 mission areas (served by 23 programs) and seven regions. USGS has 60 Science Centers, five Volcano Observatories, and over 500 laboratories. USGS scientists develop new methods and tools to enable timely, relevant, and useful information about the Earth and its processes.

Under the Water mission area, USGS works with partners to monitor, assess, conduct targeted research, and deliver information on a wide range of water resources and conditions including streamflow, groundwater, water quality, and water use and availability. To support this, the USGS operates and maintains a permanent national streamgage network. The data from this network can be viewed and downloaded from the USGS National Water Dashboard, which presents real-time stream, lake and reservoir, precipitation, and groundwater data from more than 13,500 USGS observation stations across the country. During short-term events, the USGS collects additional data, including barometric pressure, storm tide, wave height, and high water marks to aid in documenting flood events. The USGS Flood Event Viewer provides convenient, map-based access to downloadable event-based data. USGS works closely with the NOAA National Hurricane Center and FEMA to determine where to collect data based on the forecasted hurricane track and surge/run-up models. Data is collected along the coastline and on transects moving inland to capture the full range of storm hydrodynamics. The data are collected using a combination of contact and non-contact sensors and telemetry solutions including cellular, Iridium, and GOES. The water level data collected by USGS provide consistent and actionable information that is required by stakeholders.

The USGS also coordinates a Coastal Storm Team, composed of federal partners (e.g. FEMA, NOAA, USACE), state partners (Emergency Management, DOTs), and academia for any NOAA National Hurricane Center named storm. The Coastal Storm Team meets daily to report on situational awareness for emergency preparedness and response to include report outs from the various participating agencies related to forecasts and data collection activities.

Laura Rear McLaughlin, Chief, Stakeholder Services Branch, NOAA CO-OPS
NOAA CO-OPS is the authoritative source for accurate, reliable, and timely tides, water levels, currents, and oceanographic information. CO-OPS supports the nation's economy by providing data needed for mapping and charting, safe and efficient navigation, and coastal resilience and planning for coastal inundation. CO-OPS operates 210 National Water Level Observation Network (NWLON) stations around U.S. coastal waters and the Great Lakes. NWLON stations provide real-time water level data along with some meteorological and physical oceanographic data. These data are used to generate tide predictions, tidal datums, sea level trends, and in support of operational forecast systems. CO-OPS meticulously measures individual sensor model accuracy and drift to ensure that the correct combination of sensors is installed based on the location. CO-OPS installs two differing sensor technologies at each station when possible so that the environmental limitations of each technology is not duplicated. Infrastructure is one of the biggest factors to consider when deciding what sensor type to use. As long as there is a stable structure that can accommodate a sensor being mounted directly over the water with minimal obstructions, a downward-looking radar sensor is preferred because it does not require SCUBA diving to maintain it. If there is no stable infrastructure to mount a sensor directly over the water or there are obstructions that can't be bypassed, then an in situ pressure sensor is used.

Due to the increasing demand for water level data, CO-OPS is working to provide specifications for a lower-cost, scaled down version of an NWLON system that has the minimum NWLON components, including a radar water level sensor, data collection platform, solar power, sampling and processing on 6-minute average, and data telemetry. This low cost system is being field tested in the Outer Banks and Gulf Breeze, FL.

While CO-OPS recognizes that there are gaps in the NWLON network, Congressional appropriations limitations are such that they do not plan to expand the NWLON network. There are other areas where partnering with CO-OPS is possible. These opportunities include:

- The NOAA PORTS® program, where local partners fund installation, operation, and maintenance of sensors needed to enhance port operations and safety;
- The Coastal Hazards partnership, where real-time display of partner data in the Coastal Inundation Dashboard can be used for decision-making purposes; and
- The Datums partnership, where partner data that meets specific accuracy requirements can help fill CO-OPS datum gaps.

Even though some state agencies collect water level data to NWLON standards, there may be nuances in other factors, such as geodetic leveling, which make it difficult to use the partner data in an official capacity. In many cases, CO-OPS directs entities requesting partnerships to USGS for data sharing opportunities, because CO-OPS may not need the data, and such a high level of accuracy is not required for the stakeholder's intended application.

Standard Practices for Water Level Stations

This session included the following panelists:

- Athena Clark, USGS
- Gary Thompson, NCDPS
- Rudy Konou, FLDEP
- Nicole Elko, ASBPA
- Russ Clark, Georgia Institute of Technology
- Jimmy Spore, NOAA CO-OPS

The panelists were each asked to answer the same series of questions so that audience members could learn more about the processes and procedures that each organization uses to install, maintain, survey, and manage data within their water level programs. Their responses are synthesized below.

Site Reconnaissance Standards

Multiple organizations start site reconnaissance procedures by asking the local community where water level data is needed based on their experience with local flooding events. Another strategy is to seek input from NOAA's National Weather Service (NWS) Weather Forecast Offices, emergency management departments, and other local government agencies who have "on-the ground" knowledge of areas where there is repetitive flooding.

Formal agreements may be required in order to install gauges, including landowner agreements in order to site gauges on private property, or contracts with a local government to place a gauge on public infrastructure. NCDPS has worked with the NCDOT to pre-approve engineering designs for sensor installations on railings on NCDOT owned bridges. By doing this, NCDPS has reduced the time required to receive encroachment permits for sensor installations on bridges and public roadways and streamlined the installation process. Water level monitoring agencies may also collaborate with each other to maximize efficiency. For example, FLDEP collaborates with CO-OPS to utilize locations where stations have historically existed in order to reoccupy them and tie into existing records.

Gauge locations can also be identified by examining records of past events. NCDPS and CO-OPS use historical records to examine past storm events and their flooding impacts in order to predict future flood potential, while USGS uses high water mark identification from major storms to understand where flooding occurs and predict future flooding.[2] Predictive models can also be used to identify data gaps. Georgia Tech, for example, creates flood forecast models for up to three days in advance, then uses data from existing sensors to validate these models after a flooding event. Students use the model validation points to identify gaps in sensor networks.

State and regional agencies often incorporate existing recon standards from CO-OPS and USGS into their own standards. USGS is the authoritative resource on streamgaging, which is

[2] The USGS also has a standard operating procedure for storm tide monitoring in draft.

used to monitor stream discharge and plan for development that may be affected by stream elevation.[3] CO-OPS' strategy for determining where to site water level stations begins by answering the question, "What will be the station's main purpose?" while also aiming for highest accuracy possible. This purpose, whether it will be used for real-time monitoring, tsunami tracking, sea level trends, or navigation, will guide decisions on design, specifications, and geodetic references. For example, stations measuring long-term sea level trends require NWLON standards, while stations used for navigation require current conditions and can have water levels to a slightly lower accuracy (the exception being air gap sensors). Following a desktop recon, CO-OPS also completes field recon to ensure that a station will be stable at the chosen location. This includes taking measurements and pictures in order to design necessary infrastructure to support the station.

One concern when siting water level stations is the degree to which subsidence is occurring, especially when a station will measure long-term sea level rise. Organizations handle this issue with slight variations. CO-OPS and FLDEP rely on geodetic leveling and ensuring there is a robust bench mark network around the station. In addition to performing annual leveling at each of its stations, CO-OPS also performs GPS reoccupation every 5 years to capture whether the station datum is shifting relative to NAVD88. CO-OPS also co-locates GNSS sensors with some gauges as a method of validating sensor stability, though this has not been fully incorporated into operating procedures. Similarly, NCDPS co-locates its subsidence monitoring gauges with the NOAA National Geodetic Survey (NGS) Continuously Operating Reference Station (CORS) Network and monitors these locations with GPS. USGS's riverine gauges are surveyed upon sensor installation and every three years thereafter, and coastal sensors are also re-surveyed after every storm.

Sensor Installation Standards

Installation standards typically vary based on the intended application of the sensor's data. For a short-term installation, like USGS Rapid Deployment Gauges, installation requirements are determined by the severity and track of the tropical storm or hurricane and what data needs to be collected. The type of infrastructure and whether both water level and meteorological observations are required helps determine the mounting bracket and enclosure needed for an installation. Regardless of the installation, power is typically provided by solar panels and satellite antennas provide data telemetry.

For long-term installations, a few key factors are typically of paramount importance across all organizations. Safe and reliable access to the infrastructure for maintenance, as well as security of the site, is important for keeping equipment installed for a long time. Similarly, the availability and reliability of communication is critical for continuous operations, whether it be through satellite telemetry, internet, or cellular communications. One common approach to ensuring consistent delivery over the long-term is redundancy to ensure minimal gaps. Redundancy might mean installing multiple sensors of different types in the same location to avoid potential data gaps associated with a particular technology, multiple ways of transmitting data, and/or

[3] Details on USGS's streamgaging processes can be found in the documents "Stage Measurement at Gauging Stations" and "Discharge Measurements at Gauging Stations."

multiple power sources. Survivability of a station is something that also needs to be considered continuous operation is critical. Overall, the resource requirements for long-term installations are significantly greater than those needed for short-term needs.

In some locations, organizations are installing water level and meteorological sensors along with web cameras. CO-OPS has partnerships with other entities, including SECOORA, to install cameras at a few of its locations. The web cameras are available on the NOAA Coastal Inundation Dashboard. Similarly, USGS's HIVIS dashboard curates information from each of its gauges that has a camera. Cameras are primarily used to validate that flooding is occurring at a location, which can help when quality controlling data. However, there are a few factors to keep in mind when considering whether to install a camera at a water level or stream gauge station. One is whether the power source at the station allows the camera to operate continuously. Another is community privacy concerns. Notifying and/or educating the community on the installation and its purpose is one way to potentially alleviate privacy concerns. Another option that can address both of these complexities is to install a camera that does not record until the water reaches a certain flood threshold. These cameras can "flip up" or turn on once this threshold is reached to record flooding as it happens, but not at any other time.

Survey and Accuracy Requirements

Most of the workshop's participating entities tend to adhere to similar standards and procedures for geodetic leveling. CO-OPS follows NOAA National Geodetic Survey (NGS) standards for surveying and leveling, and as the authoritative source for water levels, these tend to become the de facto standard for other organizations installing water level stations as well. This procedure entails performing levels to second order class 1 NGS standards. At CO-OPS, a minimum of five bench marks are required at most locations, with three of those marks being class A or B and the remaining two being class C. A or B marks should be deep rod marks set in bedrock or on bridges or piers, with at least 60 meters (200 feet) of space between each mark (see CO-OPS User's Guide to Vertical Control and Geodetic Leveling for more details). NWLON stations are leveled upon installation, annually while the station is active, at removal, and after major storm events. Each sensor that CO-OPS uses has a designated leveling point. Microwave radar water level sensors are leveled at the top of a collar that is around the sensor, which allows sensors themselves to be swapped out without affecting the leveling point. For pressure sensors, a leveling point called a "rod stop" is established at the top of the sensor. Field crews annually perform a "tape down" procedure to make sure the distance from the leveling point to the orifice on the pressure sensor has not changed. When tricky conditions make it necessary, such as when leveling to offshore stations is required, CO-OPS also uses trigonometric leveling, and is discussing using GPS to get elevations where leveling cannot be conducted.

FLDEP and the NCDPS both follow the same NGS leveling procedures.

SECOORA's elevation uncertainty tolerance for vertical elevation is 5 centimeters (cm). In service of this goal, SECOORA invested in a land surveying team to survey many of its installed sites. This includes RTK/RTN and geodetic leveling to a sensor and three bench marks. One limitation for SECOORA (and for other entities with capacity restrictions) has been the discrepancy between paying a relatively low price for a sensor while having to invest a comparatively large amount on surveying. To help alleviate this issue, SECOORA has created a tier scheme for its stations. Reference stations, or Tier 1 stations, for example, are held to higher accuracy standards. These stations receive greater investments with regards to surveys and long-term maintenance. Tier 2 stations are generally surveyed to a slightly less rigorous standard and are used solely in partner applications. Additionally, for some applications there is less of a need for greater accuracy. For flood models, for example, attaining 6-inch accuracy over a three-day time span is sufficient since there is little harm in over-estimating flooding risk.

USGS points stakeholders to some of its published manuals for survey and leveling standards. These include Levels at Gaging Stations and Vertical Datum Conversion Process for the Inland and Coastal Gage Network Located in the New England, Mid-Atlantic, and South Atlantic.

In general, accuracy requirements vary based on the intended application of the data. Stations do not require as much accuracy if their primary purpose is for a community to monitor flooding, versus if they are intended to measure sea level rise. CO-OPS is beginning to display partner stations on the Coastal Inundation Dashboard for more widespread inundation monitoring. These stations can be held to lower accuracy standards because the data are used only for hazard alerts. Stations that cannot be leveled as regularly can still yield data that is useful for academic purposes. One point that was also raised was the importance of documenting uncertainty for each station. Understanding the uncertainty associated with the water level sensor itself, vertical controls, sampling, etc. will help users understand the data accuracy and whether the data can be used for their applications.

Metadata requirements

There was broad agreement that metadata is crucial for proper application of any data collected, though the standards vary. Some organizations have well established, documented, and published standards for their primary mission areas, while others are developing standards as the issues around data evolve.

Necessary metadata in its most basic form is summarized as what, when, where, how, and by whom something was installed, removed, or replaced. However, additional metadata is often required and can include equipment serial numbers, which bench marks were used, how surveys were conducted, photos of the process, anecdotal notes from employees in the field, recent changes in the local environment or infrastructure, whether the stated coordinates are still accurate, sensor and datum offsets, etc. The individual list of required metadata depends on the organization and its focus area and can be extensive.

For federal organizations, metadata standards are formalized and relatively unchanging. USGS provides Survey Manual 502.7, which details its metadata standards This manual helps to make sure that the metadata collected by USGS or its partners is factual and observational in nature - that is, “noninterpretive.” Metadata is similarly crucial to CO-OPS, and a large focus of its collection is to make sure processes, forms, and diagrams are standardized to make metadata more interpretable for both internal and external users. To this end, CO-OPS uses an in-house application known as eSite to track metadata and maintenance events. Within eSite, users can manage and note metadata, including what parts were installed at a station, offsets on equipment, contact information, photos of the station, and locations of equipment in latitude and longitude. is especially important to track the serial number of each piece of equipment installed across the NWLON network to help diagnose issues. If there is a problem with a specific batch of water level sensors that were installed, having the serial numbers of the equipment helps CO-OPS track down sensors to make sure the data is being collected accurately. CO-OPS also collects metadata on bench marks and the geodetic network in order to document types of bench marks, station stability, and the location of stations relative to the network. For any clarifications on or corrections to metadata, stakeholders can contact tide.predictions@noaa.gov for CO-OPS stations, or their water science center state representative for USGS stations.

For non-federal organizations, standards are evolving as water level data collection programs continue to grow. Smaller organization metadata standards are crucial because there are often different contractors installing equipment across the organization. Georgia Tech is continuing to evolve its metadata standards and is learning based on best practices from other organizations. The NCDPS has developed an application to track its metadata. This application is accessible to its field technicians and maintenance contractors, and includes metadata on installed equipment, elevation, and history of the initial installation of the equipment. Similar to CO-OPS, when there is a problem with any station, this application is used to help troubleshoot the system and its components from afar, or to ensure the right equipment is on hand for field visits. FLDEP's methods are similar. Every time a contractor does work on a station, all metadata is recorded and housed at https://www.fldep-stevens.com/login. Members of the public can access data by clicking on the public access link on the login page and can download data by contacting the site administrator, Stevens.

QA/QC

Producing high quality data requires a multi-pronged approach that ensures 1) the quality of equipment used to collect data, 2) the quality of processes that will be carried out by teams in the field through documented standards, and 3) the quality of tools, applications, and automated software that detect data discrepancies.

High quality data starts with knowing that the equipment used is in good working order. This includes calibrating equipment to manufacturer specifications and testing sensors as needed to ensure data collection will be accurate over time. Equipment must also be maintained to predefined standards to minimize human error. Error can be reduced by using field crews with training, experience, good judgment, and careful attention to detail. It is also important to provide crews with clear documentation on an organization's best practices and established guidelines. Taking the time to define the standards to which an organization will install a water level station, and how those standards can be met, can help eliminate human error. Crews should also be sure to document all work in the field and report in detail any issues as they arise.

Many water level collection agencies also use tools and applications that help monitor data QC and alert teams to suspect data. Some of these are applied to data as it is collected at a station. For example, SECOORA receives a daily email indicating the status of each water level station with QC flags highlighted when data is suspect. These alerts are based on QARTOD standards. See the “Non-Federal Resources” section below for more information. The NCDPS has also developed its own QC tools. These include alerts for gauges going offline or needing maintenance, for noise in the data, for lost data, and for storm damage to a gauge. Also, CO-OPS uses automated processes within its Continuous Operational Real-Time Monitoring System (CORMS) to flag data or even whole stations when the data transmitted is suspect. CORMS provides 24/7 data quality monitoring. CO-OPS is also exploring efforts to incorporate AI and machine learning into data QC. The eventual goal of this work is to automate some processes using AI so that human processors can spend time on other issues.

In addition to its automated QC, CO-OPS also performs manual QC. Data can be checked remotely using IP modems that exist at most CO-OPS stations, which allow CO-OPS to login and run internal diagnostics to determine if data is suspect, if there is an issue with the primary sensor, and if data collection should be switched to a backup sensor. Any problems that are identified in the data by CORMS are handed off to CO-OPS’ Data Monitoring and Analysis Team (DMAT). DMAT diagnoses suspect data to determine if CO-OPS should switch to backup sensors to keep data transmitting in real-time. Following these diagnostics, the Data Processing Team reviews and processes data from every real-time station monthly. This involves looking at the data holistically to identify anything out of the norm and identifying anything that might indicate a long-term issue with data collection at that site.

SECOORA QC standards are based on Quality Control and Assurance of Real-Time Oceanographic Data (QARTOD) standards that have been published as manuals by NOAA’s IOOS. IOOS has published a manual for 13 sensor types and these manuals outline the QC required, strongly recommend, and suggested tests that should be implemented. The manuals can be accessed online (https://ioos.noaa.gov/project/qartod/). SECOORA and its partners work with an external contractor, Second Creek Consulting, which has automated processes to implement QC tests on real-time data streams. This QC system automatically generates a daily email summarizing all quality control flags for stations. Station operators can then evaluate the data quality by reviewing whether data from a station is flagged as suspect or failed the QC test. The daily email system requires operators to engage with the data and review it thoroughly and can help the data provider focus on repeat issues that may be causing suspect data.

Takeaway: Standards Across the Water Level Network

One thing consistently noted throughout the workshop is that water level measurement standards are not uniform across water level programs and this could potentially hinder data sharing across agencies. Attendees considered if homogeneity or heterogeneity would ultimately be preferable in a water level sensor network, and whether the need for consistency is a roadblock to expanding networks. Participants agreed that allowing for different standard options is important, as all agencies and applications do not use water level data for the same purposes, nor do they have the same resources. For SECOORA, this translates into a two-tiered system of standards for stations based on the rigor of the desired applications, as mentioned above. The standard chosen for a network should fit the designated purpose. For example, a sensor installed for situational awareness (i.e., is there water on a roadway) doesn't need an expensive vertical control effort compared to a sensor suite installed to monitor long-term sea level or vertical land motion. Having a diverse set of standards allows agencies to seek funding opportunities based on the level of accuracy needed. CO-OPS practices are the agreed upon gold standard that can help organizations justify higher funding when there is a need for it.

However, some aspects of water level monitoring should be uniform across networks when possible so that data sharing is more straightforward. NOAA can play a role in this by standardizing data formats and data processing needs, while the IOOS regional associations can help disseminate this data to enable decision making. Standardization is preferable not only for efficiency of data sharing, but because it makes long-term maintenance and operations of stations easier. One suggestion was to set up a network for water level monitoring that is similar to the National Mesonet program for weather observations (https://nationalmesonet.us/). The network requires consistency in measurement standards but does not prescribe which individual sensors to use across the program. Although there are instances where standardization is neither possible nor preferable, organizations should strive for more homogeneity across certain aspects of water level networks to make data sharing and collaboration more straightforward.

Tools and Products

Each agency displays its data and products through different customized tools and applications. The sections below highlight federal and non-federal resources that are available for the public to query data for analysis and decision making.

Federal Resources

NOAA Resources

The NOAA National Weather Service (NWS) offices issue watches, warnings, advisories for coastal flooding, and other coastal forecasts (e.g. rip current warnings), and they coordinate with local emergency management officials during storms, flooding, or other weather events. There are multiple online resources for NWS data and products:

- https://www.weather.gov/
- https://www.weather.gov/erh/coastalflood
- https://water.weather.gov/ahps/

NWS also has several national centers that provide data for specific uses and applications. These include the National Hurricane Center, National Water Center, Ocean Prediction Center, and River Forecast Centers. The National Water Center is also developing a National Water Model. Its goal is to develop and train regional offices on real-time flood inundation maps at gauge locations that can then be used to predict water levels based on precipitation and flooding. This product will be shared with emergency managers for their use.

The NOAA Office of Coastal Management (OCM) has multiple data products available for public use within the Digital Coast.

- The Sea Level Rise Viewer is part of a suite of products and services that are available to help communities assess their risk because of sea level rise. The Digital Coast website allows users to download the underlying data, connect to available mapping services, learn about the methods employed in the mapping through documentation, and enroll in an instructor-led Coastal Inundation Mapping course to get hands-on experience in mapping methods. The Sea Level Rise Viewer provides:
    - Local sea level rise projections
    - Data integrating marsh migration, high tide flooding, socioeconomic impacts, mapping confidence, and impact visualizations.
- The Coastal Flood Exposure Mapper was developed to start a conversation around coastal flood hazard risks and associated vulnerabilities. OCM encourages users to obtain local data to conduct more detailed analyses, as this is a screening-level tool that incorporates existing national data. Maps show people, places, and natural resources exposed to coastal flooding and provide a community-based approach for assessing coastal hazard risks and vulnerabilities.
- The Stormwater tool provides information, tools, and methods to examine:
    - Flooding from coastal inundation
    - Impacts on community-level stormwater issues
    - When and where impacts may occur
    - Resources to help communities resolve stormwater issues
- The Sealevelcalculator (currently in beta) Provides useful and actionable information on how sea level and flood frequency are changing over time and on the ground. It integrates numerous water level data sets to provide streamlined access to NOAA's Water Level Data. The primary audience for this tool is stormwater, floodplain, and emergency managers; land use planners; public works; and engineers.

NOAA CO-OPS publishes data, products, and tools for coastal communities that are vital for coastal hazard assessment, navigational safety, and mapping and charting. Specific examples include:

- Real-time and historic water level data
    - The main CO-OPS map displays active and historic gauges with tide predictions and real-time water levels, as well as other data and products.
    - Data from this interface can also be queried via three different APIs - the Data API, Metadata API, and Derived Products API.
    - CO-OPS transmits some of its data via GOES satellite, and this data is open access. A document advising users how to access and decode raw data is currently in draft.
- Relative linear sea level trends for 146 US locations
    - At least 30 years of water level data are needed to obtain a 95% Confidence Interval to within 1.5mm/yr using a method that solves for interannual variation, seasonal cycles, and the linear trend at the same time. This legacy product is

currently being updated to incorporate a second linear trend beginning in 1993 to align with the era of satellite altimetry and highlight any acceleration that has happened in the past three decades relative to the entire period of record. The updated product will also incorporate sea level change projections from the 2022 Interagency Sea Level Report.

- Extreme Water Levels
    - Extremely high or low water levels at coastal locations are an important public concern. This product provides annual and monthly exceedance probability levels for select CO-OPS water level stations with at least 30 years of data.
    - Exceedance probability is the likelihood that water levels will exceed a given elevation, based on a statistical analysis of historic values.
    - When used in conjunction with real time station data, exceedance probability levels can be used to evaluate current conditions and determine whether a rare event is occurring. This information may also be instrumental in planning for the possibility of dangerously high or low water events at a local level.
    - This product is currently being updated with data through December 2023 and a future version of this tool will incorporate Regional Frequency Analysis Generalized Pareto Distribution extreme water levels from the 2022 Interagency Sea Level Report.[4] This product will also incorporate the sea level projections from the 2022 report so a user could see what the extreme levels could be in future decades as relative sea levels change.
- Coastal Inundation Dashboard (CID) is an interactive web-map application targeted towards coastal decision makers and the planning community.
    - The dashboard provides real-time and historic flood information.
    - Impact graphics include over 200 images taken during past flood events along with associated water level measurements at the nearest water level station so that users have a visual representation of potential flood impacts.
    - It incorporates forecast models and flood thresholds from NWS and also provides NWS coastal flood products (watches, warnings, and advisories).
    - The dashboard can present NOAA's National Hurricane Center (NHC) information about tropical storm tracks and potential impacts. NHC data updates on the fly from NOAA's nowCOAST.
    - The dashboard includes partner stations that are not in the CO-OPS database, the bulk of which are USGS stations.
- CO-OPS also creates a variety of High Tide Flooding products. These products use data, metadata, and impact graphics to visualize high tide flooding. High Tide Flooding products include:
    - Annual High Tide Flooding Outlook
        - This tool provides annual projections of high tide flooding frequency alongside sea level rise scenarios that enable decadal projections out to the year 2100.
    - Monthly High Tide Flooding Outlook

[4] Interagency Sea Level Rise Report

        - This sub-seasonal outlook supports planning at the monthly level by providing a calendar of flooding likelihoods for one year in advance.
- Tidal Analysis Datum Calculator (TAD)
    - TAD is an online user interface where non-NOAA data can be uploaded as a .csv file and tidal datums can be computed.
    - Users upload a csv file with water level data, specify the units of the data, select a time zone, input the latitude and longitude, and choose a control station.
    - Outputs include images of the time series with the selected tides, csv output of the tide, and an output log file that outlines the datum calculation method, control station datum information (if chosen) and the resulting datum plane, ratio, and range values.
    - This tool does not interface with the CO-OPS database, so any file with a consistent time series interval can be used. This tool does not replace the work of producing "official" tidal datums that take almost two decades to update and extensive human resources. It uses the same algorithmic approaches but makes some decisions based on the data file that would otherwise be made by an analyst.
- Inundation Analysis Tool (IAT)
    - The IAT allows users to select a time series of data from within the CO-OPS database and analyze the frequency and duration of inundation events at a specific location.
    - Users can choose to analyze data against stored datums or custom thresholds.
    - Outputs include plots and downloadable csv files of:
        - Inundation elevation vs. duration
        - Max elevation relative to a chosen threshold
        - Inundation duration relative to the chosen threshold
    - In FY25, CO-OPS anticipates having a public-facing version of this tool that will allow users to upload their own data files and perform inundation analysis. CO-OPS plans to integrate this tool with both TAD and CID and it will no longer be available as a standalone tool.
- Vertical Datum Transformation Tool (VDatum)
    - VDatum is a joint CO-OPS/NGS tool that converts between geodetic, ellipsoidal, and tidal datums at any location. It has the capability to convert from among 36 different vertical reference systems, including MSL, NAVD88, and GRS80.
    - Domains currently cover CONUS, Puerto Rico, US Virgin Islands, and Southeast Alaska.
    - VDatum is based on the ADCIRC circulation model, the topography of the sea surface (TSS) model, and relationships between tidal datums.
    - It can be run locally by downloading all translation files or running online using the tool available on the website.
    - Both individual point information (latitude/longitude/elevation) and DEM files can be processed.

USGS Resources

USGS has several products available for Water Resource and Emergency Managers, including:

- USGS Flood Event Viewer
  - The viewer provides access to data during an active event and for historic events.
  - During active events, data from the rapid water level sensor deployments and additional data (barometric pressure, storm tide & wave, high water marks) are provided on the viewer.
  - The viewer has incorporated non-USGS data for some events, such as the Alaska ExtraTropical Storm (remnant of Typhoon Merbok).
  - During Hurricane Ian, 242 rapid deployment water level sensors (in water and above water) and 28 wave sensors were deployed and data were shown on the Flood Event Viewer.
  - The documentation of these events helps stakeholders make decisions based on historical flood data.
- Real-time Storm Tide
  - USGS is working to install permanent or seasonal real-time stations in high risk coastal areas to reduce the number of rapid deployment gauges that are deployed prior to a landfalling storm. The sensors can be controlled remotely so they are turned on/off as needed. Currently these gauges have been installed and are being evaluated in multiple locations nationally. The data from these stations will feed into USGS products, such as the Flood Event Viewer.
- WaterWatch
  - WaterWatch is the USGS flagship product that delivers real-time water level and streamflow data.
  - The site displays maps, graphs and tables describing real-time, recent, and past streamflow conditions for the US.
  - The real-time information is updated on the dashboard every 30 minutes, and the interface highlights areas where extreme events (floods and droughts) are occurring.
- National Water Dashboard
  - This tool will eventually replace the WaterWatch. The Dashboard provides real-time water data collected by USGS stations along with weather-related data from other public sources to provide a holistic view of water data across the U.S.
  - On this dashboard, data are refreshed every minute, providing users with the most recent information.
- WaterAlert
  - This is a popular subscription service that allows users to subscribe to email or text messages when certain parameters, as measured by a USGS monitoring location, exceed the user-defined threshold.
- Flood Inundation Mapping (FIM) Program
  - The FIM Program helps communities protect lives and property by providing tools and information to help them understand their local flood risks and make cost-effective mitigation decisions. The program has two main goals:

        - Partner with local communities to assist with the development and validation of flood inundation map libraries.
        - Provide online access to flood inundation maps along with real-time streamflow data, flood forecasts, and potential loss estimates.
- Flood Event Viewer
    - The FEV provides public access to specific lengths of coastline and riverine water-level data and high-water marks that were recorded during major storms or short-term events
- NOAA/NWS and USGS Total Water Level and Coastal Change Forecasts
    - This viewer is a tool that estimates water levels and the potential for coastal change along sandy shorelines based on local tides, storm surge, waves, and beach characteristics.
    - It provides a 7 day model, color coded for the type of predicted flooding.
- Coastal Change Hazards Portal
    - The portal provides scientifically credible data suitable for use in land use planning projects; storm response and recovery protocols; and infrastructure, ecosystem, and cultural resource management decision-making.
    - Resources are organized under three coastal hazards themes:
        - Extreme storms
        - Shoreline change
        - Sea Level Rise
    - The tool runs scenarios for coastal events - bright red bands on the output means there is over a 90% chance of flooding.
- Real-Time Flood Impact Map (Experimental Product)
    - This product shows the impacts of floods on critical safety infrastructure near USGS stream gauges.
    - This is not a flood warning system, but it can be used to convey immediate flood risk by showing the locations where flooding may be currently or soon occurring.
    - Additional flood information layers include FEMA Flood Hazards, NOAA NWS radar data, NOAA NWS watches and warnings, and NOAA CO-OPS NWLON station data.
    - A Spanish version is available.

Discussion

There is a wealth of resources that capture similar data and information. To some extent, this will always happen because agencies have a requirement to provide data in different formats (e.g. the National Weather Service's warning systems). Additionally, different agencies may collect and display the same data, such as NWS and CO-OPS, which both have apps that visualize flooding. Agencies may also pull from each other's APIs, further compounding the issue when the same data is displayed with only slight differences in interface and functionality. This highlights the need for agencies to describe the product purpose and intended audience so that users can determine which tool or application is most useful for their needs.

Agencies are also working together to create cooperative agreements and pool resources to provide stakeholders with the best data. For example, FEMA is working to collate information on flood risk from various science agencies, and there is extensive collaboration happening to assemble the best sea level rise science for an interagency report. Though working within the confines of differing agency missions and budgets can be complex, one future path forward may be to begin collaborating on interagency tools, resulting in one location for all water level needs. This process is starting to be addressed between agencies and involves incorporating legacy tools as well. The delivery mechanism of these legacy tools will be updated to reflect current needs.

Another concern is the accuracy of the data used in these tools and whether this leads to greater uncertainty. In some cases, accuracy is tool-specific. Some mapping tools rely on LIDAR technology, which is continuously improving, but does have some vertical uncertainty. Data providers are responsible for disclosing the source of their data and its uncertainty (including standard error and confidence intervals), while users are responsible for taking uncertainty into account for whatever product they are using.

Accuracy of tools may also be dependent on the predictive models that underlie them. For example, NWS uses event verification to test the accuracy of its forecast models during major events. The data from these tests helps to inform the bias corrections of each model, and where skills in local climatology may need to be improved.

There are also concerns about the spatial relevance of products. For example, sea level changes at a specific location are only relevant to that location. Vertical land motion, subterranean fluid withdrawal, and effects from localized global current patterns drive relative sea levels that cannot be assumed beyond a few kilometers. Likewise, in situ data cannot be assumed to be relevant beyond a few kilometers. Understanding land deformation is critical for understanding relative sea level changes and may require in situ continuous GNSS observations or the utilization of satellite data to account for the impact of vertical land motion on relative sea level rise. It should also be noted that rates of vertical land motion might not be linear in time and can impact the true accuracy of any relative sea level change estimates.

Considering all of these potential differences across products, agencies emphasize that it is crucial for users to be aware of the specifications and potential limits of the product they are using so that the right product is paired with the right application.

Non - Federal Resources

North Carolina Department of Public Safety (NCDPS)
The NCDPS maintains and operates the NC FIMAN to provide water level and flood data for the state (https://fiman.nc.gov). FIMAN provides real-time data from more than 700 gauges across the state. FIMAN uses Contrail software to collect data, store historical data, and display gauge images and additional metadata.

- FIMAN uses color coding to allow users to identify a station's current and forecasted conditions, risk rating, and which way the station is trending (i.e. whether the flood is rising or falling, which can help determine when flooding may occur). Each station also has its own dashboard and metadata.
- Users can sign up for real-time alerts for any station and customize thresholds for the alerts they receive.
- The tool also allows users to view current inundation based on the most recent data, plan for future scenarios based on potential flooding, and forecast likely flooding using the NWS data that has been incorporated into the system.
- FIMAN also incorporates land cover types in addition to elevation to model flood potential.
- NCDPS works with communities to maintain gauges and keep them online by conducting routine surveying and general maintenance.
- Some of the gauges displayed in FIMAN allow users to enter the parameters for a flood risk scenario and visualize the resulting impact on buildings in the area. This is known as Flood Scenario Mode. Some features of this mode include:
    - Users can change the water elevation to see the number of buildings impacted by flooding, the extent of the flooding, and the estimated cost of the damage.
    - Emergency managers use Flood Scenario Mode to help inform planning, including which areas should be evacuated and which roads may close or become impassable.
    - For future enhancements, NCDPS will work with local communities to obtain elevation certificates and use them to update the database with more detailed building information. NCDPS also plans to use AI to extract building polygons with 85-90% accuracy and perform manual quality control to make corrections to these data.
    - High water mark data is used to quality control the models that feed into this tool.
- Potential FIMAN enhancements include incorporating more state gauges, as well as NOAA and USGS gauges, into the tool. NCDPS is also exploring the possibility of adding the ability to copy and paste a particular page view to share with others.

FIMAN-T

- FIMAN-T, which stands for FIMAN Transportation, is a web-based tool developed in partnership with NCDOT that focuses on bridges, roads, and other NCDOT infrastructure.
- FIMAN-T is not currently public-facing; access is provided only to government officials.
- FIMAN-T provides visualizations and metrics for roadway inundation, bridge hydraulic performance and identifies potentially impacted NCDOT assets. The tool enhances NCDOT's responsiveness during flooding events by generating data and reports for use in disaster response and planning.
- FIMAN-T leverages the real time, 3D inundation mapping coupled with LIDAR derived roadway elevation layers to compute flooding depths over roadways for both current and forecasted conditions.

Flood Risk Information System (FRIS)

- The State of North Carolina provides this website as a public service to the citizens of North Carolina. The Flood Risk Information System (FRIS) contains digitally accessible flood hazard data, models, maps, risk assessments and reports that are database driven. This site also provides geospatial base map data, imagery, LiDAR data, along with hydraulic and hydrologic models that are available for download and use.
- FRIS is used to identify potential flooding impacts at the parcel level to prepare communities for flood risks.

Florida Department of Environmental Protection (FLDEP)

FLDEP's primary tool for water level management is LABINS, or Land and Boundary Information System, located at https://www.labins.org/. This tool was created to satisfy the state's statutory obligation to identify the land/water boundary in the state of Florida. This statute also requires establishing local tidal datums and mean high water lines across the state. The primary way to query data in LABINS is through the map interface. A few features of the interface are highlighted below:

- The Data Query function allows users to search for a specific data type on the map, including tide stations.
- Blue squares on the map indicate places where there is not enough data to interpolate height, so a tide study is eventually required.
- Users can request a tidal datum through the map itself.
- The map includes a layer for viewing NGS bench marks. This is a live feature, so new bench marks will appear on the map as they are published.
- Areas on the map with no points indicate places that need stations. Some of these areas represent a critical need, such as Tampa Bay, which has a high-density population but has gaps where gauges are needed.

Another of FLDEP's applications is Stevens-Connect. This site provides some metadata on FLDEP's tide gauges and raw 6-minute water level data. Members of the public have partial access to this site, while government entities can request full access.

SECOORA Resources

SECOORA operates and maintains a Data Portal that is a regional repository academic, state, federal, and SECOORA data: https://portal.secoora.org/. The portal allows users to explore data through the interactive map or by querying the data catalog or they can access and download via ERDDAP or THEDDS servers. SECOORA has invested in a water level network website that provides access to SECOORA and partner data as well as NOAA NWLON Stations (https://wl.secoora.org).

- The site pulls data from the SECOORA ERDDAP data server to provide near real-time water level data from partners within the southwest.
- SECOORA stations are the Tier 1 stations which have been surveyed to higher standards than the partner (or Tier 2) stations.

- Users can toggle on/off Tropical Cyclone and Radar Imagery so they can view water levels in relation to weather events.
- Each station page provides a water level graph over a 3-day period. Users can change the report period to 3 months, 1 month, or 1 week. Additionally, they can download the water level data in the following formats: text, CSV, Graph, JSON.
- For coastal stations, SECOORA has used the CO-OPS tool UTide, or Unified Tidal Analysis and Prediction, to develop forecasted water levels for that station. This forecast is validated by comparing true observations against the forecast.
- When possible, the station pages will also include nearby camera feeds (such as DOT cameras) and data from nearby or co-located meteorological stations.

State Breakouts: Gaps, Priorities, and Struggles

Having dedicated the start of the workshop to discussing sensor technologies, water level networks, and online tools to access data, the week wrapped up with state-level breakout groups. The purpose of these sessions was for representatives from local, state, and federal agencies to have an open and informal discussion about gaps in water level networks in their regions, prioritize locations for future gauge installations, and identify capacity gaps and training requirements that need to be addressed to help realize water level observation goals. While the locations where sensors are needed are captured on a state by state basis, the data types, knowledge gaps, and overall challenges were consistent across states. Discussions from each breakout group are summarized below.

Top Sensor Locations by State

Florida

There are multiple needs for water level data from the east coast of Florida around to the panhandle region. FLDEP plans to install three water level stations in the western panhandle to help fill gaps near Pensacola, but there are still other priority locations that need to be filled. These include the regions from:

- St. Augustine to Cape Canaveral
- Cape Canaveral to West Palm Beach
- St. John's River (near Jacksonville, FL)
- Indian River Lagoon for tidal/non-tidal delineation
- the area between Port Charlotte and Naples
- the town of Carrabelle, near the Apalachicola National Estuarine Research Reserve.

USGS may be able to help fill gaps for inland/riverine sites, such as the St. John's River and potentially the Indian River Lagoon. The US Army Corps of Engineers (USACE) has also identified the need for oceanside water levels around the state to monitor storm surge, inundation, and sea level rise.

North Carolina

There are water level data gaps throughout North Carolina. Specific priority gaps include:

- Ocean-side water level sensors, deployed on piers or other structures, in order for NWS to better forecast storm impacts and surge.
- Riverine sensors in underserved communities such as the Alligator River; the Northeast Cape Fear River; the town of Navassa; Lumber River; and the communities of Whinton and Edenton on the Chowan River.
- Communities on the western side of the Albemarle and Pamlico Sounds see frequent flooding. Examples include Columbia, Belhaven in Beaufort County, and Carteret County's Down East community (from the Town of Beaufort to Cedar Island).
- Non-tidal flooding events also occur in locations in eastern NC such as Whiteville.

Georgia:
Priority locations identified for Georgia include:
- Lower St. Mary's below Kings Bay to support long term modeling and forecasting.
- The NWS noted that there is a need for long term water level data for boundary coupling on the Altamaha River.
- Water level sensors are needed on some of the developed coastal islands such as Jekyll Island, St Simon's Island, and Colonels Island.
- Ogeechee River, downstream of the USGS gauge at Ft. McAllister.
- Liberty County, specifically along the St Catherines sound and the rivers that dump into the sound, need water level sensors.

South Carolina
The South Carolina workshop participants identified several specific locations as top priorities for water level sensors, as well as more general recommendations based on broader regional needs.
- Jasper County
- Inland areas such as Georgetown, were identified as being in need of more robust water level data coverage in order to improve riverine flood warnings.
- There is a need for more sensors in marsh areas, as opposed to areas that are beach facing, as these areas can be less accurate due to other natural forces.
- Salkehatchie River Basin down to Beaufort would benefit from additional gauges but require additional funding for installation due to the remote nature of the river basin.

Overall Priorities for Data Types

The type of data that is needed or wanted across the states depends on the entity requiring the data and its intended purpose, though real-time data is generally a priority. Local governments, for example, need real-time data for emergency management purposes, while the NWS requires real-time data from long-term (e.g. NWLON) and rapid deployment sensors in order to improve forecasting, capture major weather events, and build up their 5 to 10 year records for improving models. Most communities are interested in predicting and monitoring local high tide flooding, which would require enough data to produce tide predictions. For inland gauges, the goal is to collect enough data to obtain a rating curve that relates river level to its discharge. Most agencies also prioritize the collection of data over a long enough time period to be able to produce tidal datums and harmonic constituents.

High tide and storm-related coastal flooding are the top priorities. Real-time data is required, and the breakout group felt that long-term stations should be installed so that long term changes, not just seasonal, can be evaluated. To collect high-tide and storm-related flooding, oceanside water level data are needed. Radar sensors would need to be installed on piers or similar structures. Radar sensors are more robust than ultrasonic sensors and can be used in areas that produce noise in the data (e.g., winds, waves). Radar sensors can sample at a higher frequency but require more data processing to "clean" the data to see the tidal signal. Finally, cameras could be co-located with water level sensors to ground truth water level data and observe immediate impacts.

Participants also noted that some of the most impactful gaps are not those that exist in physical locations, but rather the gaps in coordination among various organizations. For example, in South Carolina, there is a need for agencies to communicate and work with each other more effectively to expand data across the state.

Limitations due to lack of funding may potentially be offset by siting new gauges where old ones have previously existed based on metadata that can be provided by USGS. These can be referenced to historical gauges and existing bench marks.

Overall Knowledge Gaps

Generally, knowledge gaps exist regarding understanding what data exists and how it can be used. There are a range of training opportunities, both for students and for professionals that are available from NOAA and USGS that may help fill some of these needs:

- Agency-led webinars and training are available online for many of the NOAA OCM tools described during the workshop. NOAA training includes online learning modules that are available and easily pulled into a syllabus for student learning opportunities. These self-guided trainings are available here: https://coast.noaa.gov/digitalcoast/training/home.html
- CO-OPS-affiliated COMET modules are available through MetEd and have been curated on the CO-OPS Technical Assistance webpage. These trainings are found here: https://www.meted.ucar.edu/index.php
- CO-OPS is building out a Technical Assistance Program to assist stakeholders with collecting and using water level data by offering training resources on topics ranging from sensor selection and installation to leveling techniques to data processing and product generation. This program is anticipated to be available online in early 2026 at https://tidesandcurrents.noaa.gov/education/tech-assist.
- NGS offers many training opportunities that may help fill some capacity gaps, especially given that many mentioned lower capacity for surveying and leveling as compared to other skill sets. Online lessons are available here: https://geodesy.noaa.gov/web/science_edu/online_lessons/index.shtml and webinars are available here: https://geodesy.noaa.gov/web/science_edu/training/

- NOAA personnel can conduct virtual classroom talks that cover sea level rise trends and inundation analysis. Finally, there is a need for students to learn about geodesy and field surveying techniques.
- USGS has a range of free online training and resources. Data Management training modules are available here: https://www.usgs.gov/data-management/training and are designed to help researchers, data stewards, and managers understand data management best practices. Streamgaging Basics provides an overview of water level (or gage height) and the technologies employed by USGS. https://www.usgs.gov/mission-areas/water-resources/science/streamgaging-basics
- SECOORA offered to conduct a series of webinars for students and professionals, hosting speakers from NOAA CO-OPS, NOAA NGS, USGS, and state agencies. Topics could include online product demonstrations to discussions of the types of sensors available and their appropriate applications.

In some cases, there are gaps in technological knowledge, specifically when it comes to picking the right sensor for the right location, staying abreast of new and emerging sensor technologies, and determining when and where to apply them. Once sensors have been installed, there may be gaps in appropriately utilizing the data collected, for example to understand where flooding will occur, and this also requires instruction on tidal datum calculation.

A major gap in both knowledge and capacity is the difficulty of surveying and leveling accurately when installing stations, and this has been highlighted as an issue in the National Estuarine Research Reserve System (NERRS). More training has been requested for surveying, leveling, and using OPUS projects to determine station and bench mark vertical elevation. Specifically, there is a need for more instruction on minimum standards and accuracy requirements for vertical elevation surveys.

Overall Challenges

Workshop participants also felt that one of the biggest hurdles is not necessarily in knowledge, but in capacity and resources. Communities know the benefits of water level stations, but there is a major lack of capacity in terms of being able to fund and maintain stations long-term. Additionally, there is some lack of knowledge about what other agencies are doing. More information sharing about who maintains which gauges, or where future stations are being planned, would be beneficial to local communities. Participants recognized the logistical difficulty of bringing too many entities into the planning stage but thought that a system where individuals could be notified of new gauges in their area would be useful, especially as priorities for water level station siting differs across sectors.

Breakout attendees noted the difficulty in engagement beyond emergency managers. Frequent flooding, not just hurricane inundation, is a concern across the southeast, so getting information into the hands of the appropriate stakeholders is needed. One idea is to focus on K-12 education opportunities as well as informal education (e.g., camps, after school programs) to increase awareness of flood hazards.

Additionally, engaging underserved communities takes a lot of time and on-the-ground engagement. There is a need to leverage local partnerships, through Sea Grant, for example, to help meet local demands for water level data. Another tool that may help increase partnership opportunities is the Adopt a Gauge program, like the one that is used by NC FIMAN. This would entail appointing local experts who can help troubleshoot gauge issues as needed and act as ambassadors to the community to explain what information comes from gauges and how to use it. A similar program could be tied into local school systems, with programs and curricula for teachers and students to become more involved with water level gauges.

Finally, another major challenge is the lack of organization across each state which does not allow community needs to be met. This challenge is exacerbated by regulatory hurdles that result in an inability to properly aggregate needs between the state and local communities. With more effective communication, needs can be aggregated and met through multi-agency collaboration. For example, NWS personnel noted that there is a need for NWS to stay abreast of new sensor installations, track sensor operators, and know who to contact when sensors go down. This highlights the need for robust communications between station operators and decision support agencies.

Meeting participants are interested in partnership opportunities for future grant proposals so that priority data gaps can be filled. There is also a need to engage with other state agencies (e.g. Florida Fish and Wildlife) that were not present at the meeting.

Workshop Next Steps and Recommendations

The workshop highlighted the distinct need to expand water level monitoring across the southeast; however, this expansion needs to be more coordinated with agencies within states, between states, or between state and federal agencies. While there may be opportunities to install sensors, funding for long term maintenance is often hard to secure. Collaborative partnerships between state agencies, federal agencies, and non-profits/NGOs, along with local community investment (e.g. station stewards) may help alleviate some of the funding hurdles. Additionally, connecting with the state Sea Grant agencies and NERRS seems the most effective way to reach local communities since these organizations are aware of frontline community needs related to flooding, hazards, and data/service needs.

There were several areas of training that meeting participants felt were crucial: 1) To engage more coastal communities and coastal managers, SECOORA should develop a webinar series and host NOAA, USGS, and state agencies speakers who can discuss water level programs, data access, products/tools, etc. This series can specifically target water level end users and highlight the wealth of online water level tools resources that are already available. 2) A major gap in both knowledge and capacity has to do with the ability to survey and level accurately when installing stations. More training has been requested for surveying, leveling, and tying into NGS OPUS projects and other decision-making tools. Specifically, there is a need for more instruction on minimum standards and accuracy requirements as required by different agencies or for specific applications.

Data sharing mechanisms for lower cost sensors need to be addressed. Currently the sensor operators house data on agency/owner websites and while the data is open to the public, it is widely available in formats that can be ingested into other systems. However, there are hurdles to overcome to enable sharing of water level data with the NWS. Acceptable formats for NWS data sharing include SHEF, HADS, and MADIS. This may require water level sensor operators to make their data available in multiple formats, which will require some training. Exploring data sharing opportunities is a high priority.

Overall, participants felt that a future meeting related to water level data should be hosted within 2 years. This meeting should expand its focus to include the use of additional technologies such as:

- Web cameras (WebCOOS) for coastal monitoring, rip current identification, flood monitoring, and coastal erosion.
- Artificial Intelligence (AI) advances and how AI can help with data processing and machine learning for coastal applications.

Water Levels in the Southeast Workshop: Understanding Sensors, Tools, Products, and Gaps

June 13-15, 2023 | Jacksonville, FL | Agenda

About

Workshop and Hotel Location: All meetings and events will be held at the Aloft Jacksonville Tapestry Park, 4812 Deer Lake Drive West, Jacksonville, FL, 32246, (904) 998-4448

Workshop Purpose: Understand the variety of water level sensors in use, water level station locations, programs, and uses in the Southeast; learn about specific online data and stakeholder tools; and document priority locations for additional sensors.

Tuesday, June 13, 2023	
Time	**Activity**
12:30 - 1:00 PM	**Welcome Coffee and Registration**
1:00 - 1:30 PM	**Opening Remarks and Introductions** • Laura Rear McLaughlin, NOAA Center for Operational Oceanographic Products and Services (CO-OPS) • Jennifer Dorton. Southeast Coastal Ocean Observing Regional Association (SECOORA) • Chris Ellis, NOAA Office for Coastal Management
1:30 - 2:30 PM	**Water Level Programs Overview** Outcome: Participants will receive an overview of agency/organization water level programs in the Southeast. • NC Flood Inundation Mapping and Alert Network (FIMAN) – Gary Thompson, NC Department of Public Safety • FL Department of Environmental Protection (FL DEP) – Rudolphe (Rudy) Konou, FL DEP • SECOORA Southeast Water Level Network - Nicole Elko, American Shore & Beach Preservation Association • Water Observing Systems Network - Athena Clark, U.S. Geological Survey (USGS) • NOAA's Tides and Currents - Laura Rear McLaughlin, NOAA CO-OPS
2:30 - 2:45 PM	**Coffee Break with Sponsors**
2:45 - 3:15 PM	**Lightning Talks: Demos of Equipment and Technical Procedures** Outcome: Participants will learn about specific water level sensors and reasons the sensor was chosen, installation requirements, accuracy overview, and lessons learned. • NC FIMAN – Gary Thompson, NC Department of Public Safety • FL DEP – Rudolphe (Rudy) Konou, FL DEP

	• SECOORA Southeast Water Level Network - Brian Glazer, Hohonu Inc. • NOAA's Tides and Currents – Nathan Holcomb, NOAA CO-OPS • NOAA's Tides and Currents Low-Cost System - Laura Fiorentino, NOAA CO-OPS
3:15 - 3:25 PM	**Coffee Break with Sponsors**
3:25 - 4:25 PM	**Breakout: Equipment Showcase** Outcome: Participants will rotate around tables to view water level sensors and discuss sensor options with presenters.
4:30 – 5:00 PM	**Reflections and Adjourn** Outcome: Participants identify one thing they learned during the day. • Chris Ellis, NOAA Office for Coastal Management

Wednesday, June 14, 2023	
Time	**Activity**
8:15 - 8:30 AM	**Welcome Coffee and Registration**
8:30 - 8:45 AM	**Agenda Review and Recap of Reflections from Previous Day** • Chris Ellis, NOAA Office for Coastal Management
8:45 - 10:30 AM	**Fireside Chat: The Nitty Gritty on Water Level Stations** Outcome: Participants will learn about the decisions that go into sensor selection, deployment location, data requirements from stakeholders, etc. that ensure the provision of valuable water level data. • Gary Thompson, NC Department of Public Safety • Rudolphe (Rudy) Konou, FL DEP • Nicole Elko, American Shore & Beach Preservation Association • Russ Clark, Georgia Institute of Technology • Athena Clark, USGS • Jimmy Spore, NOAA CO-OPS
10:30 - 10:45 AM	**Coffee Break with Sponsors**
10:45 - 12:00 PM	**Tools and Products I – Federal Resources** Outcome: Participants will learn about some of the tools for processing, viewing, and understanding water level data. • NOAA Resources – David Walcott, NOAA CO-OPS, and Doug Marcy, NOAA CO-OPS • USGS Resources – Athena Clark, USGS
12:00 - 1:00 PM	**Lunch (provided)**

1:15 - 2:45 PM	**Tools & Products II – Non-Federal Resources** Outcome: Participants will learn about some of the tools for processing, viewing, and understanding water level data. ● NC Flood Inundation Mapping and Alert Network (FIMAN) – Gary Thompson, NC Department of Public Safety ● FL Department of Environmental Protection – Rudolphe (Rudy) Konou, FL DEP ● SECOORA Southeast Water Level Network Quality Assurance and Quality Control Dashboard - Charlton Galvarino, Second Creek Consulting
2:45 - 3:00 PM	**Coffee Break with Sponsors**
3:00 - 3:45 PM	**Breakout: Tools and Products Demonstrations** Outcome: Participants will rotate around tables to explore water level data viewers and applications and talk to presenters.
3:45 - 4:15 PM	**Reflections and Adjourn** • Chris Ellis, NOAA Office for Coastal Management
5:30 - 7:30 PM	**Social Sponsored by Hohonu (appetizers provided, cash bar)** • Presentation by Hohonu

Thursday, June 15, 2023	
Time	**Activity**
8:15 - 8:30 AM	**Welcome Coffee and Registration**
8:30 - 9:00 AM	**Recap of Reflections from Day 2 and Setting the Stage for Gaps, Priorities, and Struggles Breakout Session** • Overview of Alaska Water Level Watch Buildout Tool - Laura Rear McLaughlin, NOAA CO-OPS • Water Level Stakeholder Survey Results - Jennifer Dorton, SECOORA • Breakout Session Logistics – Chris Ellis, NOAA Office for Coastal Management
9:00 - 9:05 AM	**Coffee Break**
9:05 - 10:35 AM	**Breakout: Gaps, Priorities, and Struggles** Outcome: Participants will breakout by state to prioritize gaps in water level data, identify training needs from sensor installation to data access, and discuss general issues and partnering opportunities. Breakout Groups: • Florida • South Carolina

	• Georgia and North Carolina
10:35 - 10:50 AM	**Coffee Break with Sponsors**
10:50 - 11:45 AM	**Report outs and Identifying Partnerships** Outcome: Participants will understand the needs for each state and brainstorm opportunities to partner.
11:45 - 12:00 PM	**Next Steps and Recommendations** • Chris Ellis, NOAA Office for Coastal Management