Mapping Potential Sea Level Rise and Storm Surge in Boothbay Harbor, ME

Boothbay Harbor Rotary Club
May 12, 2016

Peter A. Slovinsky, Marine Geologist
Maine Geological Survey
Quickly, I’ll cover....

- What drives sea level rise change?
- Setting the stage: Maine’s glacial geology and historic sea level rise trends
- Current sea level trends from Portland, Maine
- Where might sea levels go in the future?
- Storm surges
- Sea Level Rise and Hurricane inundation mapping
What Causes Sea Level to Change?

- Changes in terrestrial water storage (groundwater, extraction, draining wetlands, land use, dams) (40%)
- Vertical land movements (tectonic activity, glacial isostatic adjustments, groundwater and hydrocarbon extraction) (10%)
- Thermal expansion (10%)
- Changes in ocean circulation (50%)
- Gravitational driven sea level changes (50%)

Figure modified from Griggs, 2001
In the past, massive adjustments of earth’s crust in response to glaciation drove much of Maine’s sea level changes...
13,000 yrs ago, glaciers covered most of Maine, compressing the land surface so it was below sea level!

By 11,000 yrs ago, the glaciers had rapidly (geologically speaking) receded, and the land “rebounded” in response.
1912-2015: 1.86 ± 0.10 mm per yr or 0.61 ft (7.3"") per century

\[
y = 1.8556x - 3643.5
\]
Annual Mean Sea Levels, Portland, Maine
1912-2015 (through December 31, 2015)

1912-2015: 1.86 ± 0.10 mm per yr or 0.61 ft (7.3"") per century
1993-2015: 3.34 ± 1.11 mm per yr or 1.10 ft (13.2"") per century

y = 1.8556x - 3643.5
y = 3.3361x - 6616.6
...if current [Antarctic and Greenland] ice sheet melting rates continue for the next four decades, their cumulative loss could raise sea level by 15 centimeters (5.9 inches) by 2050. When this is added to the predicted sea level contribution of 8 centimeters (3.1 inches) from glacial ice caps and 9 centimeters (3.5 inches) from ocean thermal expansion, total sea level rise could reach 32 centimeters (12.6 inches) by the year 2050.

Rignot and others, March 2011


Image from www.swissseduc.ch
Antarctica has the *potential* to contribute more than a meter of sea-level rise by 2100...
“We have a very high confidence (>9 in 10 chance) that global mean sea level will rise at least 0.2 meters (8 inches) and no more than 2.0 meters (6.6 feet) by 2100.” – Global Sea Level Rise Scenarios for the United States National Climate Assessment (12/6/2012)

Highest
(2.0 m, 6.6 ft)
*Combines maximum warming, thermal expansion, and possible ice sheet loss from semi-empirical models.

Intermediate-High
(1.2 m, 3.9 ft)
*Average of high end global predictions, combines recent ice sheet loss and thermal expansion

Intermediate-Low
(0.5 m, 1.6 ft)
*Includes only thermal expansion from warming from IPCC AR4.

Lowest
(0.2 m, 0.7 ft)
* Historical trend continued; no additional thermal expansion from warming

Recommend using a “Scenario” Based Approach
Potential planning scenarios based on long and short-term trends using the USNCA curve calculators:

- **Highest**: (6.3 ft) by 2090
- **Intermediate-High**: (3.7 ft) by 2090
- **Intermediate-Low**: (1.5 ft) by 2090
- **Lowest**: (0.5 ft) by 2090

- **0.2 to 0.4 ft by 2030**: (3.4 to 7.0 mm/yr)
- **0.5 to 1.0 ft by 2050**: (4.6 to 9.1 mm/yr)
- **0.8 to 2.0 ft by 2070**: (5.5 to 15.2 mm/yr)
- **1.3 to 3.1 ft by 2090**: (7.6 to 16.8 mm/yr)

**Long term trend:** 1.9 mm/yr
**Short term trend:** 3.3 mm/yr
Abrupt short-term sea level rise in the North Atlantic

Maine saw an average of approximately 5” higher than normal tides in the summer of 2009, and, especially in winter of 2010.
Annual Mean Sea Levels, Portland, Maine
1912-2015 (through December 31, 2015)

1912-2015: 1.86 ± 0.10 mm per yr or 0.61 ft (7.3") per century

y = 1.8556x - 3643.5
2010 had the highest sea levels ever for 5 months
2009 had the highest sea level ever for 1 month

Portland, Maine Sea Level Variability by Month
(1912-2014)

Calendar Month (Jan-Dec)

Data courtesy of NOAA CO-OPS, www.tidesandcurrents.noaa.gov
What about storm tides and storm surges?
So what is storm surge?

Storm surge is an abnormal rise of water generated by a storm, over and above the predicted astronomical tides. Storm surge should not be confused with storm tide, which is defined as the water level rise due to the combination of storm surge and the astronomical tide (National Hurricane Center).
Storm Surge
“Superstorm Sandy”

Kings Point, NY
10/29-10/30/2012

NOAA/NOS/CO-OPS
Verified Water Level vs. Predicted Plot
8516945 Kings Point, NY
from 2012/10/29 - 2012/10/30

“Storm Tide”
“Storm Surge”

Predicted Tide
(Obs-Pred)
Observed WL
### Storm Surges at Portland, ME 1912-2012, at any tide

<table>
<thead>
<tr>
<th>Time Interval (years)</th>
<th>Surge Height (feet)</th>
</tr>
</thead>
<tbody>
<tr>
<td>1 (100 %)</td>
<td>1.8</td>
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<tr>
<td>5 (20%)</td>
<td>3.3</td>
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<tr>
<td>10 (10 %)</td>
<td>4.0</td>
</tr>
<tr>
<td>25 (5%)</td>
<td>4.9</td>
</tr>
<tr>
<td>50 (2 %)</td>
<td>5.6</td>
</tr>
<tr>
<td>100 (1%)</td>
<td>6.3</td>
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## Storm Tides at Portland, ME 1912-2012

<table>
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<tr>
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1 foot difference!
SLR scenarios selected for mapping

- Latest Scenarios:
  - Short Term: approximately 1 ft by 2050
  - Long Term: 2-3 ft but potentially more by 2100;
- We decided to examine scenarios of 1 foot, 2 feet, 3.3 feet, and 6 feet on top of the highest annual tide (HAT).
- These SLR scenarios relate well to the National Climate Assessment, and also correspond well with evaluating potential impacts from storm surges that may coincide with higher tides today.
- Storms and storm surges can be exacerbated by Sea Level Rise, whether long-term or abrupt.
Highest Annual Tide, Sea Level Rise and Hurricane Storm Surge Mapping
LiDAR - Light Detection & Ranging Data

100,000 pulses of laser light per second are sent to the ground in sweeping lines.

Sensors measure how long it takes each pulse to reflect back to the unit and calculates an “elevation”.

Algorithms are used to “remove” buildings and vegetation types to create a “bare earth” digital elevation model (DEM).
“Coastal wetlands” means all tidal and subtidal lands; all areas with vegetation present that is tolerant of salt water and occurs primarily in salt water or estuarine habitat; and any swamp, marsh, bog, beach, flat or other contiguous lowland that is subject to tidal action during the highest tide level for each year in which an activity is proposed as identified in tide tables published by the National Ocean Service. Coastal wetlands may include portions of coastal sand dunes.

Required in Maine’s Municipal Shoreland Zoning
Some Assumptions and Limitations

• We use a “bare earth” LiDAR DEM that represents a “snapshot” of topography that may have changed since the data was captured. Also, many bridges have been removed.

• Our simulations use a bathtub approach that assumes a static rise in water, and doesn’t account for erosion, sedimentation, or freshwater flow or waves.

• We use NOAA’s VDATUM to convert from MLLW to NAVD88 to translate elevations across water surfaces. This helps adjust tidal predictions, but also adds additional vertical error (13.2 cm)
Lincoln County Sea Level Rise - Coastal Hazard Study

Lincoln County Regional Planning Commission
Lincoln County Commission
Maine Geological Survey
Maine Coastal Program

This presentation was prepared by the LCRPC under award NOAA CZM NA11NOS4190077 and NA11NOS4190188 to the Maine Coastal Program from the National Oceanic and Atmospheric Administration, U.S. Department of Commerce. The statements, findings, conclusions, and recommendations are those of the author(s) and do not necessarily reflect the views of the National Oceanic and Atmospheric Administration or the Department of Commerce.
The following scenarios were developed by the Maine Geological Survey in conjunction with the Lincoln County Regional Planning Commission for general planning purposes only. They are based on a "bathtub" simulation model and do not take into account impacts associated with erosion, accretion, or wave action. Though local, regional, and national data indicates that sea level is continuing to rise, scientific authorities cannot predict with certainty the precise increase that will be experienced along Lincoln County's tidal shoreline. Communities are advised to consider the information provided by this project as part of a "scenario-based approach" and create adaption strategies to mitigate impacts on natural systems, public infrastructure and facilities and existing and future development.

Please note the following when viewing the scenarios:

- When a road segment or a rail line is predicted to become inundated it is usually highlighted in black or gray. On occasion the highlighting may be absent so the best indicator of inundation is whether water is shown crossing a road or rail line.

- Buildings are highlighted in red when water is predicted to be present at the building’s foundation during a given scenario. The scenarios themselves do not present information on the depth of water, only that some level of water is present at the building’s foundation.

### 100yr Storm

- 100yr Storm
- 100yr Storm + 0.3m
- 100yr Storm + 0.6m
- 100yr Storm + 1m
- 100yr Storm + 1.8m

### Highest Annual Tide

- HAT
- HAT + 0.3m
- HAT + 0.6m
- HAT + 1m
- HAT + 1.8m

### Complete Scenarios Zip - download

Legend
Google Earth Download and Instructions
Arc Explorer Download and Instructions
Disclaimer
Highest Annual Tide + 6 feet of storm surge or sea level rise
Hurricane Inundation Mapping

Hurricane Sandy
Sunday October 28, 2012
5 AM EDT Advisory 24
NWS National Hurricane Center

Current Information:
Center Location 31.9 N 73.3 W
Max Sustained Wind 75 mph
Movement NE at 13 mph

Forecast Positions:
• Tropical Cyclone • Post-Tropical
Sustained Winds: D < 39 mph
S 39-75 mph H 74-110 mph M > 110 mph
Why Worry?

Past “land-falling” hurricanes

1869 - Not Named (Cat 2 and 1, east of Portland)
1944 – Not Named (Cat 1, near Isle au Haut)
1954 – Hurricane Edna (Cat 1, near MDI)
1969 – Hurricane Gerda (Cat 2, near Eastport)
1991 – Hurricane Bob (Cat 2 to TS, off Southport)

What if a Sandy-like storm hit Maine today?
The Sea, Lake and Overland Surges from Hurricanes (SLOSH) model is a computerized numerical model developed by the National Weather Service (NWS) to estimate storm surge heights resulting from historical, hypothetical, or predicted hurricanes by taking into account the atmospheric pressure, size, forward speed, and track data. These parameters are used to create a model of the wind field which drives the storm surge.
Composite Approach - Predicts surge by running SLOSH several thousand times with hypothetical hurricanes under different storm conditions. The products generated from this approach are the Maximum Envelopes of Water (MEOWs) and the Maximum of MEOWs (MOMs) which are regarded by NHC as the best approach for determining storm surge vulnerability for an area since it takes into account forecast uncertainty. The MEOWs and MOMs play an integral role in emergency management as they form the basis for the development of the nation’s evacuation zones.
Storm Surge Product Decision Support Wedge

Which storm surge product should I use when?

- **NHC Advisory/NWS Local Statements**
  - Probabilistic Storm Surge
  - *MEOWs*

- **MEOWs**
  - *MOMs*

- **MOMs**

**Tier 1**
- RESPONSE
- < 48 h of landfall

**Tier 2**
- READINESS
- 48 h – 120 h of landfall

**Tier 3**
- PLANNING/MITIGATION
- > 120 h of landfall

Surge Overview | Storm Surge Unit | SLOSH | P-SURGE | Surge Products | Local Impacts | FAQ | Resources
Important assumptions and limitations

1) SLOSH model only outputs an anticipated **STORM TIDE** and **SURGE** onto a predicted tide for a Category 1-4 event making landfall at mean high tide.

2) SLOSH Model **does not include impacts of waves, normal river flow, or rain flooding on top of surge**, nor changes in the astronomical tide. The model may thus **under-predict coastal flooding**, especially in areas open to wave attack.

3) Results from SLOSH simulations is especially geared towards **emergency management planning and response**.
LCRPC, the Maine Geological Survey and the Maine Coastal Program cooperated to develop maps of coastal areas within the Lincoln County that could be impacted by a Category 1 hurricane. The predicted areas of inundation reflect worst-case conditions of forward speed, trajectory and tide level. The maps were developed to help support emergency planning and preparedness efforts in Lincoln County. Areas predicted to be inundated with some level of water are shown in blue while potentially impacted buildings and public and private roads are highlighted in red and green, respectively. These maps do not provide information on predicted water levels, only that some level of water is projected to be at a building’s foundation or on a road surface. To view the maps, click here.
Maximum of Maximum Envelopes of Water (MOM) from a Category 1 Hurricane at Highest Mean Tide

SLOSH Sea, Lake, and Overland Surges from Hurricanes (SLOSH) model was developed by the National Weather Service for estimating storm surge from Hurricanes.

The SLOSH model outputs worst-case storm tide elevations (called MOMs), which are a combination of predicted normal mean high tide and storm surge associated with a Category 1 storm event. Outputs do not take into account the potential impacts from waves, abnormal tides, freshwater flow, precipitation, or potential future scenarios of sea level rise.

These maps were developed using data from the Potential Hurricane Inundation Maps (PHIMs) developed by the Maine Geological Survey. PHIMs were developed using outputs from the latest NHC SLOSH model and the most recently available LiDAR datasets for the Maine coastline. PHIMs are currently not approved products from the National Hurricane Center, but represent the best available information for the Maine coastline.

This project was designed for use by Lincoln County Emergency Management Administration to assist with disaster preparedness.

Made possible by...

LCRPC
Lincoln County Regional Planning Commission

Source: Maine Geological Survey, 2014

The project was funded jointly by the Lincoln County Commission and a grant from the Maine Coastal Program under award NOAA CZM NA11NOS4190066 and NA11NOS4190188 to the Maine Coastal Program from the National Oceanic and Atmospheric Administration, U.S. Department of Commerce. The statements, findings, conclusions, and recommendations are those of the author(s) and do not necessarily reflect the views of the National Oceanic and Atmospheric Administration or the Department of Commerce.
Category 2 storm at MHT

boothbay harbor, me

Inundation Depths
Depth (ft)
- 0 - 3
- 3 - 6
- 6 - 9
- > 9

USDA FSA, DigitalGlobe, GeoEye, Microsoft, CNES/Airbus DS
Thank you!

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Boothbay Harbor High Tide and Flood Heights

February 11, 2016
Boothbay Harbor High Tide and Flood Heights

February 11, 2016 was the highest tide for the month at 10.7’ MLLW. MLLW is Mean Lower Low Water or the average lower low water height. This is the datum that is used to reference elevations from the NOAA Tide Tables, like the one that is printed for BBH.

New FEMA Flood Insurance Rate Maps are referenced to NAVD88, which is the North American Vertical Datum 1988 and is used for vertical control for most land surveying. In order to understand high tide elevations in reference to the FEMA flood maps a common datum is needed, in this case NAVD88. The FEMA flood maps show areas that would be affected during a "100-year" flood, or the flood that has a 1% chance of happening in any year.
The 10.7’ MLLW from February 11 is equal to about 5.4’ NAVD88. The HAT (highest annual tide) in BBH in 2016 will be 11.6’ MLLW or 6.3’ NAVD88. The “stillwater” 100-year (1% storm) flood, which is the average water level before waves or surge are taken into consideration, would be about 15’ MLLW or about 9.7’ NAVD88. This elevation is the basis for the calculation of different flood zones, which then additional surge or wave impacts, depending on whether it is an “AE-zone” or a “VE-zone”.

The new FEMA flood maps differ from the previous maps in several important ways. First, previous maps were referenced to NGVD1929, which is a different vertical datum than NAVD88. Second, the new maps are based on LiDAR topographic mapping, which is accurate to about 1’ in elevation. The previous maps were based on the old USGS mapping, which was accurate to about 5’. That makes a lot of difference when determining areas potentially impacted by flooding.
The new maps are also based on several hundred transects or horizontal profiles along the county coastline. The transects are topographic profile of locations along the coast, allowing FEMA to better understand how flood waters will move up the shore and to develop estimates of wave setup and run-up.
Wave setup and run-up represent increases in flooding beyond the 9.7’ NAVD88 stillwater elevation of water in a 100-year flood.

Wave setup is additional increase in the water level due to waves pushing water up against the coast. Wave run-up is an additional increase in the water level, over and above wave setup, due to waves breaking along the shoreline.
The new maps include determinations of several different "flood zones".

VE zones are "Velocity" zones with calculated flood elevations. These are generally the most at-risk zones, and include wave setup and wave run-up. VE zones expect to have waves greater than 3 feet during the 1% storm event. So a VE zone of elevation 15 ft NAVD88 means that during the 100-year storm, that zone can expect water levels to reach about 15 feet NAVD88, and include waves greater than 3 feet in height.

The next zone in terms of risk is called a "Coastal A-zone", and is defined using what is called the "LiMWA", or "Limit of Moderate Wave Action". These zones expect to have flood heights that include waves between 1.5 and 3 feet in height during the 1% storm event.
AE zones, or A-zones with a calculated flood elevation, are generally lower-energy flood zones, where waves will be less than 1.5 feet during the 1% storm event. So an AE zone of 10 feet NAVD means that flood waters, including waves less than 1.5 feet, will reach 10 feet NAVD88.

Then, some areas have "A-zones" with no calculated elevation. That means these areas expect to see flooding, but no flood elevation has been calculated.

Finally, X-zones are areas that are outside of the 100-year flood area, but may see flooding during the 500-year, or 0.2% annual chance, flood event.
This map shows the new flood zones in a portion of BBH.
This map shows the actual 100-year flood elevations in feet in NAVD88 (areas outside the 100-year flood zone have a default elevation of 9999)
<table>
<thead>
<tr>
<th>February 11, 2016 High Tide</th>
<th>100-year Storm</th>
</tr>
</thead>
<tbody>
<tr>
<td>Water Level</td>
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</tr>
<tr>
<td>5.4’ NAVD88</td>
<td>12’ NAVD88</td>
</tr>
<tr>
<td>February 11, 2016 High Tide</td>
<td>100-year Storm</td>
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<td>12’ NAVD88</td>
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<td>Date</td>
<td>Event</td>
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</tr>
<tr>
<td>5.4’ NAVD88</td>
<td>10’ NAVD88 (building)</td>
</tr>
<tr>
<td></td>
<td>14’ NAVD88 (pier)</td>
</tr>
</tbody>
</table>
Downtown Boothbay Harbor Flood Impact Preliminary Engineering Study and Adaption Options to Protect Governmental and Commercial Structures From Flooding Associated with a 1% Storm
Project Tasks

Retain an engineering consultant and surveyor to:

• Determine the 1% flood elevation at all participating properties
• Determine the elevations of potential points of water access into buildings as well as critical at-risk building infrastructure such as fuel tanks, electrical entrances, furnaces, etc.
• Identify and evaluate potential adaptations techniques to make buildings and infrastructure more resilient to flooding
• Estimate costs associated with such adaption techniques.
• Recommend ordinance changes to improve flood resiliency of future buildings and major additions to existing buildings
Assessment of Options to Mitigate the Impacts of Long-Term Sea Level Rise and Storm Surge on the Boothbay Harbor Wastewater Treatment Facility

Flooding during a 100-year storm with 2’ SLR
County-Wide Coastal Flood with SLR Study

Legend
- Red: Flood Zones after 3ft SLR
- Blue: Flood Zones after 1ft SLR
- Light Blue: Original Flood Zones

Service Layer Credits: Sources: Esri, HERE, DeLorme, USGS, Intermap, increment P Corp, NRCAN, Esri Japan, METI, Esri China (Hong Kong), Esri (Thailand), MapmyIndia, © OpenStreetMap contributors, and the GIS User Community