NOAA's Tides & Currents Program

Planning before planting

Tools for habitat restoration and sound coastal management practices

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NOAA's Center for Operational Oceanographic Products and Services (CO-OPS) operates a network of 200 long-term water level stations on all U.S. coasts, called the National Water Level Observation Network (NWLON) (see map). Continuous water level observations of several decades have been recorded on stations in the network, including over 150 years at the longest continuously operating tide station in San Francisco. This network is augmented by hundreds of historic and currently operational short-term water level stations utilized for a variety of coastal applications, including tidal correction for hydrographic and photogrammetric surveys and shoreline delineation, creating a robust and valuable database of national water level data covering the past two hundred years. While CO-OPS and its predecessors have historically supported navigation and mapping through water level observation, growing concern for coastal issues such as the ecological effects of climate change and sea level rise, vulnerability to storm surge and inundation, and conservation and restoration of wetland habitats has led to this information being applied in new ways. In 2002, CO-OPS developed the Coastal Oceanographic Applications and Services of Tides And Lakes (COASTAL) Program to address these non-navigational applications, in particular habitat restoration. Since then, COASTAL has expanded to successfully partner with a wide variety of federal, state, and local agencies and academic institutions on projects ranging from restoration to emergency management and coastal hazard mitigation.

The National Water Level Observation Network is comprised of 200 long-term tide and water level stations on all U.S. coasts.

Measuring the water's edge

While the measurement of water levels might seem straightforward, simply measuring the depth of the water using a sensor located at an arbitrary point in space is no longer sufficient for most applications, particularly engineering or restoration, which require high levels of precision in determining land and water elevation.

All water level stations operated and maintained by CO-OPS are tied through differential leveling to a network of vertically stable bench marks, typically a combination of surface and deep rod marks within a one kilometer radius. Annual levels are run to the bench marks to ensure vertical stability of the station and the marks. These bench marks allow for a point of vertical reference into the future from which tidal datums can be recovered, should the station be destroyed or removed.

For marine applications, datums are defined as a base elevation. Datums are used as a reference from which to reckon heights or

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depths; they are called tidal datums when defined in terms of a certain phase of the tide.

Tidal datums, which are local datums, are computed based on water level measurements over a 19-year period, or, the National Tidal Datum Epoch (NTDE). NOAA updates the NTDE approximately every 25 years to account for changes in sea level. The first NTDE utilized observations from 1941-1959, followed by 1960-78; the current NTDE comprises observations made in 1983-2001. Prior to the 1941-1959 Epoch there was no systematic approach for utilizing tidal datum elevations from a common epoch system-wide, even though 19-year datum computations were done.

Maintaining accurate tidal datums is important for understanding tidal variations, but the datums provide only part of the information necessary to characterize the water's edge. One needs to know what the relationship between land and water elevations is at this "edge" to design and implement sustainable coastal structures, be they buildings, levees, sea walls, or created marshes. To make the connection between the land and water, connections should also be made between tidal and geodetic datums (e.g. North American Vertical Datum of 1988 (NAVD88).

Whenever possible, connections are made between tidal bench marks and geodetic bench marks, or geodetic marks may be used as tidal bench marks. These connections can be made either through differential leveling or GPS, depending on the accuracy required, or physical constraints of the project site (such as great distance or other impediments to leveling).

An additional connection should then be made to other important features within the project site. For instance, if a marsh is to be created from a diked field, tidal datums need to be computed, but ties must also be made to the surface of the marsh as well as adjacent commercial and residential properties, or levees and other flood protection structures.

It is also often important to establish land and water elevation relationships with near-shore shallow water bathymetry for input into local wave models and storm surge and other inundation models. Only then can the impact of the project be truly understood, and a sustainable design developed.

It should be noted, however, that single connections between the water and land are insufficient over time. Between horizontal and vertical crustal motion, which varies regionally and is not entirely predictable, and the changes of water level over time, through both natural variations and long-term trends associated with climate change, the intersection between the water's surface and the shore is dynamic.

Relative sea level trends can be determined using observations at NWLON stations. However, to capture absolute sea level changes, trends in land-based motion must be removed. These signals can be de-coupled through observations collected at continuously operating GPS stations (Continuously Operating Reference Stations (CORS); http://geodesy.noaa.gov/CORS/cors-data.html) maintained by NOAA's National Geodetic Survey. Efforts are underway to co-locate CORS with NWLON in order to provide this valuable information.

In areas such as the Gulf of Mexico, which are experiencing absolute sea level rise as well as regional and local land subsidence, relative sea level trends are compounded, with rates of greater than 10 mm/year in some locations. Conversely, in areas of the Pacific Northwest and southern Alaska, which are currently experiencing changes in land-based heights due to isostatic glacial rebound, these trends, coupled with absolute sea level changes result in negative relative sea level trends, or an apparent sea level decrease.

It is important to understand the components of sea level rise, although from a design and implementation perspective, observed changes in long-term sea level relative to the land and to a particular project site or feature, are

Figure 1. Observations from a short-term tide station, such as McCready's Creek, Maryland (top) can be compared with observations from a long-term tide station, such as Solomons Island, Maryland (bottom) to interpolate long-term sea level trends.

more important.

Water level observation

Operation of a long-term water level station can be costly, albeit an important component of establishing long-term water level trends, critical for assessing and forecasting the impacts of sea level rise, and in planning for changes in sea level in coastal design and implementation practices. Observing water levels over a short period of time degrades ones ability to account for short and long-period fluctuations in water level caused by hydrologic, oceanographic, and meteorological variations, thereby introducing error in associated calculations or project design.

However, depending on the scope and time frame of a particular coastal project, such as a small-scale habitat restoration project, it may not be economical to operate and maintain a water level station several years beyond the life of the project. In those cases, it is possible to utilize a process commonly used by NOAA's National Ocean Service for short-term projects, such as designing a restoration project or applying tidal correctors to hydrographic survey soundings, involving the simultaneous comparison of water levels at the short-term station to the long-term control station.

By utilizing the appropriate datum computation method for the geographic region and type of tide, a relationship between time and ranges of tide are established, and applied to accepted datums at the control station to compute equivalent 19-year tidal datums at the short-term tide station.

The accuracy of this method varies both regionally and based on the length of observation at the short-term station. To be effective, at least one month of data should be collected, in order to capture as many full periods of daily, monthly, seasonal, and annual variations as possible.

Areas with higher hydrodynamic and meteorological influence on local water levels will require longer periods of observation than deep water locations with primarily astronomically-driven variations in water level in order to reduce the uncertainty in the datum elevations. Utilizing a short-term water level station to aid in the design of a coastal project can be quite effective, as long as the additional step of making a simultaneous comparison to a long-term station is taken (Figure 1).

Tools and products

Once water levels have been collected and tidal datums computed, a series of short and long-term water level analysis can be conducted. This analysis can help better define the relationship between water levels and the coast both at the present time and into the future.

Frequency and duration of inundation analysis is useful for a number of coastal applications. The dimensions of frequency, height, and duration of high waters are all required for most applications. Knowing the inundation trends at a given site, coupled with tidal datums and knowledge of historic extreme water level events, will facilitate better design of habitat restoration projects, and help coastal managers anticipate the impact of storm events over time (Figure 2).

Assessing the seasonal variability in water level heights can also play an important role in restoration design, as well as planning field activities, such as volunteer marsh grass planting events. Finally, understanding long-term relative sea level trends and the extremes both regionally, and at a particular site, is very important for sustainable design (Figure 3).

Biological analysis can also be coupled with physical oceanographic and hydrologic information to enhance restoration design and implementation. Coupling known habitat ranges (relative to tidal datums) with tidal datum information at a project site and accurate land elevations, one can determine where to plant particular marsh grass species in a created or restored marsh to ensure sustainability over time, and decrease the potential for impact by invasive plant species (Figure 4).

Restoration projects that fail often do so because of poorly understood (or

Figure 2. Monitoring water level relative to the height of major evacuation routes can help emergency managers issue timely evacuation orders before a storm makes landfall.

Figure 3. Water level at any given location varies over time. Defining this relationship, relative to land-based features, is important.

incorporated) elevations, both in land and water, and the associated impacts on vegetation. Slight errors in the calculation of tidal datums and land elevations, can result in major design flaws, resulting in failing marshes, or flooding issues, and have a detrimental impact on a natural ecosystem, as well as manmade structures and coastal populations. Measuring and accounting for this information early, to incorporate it in the design phase of restoration or coastal engineering efforts will exponentially increase the potential for success over time.

Conclusions

The land-water interface is complex and ever-changing. To correctly and comprehensively plan for any coastal project, consideration must be given both to the vertical and horizontal relationships between land and water, and to the ways in which those relationships vary spatially and temporally. NOAA provides tools to leverage continuous measurement systems, such as the NWLON and CORS networks, and the products derived from these observations, for coastal applications such as restoration and coastal resource management. NOAA has also been developing tools that integrate water level, topographic, and bathymetric information to produce baseline digital elevation surfaces that can be used in Digital Elevation Models and GIS layers. Knowing that these tools exist, and how to access the information, allows for more efficient coastal planning and design. Accurately defining and understanding the land–water interface is a fundamental component of sound decision making and sustainability into the future.

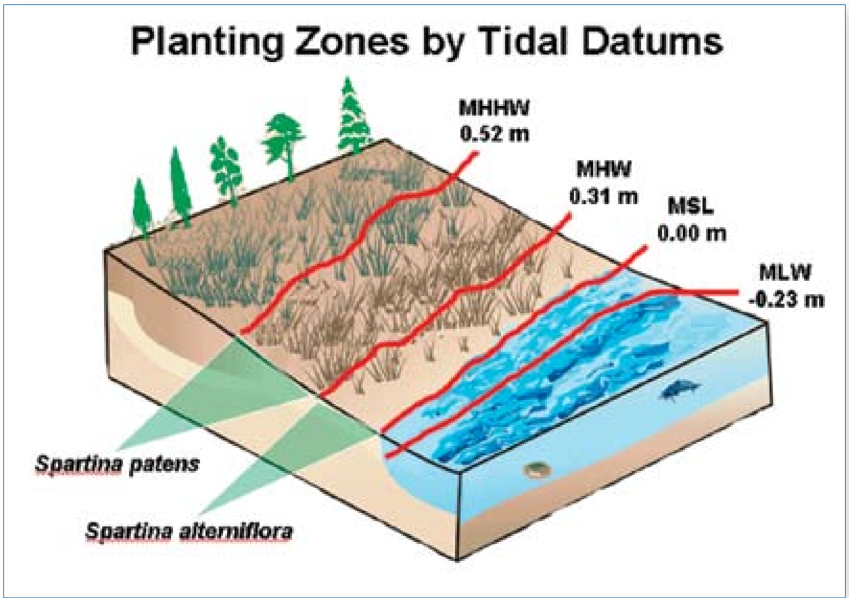

Figure 4. Relationships between tolerances of marsh vegetation species to inundation can be used to correlate habitat ranges with tidal datums. This information can be married on a digital elevation model for a comprehensive understanding of the ecosystem.

References

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