NOAA Technical Report NOS CO-OPS 107

NATIONAL WATER LEVEL OBSERVATION NETWORK (NWLON) REQUIREMENTS

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U.S. DEPARTMENT OF COMMERCE
National Ocean Service
Center for Operational Oceanographic Products and Services

Center for Operational Oceanographic Products and Services
National Ocean Service
National Oceanic and Atmospheric Administration
U.S. Department of Commerce

The National Ocean Service's (NOS) Center for Operational Oceanographic Products and Services (CO-OPS) provides the National infrastructure, science, and technical expertise to collect and distribute observations and predictions of water levels and currents to ensure safe, efficient and environmentally sound maritime commerce. The Center provides the set of water level and tidal current products required to support NOS' Strategic Plan mission requirements, and to assist in providing operational oceanographic data/products required by NOAA's other Strategic Plan themes. The Center manages the National Water Level Observation Network (NWLON), a national network of Physical Oceanographic Real-Time Systems (PORTS®) in major U.S. harbors, and the National Current Observation Program. The Center: establishes standards for the collection and processing of water level and current data; collects and documents user requirements, which serve as the foundation for all resulting program activities; designs new and/or improved oceanographic observing systems; designs software to improve CO-OPS' data processing capabilities; maintains and operates oceanographic observing systems; performs operational data analysis/quality control; and produces/disseminates oceanographic products. This report documents the requirements for and the detailed considerations that go into each NWLON station. It is meant for internal and external partner use.

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NATIONAL WATER LEVEL OBSERVATION NETWORK (NWLON) REQUIREMENTS

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EXECUTIVE SUMMARY

For more than 2 centuries, the National Oceanic and Atmospheric Administration (NOAA) National Ocean Service (NOS) Center for Operational Oceanographic Products and Services (CO-OPS) and its predecessors have gathered water level data for our nation and turned those data into meaningful information to protect life, property, and the environment. Federal, state and local partners, researchers, communities, businesses, and the general public rely on this information to make decisions on a range of topics including safe and efficient transportation and commerce, coastal planning and marine conservation, and the protection and restoration of habitats and ecosystems. These data are primarily collected and delivered by the NOAA National Water Level Observation Network (NWLON), a network of over 200 real-time, long-term, tide and water level monitoring stations along the U.S. coasts, Great Lakes, and territories. A comprehensive documentation of the technical specifications and performance attributes required for this observing network (referred to throughout as "requirements") is essential to ensure the collection of continuous, accurate, high-quality water level observations.

The purpose of this technical report is to define the observing system requirements for the NOAA NWLON. This report provides background information on the NWLON, explains how the observing system requirements fit into the context of the NOAA observing system requirements framework, and includes a comprehensive list and description of the NWLON requirements. These requirements include components focused on:

- data accuracy and uncertainty;
- station and data continuity;
- data collection, transmission, and access;
- documentation; and
- survivability.

This report is intended for use as a clear and transparent, publicly available guide for CO-OPS, other NOAA offices, and for external partners, users, and stakeholders. The goal is to provide the foundational requirements from which best practices, standard operating procedures (SOPs), and operational specifications are developed and implemented. Though modifications or additions to these requirements may occur in the future, the expectation is that the vast majority of these requirements are foundational and should largely remain unchanged.

A previous version of this report was written in 2018 as a CO-OPS internal document. Internal SOPs meant to assist with implementing these requirements were cited in that document; however, due to accessibility, they have not been referenced here. The authors have synthesized multiple CO-OPS internal SOPs, common practices, lessons learned, and both internal and published technical manuals and reports to create this document. All publicly available references are cited throughout the document and listed when they support the justification for a particular requirement.

INTRODUCTION

For more than 200 years, the National Oceanic and Atmospheric Administration (NOAA) and its predecessors have gathered water level data for our nation and turned those data into meaningful information to protect life, property, and the environment. Businesses, communities, and people's daily lives rely on this information when making decisions that affect such things as safe and efficient transportation and commerce, coastal planning and marine conservation, and the protection and restoration of habitats and ecosystems. The National Ocean Service (NOS) Center for Operational Oceanographic Products and Services (CO-OPS) is one of NOAA's key information providers. CO-OPS's mission mandates derive from legislative authority to conduct water level and current observations and to maintain the legal definition of tidal datums for the United States, which legally delineate important marine boundaries[1,2].

CO-OPS operates and maintains the National Water Level Observation Network (NWLON). As shown in Figure 1, the NWLON is a network of precise, long-term tide and water level monitoring stations along the U.S. coasts, Great Lakes, and territories (U.S. Virgin Islands, Puerto Rico, American Samoa, Midway Island, Wake Island, the Marshall Islands, and Guam). NWLON water level observations provide the foundation of the nation's coastal vertical reference framework—that is, authoritative tidal and Great Lakes datums. NWLON observations also support many other mission areas, both internal to NOAA and to our interagency partners, including coastal weather forecasting, emergency response, storm surge and tsunami warnings, climate monitoring, coastal resilience planning, and habitat restoration (McLaughlin et al. 2024). CO-OPS has developed and maintained the NWLON as the U.S. government's authoritative source for accurate, timely, and sustained water level observations.

[1] Coast and Geodetic Survey Act of 1947 (33 U.S.C. §883 *et seq.*)

[2] Hydrographic Services Improvement Act Amendments of 2008

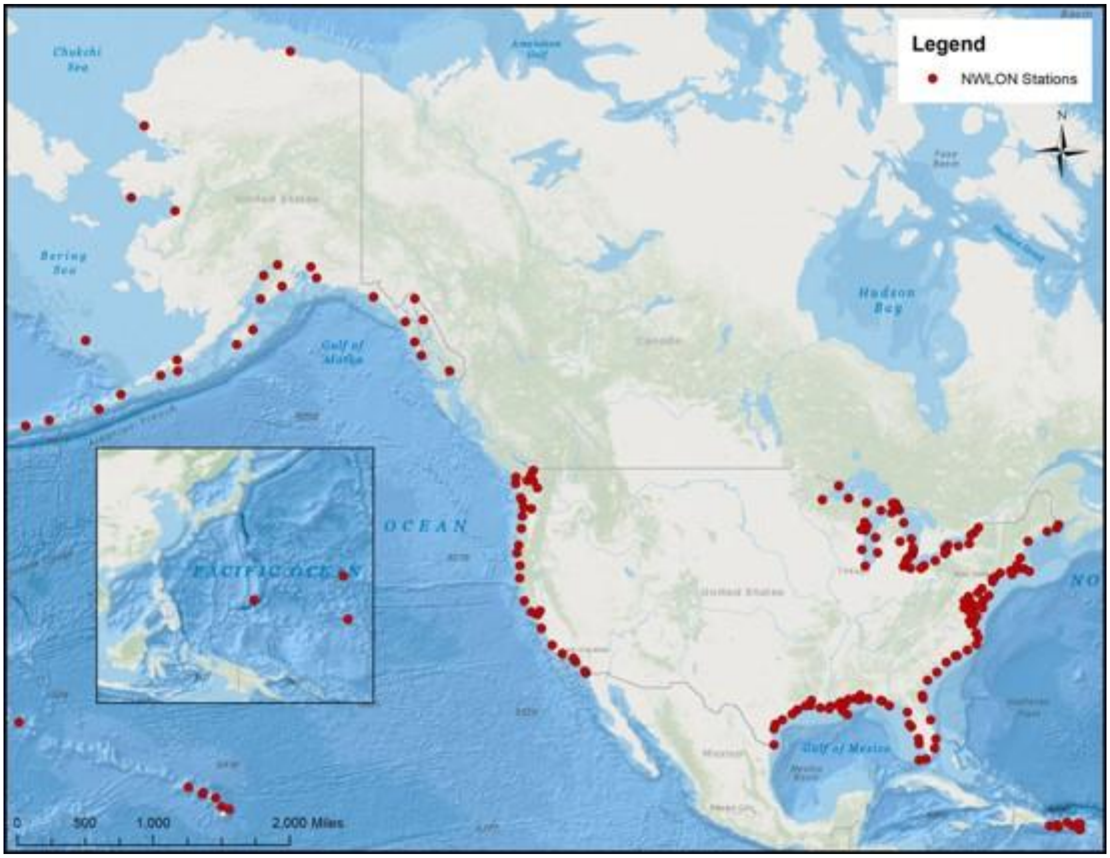

Figure 1. A map showing all operational National Water Level Observation Network (NWLON) stations.

CO-OPS uses water level measurements from the NWLON, the Physical Oceanographic Real-Time System (PORTS), partner stations, and other long- or short-term stations to meet its mission requirements as well as to support a variety of other purposes. Each of these applications vary in requirements, accuracies, and specifications; however, comprehensively, they provide the critical and actionable information mariners, emergency and ecosystem managers, coastal planners, and the public need for timely decision making.

This document defines the minimum requirements for operation of the NWLON. This network provides sustained observations to CO-OPS's core mission area as noted above. These observations are designed to meet the most rigorous standards and incorporate decades of scientific and engineering expertise and international best practices. Since NWLON requirements represent CO-OPS's most rigorous standards, data from the network supports the entire range of CO-OPS applications. However, a station installed primarily to meet another application, (e.g., a PORTS station, tsunami station, or short-term hydrographic station; OCS 2022) may not meet requirements for the NWLON.

The observing system requirements presented here represent what has been institutionalized at CO-OPS and generally followed over the past few decades, with a focus on the following components:

- data accuracy and uncertainty;
- station and data continuity;

- data collection, transmission, and access;
- documentation; and
- survivability.

Maximizing the quality of sustained water level observations while obtaining the highest accuracies needed across the entire NWLON are the 2 primary goals for defining and implementing these minimum requirements. Further, these requirements will enable CO-OPS to ensure that future changes to NWLON standards or operating procedures align with the requirements and maintain the accuracy, continuity, and quality of NWLON data.

This requirements document is an adaptation of an internal CO-OPS document originally written and accepted by CO-OPS leadership (the CO-OPS director and chief scientist) in 2018. Thus, the requirements documented here are consistent with the earlier version with some minor modifications. Though modifications or additions to these requirements may occur in the future, the expectation is the vast majority of these requirements are foundational and should largely remain unchanged.

NOAA REQUIREMENTS FRAMEWORK

CO-OPS manages the NWLON in accordance with NOAA Administrative Order (NAO) 212-16: Policy on NOAA Observing Systems Portfolio Management[3] with guidance from NOAA's Observing System Council (NOSC)[4]. The NOSC is a NOAA strategic council responsible for the management of NOAA's observing systems portfolio against rigorous standards. Its vision is to achieve and sustain an observing system portfolio that is mission-effective, integrated, adaptable, and affordable.

NOAA's guiding principles for managing observing systems are detailed in NAO 212-16, Section 4 which states that NOAA's observing systems portfolio should include the following characteristics:

- It is mission-effective, integrated, adaptable, and affordable.
- It provides superior performance, meeting or exceeding requirements for current and future missions.
- It is able to adapt quickly to a variety of measurement and data sources.
- It is cost effective and sustainable.
- It integrates with partners both within NOAA and beyond NOAA, including domestic and international partnerships, and integrates across observing system domains (atmosphere, ocean, space, land, and cryosphere).
- It ensures access to the global observations needed to generate accurate forecasts, warnings, and other services.
- It ensures that NOAA retains the in-house expertise necessary to support well-managed and integrated observing systems.
- The management system is efficient, transparent, and unbiased.

[3] NAO 212-16 can be found at: https://www.noaa.gov/organization/administration/nao-212-16-policy-on-noaa-observing-systems-portfolio-management
[4] NOSC website: https://nosc.noaa.gov/

NOAA observing system requirements take into consideration mission, user observation, business, functional, and supplemental operational, sensor, and budgetary concerns. Requirements are outcome-oriented, concise, actionable, customer-oriented, and within budgets to build, operate, maintain, and recapitalize.

CO-OPS has developed the requirements outlined here within this frame of reference. In general, the components of NOAA observing system requirements include:

1. *Mission Requirements* - NOAA responsibilities resulting from 1 or more requirements drivers. These should be understandable, outcome-oriented, concise, and actionable. These should identify the need but not prescribe specific solutions. For CO-OPS, the primary mandates are the Coast and Geodetic Survey Act of 1947[5] and the more recent Hydrographic Services Improvement Act Amendments of 2008.
2. *Business Requirements* - Describe why the organization is undertaking the project and state benefits that customers expect to receive from the products and services. These requirements describe the end-to-end pipeline from observation to quality-reviewed product and ensure end users are receiving products that meet their needs. CO-OPS has driven the establishment and evolution of the NWLON.
3. *User Observation Requirements* - System-independent, validated user needs of environmental parameters, with their associated attributes, required to produce specific products and services to meet mission objectives. These user requirements for many NOAA observational data sets, including CO-OPS water level observations, are documented via NOAA's Consolidated Observation User Requirements List (COURL)
4. *Observing System Requirements* - These are the building blocks used to develop and build the observing system. They often use "shall" statements that describe what the system "must" do. They are classified as either functional or supplemental. CO-OPS observing system requirements have been developed through the years and are captured in this living document.
5. *Sensor Requirements* - The technical specifications for a sensor attached to the observing system that are used to test, evaluate, and procure sensors that can meet User Observation and Observing System Requirements. CO-OPS conducts rigorous evaluation of potential sensors and draws on community expertise to identify appropriate sensors. Reports on the results of these evaluations are made publicly available on the CO-OPS Website[6].
6. *Observing System Budget Requirements* - Budget of a project to build, operate, maintain, and recapitalize an observing system. It is defined and reported annually through a standardized methodology tied directly into NOAA's financial management system. While CO-OPS meets this requirement, budget information is beyond the scope of this document.

This document defines the *Observing System Requirements* for the NWLON. In addition to ensuring these requirements build on the relevant Mission, Business, and User Observation Requirements, our NWLON observation system requirements align with standards defined by

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[5] 33 U.S.C. §883 et seq. (n1)

[6] CO-OPS Reports can be found at: https://tidesandcurrents.noaa.gov/pub.html

pertinent international organizations. The two primary organizations are the Global Sea Level Observing System (GLOSS)[7] , which is focused on the collection of water level measurements for climate studies, and the International Hydrographic Organization (IHO)[8], which ensures high-quality environmental observations to support maritime commerce.

NATIONAL WATER LEVEL OBSERVATION NETWORK

The NWLON provides the national standard for the collection of high-quality water level observations to fulfill the primary goals of calculating water level reference datums and sea level trends (Gill and Schultz 2000; Gill 2014; Miller and Luscher, 2019). Authoritative measurements by NWLON stations maintain the most strict data accuracy and continuity requirements and are able to legally support boundary determinations and international treaty adherence as well as long-term sea level and coastal resilience studies.

Each coastal NWLON station must provide continuous measurements for a minimum of 1 lunar-nodal tidal cycle of about 18.6 years (Parker 2007) to sufficiently capture tidal variability for the calculation of the 19-year National Tidal Datum Epoch (NTDE)[9]. As detailed below, this is a requirement of the NWLON, and though some more recent stations will have yet to reach this requirement, NWLON stations are installed with this intent. To make a robust determination of sea level change and to calculate and monitor a long-term trend requires relatively continuous water level observations over a period of approximately 30 years. (Zervas 2009). And though this is not a requirement, NWLON stations are typically operated for more than 30 years.

The NWLON stations are designed with an end-to-end system of data acquisition, data management, data quality control, and product delivery. The federally-funded NWLON enables NOAA to collect water level observations in specific mission-driven locations and to ensure that sufficiently long data records can be acquired and maintained (McLaughlin et al 2024). To maximize public benefits, NWLON observation platforms also support real-time data dissemination and the capability to add a suite of ancillary oceanographic and meteorological sensors, such as water temperature, salinity, wind speed and direction, and barometric pressure, among others.

The NWLON is defined by highly accurate and quality-controlled data; established vertical position and a stable vertical reference frame; connection to terrestrial datums; sound structure and design; and long-term continuous data records. These attributes differentiate the NWLON from other water level observations

Each NWLON station is:

- Robust: NWLON stations meet or exceed local building codes. Stations are designed and constructed to withstand local extremes including flooding, wind, precipitation, ice, and changes in air temperature, such that they provide oceanographic and meteorological observations before, during, and after such events.
- Reliable: NWLON stations are configured with redundant sensors, power supplies, and communication paths to ensure data availability and reliability. Near real-time data communications occur via automated acquisition over cellular and satellite networks (Geostationary Operational Environmental Satellite [GOES] or Iridium).

[7] GLOSS Website: https://gloss-sealevel.org/
[8] IHO Website: https://iho.int/
[9] See https://tidesandcurrents.noaa.gov/datum-updates/ntde/

Backup communication capabilities and on-site data storage ensure data is not lost due to primary transmission failures.

- Long-term: NWLON stations are designed, constructed, and maintained to operate over several decades. This sustained operational period is driven primarily by the need for continuous water level measurements over 19 years to support the development of authoritative tidal datums, and the need for a minimum of 30 to 40 years of water level observations to support the development of authoritative relative sea level trends.
- Serviceable: NWLON stations are designed for continual preventative maintenance to station components, which is significantly less expensive than periodic replacement of the entire station.

NWLON station structures and shelters vary from site to site to meet these requirements (see Figures 2-5). A typical coastal water level station is installed on an existing wharf or pier. Nearshore stations may be installed on a hurricane-hardened steel monopile or other similar structures. A typical location on the Great Lakes includes protection against extreme cold conditions and ice. CO-OPS has developed operations, maintenance, and recapitalization plans for NWLON stations in order to achieve a strong return on the taxpayers' investment and to assist in cost management and planning. These plans cover periodic maintenance, service life extension, reinstallation when a pier is rebuilt, and end of life replacement over the desired life span (20, 25, or 50 years) which varies by site and environmental conditions (Edwing et al. 2021).

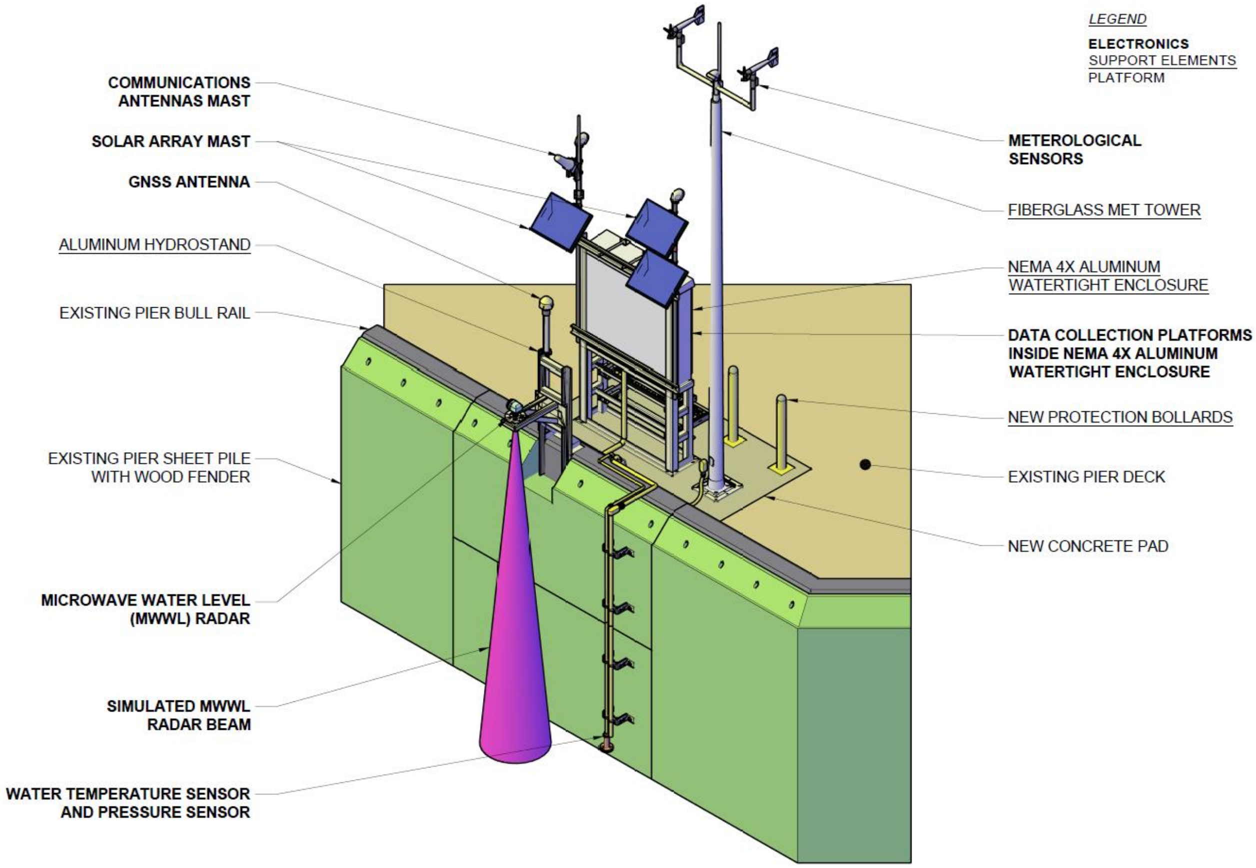

Figure 2. Typical coastal National Water Level Observation Network (NWLON) station configuration.

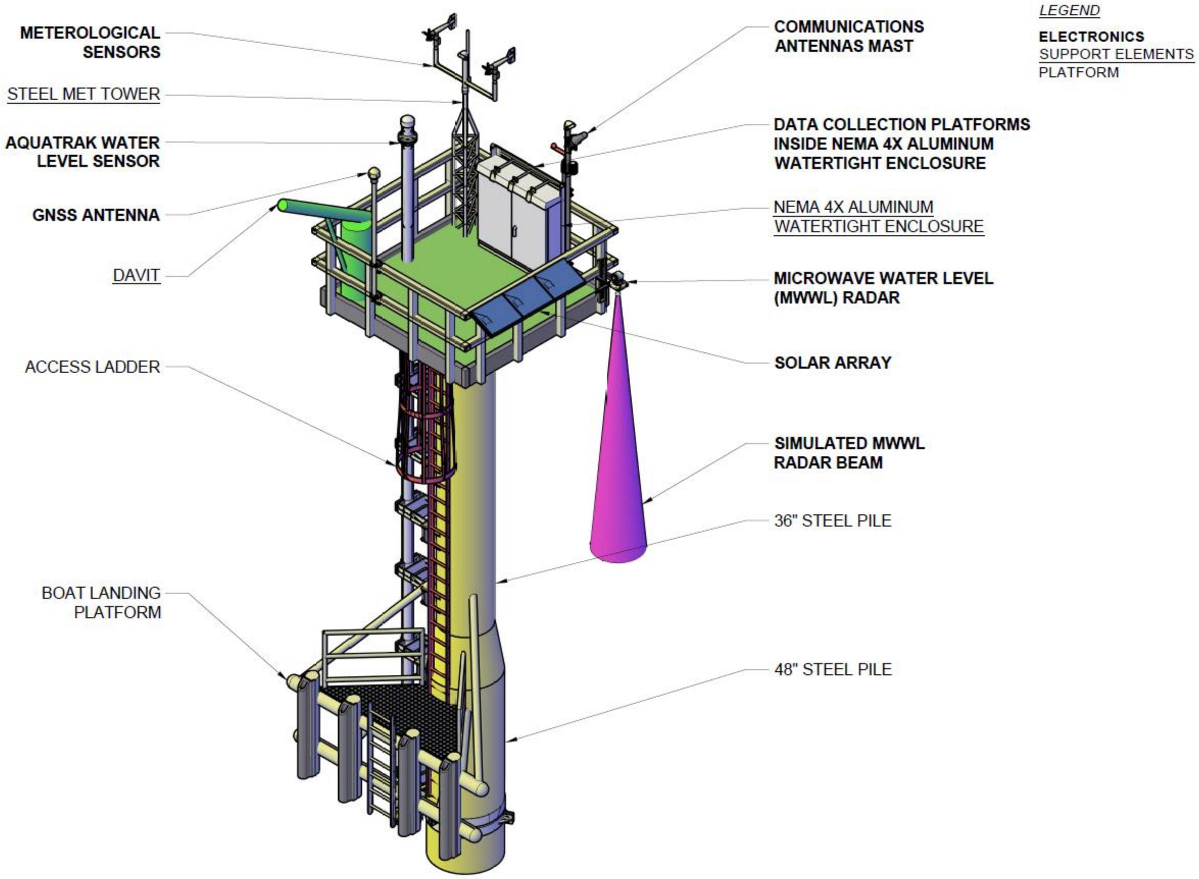

Figure 3. Typical nearshore National Water Level Observation Network (NWLON) station on a hurricane-hardened steel monopole.

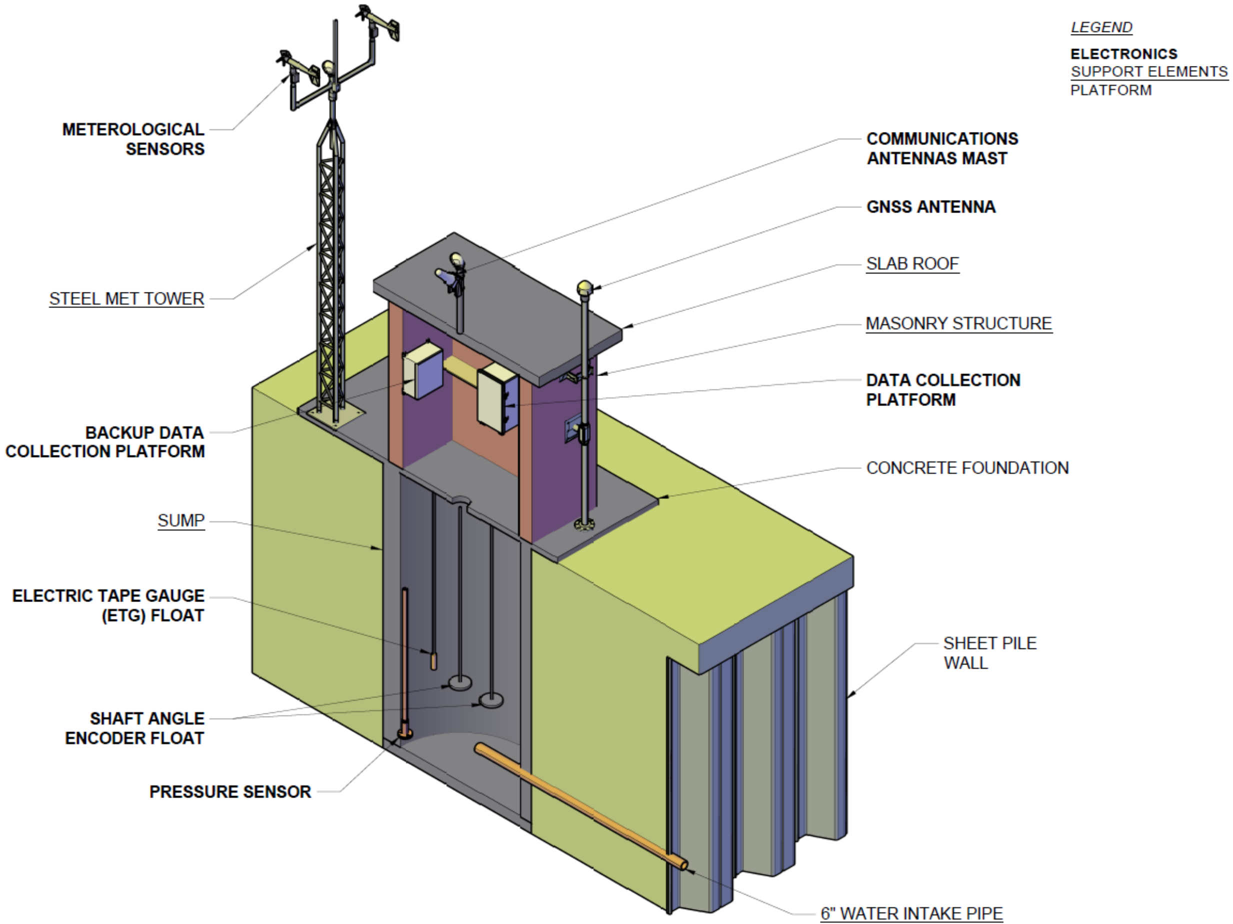

Figure 4. Typical Great Lakes gauge house and sump National Water Level Observation Network (NWLON) station

Figure 5. Examples of National Water Level Observation Network (NWLON) stations at Galveston Pier 21, TX (A); Apalachicola, FL (B); Great Lakes station with a stilling well at Holland, MI (C); Great Lakes station at Alexandria Bay, NY (D); Single Pile Instrumentation Platform (SPIP) station at Shell Beach, LA (E); and the station at Sandy Hook, NJ (F).

OBSERVING SYSTEM REQUIREMENTS

The documents listed at the end of each component are cited in the reference section of this report.

1. Data Accuracy and Uncertainty

1.1 The total error of 6-minute water level observations relative to a defined vertical datum must not exceed 5 cm (at 95% confidence) for stations with at least 19 years of data.

Total error is a combination of random error and systematic error and includes error from 4 components that must not exceed the following:

- Vertical position error - Sensor (random) - 1.2 cm
- Vertical position error - Reference System (systematic) - 0.9 cm
- Measurement error (random) - 0.9 cm
- Data Processing error (random) - 1 cm

The individual requirement for each of the 4 error components is detailed below. Random errors indicate a root mean square error (RMSE) over 19 years of data, and systematic errors indicate a mean bias over 19 years of data. A datum error is assumed 0 for a full 19-year time series but will be included as a systematic error dependent on the time series length and location if a station has less than 19 years of data. Wherever possible, known error sources for each sensor shall be documented and handled appropriately through ancillary measurements and/or correction algorithms.

1.1.1 Vertical position error - Sensor

Water level observations must be collected relative to a known vertical reference, called Station Datum. Vertical movement of the water level sensor relative to Station Datum must be measured regularly at an accuracy within 1.2 cm. Vertical control is the process of monitoring the vertical position of the water level sensor to ensure a continuously known vertical position relative to Station Datum. Vertical control must be assessed on a systematic basis and at installation, modification, and removal of the water level sensor. Station Datum must be tied to a nationally recognized reference frame (e.g., NGVD29, NAVD88, WGS84). If vertical motion exceeds 1.2 cm and the time of motion can be determined, the historic data are corrected accordingly (USCGS 1965; CO-OPS 2003; CO-OPS Hicks et al. 1987; NOS 1981; CO-OPS 2013; UNESCO 2016).

1.1.2 Vertical position error - Reference System

The vertical position of Station Datum must be defined relative to a vertical reference system to an accuracy within 0.9 cm over the NTDE. Vertical control for coastal stations over long time periods must be maintained to ensure accurate calculation of tidal datums over the NTDE (19+ years to cover the lunar nodal cycle) and to reduce the uncertainty of sea level trends (30+ years). The same accuracy and time frame requirements are also established for Great Lakes stations to minimize long-term observation bias. If a station's reference system deviates by more than 0.9 cm and the time of this change can be determined, the historic data is corrected accordingly (Hicks et al. 1987; CO-OPS 2014; CO-OPS 2013).

1.1.3 Measurement error

The instrumentation used for water level observations must be able to measure the true mean water level to an accuracy within 0.9 cm for each 6-minute observation. Measurement errors are a combination of inherent limitations of the sensor itself, sensor calibration errors, and errors resulting from the dynamic effects of waves, currents, and water density (CO-OPS 2003; CO-OPS 2013; CO-OPS 2014; CO-OPS 2023).

1.1.4 Data processing error

Regular automated and manual quality control must be conducted to ensure error introduced through the collection and processing of raw water level data is within 1.0 cm. Data spikes, bad data points, and missing data are several examples of how uncertainty can be increased for raw water level observations. A variety of regular automated (e.g., computer algorithms) and manual (e.g., monthly processor verification) quality control steps must be completed to ensure water level observations used for downstream products are as accurate as possible.

2. Station and Data Continuity

2.1 Stations must be continuously operated and maintained for a minimum of 19 years.

A primary goal of an NWLON installation is to achieve a continuous time series of a minimum 19 years to enable the calculation of datums for a full tidal epoch and to minimize datum error. This same requirement is held in the Great Lakes to support calculation of the International Great Lakes Datum (IGLD) and to enable long-term process studies. Stations operating for more than 30 years are used to calculate relative sea level trends. Gaps in the long-term data record should be minimized. For coastal stations, accurate datum and sea level trend calculations require minimizing the number of gaps greater than 3 days. For Great Lakes stations, gaps must be minimized to enable monthly mean and daily mean calculation.

2.2 All stations must have redundant data collection platforms (DCPs) and backup water level sensors.

A minimum of 2 DCPs and 2 water level sensors (a primary and a backup) must be operated to mitigate potential loss of data. The backup water level sensor must use a different measurement technology, and it must be of sufficient quality to be used for real-time data dissemination and to fill data gaps through processing and data verification.

2.3 New critical components must be assessed before implementation. A period of overlapping data must be collected before the system is declared operational if data quality or accuracy is potentially affected.

Critical components are station components which potentially affect data quality, accuracy, or continuity (examples include new sensors or DCPs). All new critical components must be tested prior to a system being declared operational. The significance of the component to data quality, accuracy, or continuity will dictate the level of testing required. Testing must include a time period of parallel operation of the replacement and existing components if data quality or accuracy is potentially affected. Any changes to data uncertainty introduced by new components shall be documented.

2.4 A station and its systems must be designed to minimize data loss and to ensure that the full range of water level is recorded during extreme events.

Storm conditions and associated extreme high and low water levels can be difficult to measure if a station is not designed appropriately. Stations must be designed with consideration to storm frequency and water level exceedance probabilities to ensure continuous and uninterrupted observation during the occurrence of extreme water levels. Other extreme environmental conditions (e.g., ice coverage) that might limit data collection must also be considered during station design (Schureman 1940).

3. Data Collection, Transmission, and Access

3.1 The standard sampling interval for water level observations shall be every 6 minutes.

A mean water level value must be calculated and recorded every 6 minutes to maintain consistency with historical data records and to ensure accurate representation of high and low tides.

3.2 Data must be stored locally in the DCP and be recoverable in order to fill data gaps.

Water level data must be able to be stored locally on the DCP for a minimum of 18 months, such that it can be manually retrieved if needed. This requirement will mitigate data loss caused by system, communication, or catastrophic failures and help ensure data continuity.

3.3 Data must be transmitted and disseminated in real-time with minimal latency, balancing technical capabilities and resource constraints. The maximum acceptable latency is 18 minutes.

Real-time data access supports quality control procedures and is critical for a range of user needs. Quality control of real-time data is necessary to reduce initial data errors and to ensure high-quality preliminary data. NWLON preliminary water level observations must be publicly accessible through the CO-OPS website within 18 minutes from the end of each 6-minute sampling period. This requirement acknowledges that CO-OPS will strive to reduce latency as much as feasible given technical and resource constraints.

4. Documentation

4.1 System metadata, installation and operation procedures, data processing algorithms, and data analysis procedures must be documented.

Details of a station including local conditions, pertinent metadata, and standard operating procedures (SOPs) shall be held to the same standards as the data itself. These are important when maintaining a continuous long-term data record and are essential for all aspects of station operation. All NWLON documentation including metadata and relevant SOPs must be stored, maintained, easily retrieved, and publicly accessible. These and related SOPs can be found in the CO-OPS Field Library[10].

5. Survivability

5.1 The station must continue to disseminate near real-time data throughout extreme events.

The station shall be designed, installed, and maintained to survive (i.e., meet the Station Functionality Requirement; see below) during extreme events which have a minimum mean recurrence interval (MRI) of 300 years (i.e., 300-year storms). This results in a predicted exceedance of 6% over a 19-year tidal epoch (6% of stations are predicted to fail the functional requirement during an extreme event over a 19-year period). While 300 years will be the default station design MRI, certain stations specified as "critical infrastructure" for emergency management or other purposes will have an elevated MRI (> 300-year storm). The design, installation, and maintenance of the station shall comply with applicable building codes and environmental regulations.

5.2 Station Functionality Requirement:

To continuously collect, store, transmit, and disseminate near real-time data, including during extreme events (as defined above).

[10] https://tidesandcurrents.noaa.gov/fieldlibrary/Welcome

CONCLUSION

This set of observing system requirements represents the minimum standard station criteria for a water level station to be a part of the NWLON. The goal of this document is to ensure long-term, continuous, and accurate water level measurements for existing stations in the network and that new stations are installed to meet these requirements. This document can also be used as a resource for other programs that wish to collect water level data to the standards of the NWLON. Though only high level information is included here, readers are encouraged to review the references for additional detail and for best practices to meet these requirements.

This is a living document. As new needs for the NWLON are identified and as new technologies emerge, this document will be updated regularly to capture updated requirements and updates to station design based on them. Examples may include documenting additional measurement type requirements such as meteorological measurements, updating data accuracy needs based on new uses for the data, updating vertical position error based on updates to the vertical reference system and updated survivability requirements based on changes to engineering standards.

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APPENDIX. GLOSSARY OF TERMS

Data Collection Platform (DCP)

A comprehensive system designed to monitor, collect, and transmit environmental data in real-time from various marine and coastal locations. These platforms typically consist of data loggers, sensors, and instruments configured for the collection of water level and meteorological data.The data is collected, processed, and transmitted (via satellite or cellular modem) in near-real-time. Data is also stored (via flash memory) for remote download via cellular, direct connection via laptop, physical retrieval.

International Great Lakes Datum (IGLD)

IGLD is the vertical height reference datum used in the Great Lakes/St. Lawrence River System for engineering, charting, channel dredging, navigation safety, power generation, and water resource management. It is a coordinated datum between the United States and Canada that ensures both countries are using the same reference for projects in the Great Lakes basin.

National Geodetic Vertical Datum of 1929 (NGVD29)

The NGVD29 is a vertical control datum in the United States. It was established in 1929 by holding mean sea level fixed at the sites of 26 tide gauges—21 in the United States and 5 in Canada. The datum is defined by the observed heights of mean sea level at the 26 tide gauges and by the set of elevations of all benchmarks resulting from the adjustment. A total of 106,724 kilometers of leveling was involved, constituting 246 closed circuits and 25 circuits at sea level**.**

National Tidal Datum Epoch (NTDE)

The specific 19-year period adopted by the National Ocean Service as the official time segment over which tide observations are taken and reduced to obtain mean values (e.g., mean lower low water) for tidal datums. It is necessary for standardization because of periodic and apparent secular trends in sea level. The present NTDE is from 1983 through 2001. It is reviewed annually for possible revision and must be actively considered for revision every 25 years.

NOAA Observing System Council (NOSC)

The NOSC serves as the principal advisory body to NOAA leadership and focal point for the agency's observing system activities. The purposes of the Council include coordinating observational and data management activities across NOAA; proposing priorities and investment strategies for observation related initiatives; and identifying programs that might benefit most from integration of observing assets. (https://nosc.noaa.gov/)

North American Vertical Datum of 1988 (NAVD 88)

The NAVD 88 is the vertical control datum established in 1991 by the minimum-constraint adjustment of the Canadian-Mexican-United States leveling observations. The height of the primary tidal benchmark is referenced to the new International Great Lakes Datum of 1985 local mean sea level height value, at Father Point/Rimouski, Quebec, Canada. In 1993 NAVD 88 was affirmed as the official vertical datum in the National Spatial Reference System (NSRS) for the conterminous United States and Alaska.

Physical Oceanographic Real Time System (PORTS®)

PORTS® collects and disseminates observations of water levels, currents, salinity, bridge air gaps, and meteorological parameters (e.g., winds, atmospheric pressure, air and water temperatures) that mariners need to navigate safely. The objectives of the PORTS® program are to promote navigation safety, improve the efficiency of U.S. ports and harbors, and ensure the protection of coastal marine resources. (https://tidesandcurrents.noaa.gov/ports_info.html)

Station Datum

A permanent base elevation at a tide station to which all water level measurements are referred. The datum is unique to each station and is established at a lower elevation than the water is ever expected to reach. It is referenced to the primary benchmark at the station and is held constant regardless of changes to the water level gauge or tide staff.

World Geodetic System (WGS84)

The WGS84 is a 3-dimensional coordinate reference frame for establishing latitude, longitude and heights for the practical applications of mapping, charting, geopositioning, and navigation.