Establishing a High-Precision Tide Station in the Great Bay Estuary

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Introduction

Monitoring water levels in coastal systems is vital to understanding current and future impacts to the Great Bay Estuary and its surrounding watershed. Impacts from rapidly rising seas have already been observed in Great Bay and are predicted to exacerbate over time. Sea-level-rise has impacted natural ecosystems as well as human communities. One example of rapid predicted change is to the plants and animals inhabiting tidal marshes, with flood-sensitive plant species dying off and a declining population of the saltmarsh sparrow, which nests directly in the marsh. Direct human impacts have also been observed in surrounding coastal towns, with greater nuisance tidal flooding threatening homes and public infrastructure. Finally, changing tidal hydrology has impacts to water quality (nutrient, total suspended sediment, and emerging contaminants [e.g., microplastic, PFAS]) that affect both natural communities (e.g., filter feeding organisms, seagrasses, macroalgae) and human health and economy.

Establishing a high-precision tide station in Great Bay fills a much-needed spatial gap of tide data in the region which enhances our monitoring and research capabilities. As noted in Great Bay’s Vertical Control & Progress Report of 2011, “highly accurate measurement of sea-level is crucial to assessing and modeling impacts of coastal climate change.” The determination of accurate local tidal datums, or reference elevations for different tidal stages such as mean sea level (MSL), mean higher-high water (MHHW), and mean lower-low water (MLLW) is critical for improving navigation safety, designing stormwater and other coastal infrastructure, and managing natural resources such as salt marshes that depend upon narrow ranges of salt water inundation. There are no active long or short-term tide stations within Great Bay. The closest tide stations are operated by the National Oceanic and Atmospheric Organization (NOAA), which has a network of long and short-term tide stations around the country. The closest long-term National Water Level Observation Network (NWلون) stations are located over 70 km away in Portland, ME and Boston, MA. Short-term tide stations are geographically closer located near the mouth of the Great Bay Estuary (Fort Point and Seavey Island), but still remain over 15 km away from the middle of Great Bay by tidal distance, which experience distinctly different water levels. Historically, there were four tide stations located in the Great Bay Estuary, but were only active for less than five months back in 1975.

Methods

A high-precision and frequency tide station was installed at the southern end of Great Bay from 2017 to 2019. Tides were measured with a vented pressure sensor tied into a single orifice gas purged bubble system set to transmit data via satellite telemetry which is one of the primary sensors used for NOAA’s Center for Operational Oceanographic Products and Services (CO-OPS) water level stations around the country. Specific models include: Paroscientific digiquartz precision gauge pressure transmitter, YSI WaterLOG H-3551 Smart-Gas Bubbler System, Sutron g3 Hydrographic gauge. The tide station was located at the mouth of the Squamscott River, attached to a series of unused railroad pilings, just off the main channel in subtidal waters (Figure 1). Using construction timber, railroad pilings were stabilized, and a vertical mast and platform were constructed to help install and maintain the station (Figure 2a-d).

Figure 1 – Great Bay Estuary including the location of Great Bay National Estuarine Research Reserve’s tide and weather stations and the nearest active NOAA CO-OPS tide station (Fort Point).
The location of the tide station at the mouth of the Squamscott River was chosen because it was co-located with a short-term historic tide station in 1975 with associated benchmarks and infrastructure to more easily attach a new station to, and filled a spatial data gap (nearest tide station is located in the north, >15 km away) that would inform specific restoration projects and development planning for local engineers. Additionally, the location contains an active long-term System-wide Monitoring Program (SWMP) water quality station (GRBSQ) on a nearby piling 30 m north of the tide station, allowing comparison of water levels and pairing of physical and chemical parameters. A long-term SWMP weather station is also located in the southern portion of the Bay, 6.5 km to the east on the edge of the Bay, allowing for QA/QC with meteorological parameters and correction of the non-vented SWMP data sonde (YSI exo 2).

GBNERR enhanced an existing vertical control network at the tide station by installing new benchmarks in 2018. Three existing benchmarks are located along the railroad track in the form of survey disks in granite blocks (Figure 3a), while three deep rod benchmarks were installed in the adjacent marsh to the east and west using steel rods driven “to refusal”, topped by survey disks and ~0.6 m of concrete (Figure 3b). Elevations of newly installed benchmarks were obtained using static GPS surveys (6-8 hrs) with an RTK GPS and tied into the North American Vertical Datum of 1988 (NAVD88; Figure 4). A bolt installed

Figure 2 – Photos of the a) tide and SWMP station, including the b) tide station instrument housing, c) YSI gas bubbler-system, and the d) single orifice leading to subtidal waters.

Figure 3 – Examples of benchmarks used to establish vertical control for the tide station for a) existing and b) newly installed survey disks.
on the tide station platform, adjacent to the single bubbler conduit pipe and above the high-water elevation, was then leveled into all these benchmarks using a digital level, with equidistant forward and back shots (<70m). The vertical distance of the bolt was measured to the reference of the tide station (orifice opening) to tie water levels into NAVD88 (m) based on the elevation at the primary tidal benchmark. The resulting orifice elevation is -1.758 NAVD88 (m), based off the bolt elevation of 1.541 NAVD88 (m), which is 3.299 (m) above the orifice.

**Results and Discussion**

The tide station collected water levels from 2017-2019 in 6-minute intervals, stored on a local data logger, and transmitted via satellite to NOAA CO-OPS, allowing for desktop monitoring of real-time and past data. Data were collected in 2017 from Oct 24th to Dec 7th, in 2018 from Apr 18th to Nov 28th, and in 2019 from Apr 26th to Oct 12th (Figure 5). No data were collected in the winter because of the potential of ice damage. A complete list of maintenance and data disruptions is found in Table 1.

Tidal datums were calculated with data from 2017, 2018, and 2019 using NOAA CO-OPS tidal analysis datum calculator tool (https://access.co-ops.nos.noaa.gov/datumcalc/). Data were first QA/QCed before processing, which included identifying suspect data and removing or correcting it. Data from April 12th to April 25th 2018 were removed because of an air leak causing erroneous measurements. Other suspect data occurred when the raw data suddenly jumps to “0” out of sequence for a single six-minute record. This occurred at what appears to be random and sporadic times for about a dozen separate events, and were clearly erroneous because “0” represents the height of the orifice, which is always submerged and deployed. We interpreted these as No Data values and attributed them to data drops from the system. Other than these suspect points, the lowest recorded raw datum was 0.221m above the orifice. These erroneous zeros as well as known data gaps (Table 1) that were less than three hours in duration were interpolated using a best fit spline. Data were then converted to NAVD88 (m) and formatted to specification of CO-OPS’s web-based datum calculator. Tidal datums were calculated using the datum calculator for four separate data blocks (2017, 2018a, 2018b, 2019; Figure 5) per guidelines for data gaps of greater than three hours.

![Figure 4- Map of the survey plan including the locations of the tide station, benchmarks, and survey instrument locations.](image)

<table>
<thead>
<tr>
<th>Date</th>
<th>Action</th>
</tr>
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<tr>
<td>10/24/17</td>
<td>Installed/recording</td>
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<td>04/18/18</td>
<td>Re-installed/recording</td>
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<td>05/10/18</td>
<td>Offline 1-hour, inline fuse to gas bubbler</td>
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<tr>
<td>08/16/18</td>
<td>Offline 7 days, inline fuse to datalogger</td>
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<td>11/28/18</td>
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<tr>
<td>04/12/19</td>
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<tr>
<td>04/25/19</td>
<td>Air leak fixed; accurate measurements</td>
</tr>
<tr>
<td>10/12/19</td>
<td>End record: permanently removed</td>
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</table>

*Table 1 - Tide station maintenance & troubleshooting log. Note, times are listed in UTC.*

Note, 2018 data were split into two data blocks because a gap of seven days occurred in August from problems with an inline fuse. The nearest NOAA station active during 2017-2019 (Fort Point in NH station ID #8423898) was used as a control station for all calculations, thus tying the Great Bay water levels to the current National Tidal Datum Epoch (NTDE83-01). Calculated tidal datums for each data block were then averaged together to produce mean tidal datums across (Table 2), which can be informative to tidal marsh species ranges and restoration (Figure 6). Tidal lags from the Fort Point station were calculated by averaging the time offset of both low and high tides (n = 828 each) across 2017-2019.
Figure 5 – Full tidal station data record relative to NAVD88 (m) for Great Bay showing data gaps (> 3 hours). In 2018, data were treated as two separate blocks (a, b) for the calculation of tidal datums.

Table 2 – Calculated tidal datums referenced to NAVD88 (m) for the Great Bay tide station and the nearest NOAA CO-OPs station (Fort Point, NH). MHHW = mean higher-high water, MHW = mean high water, DTL = mean diurnal tide level, MTL = mean tide level, MSL = mean sea level, MLW = mean low water, MLLW = mean lower-low water, DHQ = mean diurnal high water inequality, DLQ = mean diurnal low water inequality, GT = great diurnal range, MN = mean range of tide.

In general, tides at the southern end of Great Bay show a similar, but lagged and muted signal relative to the tides at the mouth of the Estuary at Fort Point (Figure 7). As such, Great Bay high tide datums (MHW, MHHW) are delayed by 2:19:37 and are 0.28 m lower than Fort Point. Great Bay low tide datums (MLW, MLLW) are delayed by 2:38:16 and are 0.30 m higher than Fort Point. In contrast, mean tide datums (MTL, MSL, DTL) are very similar between the two tide stations only deviating by 0.01 m or less. During the deployment of the Great Bay station, the Max Tide (MT) was 1.749 m, compared to 2.207 m for Fort Point. This similar but lagged and muted relationship between tides in Great Bay and at the coast are expected because Great Bay is a highly recessed Estuary with a relatively narrow hydrologic pathway via the Piscataqua River, connecting it to the ocean.
Data from the temporary tide station at Great Bay help fill a much-needed regional data gap, but still fall short in providing a long-term record. The tide station in Great Bay was deployed across three years with a discontinuous record. A longer-term record in Great Bay would further aid in research and management of natural and human communities by providing the most accurate and most predictive data. Most NOAA CO-OPs stations have multiple decades of continuous data to account for temporal variability associated with weather patterns and the moon’s orbit. Longer-term NWLON stations have a much longer continuous record, spanning around a century. Future planning may consider extending the data record in Great Bay by re-establishing another high-precision tide station. However, high precision tide stations are expensive and the deployment/maintenance is technical. There are less expensive and easier to use water level loggers (e.g., Hobo U20 pressure logger, YSI Exo pressure sensor), however the accuracy and reliability of these cost-effective instruments should be further investigated.

Figure 6 – Tidal marsh ecotone boundaries with approximate corresponding locations of Great Bay tidal datums. Graphics by Rachel Stevens.

Figure 7 – One-month tidal record in May 2018 for Great Bay (orange) and Fort Point (blue). The dashed light blue line represents Mean Higher High Water (MHHW).
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