

Planning for Sea Level Rise and Coastal Flooding

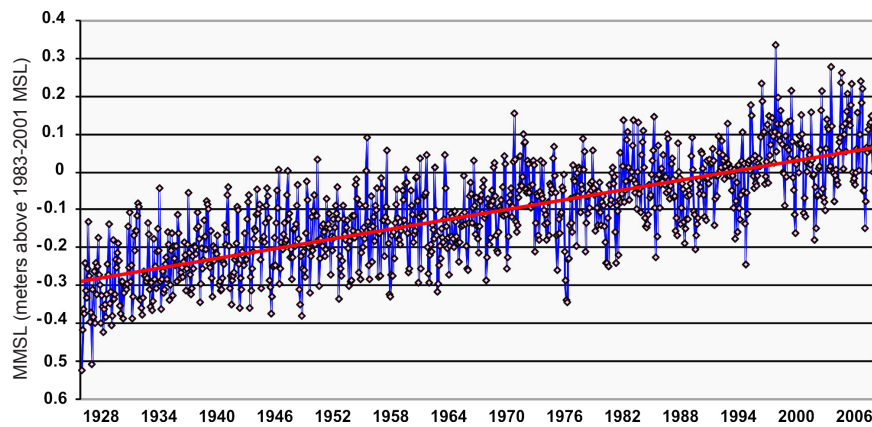
Evidence for Sea Level Rise

A consensus of scientific opinion reported by the Intergovernmental Panel on Climate Change (IPCC) holds that global average sea level rose at an average rate of 1.8 mm per year (0.59 feet per century) from 1961 to 2003, and may have risen up to 3.1 mm per year (1.02 feet per century) from 1993 to 2003.¹ Local sea level rise averages 3.6 to 7.0 mm per year (1.18 to 2.30 feet per century) in Virginia's lower Chesapeake Bay region and between 3.1 and 3.5 mm per year (1.02 and 1.15 feet per century) in Maryland's mid-to-upper Chesapeake Bay region.²

Global and local sea level trends differ because the former are derived mostly through studies of the change in volume of the world's oceans while the latter are based on long-term water-level measurements relative to the land at fixed locations. Just as water levels rise and fall, the earth's crust in many regions also moves up or down, adding or subtracting from the apparent sea level trend. In Scandinavia, where glacial ice has been removed since the last ice age, crustal "rebound" has resulted in falling relative sea level trends. More often, coastal subsidence due to a number of causes, including ground-water removal, adds to global rise rates to produce positive trends. This is the case along the U.S. East Coast in general and Virginia in particular.

Ocean volume changes with varying river inflows, evaporation, and rainfall and, most importantly amid climate change, added water from melting ice (Antarctica and Greenland ice sheets and glaciers). Ocean volume will also increase through thermal expansion as the ocean warms,³ raising sea level even further.

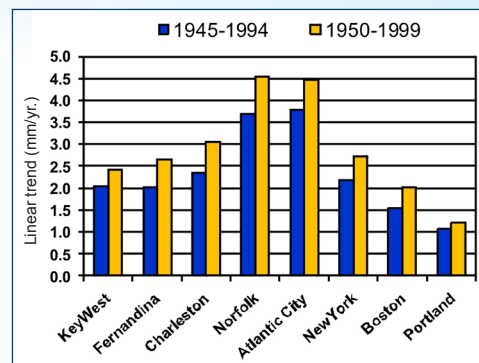
Measured sea level trends provide the parameter most important to governments and agencies concerned with coastal erosion and flooding in the next few decades: local sea level rise relative to the land we live on.⁴ For the Virginia portion of Chesapeake Bay, four water level stations have records longer than 50 years and three others have suit-



Monthly mean sea level and sea level trend (red line) at Sewells Point, VA. For the years 1928 through 2007, the trend is +4.43 mm/year (+1.45 ft/century).

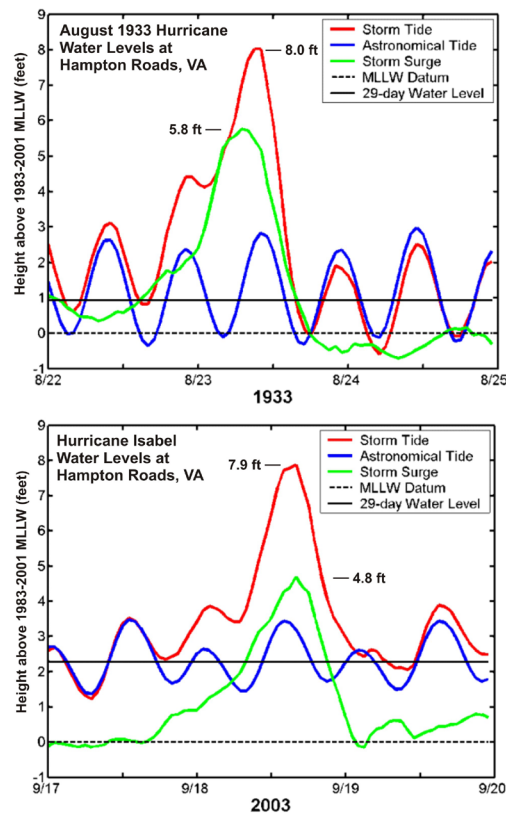
Science & Solutions

- Hurricanes or "northeasters" that have not caused significant flooding of homes and property in the past will begin to do so in the future because of sea level rise.
- Long-term sea level rise will permeate all levels of Virginia's resources, including transportation, infrastructure, military installations, marine ecosystems, agriculture, human health, and recreation.
- With the advance of technology, real-time observations coupled with model predictions can be of great value beginning about 48 hours before predicted landfall.
- Due to the sensitivity of water levels to changes in wind speed and direction, observations and short-term forecasts of the Chesapeake Bay wind field are critical for accurate prediction of coastal flooding.
- Further research is needed to develop and refine storm-tide projections with a given probability of occurrence per month and year in Chesapeake Bay. These projections can be used to estimate the design life of coastal development projects.



Relative sea level trends for two 50-year periods, 1945-1994 and 1950-1999, at eight cities along the U.S. East Coast from Florida to Maine. Data from Zervas, 2001.

Whereas tidal predictions have long been essential to the mariner concerned with safe navigation, waterfront property owners have little reason to be concerned until water levels exceed the vertical limits of the astronomical tide and become “extratidal.”



Comparison of hurricane storm surge, storm tide at Sewells Point, Hampton Roads, VA, in feet above 1983-2001 Mean Lower Low Water (MLLW).



Northeaster of October 7, 2006, Gloucester Point, VA. Photo courtesy of Dr. David Forrest.

able records longer than 30 years. From the evidence these stations provide, local rise rates are expected to be nearly twice the global rate, or about 4 mm per year, and may prove to be as high as 5 to 7 mm per year. This equates to up to one foot (0.3 m) of sea level rise, relative to the land, by 2050.

Consequences of Sea Level Rise

The impact of sea level rise on coastal flooding is amply demonstrated by comparing Hurricane Isabel of 2003 with another major storm: the hurricane of August 1933, widely regarded as the “storm of the century” for Hampton Roads. The 1933 hurricane was more powerful than Isabel and produced a storm surge (rise in water level due to the effects of the storm) of 1.8 m (5.8 feet) as compared to 1.5 m (4.8 feet) for Hurricane Isabel in Hampton Roads. Yet the maximum water level or storm tide (sum of the storm surge and the astronomical tide) for both storms was about the same: 2.4 m (8.0 feet) for the 1933 hurricane and 2.4 m (7.9 feet) for Isabel.⁵ The reason the weaker of the two storms produced an equivalent storm tide is that monthly mean sea level during Isabel stood about 0.43 m (1.4 feet) higher than the monthly mean during the August 1933 hurricane. Most of the difference is due to sea level rise during the 70 years between these two storms.

Contingency Planning: Storm Tide Emergency Management

As the standard long used in the U.S. for coastal planning, the “100-year storm” can be grossly misleading without the necessary updates dictated by sea level rise. In addition, sea level rise expressed in mm per year is only an average; hourly, daily, and monthly sea level variations also affect flooding risk. Ongoing changes in sea level, both short- and long-term, are important because they dictate the base water level for a storm tide—the storm surge in combination with the astronomical tide—to build upon as a major storm approaches the coast. Whatever else may happen, the situation will be made worse by an elevated monthly mean sea level—a condition known in advance where water-level monitoring is active. As the storm arrives, chance again plays a part through the tidal range (spring or neap) and phase (high water, mid-tide or low water) that eventually combines with the surge delivered by the storm. This uncertainty, lasting until the final hours before the event, can be addressed through a combination of near real-time observations and computer models capable of predicting coastal flooding in the near-term, tens of hours beforehand.

Sophisticated dynamic computer models developed at the Virginia Institute of Marine Science^{6,7} have been used to simulate storm flooding at various locations within Chesapeake Bay and its major tributaries. Along with improvements in computer modeling, recent developments include new technology such as airborne Light Detection and Ranging (LIDAR) used to delineate coastal topography (i.e., land elevation) with high precision, and high-resolution, short-term wind forecasts generated by the National Weather Service.

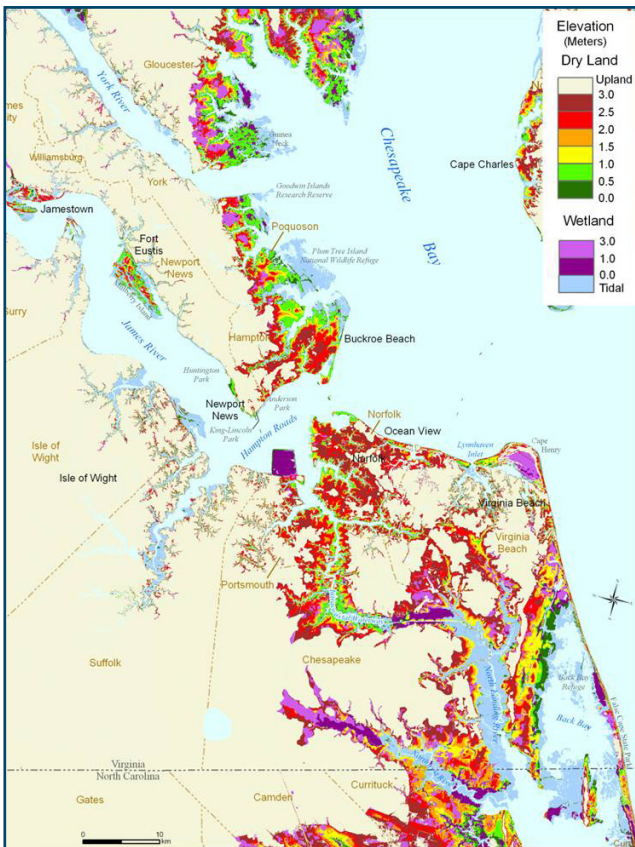
Trust but Verify

Close agreement between measured and modeled flood levels allows confidence in future model predictions. Accurate water-level measurements therefore go hand-in-hand with model simulations. Web-based observational networks such as the NOAA Physical Oceanographic Real Time System—PORTS (www.tidesandcurrents.noaa.gov) and the VIMS TideWatch System (www.vims.edu/tidewatch) can be used to not only verify past model predictions but to feed data to real-time modeling systems during an event. These techniques can also be used to answer questions that arise during post-storm evaluations:

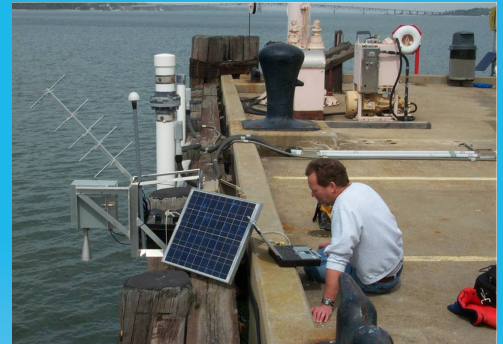
- Do certain areas, tributaries, or small embayments tend to experience storm tide flooding to a greater degree or more frequently than others?
- Can risks be mitigated through improved planning or engineering?
- Are water-level extremes increased or locally prolonged because of increased runoff from modified watersheds?

Extratidal Water Levels

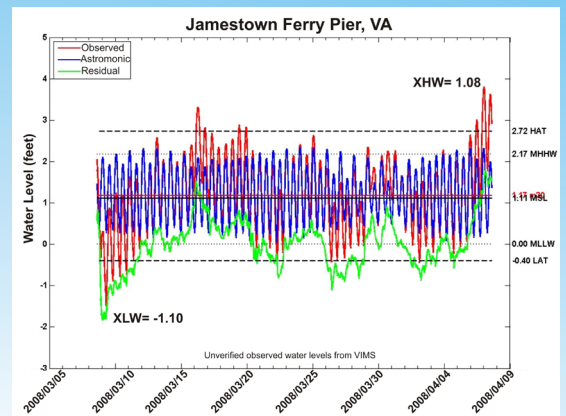
Planning for coastal flooding requires new methods and metrics. Whereas tidal predictions have long been essential to the mariner concerned with safe navigation, waterfront property owners have little reason to be concerned until water levels exceed the vertical limits of the astronomical tide and become "extratidal." This occurs at Highest Astronomical Tide (HAT), a tidal datum commonly used outside the U.S. By referencing a storm tide to the HAT datum, coastal planners and emergency managers will be able to isolate that part of the extreme that exceeds the normal range of the tide.



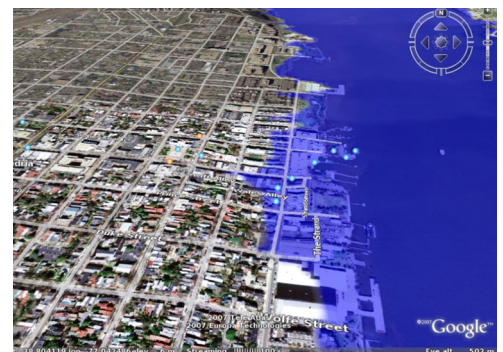
Hampton Roads inundation estimates under different sea level rise scenarios. From Titus and Wang (2008) EPA.



A VIMS microwave radar gauge measures water levels at Yorktown, VA. The device, unlike older gauges with stilling wells, has no contact with the water. Data is transmitted to VIMS through a NOAA Geostationary Operational Environmental Satellite (GOES).



Examples of extratidal high water and extratidal low water at Jamestown, VA during March 9 through April 7, 2008.



Model-simulated inundation at Alexandria, VA.



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Because tidal range varies from place to place, the level that separates "normal" from "above normal" varies as well. Thus extratidal high water, measured in either feet or meters above HAT, provides a true measure of the flooding potential at all locations regardless of tidal range. By documenting this measure precisely for more storms at more locations, a better understanding of the flooding threat in Virginia—and the response required—will result. Graphs showing extratidal water levels for several lower Chesapeake Bay locations can be seen at www.vims.edu/tidewatch as they occur.

Strategic Planning: Smarter Future Development in the Coastal Zone

Evidence suggests that hurricane activity has increased since 1995 after a quiet period from 1971 to 1994.⁸ But even without a major tropical storm or hurricane, extratropical storms or 'northeasters' that have not caused significant flooding of homes and property in the past will begin to do so in the future due to rising sea level. Affected citizens will pressure local government to "fix" a problem for which there are few permanent solutions—all of them complex and involving considerable cost to the taxpayer. Smarter planning will see coastal managers and planners anticipating rather than simply reacting to these problems.

Present planning and management concepts will be ineffective if they remain "static" and do not account for sea level rise. Tidal datums are periodically updated for this very reason as mandated by national agreement.⁹ An example of a static concept is the 100-year flood, which stipulates the same 1-in-100 chance of a specified flood level in any given year, whether now or a hundred years from now. While this concept may serve present-day flood insurance purposes, it is of little use when planning for the life expectancy of a coastal development: the number of years until the infrastructure is deemed liable to partial or total loss from recurring flooding or becomes inaccessible due to repeated flooding of roadway access.

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