Adaptation to Sea Level Rise Chapter

Comprehensive Plan
Inventory & Analysis

November 5, 2013

Prepared in conjunction with Southern Maine Regional Planning Commission

<u>ENACTMENT BY THE LEGISLATIVE BODY</u>

Date of Town vote to enact this Chapter of the Comprehensive Plan: ______________.

Certified by the Town Clerk: ________________________________ on ___________.
(signature) (date)

ADAPTATION TO SEA LEVEL RISE

This chapter is a portion of the Inventory and Analysis section of the York Comprehensive Plan. Its purpose is to provide information about anticipated changes in sea level rise. The text of this Chapter is organized into 3 sections: Introduction to Sea Level Rise; Vulnerability Assessment – Sea Level Rise; and Tidal Surge and Freshwater Contributions. There are also 3 appendices: Measuring Sea Level; Other Sea Level Rise Adaptation Efforts in Maine; and Presentation Slides - Adaptation to Sea Level Rise

Comprehensive Plans in Maine must comply with the legal requirements of state law, specifically Title 30-A §4326. The law establishes that land use policy must be based on information and analysis, and accordingly the law establishes that comprehensive plans must contain an Inventory and Analysis section. This Chapter is one part of the Inventory and Analysis section of the York Comprehensive Plan. The Inventory and Analysis section of the York Comprehensive Plan is a series of technical reports on individual subjects (population, housing, land use, natural resources, etc.). Each is complete as a stand-alone report on its specific subject, but taken as a set they comprise the complete Inventory and Analysis section.

Before starting the text, a brief note about units of measure is in order. Most of the science about sea level rise is performed and reported in metric units. The Town Comprehensive Plan and land use codes all utilize standard units, and it is unlikely there will be a public demand to convert to metric any time soon. That said, both measures are provided in the text of this report. Most, but not all conversions were from metric to standard, and the converted numbers are approximate. In graphics borrowed from other sources, expect to see metric units only. Metric abbreviations used here include “mm” for millimeter and “M” for meter.

Introduction to Sea Level Rise

Sea level is rising according to one hundred years of records from the Portland, ME tide gauge. Along with this change, storms are becoming more frequent and intense, and damages are increasing. The important question for the Town of York is: “How should the Town respond and adapt?” This chapter inventories the best available data on historical and recent trends in sea level change, and offers the best available current predictions for the future. This Chapter establishes the rational basis on which the Town’s policy response to sea level rise is based. See the Policy Section of the Plan for the actual policies.

This chapter does not delve into the underlying causes of the observed changes in sea level. The underlying causes of sea level rise are being debated nationally and internationally, and are the subject of extensive scholarly investigation worldwide. This chapter simply acknowledges the sea level changes as documented over the past century at the Portland tide gauge. Whatever the cause may be, it is important for the Town to react to changing physical conditions.

1. Trends in Sea Level Rise

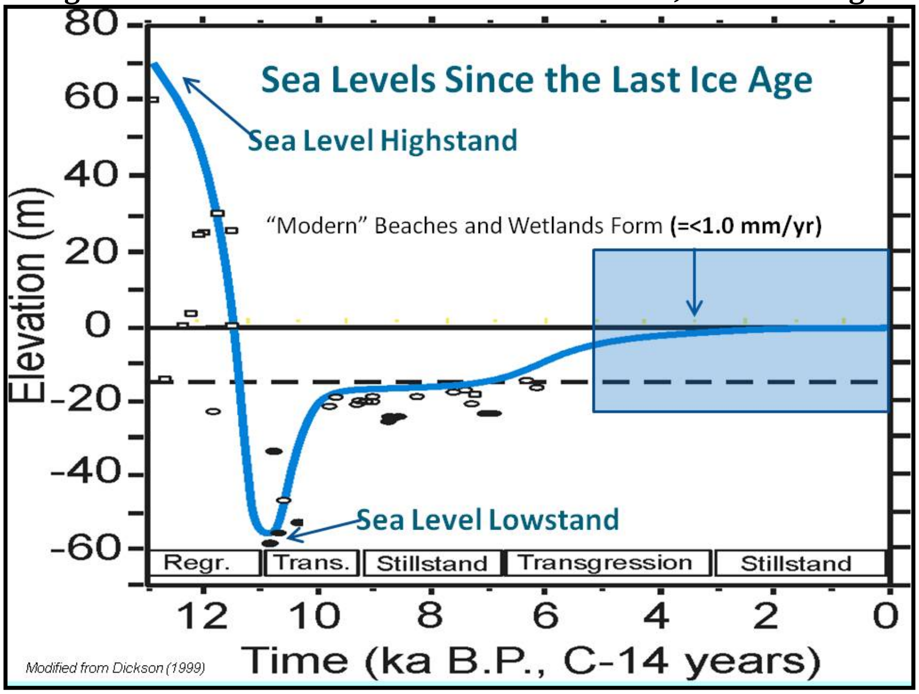
As shown in this section, there is a clear historical pattern of sea level rise which began about 11,000 years ago and which is still occurring today. For the past couple thousand years there has been a pattern of only minor, gradual increases in sea level, although the most recent data appears to be showing an increasing rate of sea level rise.

Scientists believe that there are two dominant components to what is happening when global sea level is observed to increase. The first is thermal expansion, as the ocean temperature warms. The second is volumetric increase when the volume of water in the ocean increases, caused by melting of glaciers and ice sheets located on land.

When scientists look at data on a specific piece of coast, like at the shoreline of York, Maine, there are more local reasons for changes in sea level, other than those at the global level. Some movement of the land up or down is left over from the end of the last ice age. As the crust of the earth in this area was covered with thousands of feet of ice, it sank in response, just like when you lie down on a mattress. When the ice age ended, the land experienced “isostatic rebound,’ as the crust bounced back up. Some isostatic rebound is still happening today after thousands of years, but the effect now is very slight. However, in the past, this phenomenon had a tremendous effect on Maine. In other parts of the United States, there was no ice age, and sinking of the land or “subsidence” is a problem. This is pronounced in the Chesapeake Bay area and the Louisiana coast, where higher rates of sea level rise are happening right now, compared to York, Maine. It should also be noted that seasonal wind patterns can change tide levels during different periods within each year. In our area, tides will run lower during periods of sustained northwest winds during the winter which blow water offshore.

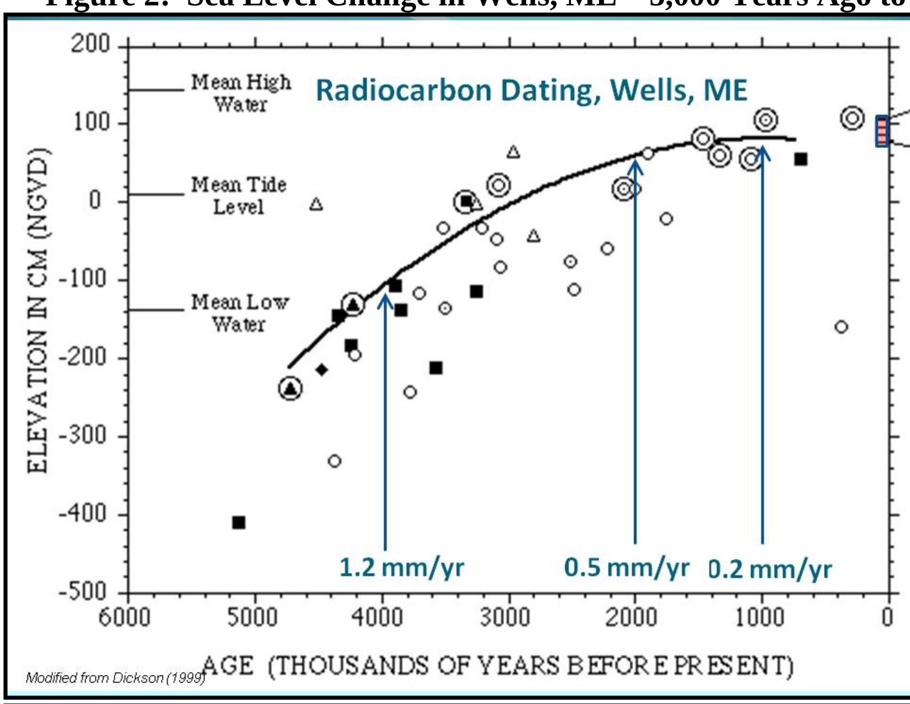
Thirteen thousand years ago at the end of the last ice age, the land in Maine was so crushed by ice that sea level was 230 feet (70 meters) higher than it is today. At eleven thousand years ago after the ice had receded, the land rebounded so that sea level was about 200 feet (60 meters) below today’s levels. Continued melting of ice filled the oceans, and in the last five thousand years, levels in Maine have been very stable. It is important to note that this is the period when our modern beaches and wetlands that we know today were formed. See Figure 1.

Figure 1: Elevation of Sea Level in Maine – 13,000 Years Ago to Present



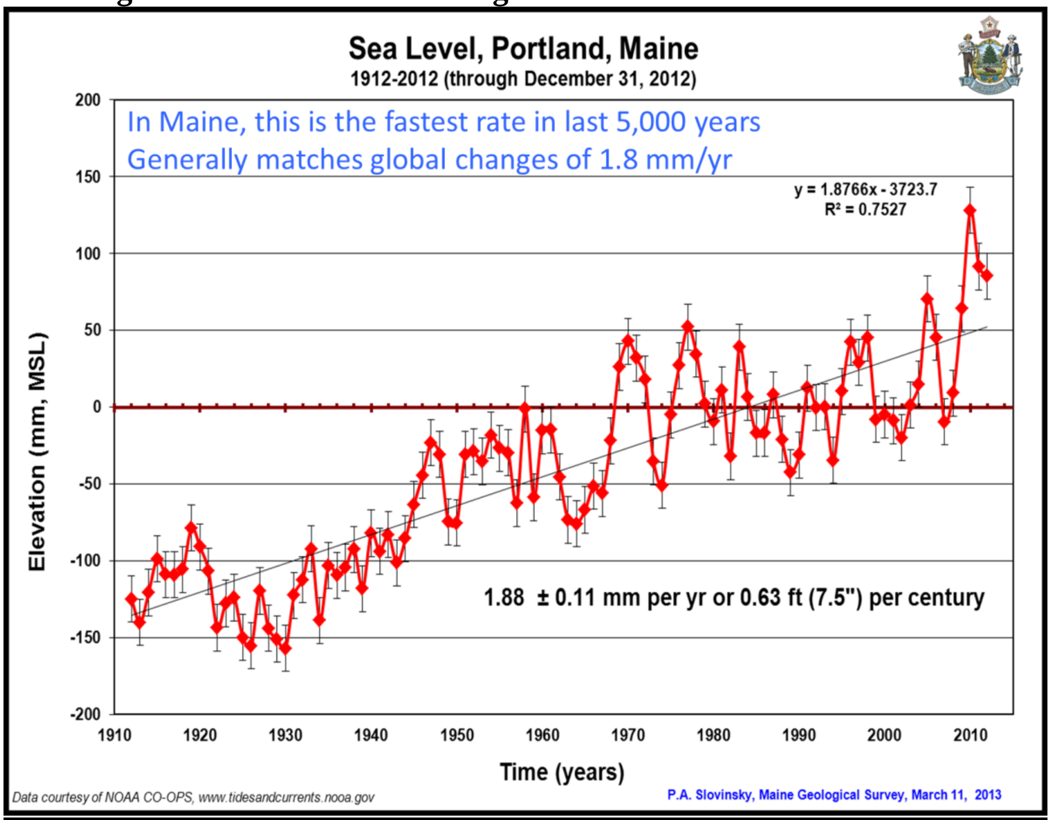
Close to York, studies of marshes in Wells show that in the last five thousand years (the area shaded in blue in figure 1) the rate of change in sea level has leveled off from over 3/64 inch (1mm) per year to only 1/64 inch (0.2 mm) per year about a thousand years ago. This data was derived by radiocarbon dating of marsh borings. See Figure 2.

Figure 2: Sea Level Change in Wells, ME – 5,000 Years Ago to Present



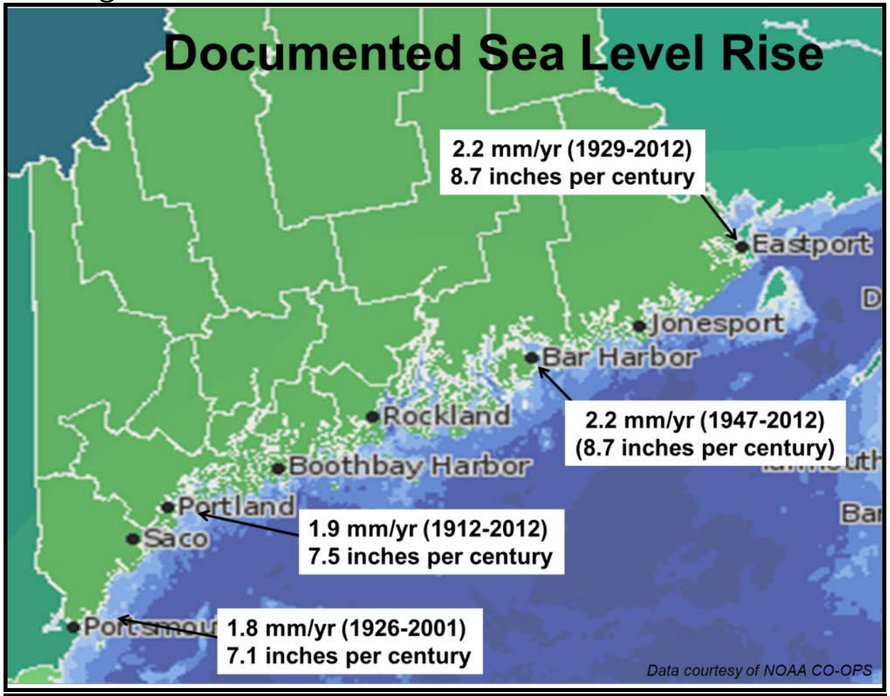
The peaceful period of gradual sea level rise that has been experienced for the past several thousand years appears to be over. The Portland tide gauge shows that over the last hundred years, since 1912, sea level has been rising at a rate of 1.9 mm per year. That would be 7½ inches (190 mm) during this period. This mirrors global ocean changes, as measured from orbiting satellites, of about 5/64 inch (1.8 mm) per year. See Figure 3.

Figure 3 – Portland Tide Gauge – Mean Sea Level – 1912 to 2011



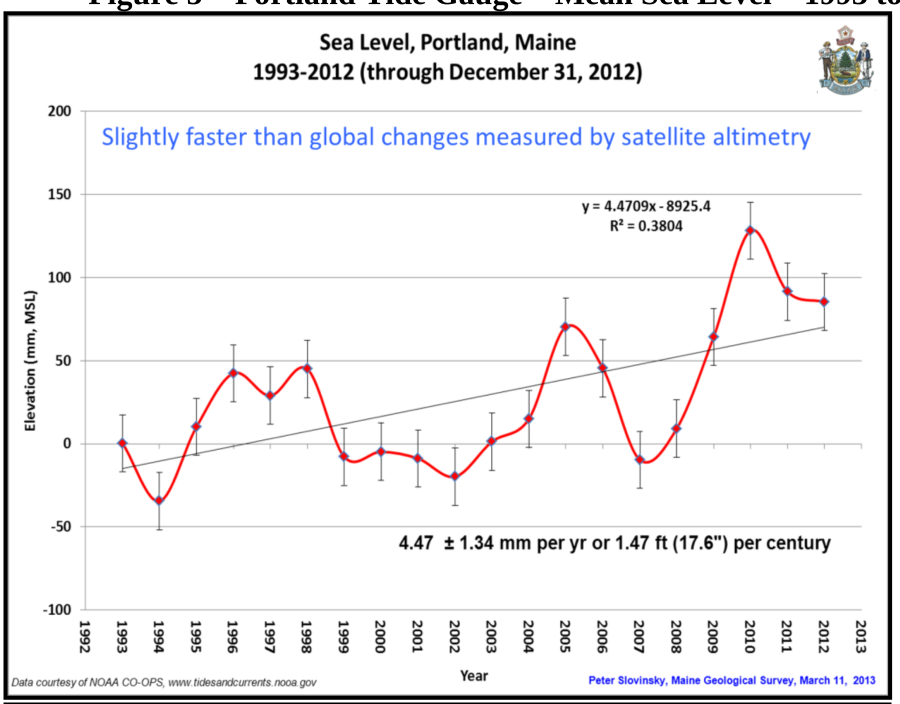
Similar results are found up and down the coast, as documented at nearby tide gauges. See Figure 4.

Figure 4 – Recent Rates of Sea Level Rise – Portsmouth to Eastport



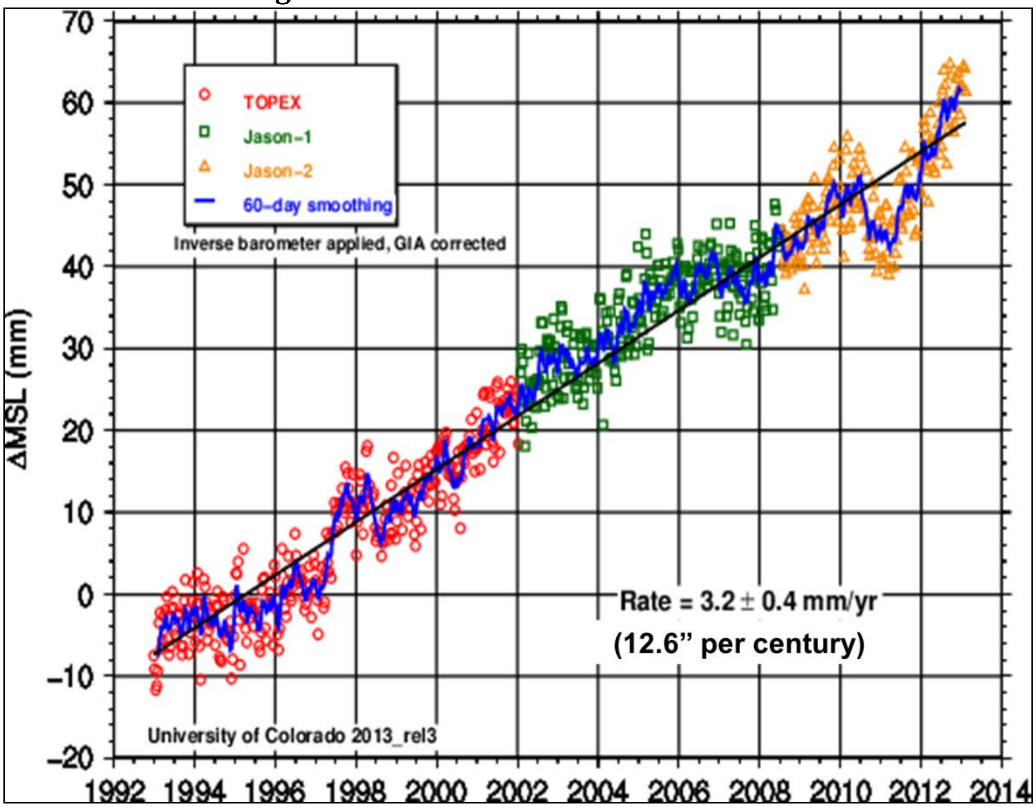
Not only has the pace of sea level rise picked up over the last hundred years, the rate is increasing, and is up substantially since 1993. For the last 20 years or so, the rate of sea level rise has increased to 11/64 inch (4.3 mm) per year, or 17 inches (430 mm) per century. See Figure 5.

Figure 5 – Portland Tide Gauge – Mean Sea Level – 1993 to 2011



Not only has the pace of sea level rise picked up locally here in Maine, but the rate of rise has picked up on global sea level, as measured by orbiting satellites. Since 1993, global sea level has risen at a rate of 8/64 inch (3.2 mm) per year, or 12.5 inches (320 mm) per century. See Figure 6.

Figure 6 – Global Rates of Sea Level Rise



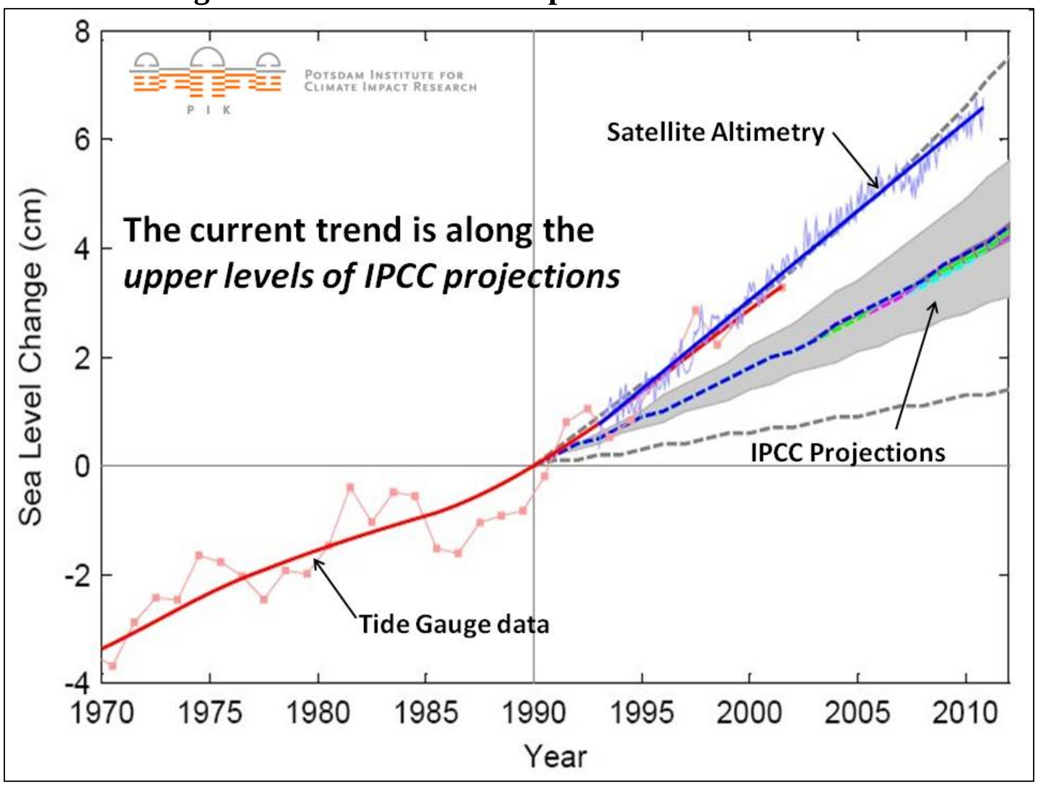
2. Best Predictions of Future Sea Level Rise

Having an overall understanding of past changes to sea level is essential to understanding the range of projections of future conditions. There seems to be widespread consensus in the science community that sea level will continue to rise in the coming century. A rising sea level has planning implications for coastal communities like York. Some buildings, roads and public facilities will be impacted on a daily basis or during storms where overall rising sea levels will worsen storm-related impacts. While the degree of certainty is unknown, it is nonetheless important to gaze into the crystal ball and consider the range of likely alternatives.

For planning purposes, and under the rules of the Sand Dune Act administered by the Maine Department of Environmental Protection, 2 feet (0.6 M) of sea level rise is expected by 2100. The current trends since 1993 shown on our local tide gauge, as well as the satellite measurements of the global ocean levels, are showing faster increases than we have seen before. The amount of sea level rise in the last 100 years since 1912 has been about 7.5 inches (190 mm). The next hundred years will probably be triple that, according to the projections of the Intergovernmental Panel on Climate Change (IPCC) and reach at least two feet. The IPCC projections do not include contributions from the melting of glacial, land-based ice sheets.

Figure 7 shows that if you superimpose the Portland tide gauge data from 1993 to the present, as well as the satellite measurements of the global ocean level, that sea level rise during the last 20 years is tracking the HIGHEST PROJECTION curve of the IPCC.

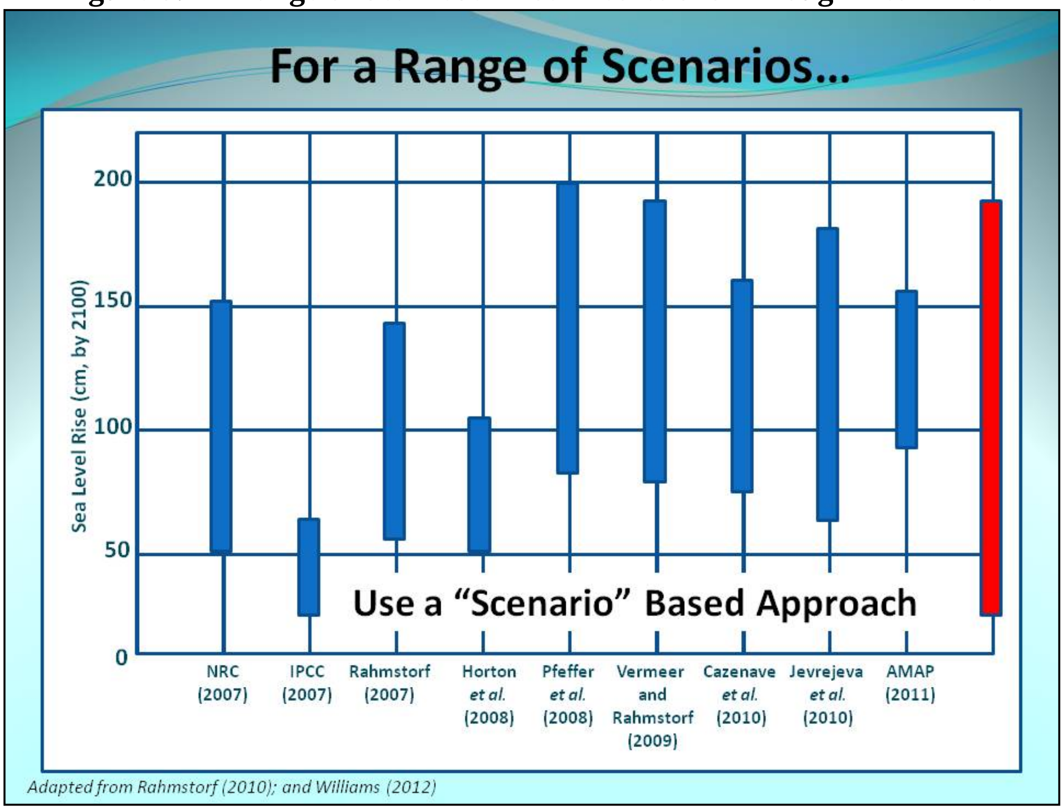
Figure 7: Recent Data Compared to Past Predictions



There is another factor at work, which should be considered by the Town of York, which makes the prediction of one foot (0.3 M) of sea level rise by 2050, and 2 feet 0.6 M) of sea level rise by 2100, conservative numbers. Geologists are measuring that ice sheets on land in Greenland and the Antarctic are melting, which could add substantial amounts of water to the world's oceans. This has not been a factor over the past hundred years. The recent SWIPA report (Snow, Water, Ice, and Permafrost in the Arctic) by Rignot and Others, from March 2011, predicts that "if the current Antarctic and Greenland ice sheet melting rates continue for the next four decades, their cumulative loss could raise sea level by 5.9 inches (150 mm) by 2050. When this is added to the predicted sea level contribution of 3.1 inches (79 mm) from glacial ice caps and 3.5 inches (89 mm) from ocean thermal expansion, total sea level rise could reach 12.6 inches (320 mm) by the year 2050." (More information is available from the American Geophysical Union, via the Web: http://www.agu.org).

Figure 8 shows a review of 9 recent peer reviewed studies that indicate between one and six feet of sea level rise by the year 2100, when the influence of ice sheets is included in sea level rise scenarios. The center of the red bar on the right side of the figure is the middle of all predictions, at around 4 feet (1.2 M). Most newer authors are factoring in a contribution from ice sheet melting processes, which drives their predictions higher.

Figure 8: A Range of Sea Level Rise Predictions Through Year 2100



It seems clear from these expert projections that York can expect and should plan for some degree of sea level rise in the coming years. How much and in what timeframe are the key unknowns.

Vulnerability Assessment – Sea Level Rise

Buildings, roads and public infrastructure are susceptible to impact as sea level rises. GIS analysis was conducted to estimate the changes to impacts associated with sea level rises of 1 foot (0.3M), 2 feet (0.6M), 3.3 feet (1M) and 6 feet (1.8M). These are general estimates based solely on the current building stock and current infrastructure, and are suitable for planners to understand the relative changes in impacts at varying states of sea level rise.

In addition to a simple increase in the water level at highest annual tide, the analysis was repeated to consider the impacts of storm conditions under those higher sea level scenarios. Storms such as this effectively increase the sea level for the duration of the storm. The 1978 storm is the storm of record with respect to ocean-related storm impacts, and it produced a temporary increase in sea level of about 2½ feet.

1. Impacts to Buildings

Figure 9 shows the results of the vulnerability assessment of York's buildings to sea level rise. Under normal conditions, a one-foot sea level rise impacts only a couple additional buildings, but if a large storm hits during a high tide then storm-related building damage would about double, jumping from 101 to 204 buildings impacted. With two feet of sea level rise, 38 buildings will routinely be flooded by astronomical high tides several times each year, without any storm or wave activity. Adding storm-related impacts, 342 buildings would be damaged. The number of buildings damaged increases at an increasing rate as the sea level increases. The areas of greatest vulnerability are behind Long Sands Beach, in the village at Short Sands, and near the mouth of the Cape Neddick River.

Figure 9. Buildings Damaged Under Varying Scenarios

Summary of Potentially Vulnerable* Building Infrastructure

Scenario	Highest Annual Tide (6.4 ft)	1978 Storm (8.9 ft)
Existing	4	101
+0.3 m (1 ft) SLR	6	204
+0.6 m (2 ft) SLR	38	342
+1.0 m (3.3 ft) SLR	192	528
+1.8 m (6.0 ft) SLR	564	868

includes only primary buildings, excludes decks, dock structures, outbuildings, pools, mobile homes

elevations referenced to NAVD88

** Assumes "bathtub" flooding, no wave setup, static topography, and that a building is "inundated" if the flooding scenario **covers** the centroid of the building footprint, regardless of the flooding depth. Does not assign any kind of damage function.*

The vulnerability assessment did not estimate the dollar value of damage to buildings. In order to find out the economic impact of such damage, further GIS analysis would be necessary, estimating the predicted depths of floods in various locations. Such "depth-damage" function can be applied and summed over the areas shown as flooded on a computerized mapping system.

2. Impacts to Transportation Infrastructure

Figure 10 shows the results of the vulnerability assessment of York's roads to sea level rise. Under normal conditions, a one-foot sea level rise has a relatively limited impact, but if a large storm hits during a high tide then an additional 2 miles of roads would be inundated. With two feet of sea level rise, the amount of inundated roads jumps to 1.1 miles under astronomical high tides, and up to 6.6 miles during storm events. The amount of road inundation increases at an increasing rate as the sea level increases.

Figure 10. Miles of Road Flooded Under Varying Scenarios

Summary of Potentially Vulnerable* Road Infrastructure

Scenario	Highest Annual Tide (6.4 ft)	1978 Storm (8.9 ft)
Existing	0.1 miles	1.9 miles
+0.3 m (1 ft) SLR	0.2 miles	4.1 miles
+0.6 m (2 ft) SLR	1.1 miles	6.6 miles
+1.0 m (3.3 ft) SLR	3.8 miles	9.5 miles
+1.8 m (6.0 ft) SLR	9.9 miles	15.9 miles

elevations referenced to NAVD88

excludes bridges removed from LiDAR

** Assumes "bathtub" flooding, no wave setup, static topography, and that a road is "inundated" if the flooding scenario **covers** the entire road, regardless of the flooding depth. Does not assign any kind of damage function.*

The vulnerability assessment did not estimate whether these flooded roads in the scenario would be able to be reopened after flood waters receded, or whether they would be damaged and closed until repairs could be made. A depth-damage analysis would need to be conducted to predict damage levels, as discussed in the previous section.

Road impacts are primarily limited to the vicinity of Long Sands Beach, Short Sands Beach, and the mouth of the Cape Neddick River. With 2 feet of sea level rise, the most significant impact is Shore Road just north of the bridge over the Cape Neddick River. There the road will be impassable during the periods of highest tide during good weather. Adding storm conditions to sea level rise, additional blockages of Route 1A in the Short Sands and Long Sands area are predicted, and many of the side streets in the bowl behind these beaches will also be inundated. At 2 feet of sea level rise, the neighborhood on the northern shore at the mouth of the Cape Neddick River (accessed via Wanaque Road) will become inaccessible at highest annual tides. During a big storm with 2 feet of sea level rise, the neighborhood around the Cape Neddick Lobster Pound and campground will also be inaccessible. With 3 feet of sea level rise, a large storm event will isolate not only these neighborhoods, but also the entire RES-6 zone (the neighborhood around Freeman and Main streets) will become isolated, and the entire Nubble neighborhood will have marginal access to Route One via Long Beach Ave (likely to be closed during a storm) and through Rogers Road

3. Impacts to Sewage Treatment

The most important public facility likely to be impacted is the sewage treatment plant. Sewage treatment plants historically have been located near or on the shore, as this is typically the lowest point in a community. The more sewage can run downhill to the plant without the need for extensive pumping, the more energy and money can be saved. York is no different than most places in this regard, with its sewage treatment plant located adjacent to Cape Neddick harbor at an elevation close to sea level. This leaves the facility vulnerable to sea level rise.

Analysis shows that a 1 foot increase in sea level, even with an associated storm, will not likely inundate any part of the treatment plant. Figure 11 shows that with two feet of sea level rise, the area immediately adjacent to the plant site would be routinely inundated during astronomical high tides several times each year, without any storm of wave activity. Figure 12 shows that should a storm with water heights seen during the 1978 event happen with 2 feet of sea level rise, with 2.6 feet of wave action (which might easily be expected in this coastal area), the plant could be flooded enough to compromise its ability to operate. Needless to say, should a sewage treatment plant be flooded, bypassing of untreated sewage could result, and this would have an adverse impact on the local marine environment and the nearby beach.

Figure 11. Potential Impact to Sewer District Treatment Plan with 2 feet of Sea Level Rise, on top of the highest annual tide

Figure 12. Potential Impact to Sewer District Treatment Plan with 2 feet of Sea Level Rise, and 2.6 feet of wave setup action, during a storm equivalent to the 1978 Storm.

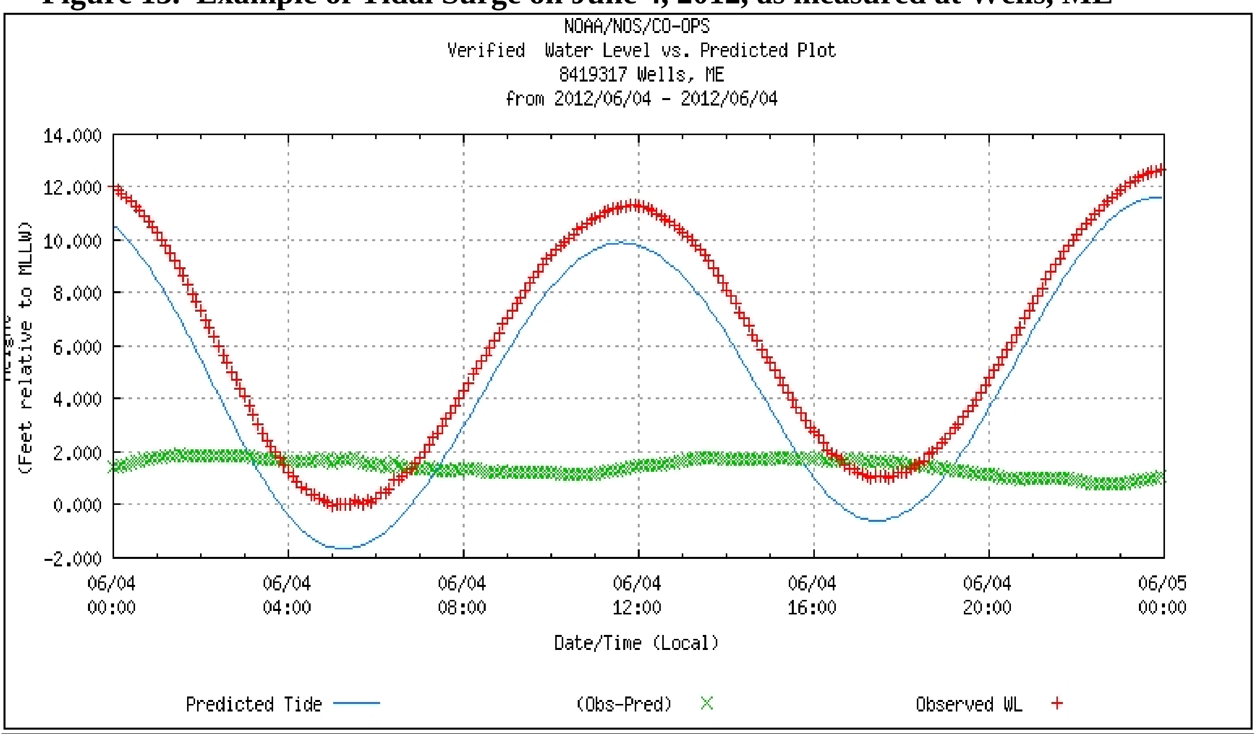
It should be noted that in neighboring Ogunquit, the sewage treatment plant has also been identified as vulnerable to sea level rise. A study recently completed for the Ogunquit Sewer District by Woodard and Curran Engineers has recommended that Ogunquit consider relocating away from its current site in 30 years, with the main recommendation that Ogunquit should connect alternately to the Wells sewage treatment system.

Tidal Surge and Freshwater Contributions

The Maine Coastal Program and Maine Geological Survey point out that when Towns prepare for long term sea level rise, any actions taken will also protect against tidal surges which can happen at any time in the short term. Therefore, these State agencies counsel Towns that many actions to adapt to sea level rise can be made now with no regrets.

Tidal surge is the term for any time the observed water level in a tidal water body is higher than the predicted level in the tide tables. Figure 13 illustrates that during June 4, 2012, there was a surge of almost 2 feet recorded at the Wells tide gauge, associated with a not particularly notable rain storm. This means that tides were running almost two feet higher than on the chart. On this particular night early that summer, seaweed was washed up onto the road at Long Sands and needed to be removed by the Town Public Works Department. Any actions taken to adapt the road at Long Sands Beach to protect against 2 feet of sea level rise would also have helped with this sort of public works maintenance problem.

Figure 13. Example of Tidal Surge on June 4, 2012, as measured at Wells, ME



If surge happens at low tide, any associated problems are minimal or non-existent. When surge happens at a high tide, flooding and damage can occur. Figure 14 shows the frequency of surges in our area, between 3 and 4 feet, which occur at high tide.

Figure 14. Frequency of various tidal surges.

Interval (yrs)	Surge at MHW (ft)	High Water Level (ft, MLLW)
1	1.1	11.7
5	2	12.6
10	2.4	12.9
25	2.9	13.4
50	3.3	13.7
100	3.7	14.1

Based on statistical analysis of hourly annual maximum tidal data at the Portland tide gauge from 1912-2012.

Surge levels and tide levels found on NOAA charts are "Still Water" elevations, like the waterline in a calm bath tub. Of course, it is unusual for the salt water in our area to be that still. Most of the scenarios of sea level rise found in the vulnerability assessment for this Plan did not take into account wave action or changes to shoreline from erosion. It is relatively easy to predict static water levels over time – tide tables have done it for years. Wave action and erosion are harder to predict. Erosion events can be very dramatic, and cause drastic changes, or can happen gradually over time, or both.

Predicted tide and surge levels also do not take into account concurrent intense rain events, which add freshwater runoff to the saltwater. During the Mother's Day and Patriot's Day storms in 2006 and 2007, as experienced in York Beach, the impacts from freshwater flooding greatly compounded the saltwater tidal surge levels. Therefore the scenarios of possible damages from sea level rise to buildings, roads, and the sewage treatment plant are very conservative. Any of the predictions can be considered to be on the low side, with any extreme rainfall, erosion or wave action that happens during storms, surely making things even worse.

APPENDIX A

Measuring Sea Level

"How Do They Measure Sea Level"

An accurate measurement of sea level is very hard to pin down. But it is an important measurement for two main reasons:

- By having an accurate sea level measurement, it is possible to measure the height of everything on land accurately. For example, calculating the height of Mt. Everest is complicated by sea-level measurement inaccuracies.

- By knowing sea level, we can determine if the oceans are rising or falling over time. The concern is that global warming and other weather changes caused by man might be leading to an overall rise in sea level. If so, coastal cities are in big trouble.

The problem with measuring the sea level is that there are so many things that perturb it. If you could take planet Earth and move it out into deep space so that the sun, moons and other planets did not affect it and there were no temperature variations worldwide, then everything would settle down like a still pond. Rain and wind would stop, and so would the rivers. Then you could measure sea level accurately. If you did this, the level of the ocean's water projected across the entire planet would be called the geoid. On land, you can think of the geoid as the level that ocean water would have if you were to dig a canal from the ocean's shore to any point on land.
But the Earth is not in deep space -- it is in the middle of a chaotic solar system. There are all sorts of things changing the water level at any given point, including:

- The tides, caused by the moon

- Large and small waves caused by wind and the tides

- High- and low-pressure areas in the atmosphere, which change the surface level of the ocean

- Temperature changes in the ocean, which change the density and volume of the water

- Rainfall and river water flowing into the ocean

If you were to stand on the ocean shore and try to measure sea level with a ruler, you would find it to be impossible -- the level changes by the second (waves), by the hour (tides) and by the week (planetary and solar orbit changes). To get around this, scientists try using tide gauges. A tide gauge is a large (1 foot [30 cm] or more in diameter), long pipe with a small hole below the water line. This pipe is often called a stilling well. Even though waves are changing the water level outside the gauge constantly, they have little effect inside the gauge. The sea level can be read relatively accurately inside this pipe. If read on a regular basis over a time span of years and then averaged, you can get a measurement of sea level.

You can see that getting an accurate reading (for example, down to the millimeter level) is extremely difficult. Satellites are now used as well, but they suffer from many of the same problems. Scientists do the best they can, using extremely long time spans, to try to figure out what the sea level is and whether or not it is rising. The general consensus seems to be that the oceans rise about 2 millimeters per year (although the last link below has an interesting discussion on that consensus...).

Source: www.science.howstuffworks.com; downloaded verbatim on May 2, 2013.

APPENDIX B

Other Sea Level Rise Adaptation Efforts in Maine

Peter Slovinsky, Senior Coastal Geologist with Maine Geological Survey, has identified 4 regional efforts in Maine to address coastal resiliency. These include:

Coastal Hazard Resiliency Tools (CHRT). This is a NOAA- and Maine Coastal Program- funded project, with input from Maine Geological Survey, Southern Maine Regional Planning Commission, and the Greater Portland Council of Governments. It is an overall effort to analyze impacts of varying storm and sea level rise scenarios on the built and natural environment. The area of coverage included: Kittery, York, Ogunquit, Kennebunk, Biddeford*, Saco*, Old Orchard Beach*, Scarborough*, South Portland, Portland, and Freeport. The 4 communities designated by an asterisk are also members in the Saco Bay Sea Level Adaption Working Group (SLAWG).

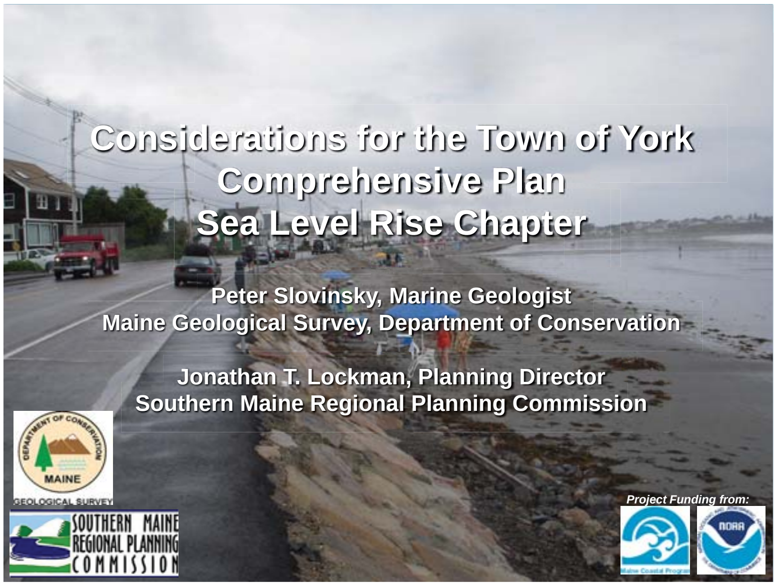
Marsh Migration Project. This was an EPA-funded project from 2010 through 2012, with input from Maine Geological Survey and the Maine Natural Areas Program. This involved simulation of marsh migration with 2 feet and 1 meter of sea level rise. The area of coverage included: Kittery, York, Ogunquit, Wells, Kennebunk, Kennebunkport, Biddeford, Saco, Old Orchard Beach, Scarborough, Cape Elizabeth, South Portland, Portland, Falmouth, Cumberland, Yarmouth, Freeport, Brunswick, Harpswell, Phippsburg and Georgetown.

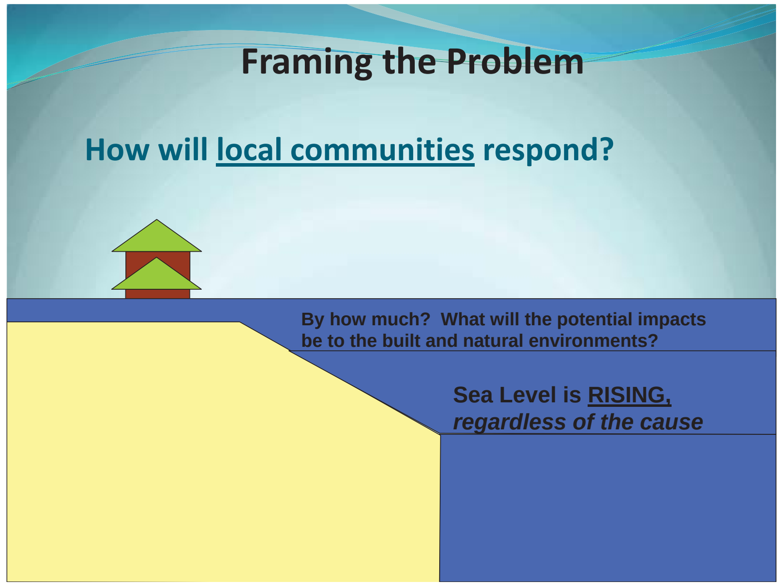
Lincoln County Resiliency Project. This was a Maine Coastal Program project from 2012 through 2013, with input from the Lincoln County Regional Planning Commission. This is a study to assess the vulnerability of infrastructure to varying storm and sea level rise scenarios. This included all the coastal communities in the County.

Marsh Migration Project. A NOAA Project of Special Merit from 2012 through 2014, with input from the Maine Geological Survey, Maine Coastal Program, and Maine Inland Fisheries and Wildlife. This is a similar though not identical study to that listed above, and covering a different mix communities – Topsham, Bath, Bowdoinham, Georgetown, Phippsburg and Scarborough.

APPENDIX C

Presentation Slides – Adaptation to Sea Level Rise





Why *does* sea level change?

Global Sea Levels…

Thermal Expansion (the ocean heats up and expands as the atmosphere warms)

Volumetric Increase (volume increases with water from melting glaciers and land-based ice sheets)

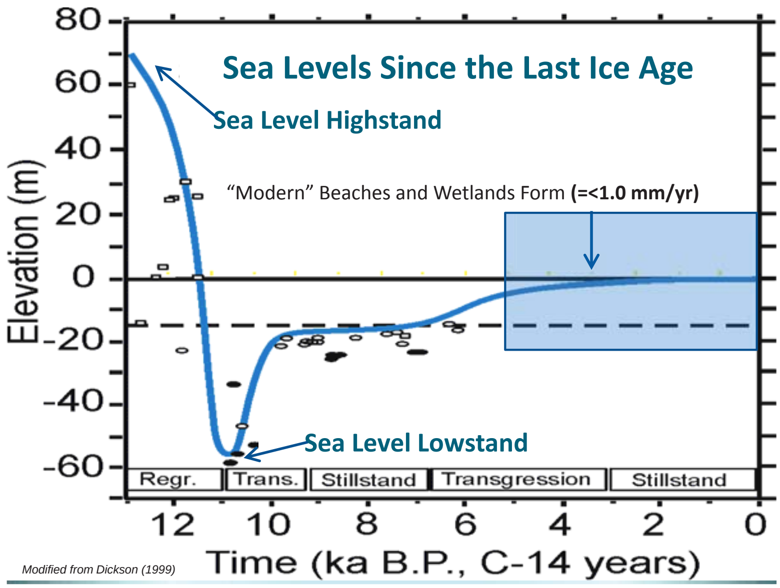
Global climate variation (impacts of ENSO, i.e., El Nino/La Niña)

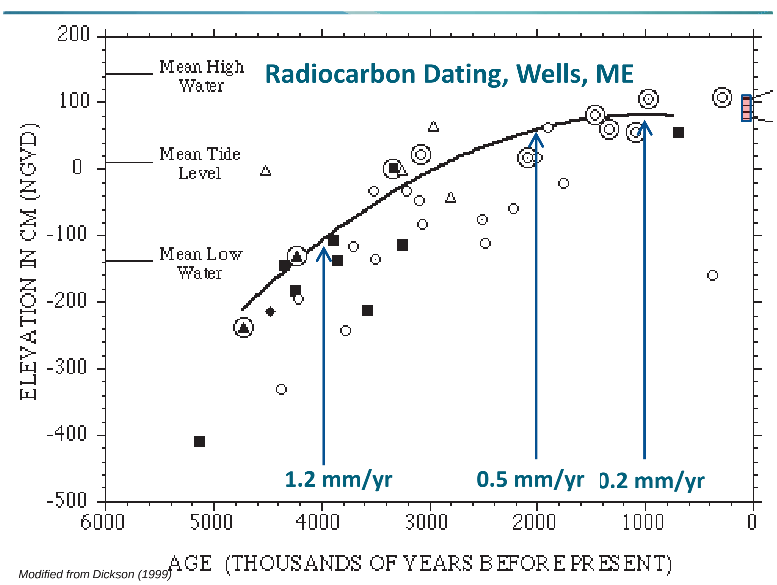
Relative (or "Local") Sea levels…

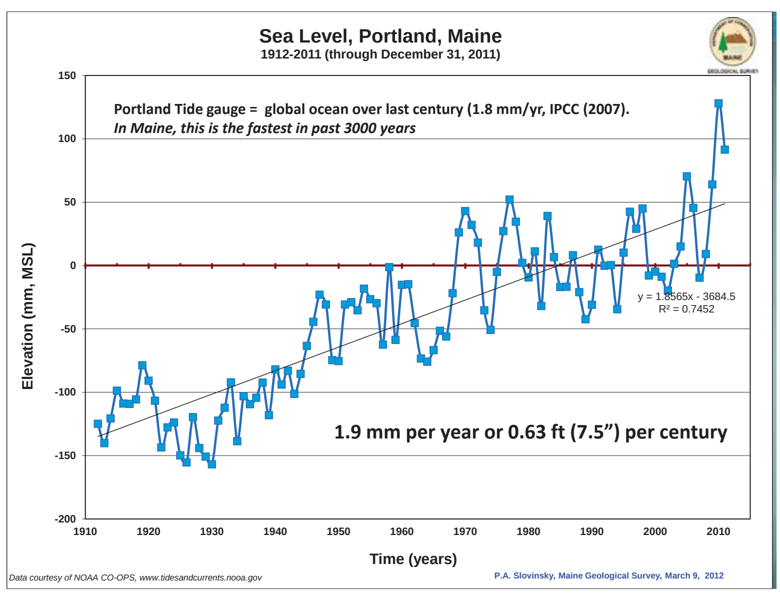
Isostatic rebound (response of the crust to glaciation)

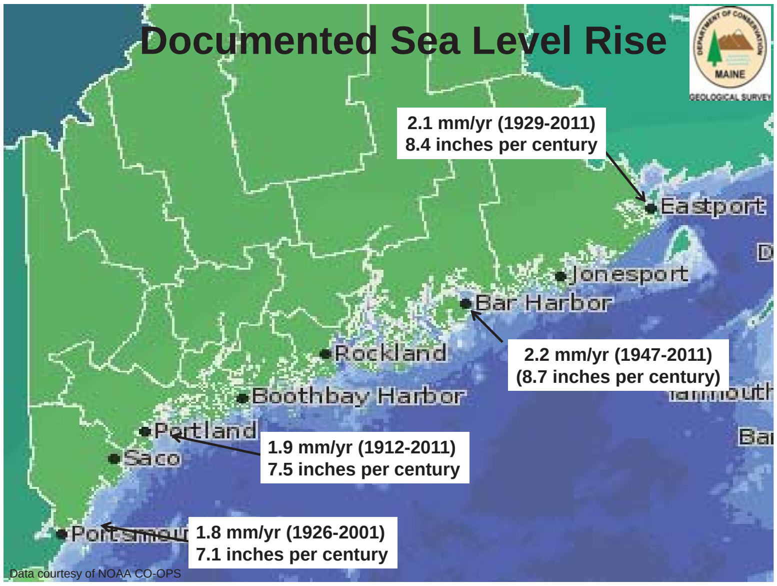
Subsidence (sinking of the land due to other factors than isostasy)

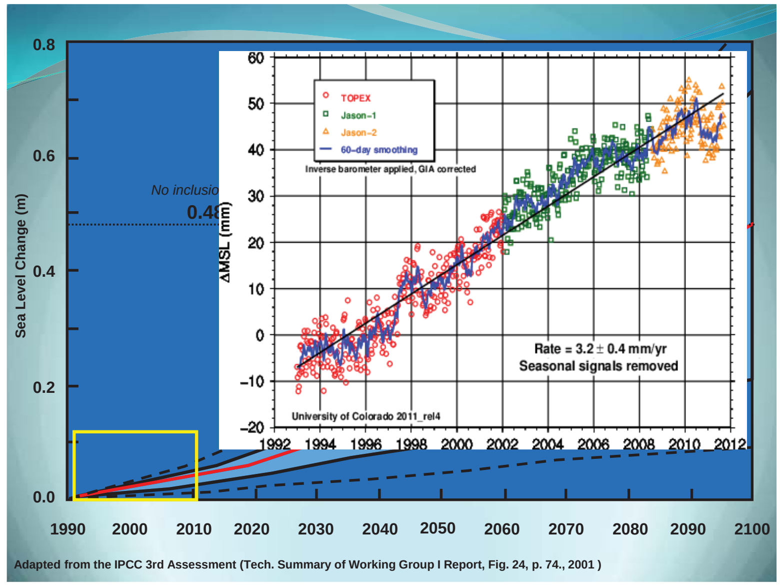
Seasonal Variations (due to local or regional weather patterns)

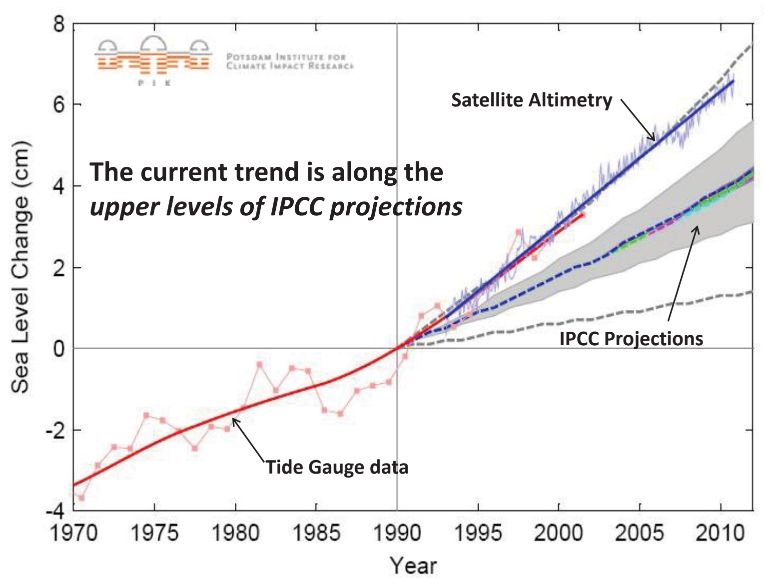


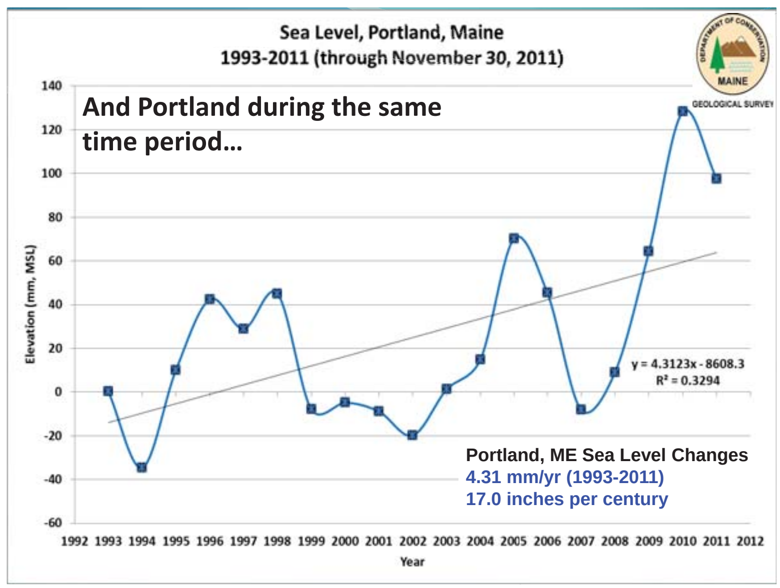


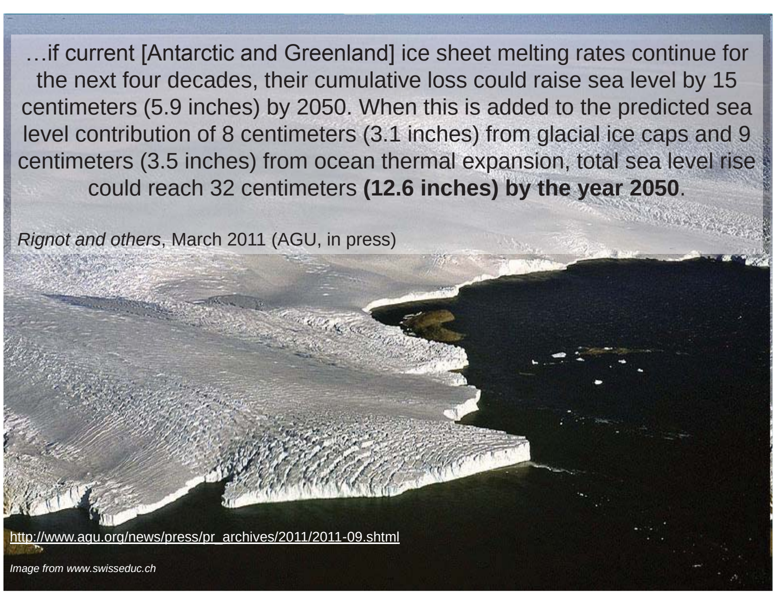


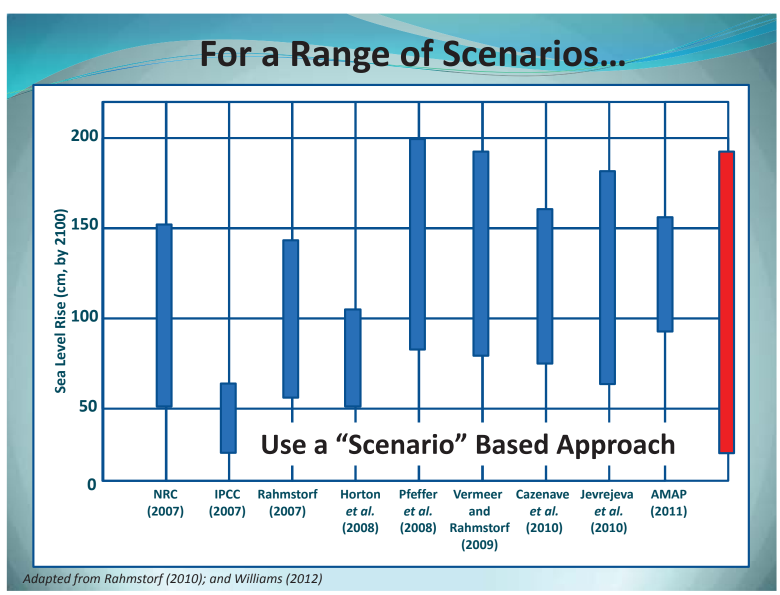

Documented Sea Level Rise
MAINE GEOLOGICAL SURVEY
2.1 mm/yr (1929-2011)
8.4 inches per century
Eastport
Jonesport
Bar Harbor
2.2 mm/yr (1947-2011)
(8.7 inches per century)
Rockland
Boothbay Harbor
Portland
1.9 mm/yr (1912-2011)
7.5 inches per century
Saco
1.8 mm/yr (1926-2001)
7.1 inches per century
Data courtesy of NOAA CO-OPS


Sea Level Change (m)
No inclusio
0.48
ΔMSL (mm)
TOPEX
Jason−1
Jason−2
60−day smoothing
Inverse barometer applied, GIA corrected
Rate = 3.2 ± 0.4 mm/yr
Seasonal signals removed
University of Colorado 2011_rel4
Adapted from the IPCC 3rd Assessment (Tech. Summary of Working Group I Report, Fig. 24, p. 74., 2001)


POTSDAM INSTITUTE FOR CLIMATE IMPACT RESEARCH
PIK
Satellite Altimetry
The current trend is along the
upper levels of IPCC projections
IPCC Projections
Tide Gauge data
Sea Level Change (cm)
Year


Sea Level, Portland, Maine
1993-2011 (through November 30, 2011)
MAINE GEOLOGICAL SURVEY
And Portland during the same
time period…
Elevation (mm, MSL)
y = 4.3123x - 8608.3
R² = 0.3294
Portland, ME Sea Level Changes
4.31 mm/yr (1993-2011)
17.0 inches per century
Year


…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 (AGU, in press)
http://www.agu.org/news/press/pr_archives/2011/2011-09.shtml
Image from www.swisseduc.ch


For a Range of Scenarios…
Sea Level Rise (cm, by 2100)
Use a "Scenario" Based Approach
NRC (2007)
IPCC (2007)
Rahmstorf (2007)
Horton et al. (2008)
Pfeffer et al. (2008)
Vermeer and Rahmstorf (2009)
Cazenave et al. (2010)
Jevrejeva et al. (2010)
AMAP (2011)
Adapted from Rahmstorf (2010); and Williams (2012)

Vulnerability Assessment

Sea level rise scenarios (by 2100, or a "phased" approach):

- **0.3 meters (1 foot)**
- **0.6 meters (2 feet)**
- **1.0 meters (3.28 feet)**
- **1.8 meters (5.95 feet)**

"Scenario-based" Approach

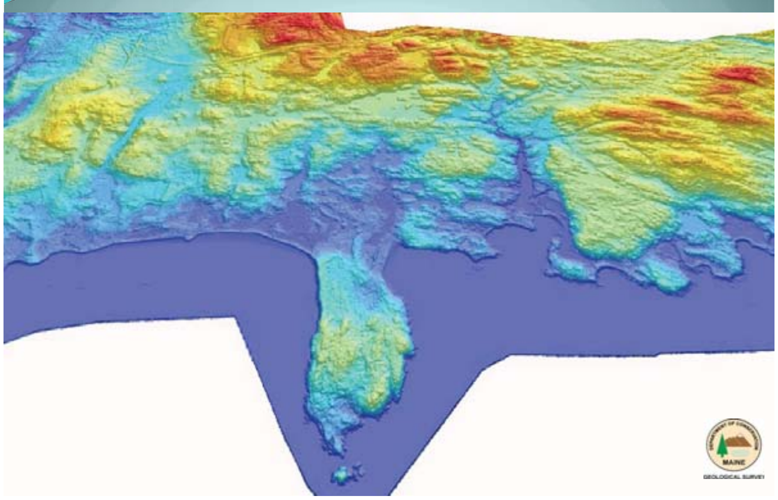
- Scenarios **assume static topography** ('bathtub model').
- Scenarios **do not include** the effects of **freshwater runoff from rain events or waves.**
- The **Highest Annual Tide (HAT)** and the **1978 storm** stillwater elevation were used as a basis for simulating impacts to infrastructure.
- For assessing impacts to buildings, it was assumed that the **entire building was impacted** if inundation intersected the building footprint.
- For assessing impacts to roads, it was assumed that inundation of a road made it **impassable** but did not assume the road would be damaged.
- For assessing impacts to wetlands, tidal elevations were used as proxies for different marsh surfaces.

Using the Sea Level Rise Simulation Tool

Steps:

1) Groundtruth **LiDAR** data for representing ground conditions using RTK – GPS *(very accurate).*
2) Determine Tidal Elevations as proxies for existing marsh surfaces using nearby tide gauge data
3) Demonstrate accuracy in simulating **existing conditions** using **tidal elevations** to define marsh habitats and inundation
4) Simulate **potential impacts of sea level** rise on:
   a) Marsh Habitat
   b) Existing Buildings and Road Infrastructure
5) Identify areas potentially suitable for marsh migration and at-risk built infrastructure

Couldn't do it without LIDAR!



Coastal wetlands

"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

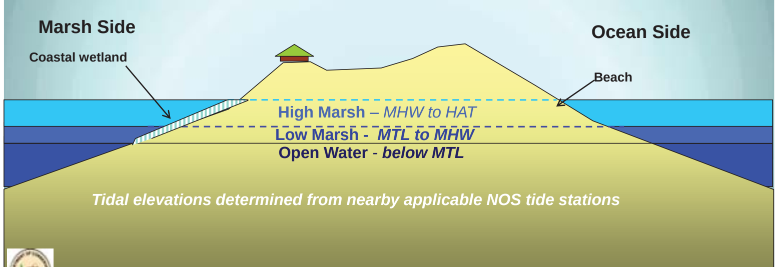
P.A. Slovinsky, MGS

Setting the Stage with Tidal Elevations

Highest Annual Tide (HAT) - "spring" tide, the highest predicted water level for any given year but is reached within several inches numerous tides a year

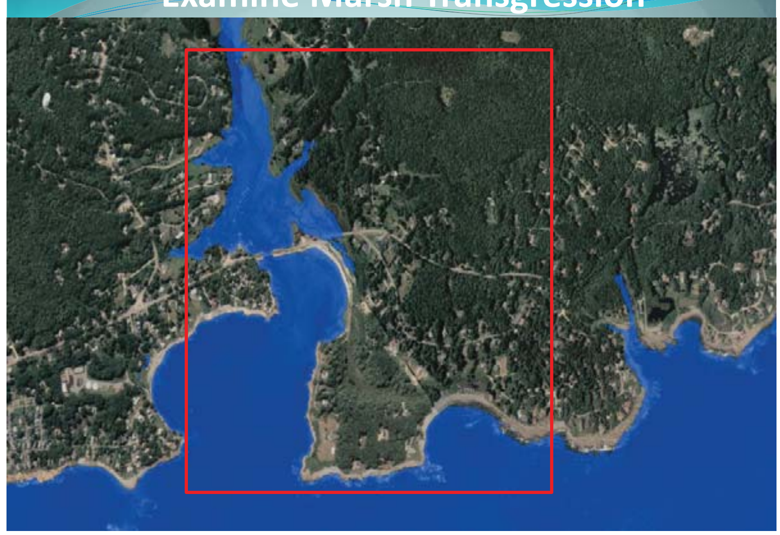
Mean High Water (MHW) - the average normal high water level.

Mean Tide Level (MTL) = average height of the ocean's surface (between mean high and mean low tide).



P.A. Slovinsky, MGS

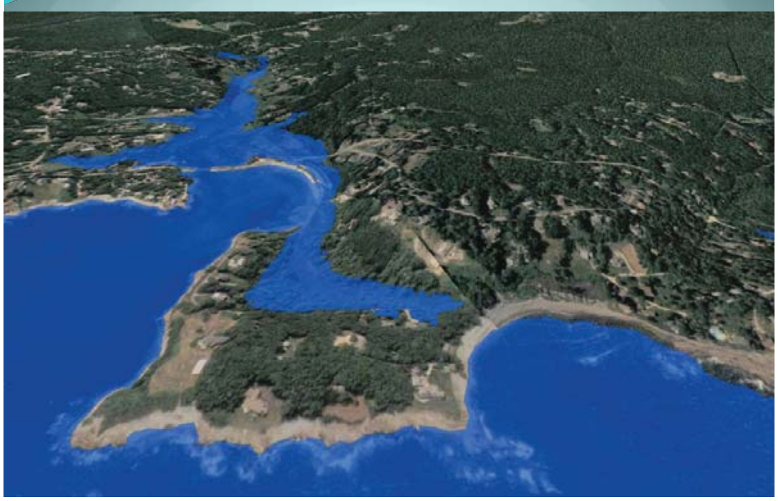
Examine Marsh Transgression



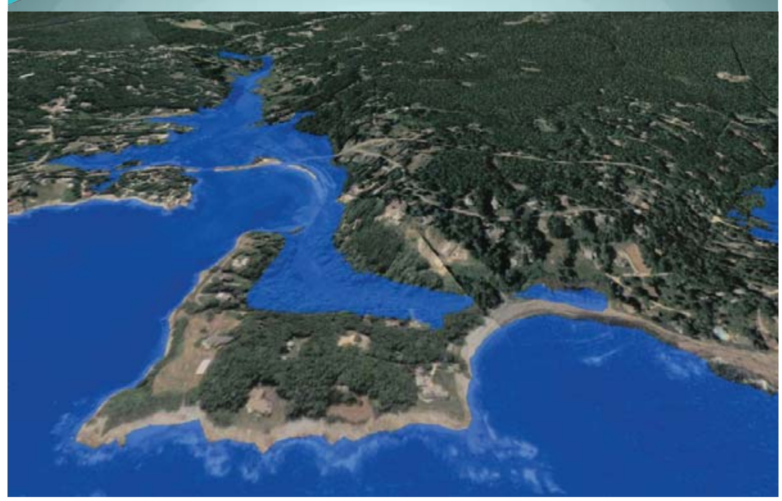
Existing Conditions (HAT)

Future Conditions (HAT+0.3m)

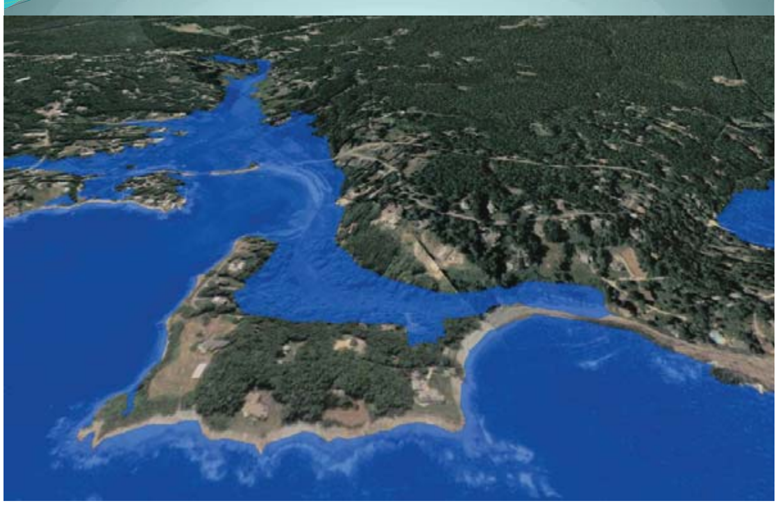
Future Conditions (HAT+0.6m)



Future Conditions (HAT+1.0m)



Future Conditions (HAT+1.8m)



Implications

Use Tidal Elevations to simulate existing wetlands, and potential future coastal wetland migration in response to SLR.

This will help identify low-lying, undeveloped uplands where marshes may migrate unimpeded, and areas where development (roads, buildings, etc.) may be inundated.

Infrastructure Vulnerability Assessment

Highest Annual Tide (HAT), is the highest predicted water level for any given year. For 2012, the predicted HAT was 6.4 ft NAVD88 (11.6 ft MLLW).

1978 Storm is the highest recorded water level at the Portland Tide Gauge which occurred on the February 7, 1978 Noreaster' Storm (~3.0 feet of surge). The "100-year" storm, 8.9 ft NAVD88, (14.1 ft MLLW). *Does not include wave impacts!*

Scenario	Highest Annual Tide	1978 Storm
Existing	6.4 feet	8.9 feet
+0.3 m (1 ft) SLR	7.4 feet	9.9 feet
+0.6 m (2 ft) SLR	8.4 feet	10.9 feet
+1.0 m (3.3 ft) SLR	9.7 feet	12.2 feet
+1.8 m (6.0 ft) SLR	12.2 feet	14.9 feet

All elevations referenced to NAVD88; 0 ft NAVD88 approximately 5.2 ft above MLLW.

Infrastructure Vulnerability Assessment

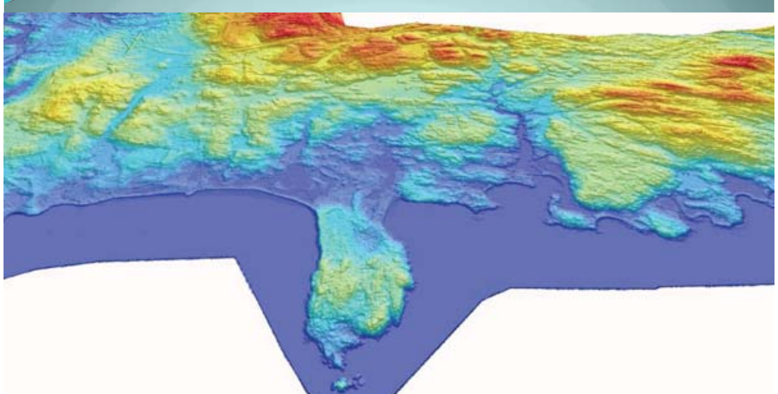
** Plan for **"Today's Storms and Tomorrow's Tides"** **

Surge Amount	Frequency	Last Occurred
3.0 feet or more*	1 in 7 years	Oct 30, 1991
3.5 feet or more*	1 in 14 years	Oct 30, 1991
4.0 feet or more*	1 in 47 years	Mar 3, 1947

**at time of high tide only; surges of these levels are much more frequent (i.e., February 26, 2010 had a surge of 4.4 feet but at mid-falling tide)*

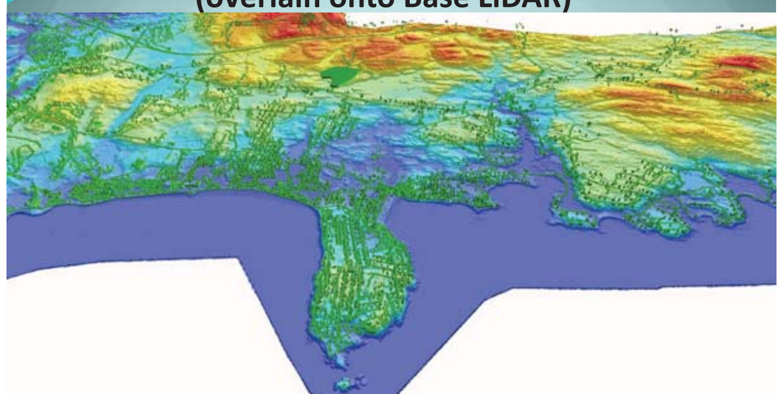
Source: John Cannon, NWS, Gray, Maine. May include storms through 2008.

Base LiDAR Data



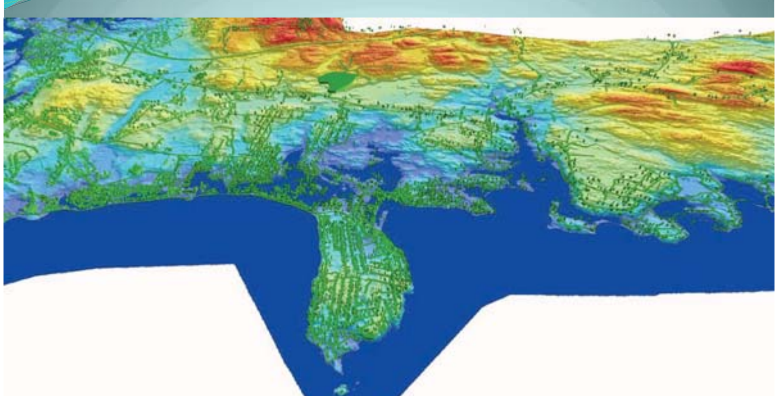
2006 LiDAR tiles (18 cm RMSE)
Mosaic and clip to municipal boundaries

Buildings and Transportation Infrastructure (overlain onto Base LiDAR)



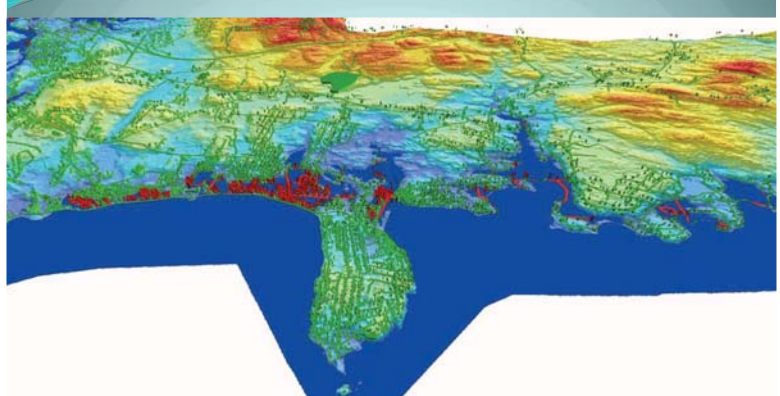
Add Polygon layers for buildings and roads (municipal)

Simulate Inundation Levels



Determine future inundation levels under different scenarios
Raster queries to determine areas below certain water levels

Identify Potentially Inundated Infrastructure



Determine inundation impacts to buildings and infrastructure

Preliminary Evaluation of Impacts from Highest Annual Tide (HAT) and 1978 Storm Inundation

Buildings

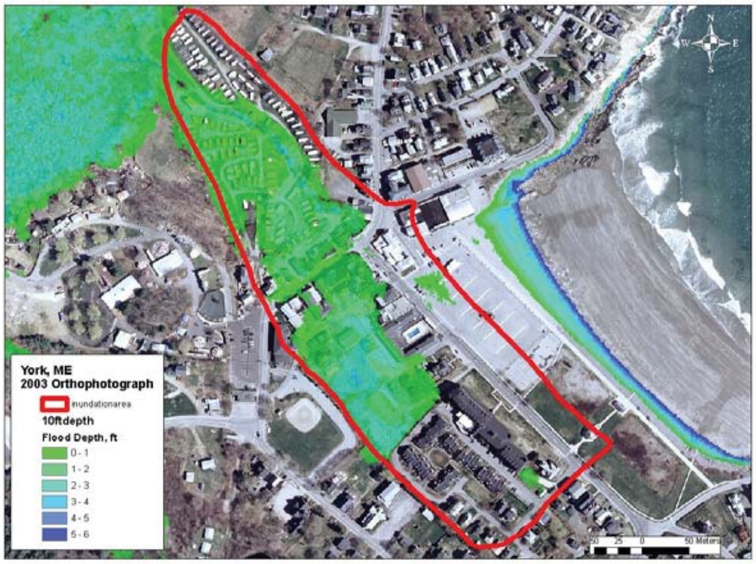
Highest Annual Tide Simulations

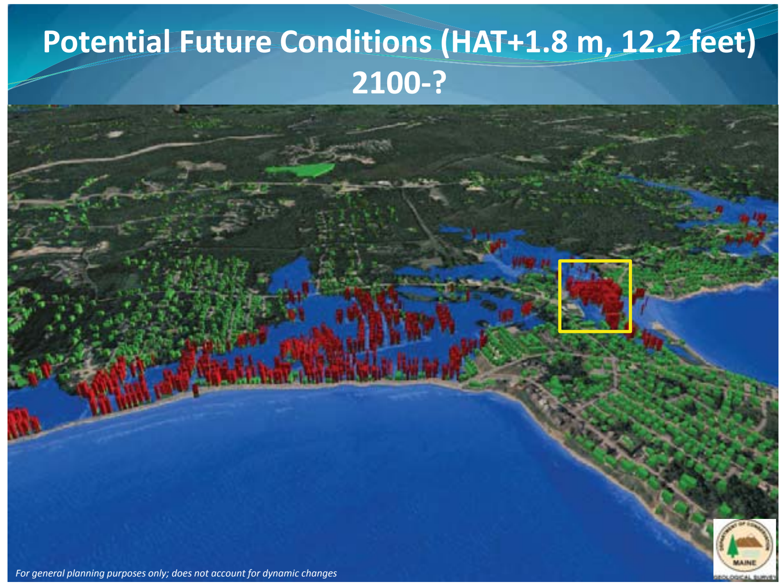
Existing Conditions – HAT (6.4 feet)

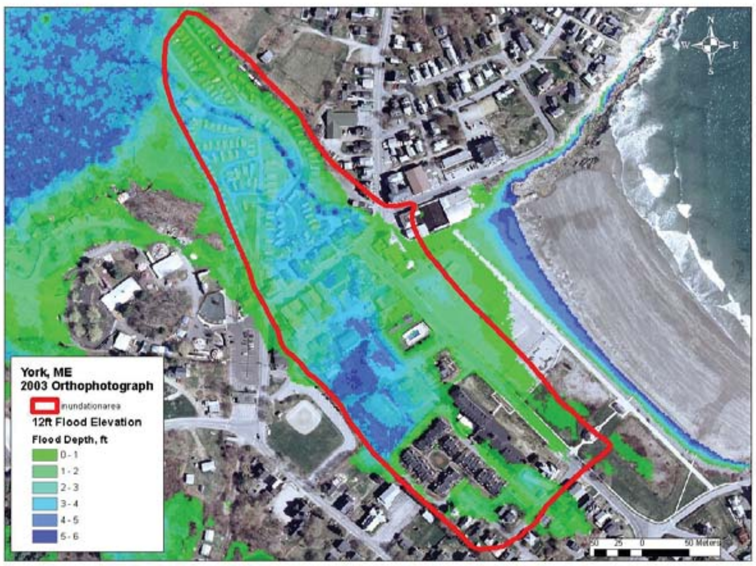
Potential Future Conditions (HAT+0.3 m) 2030-2050?

Potential Future Conditions (HAT+0.6 m, 8.4 feet) 2050-2100?

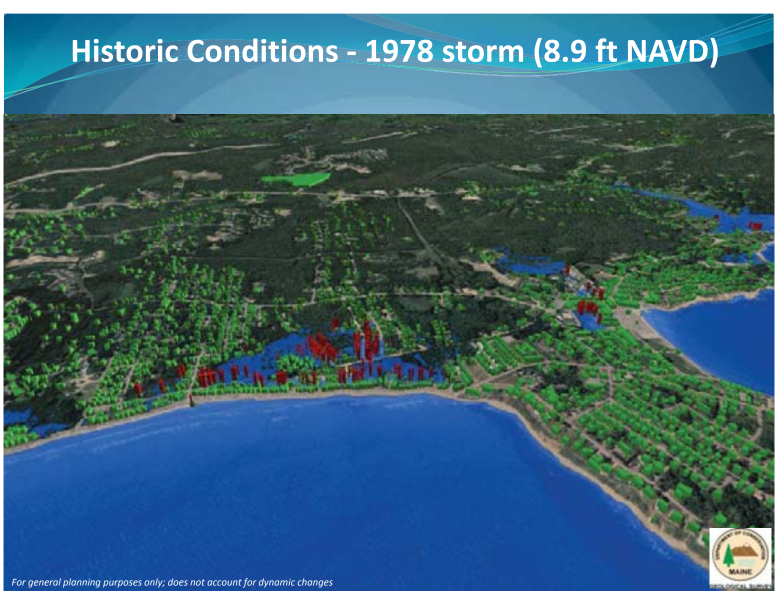
Potential Future Conditions (HAT+1.0 m, 9.7 feet) 2100?

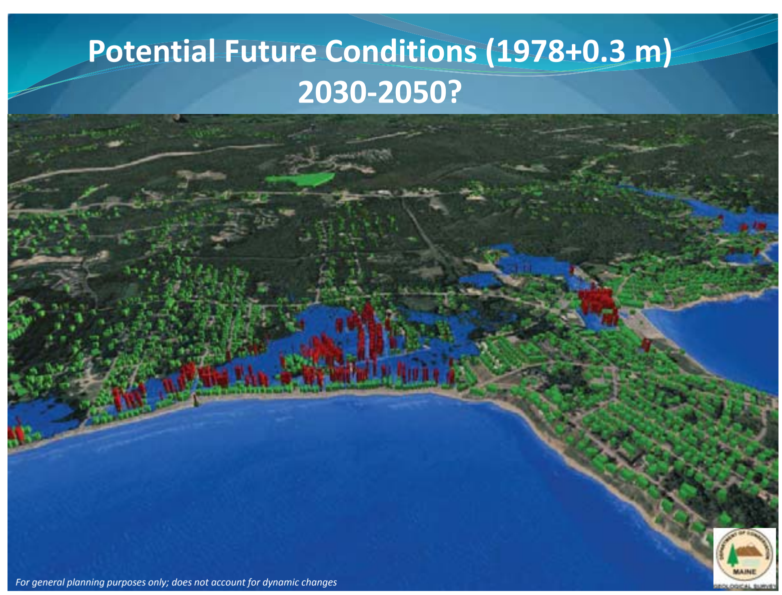

York, ME
2003 Orthophotograph
inundationarea
10ftdepth
Flood Depth, ft
0 - 1
1 - 2
2 - 3
3 - 4
4 - 5
5 - 6
50 25 0 50 Meters


Potential Future Conditions (HAT+1.8 m, 12.2 feet)
2100-?
For general planning purposes only; does not account for dynamic changes


York, ME
2003 Orthophotograph
inundationarea
12ft Flood Elevation
Flood Depth, ft
0 - 1
1 - 2
2 - 3
3 - 4
4 - 5
5 - 6
50 25 0 50 Meters

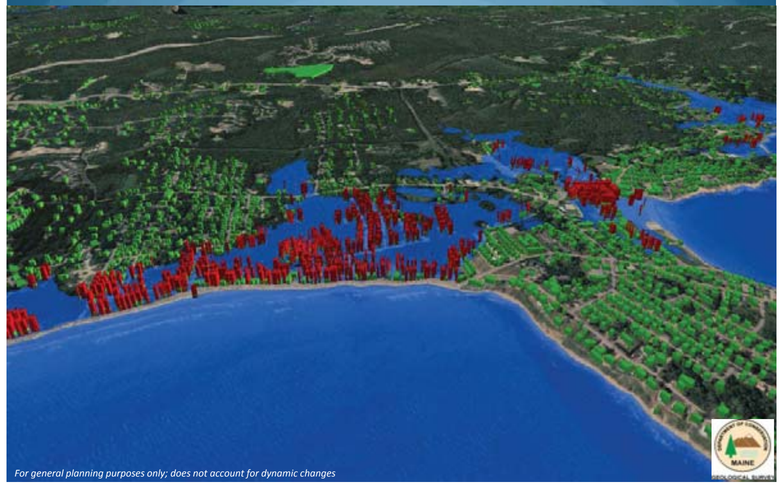

1978 Storm ("100 year") Simulations
For general planning purposes only; does not account for dynamic changes


Historic Conditions - 1978 storm (8.9 ft NAVD)
For general planning purposes only; does not account for dynamic changes


Potential Future Conditions (1978+0.3 m)
2030-2050?
For general planning purposes only; does not account for dynamic changes

Potential Future Conditions (1978+0.6 m) 2050-2100?

Potential Future Conditions (1978+1.0 m) 2100?



Potential Future Conditions (1978+1.8 m) 2100-?

Summary of Potentially Vulnerable* Building Infrastructure

Scenario	Highest Annual Tide (6.4 ft)	1978 Storm (8.9 ft)
Existing	4	101
+0.3 m (1 ft) SLR	6	204
+0.6 m (2 ft) SLR	38	342
+1.0 m (3.3 ft) SLR	192	528
+1.8 m (6.0 ft) SLR	564	868

includes only primary buildings, excludes decks, dock structures, outbuildings, pools, mobile homes

elevations referenced to NAVD88

** Assumes "bathtub" flooding, no wave setup, static topography, and that a building is "inundated" if the flooding scenario **covers** the centroid of the building footprint, regardless of the flooding depth. Does not assign any kind of damage function.*

Preliminary Evaluation of Impacts from 1978 Storm Inundation (no wave setup)

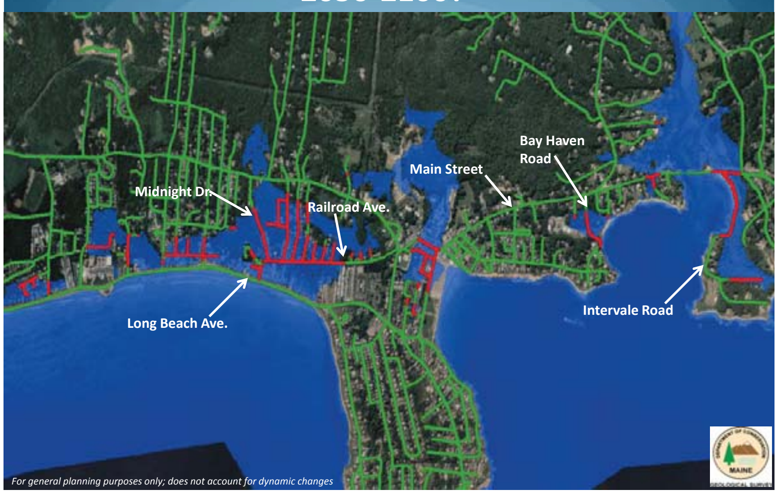
Transportation Infrastructure

Transportation Infrastructure

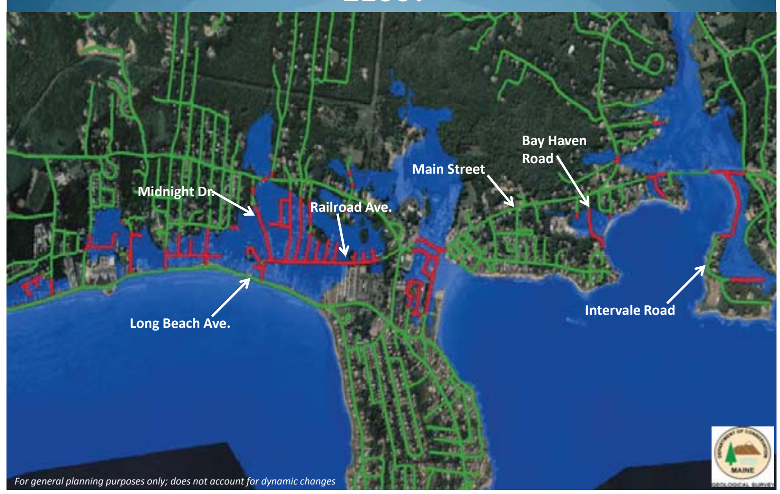
Historic Conditions - 1978 storm (8.9 ft NAVD)

Potential Future Conditions (1978+0.3 m) 2030-2050?

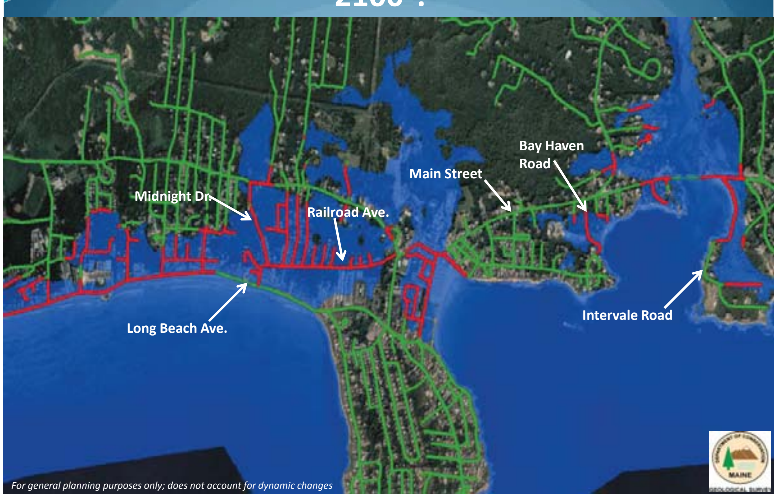
Potential Future Conditions (1978+0.6 m) 2050-2100?



Potential Future Conditions (1978+1.0 m) 2100?



Potential Future Conditions (1978+1.8 m) 2100-?



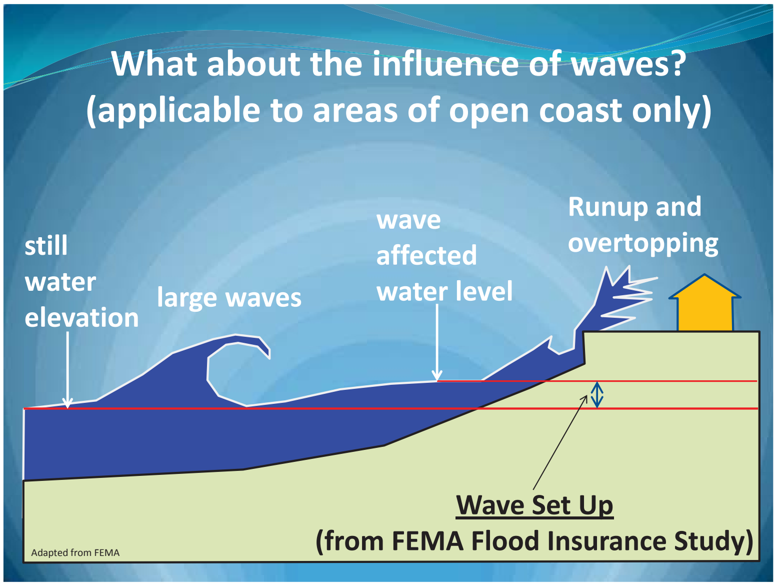
Summary of Potentially Vulnerable* Road Infrastructure

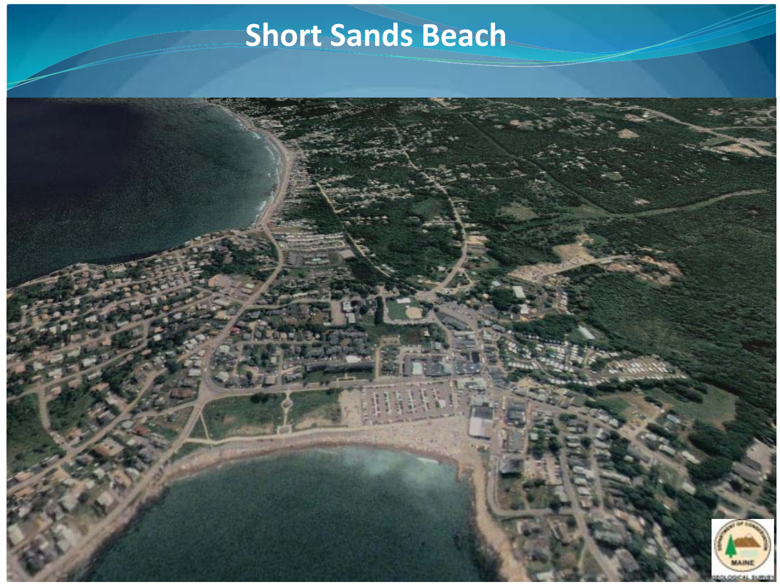
Scenario	Highest Annual Tide (6.4 ft)	1978 Storm (8.9 ft)
Existing	0.1 miles	1.9 miles
+0.3 m (1 ft) SLR	0.2 miles	4.1 miles
+0.6 m (2 ft) SLR	1.1 miles	6.6 miles
+1.0 m (3.3 ft) SLR	3.8 miles	9.5 miles
+1.8 m (6.0 ft) SLR	9.9 miles	15.9 miles

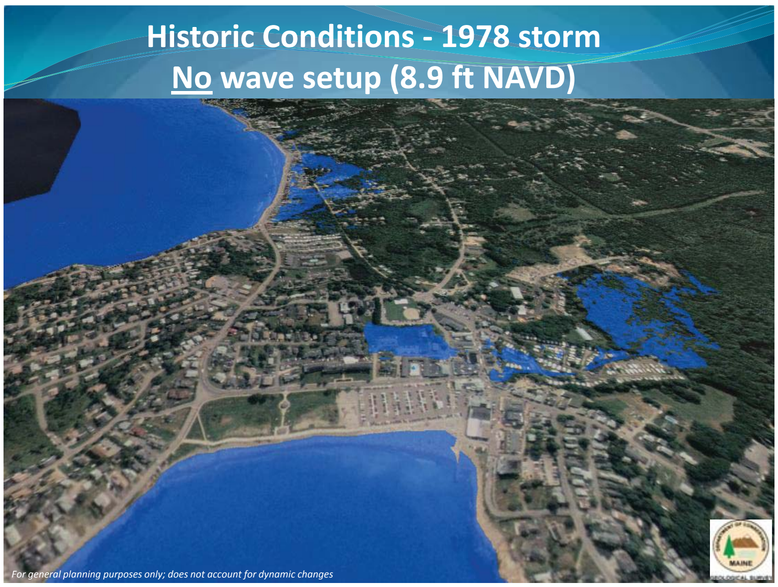
elevations referenced to NAVD88

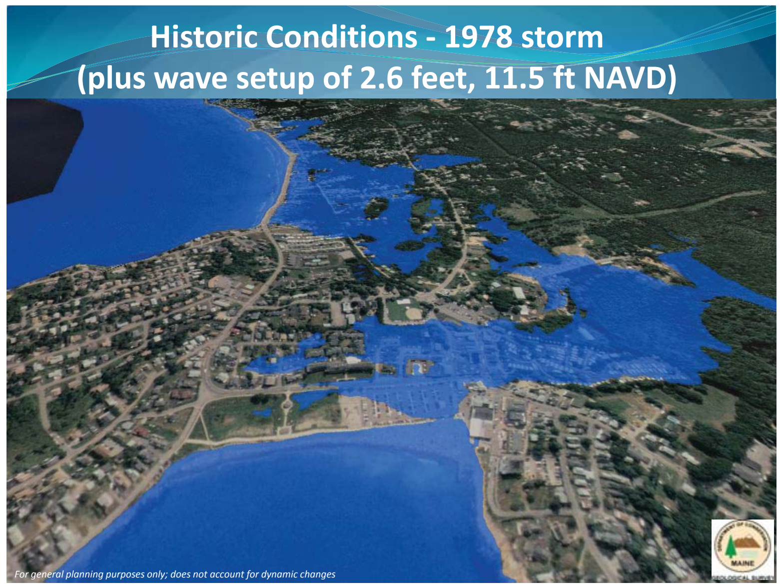
excludes bridges removed from LiDAR

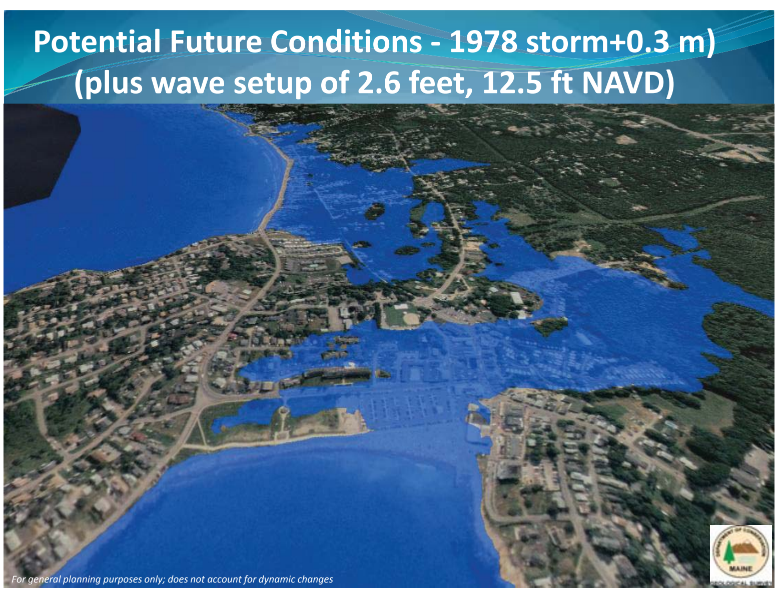
** Assumes "bathtub" flooding, no wave setup, static topography, and that a road is "inundated" if the flooding scenario **covers** the entire road, regardless of the flooding depth. Does not assign any kind of damage function.*

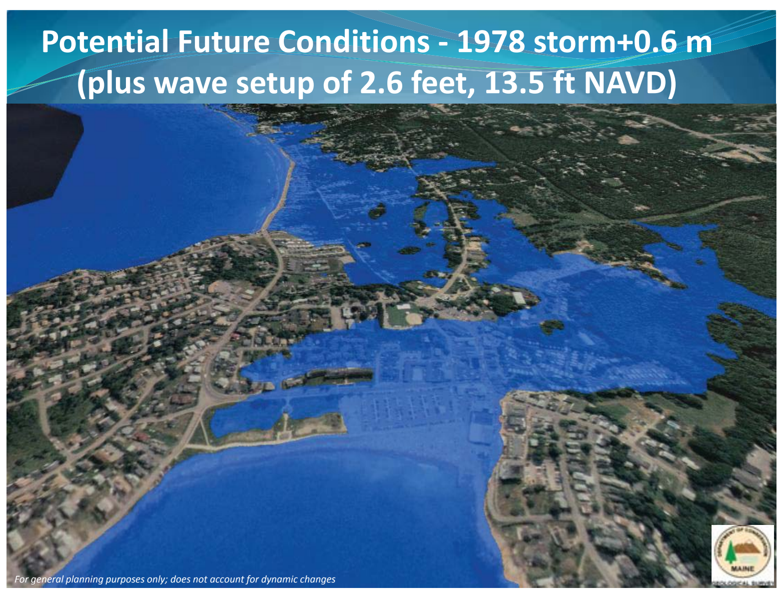

What about the influence of waves?
(applicable to areas of open coast only)
still
water
elevation
large waves
wave
affected
water level
Runup and
overtopping
Wave Set Up
(from FEMA Flood Insurance Study)
Adapted from FEMA

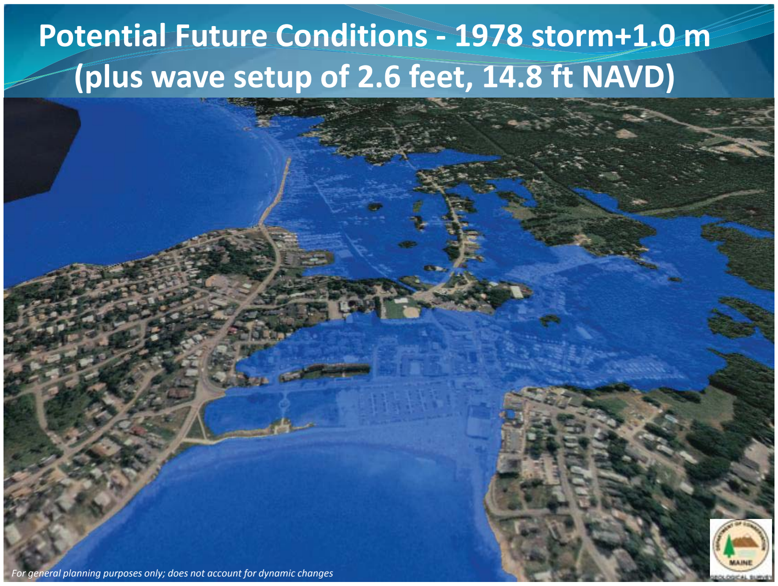

Short Sands Beach

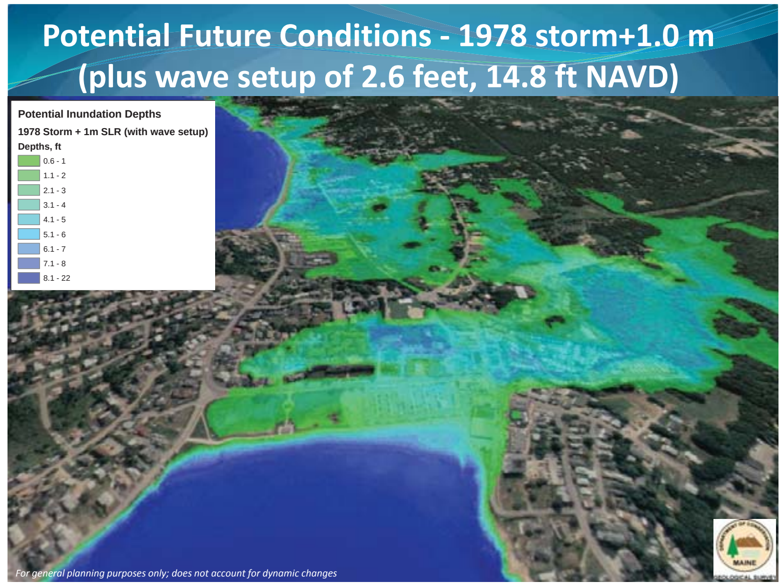

Historic Conditions - 1978 storm
No wave setup (8.9 ft NAVD)
For general planning purposes only; does not account for dynamic changes

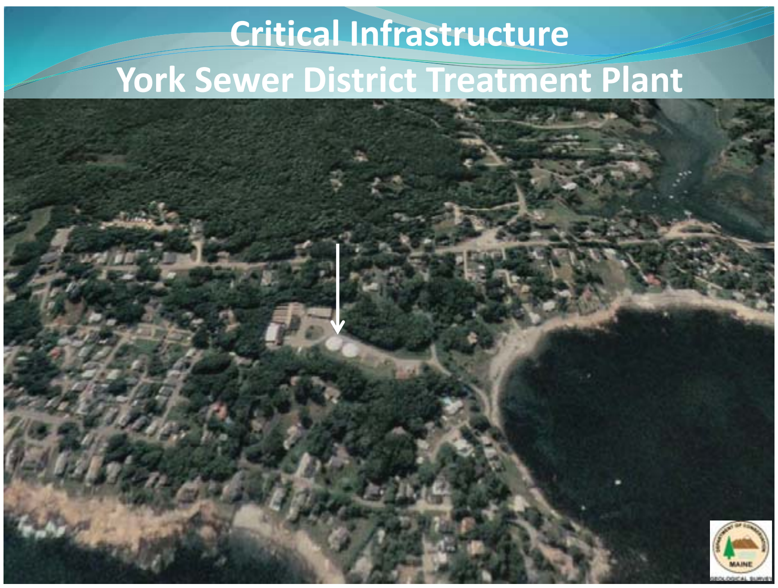

Historic Conditions - 1978 storm
(plus wave setup of 2.6 feet, 11.5 ft NAVD)
For general planning purposes only; does not account for dynamic changes


Potential Future Conditions - 1978 storm+0.3 m)
(plus wave setup of 2.6 feet, 12.5 ft NAVD)
For general planning purposes only; does not account for dynamic changes

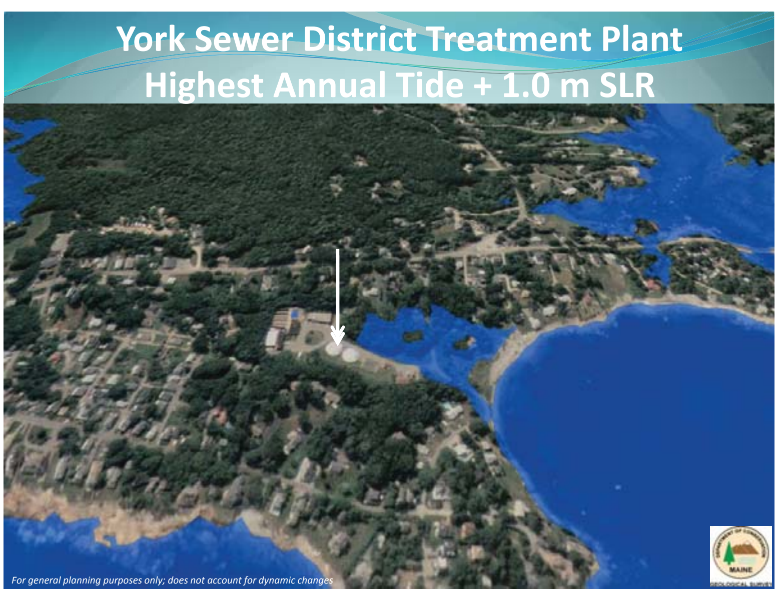

Potential Future Conditions - 1978 storm+0.6 m
(plus wave setup of 2.6 feet, 13.5 ft NAVD)
For general planning purposes only; does not account for dynamic changes

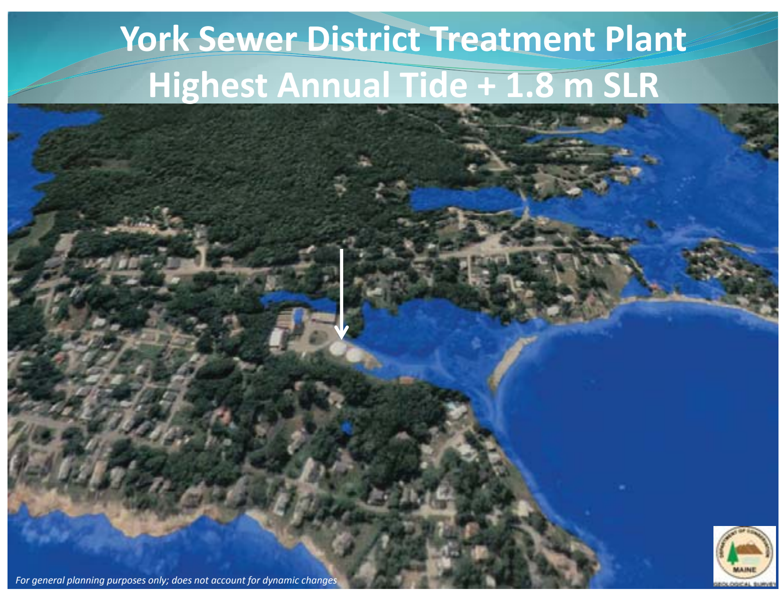

Potential Future Conditions - 1978 storm+1.0 m
(plus wave setup of 2.6 feet, 14.8 ft NAVD)
For general planning purposes only; does not account for dynamic changes

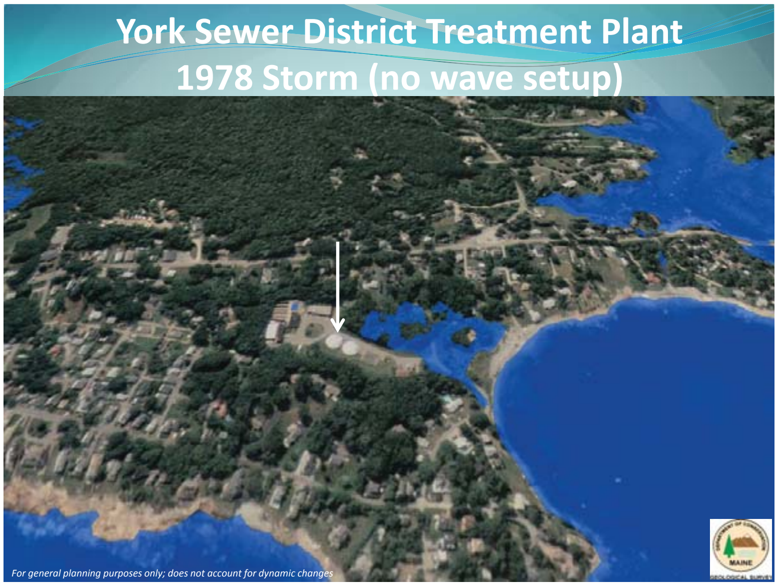

Potential Future Conditions - 1978 storm+1.0 m
(plus wave setup of 2.6 feet, 14.8 ft NAVD)
Potential Inundation Depths
1978 Storm + 1m SLR (with wave setup)
Depths, ft
0.6 - 1
1.1 - 2
2.1 - 3
3.1 - 4
4.1 - 5
5.1 - 6
6.1 - 7
7.1 - 8
8.1 - 22
For general planning purposes only; does not account for dynamic changes


Critical Infrastructure
York Sewer District Treatment Plant


York Sewer District Treatment Plant
Highest Annual Tide + 0.6 m SLR
For general planning purposes only; does not account for dynamic changes


York Sewer District Treatment Plant
Highest Annual Tide + 1.0 m SLR
For general planning purposes only; does not account for dynamic changes


York Sewer District Treatment Plant
Highest Annual Tide + 1.8 m SLR
For general planning purposes only; does not account for dynamic changes

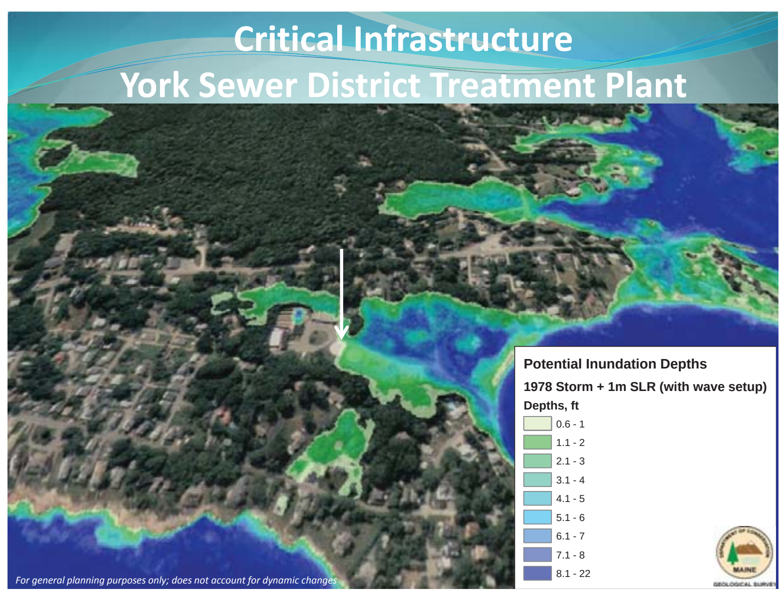

York Sewer District Treatment Plant
1978 Storm (no wave setup)
For general planning purposes only; does not account for dynamic changes


York Sewer District Treatment Plant
1978 Storm (2.6 ft wave setup)
For general planning purposes only; does not account for dynamic changes


York Sewer District Treatment Plant
1978 Storm + 0.3 m SLR (2.6 ft wave setup)
For general planning purposes only; does not account for dynamic changes


York Sewer District Treatment Plant
1978 Storm + 0.6 m SLR (2.6 ft wave setup)
For general planning purposes only; does not account for dynamic changes


York Sewer District Treatment Plant
1978 Storm + 1.0 m SLR (2.6 ft wave setup)
For general planning purposes only; does not account for dynamic changes


Critical Infrastructure
York Sewer District Treatment Plant
Potential Inundation Depths
1978 Storm + 1m SLR (with wave setup)
Depths, ft
0.6 - 1
1.1 - 2
2.1 - 3
3.1 - 4
4.1 - 5
5.1 - 6
6.1 - 7
7.1 - 8
8.1 - 22
For general planning purposes only; does not account for dynamic changes

Adding Visualization Techniques to help image potential impacts of Sea Level Rise

Implications

Consider using the HAT elevation to simulate static, monthly, tidal flooding that may occur in the future under various SLR scenarios.

At a minimum, consider using the base 1978 stillwater elevations with a variety of SLR scenarios to develop a ***phased*** or ***criticality*** approach. Instead, consider using the 1978 stillwater elevations ***including wave setup*** for potential impacts along the open coast and critical infrastructure.

What Can Towns do to Adapt?

Operating Principles for Our Efforts

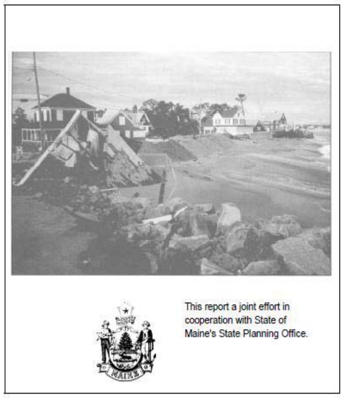
- Use the best science and tools for GIS inundation scenarios, but be conservative
  (e.g., 2 feet of SLR by 2100 is probably not enough to plan for, so we are now looking at 1 m or 1.8 meters).
- Adapting to Sea Level Rise will protect you from Storm Surges
- Don't separate discussion of natural from built environment impacts – keep environmentalists, public works staff, and emergency personnel around the same table

Operating Principles for Our Efforts

- Some Maine communities are willing to go over and above minimum ordinances or regulations – because of their actual experiences with flooding.
- Expect unforeseen delays (e.g. Disputing FEMA FIRM remapping efforts). Expect to take your time!

SLR Policy in Maine…

There is a long history, from way before Al Gore.



United States Environmental Protection Agency | Policy, Planning, And Evaluation (2122) | EPA-230-R-95-900 September 1995

EPA

Anticipatory Planning For Sea-Level Rise Along The Coast of Maine

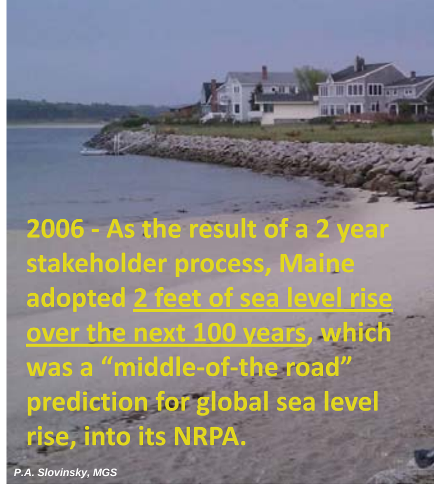
This report a joint effort in cooperation with State of Maine's State Planning Office.

On the right track… in 1995!

But it was never <u>brought to the local level</u>

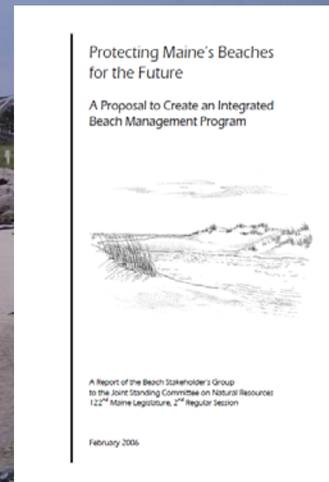
So it was LOST in the archives.

More reports…and updated sea level regulations



2006 - As the result of a 2 year stakeholder process, Maine adopted <u>2 feet of sea level rise over the next 100 years</u>, which was a "middle-of-the road" prediction for global sea level rise, into its NRPA.

P.A. Slovinsky, MGS

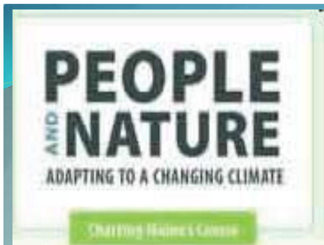


Protecting Maine's Beaches for the Future

A Proposal to Create an Integrated Beach Management Program

A Report of the Beach Stakeholder's Group to the Joint Standing Committee on Natural Resources 122nd Maine Legislature, 2nd Regular Session

February 2006



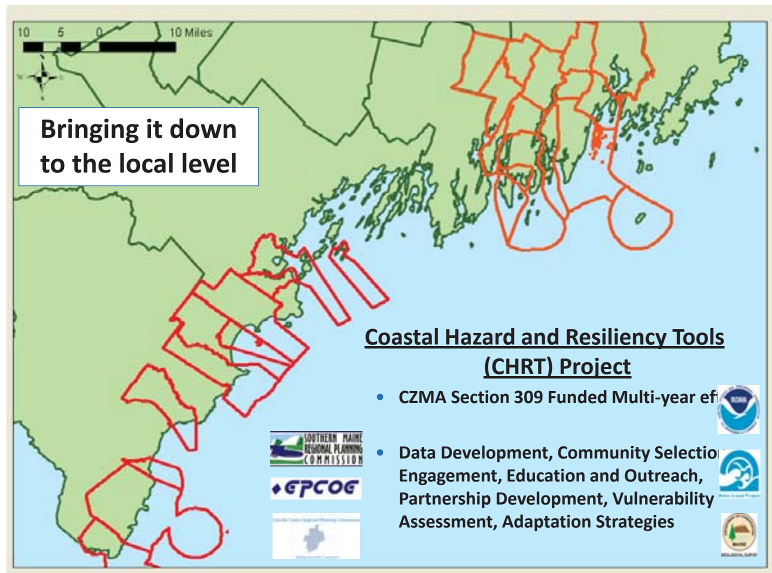
Even More recently…

<u>Working Groups:</u>

Built Environment
Coastal Environment
Natural Environment
Social Environment

- Year-long Stakeholder Process led to the production of a report in early 2010.
- Major recommendations related to ***bringing tools, models, and technical data to the local decision-making level relating to sea level rise planning.***

Resolves, Chapter 16, LD 460, "Resolve, To Evaluate Climate Change Adaptation Options for the State"



Bringing it down to the local level

<u>Coastal Hazard and Resiliency Tools (CHRT) Project</u>

- **CZMA Section 309 Funded Multi-year ef**
- **Data Development, Community Selectio Engagement, Education and Outreach, Partnership Development, Vulnerability Assessment, Adaptation Strategies**

SOUTHERN MAINE REGIONAL PLANNING COMMISSION

GPCOG

A comprehensive plan should do more than paint a disturbing picture of the future…it should move the community toward doing something!

Why not form include an implementation step to create a Sea Level Adaptation Working Group?

A regional committee of course (safety in numbers)! That's what they did in Saco Bay!

Multi-municipal Standing Committee Sea Level Adaptation Working Group

Local Participation:

Science/Technical Support:

MAINE GEOLOGICAL SURVEY

Additional Support Funding:

SOUTHERN MAINE REGIONAL PLANNING COMMISSION

Maine Coastal Program

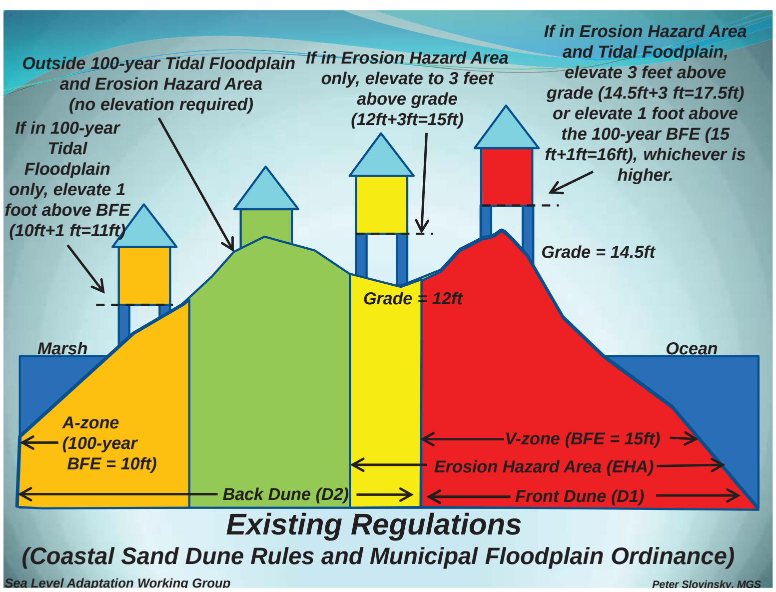
Sea Level Adaptation Working Group

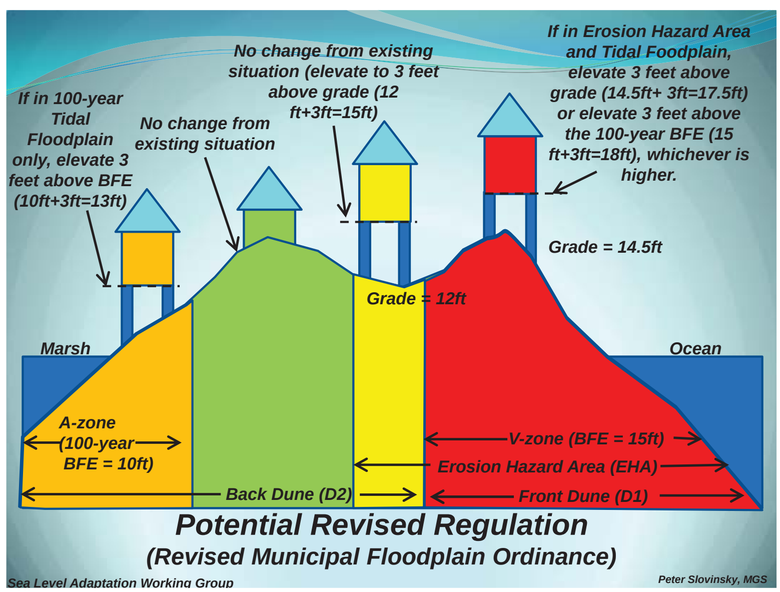
Steering Committee
- Met numerous times over summer of 2010 to develop an ***Interlocal Agreement*** outlining the creation of a Working Group and its potential duties and action plan.
- Received approval from each municipal council.
- Funded by Regional Challenge Grant (SPO) and local matches

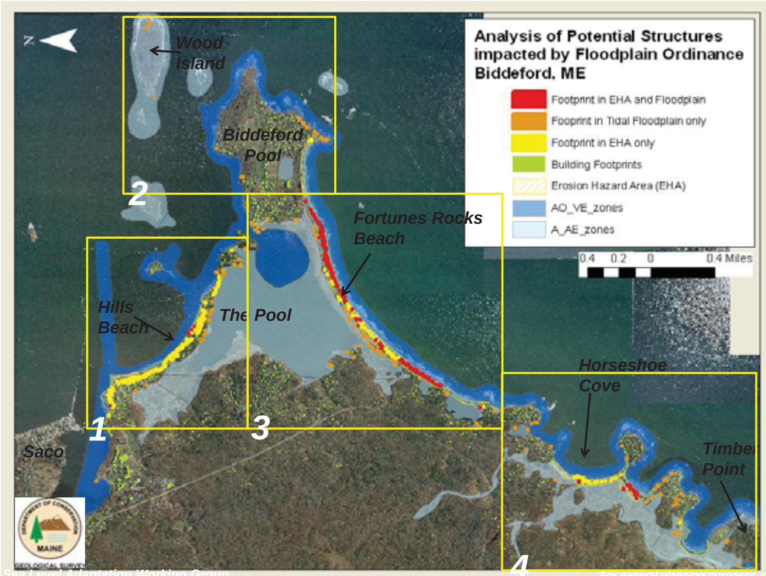
Working Group
- Comprised of two assigned members from each community; and an SMRPC planner; with technical support from MGS.
- Includes Coastal Citizens and Municipal Planners
- Met during 2010/2011 to complete a ***Vulnerability Assessment*** and ***Action Plan*** that were submitted to municipal councils for approval.
- Initial Project – Floodplain Management Ordinances

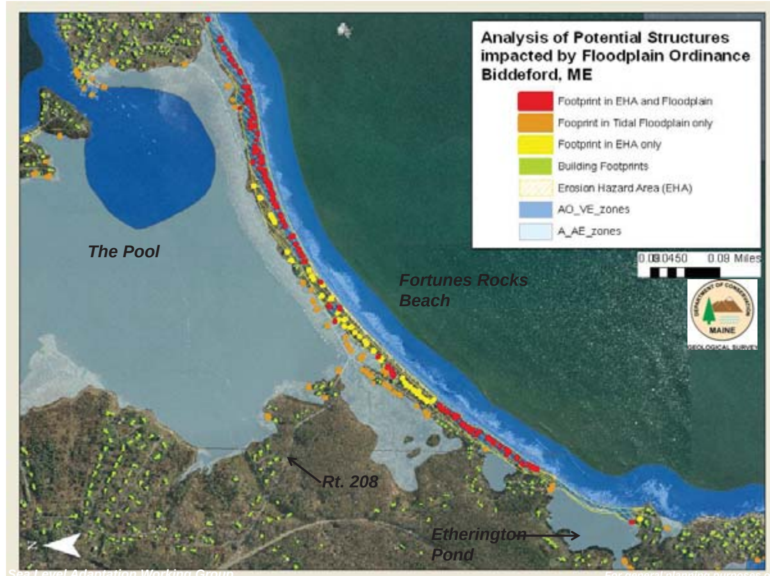
Without implementation, there is not much point in making plans!

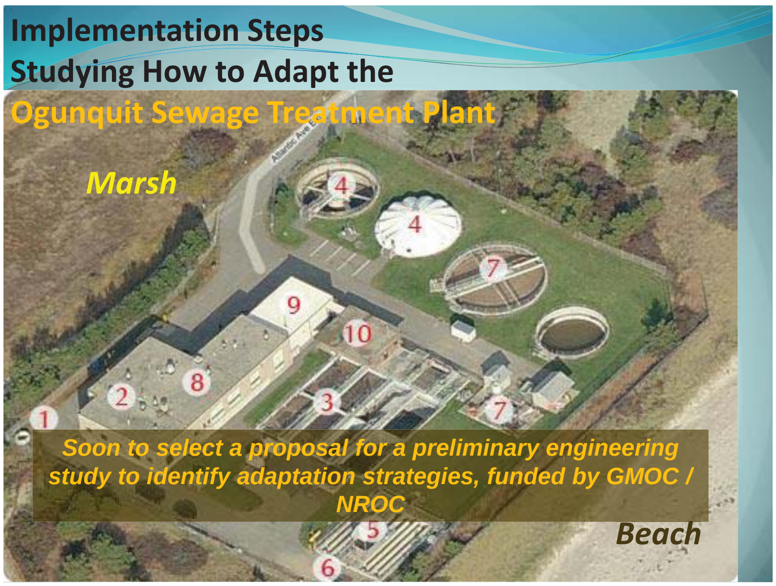
- ***What are other communities doing?***
- ***Can these efforts be duplicated in York?***



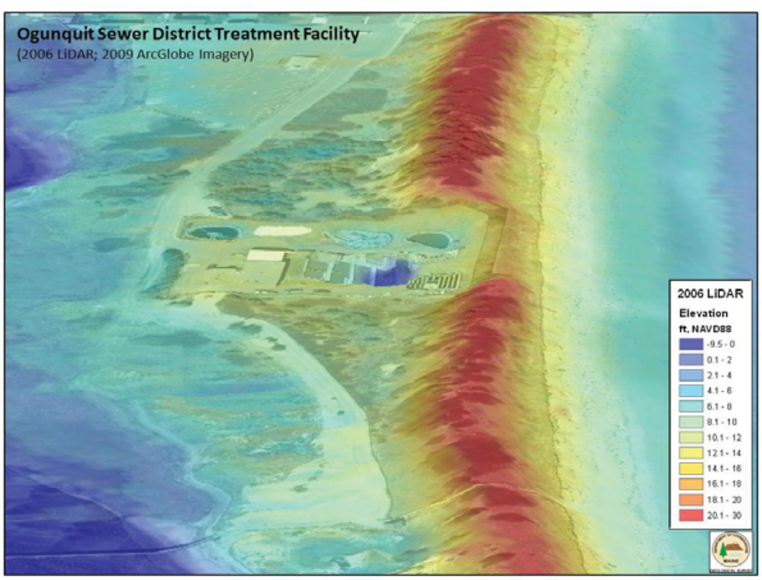


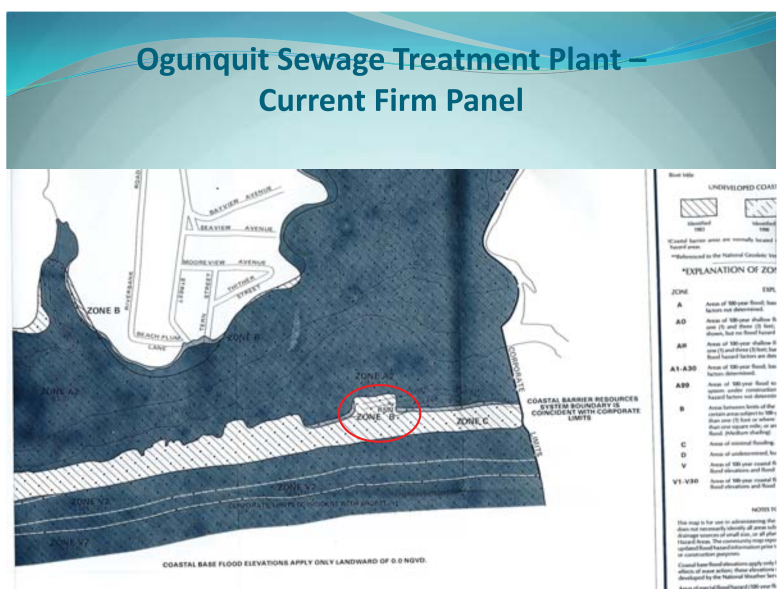

Analysis of Potential Structures impacted by Floodplain Ordinance Biddeford, ME
Footprint in EHA and Floodplain
Footprint in Tidal Floodplain only
Footprint in EHA only
Building Footprints
Erosion Hazard Area (EHA)
AO_VE_zones
A_AE_zones
0.4 0.2 0 0.4 Miles
Wood Island
Biddeford Pool
Fortunes Rocks Beach
Hills Beach
The Pool
Horseshoe Cove
Timber Point
Saco
1
2
3
4
Sea Level Adaptation Working Group

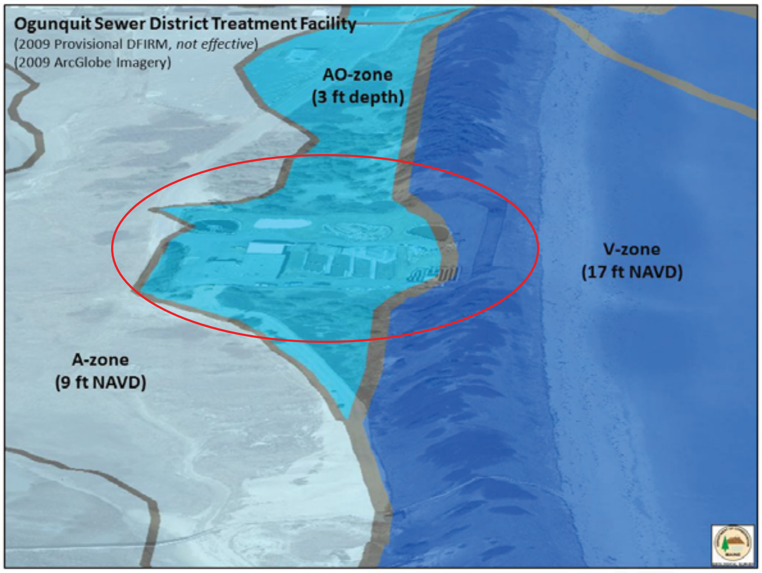

Analysis of Potential Structures impacted by Floodplain Ordinance Biddeford, ME
Footprint in EHA and Floodplain
Footprint in Tidal Floodplain only
Footprint in EHA only
Building Footprints
Erosion Hazard Area (EHA)
AO_VE_zones
A_AE_zones
The Pool
Fortunes Rocks Beach
Rt. 208
Etherington Pond
Sea Level Adaptation Working Group

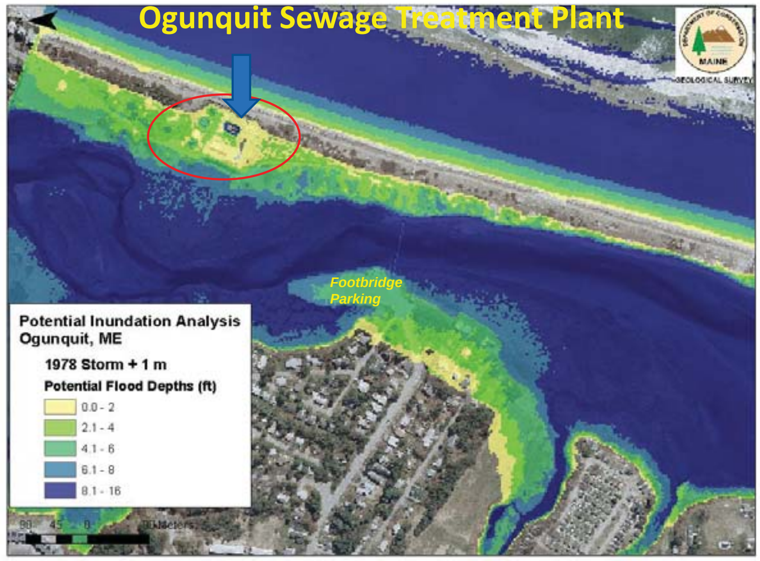

Implementation Steps
Studying How to Adapt the
Ogunquit Sewage Treatment Plant
Marsh
Soon to select a proposal for a preliminary engineering study to identify adaptation strategies, funded by GMOC / NROC
Beach


Ogunquit Sewage Treatment Plant Context
Ogunquit Sewage Treatment Plant
2006 Aerial Photography
1 inch = 50 feet
Treatment Plant
Ogunquit
Wells

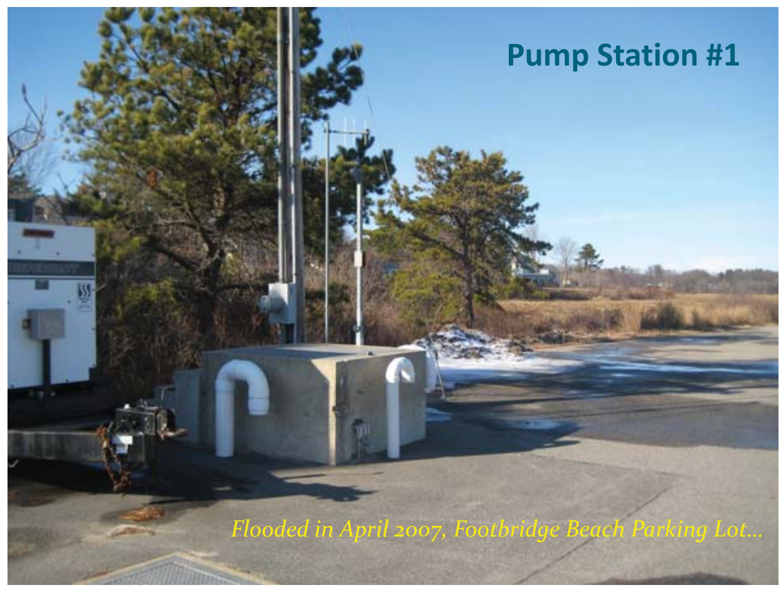

Ogunquit Sewer District Treatment Facility
(2006 LiDAR; 2009 ArcGlobe Imagery)
2006 LiDAR
Elevation
ft, NAVD88
-9.5 - 0
0.1 - 2
2.1 - 4
4.1 - 6
6.1 - 8
8.1 - 10
10.1 - 12
12.1 - 14
14.1 - 16
16.1 - 18
18.1 - 20
20.1 - 30


Ogunquit Sewage Treatment Plant –
Current Firm Panel
ZONE B
ZONE C
COASTAL BARRIER RESOURCES SYSTEM BOUNDARY IS COINCIDENT WITH CORPORATE LIMITS
COASTAL BASE FLOOD ELEVATIONS APPLY ONLY LANDWARD OF 0.0 NGVD.


Ogunquit Sewer District Treatment Facility
(2009 Provisional DFIRM, not effective)
(2009 ArcGlobe Imagery)
AO-zone
(3 ft depth)
V-zone
(17 ft NAVD)
A-zone
(9 ft NAVD)


Ogunquit Sewage Treatment Plant
Footbridge Parking
Potential Inundation Analysis
Ogunquit, ME
1978 Storm + 1 m
Potential Flood Depths (ft)
0.0 - 2
2.1 - 4
4.1 - 6
6.1 - 8
8.1 - 16


Ogunquit Sewage Treatment Plant
Looking NE across river, from Footbridge Beach Parking Lot...


Pump Station #1
Flooded in April 2007, Footbridge Beach Parking Lot...

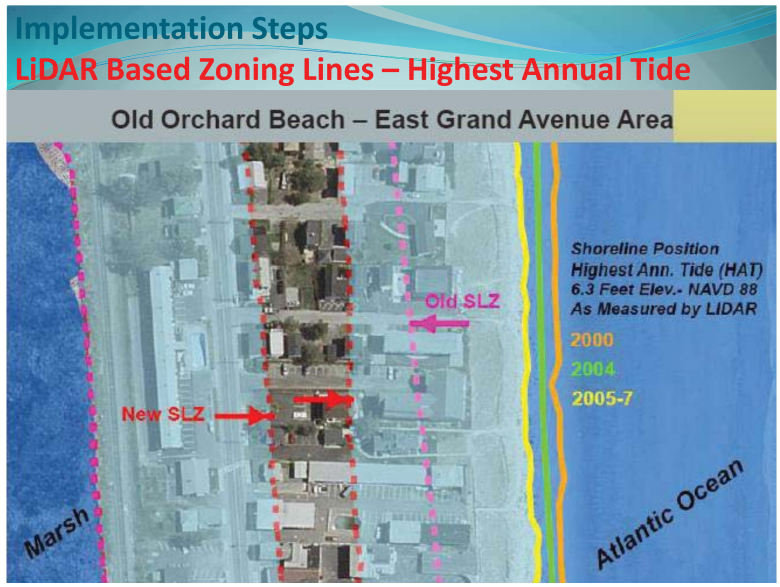

Ogunquit Sewage Treatment Plant
Looking west out the main gate, towards the salt marsh....


Ogunquit Sewage Treatment Plant
Looking south down the road to the main gate,
marsh on right...

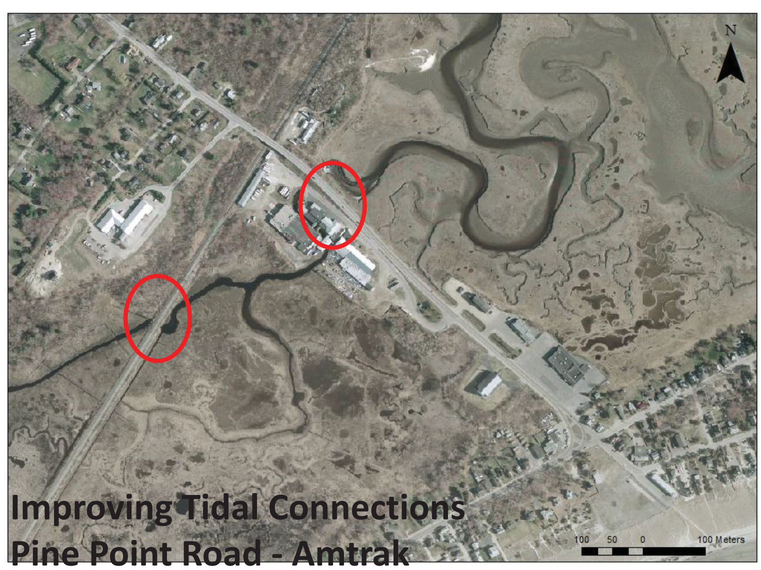

Ogunquit Sewage Treatment Plant
Looking South along the dune line,
Steel Storm Barrier on right…

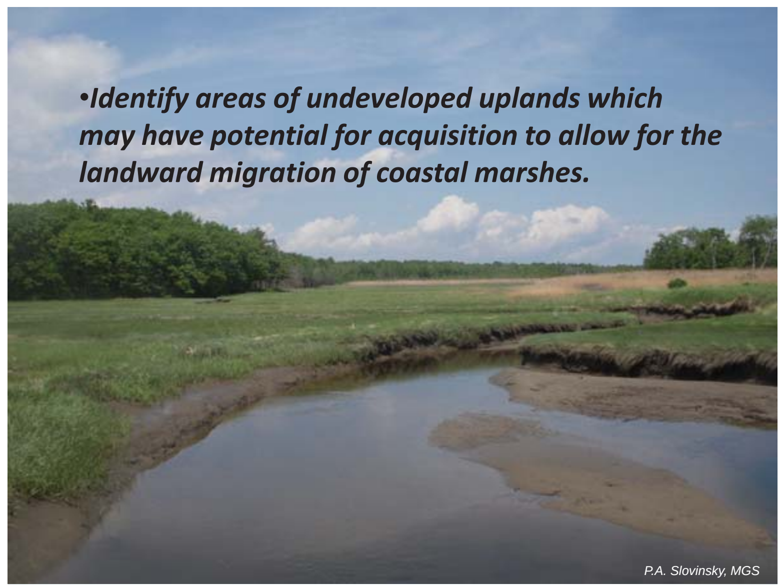

Ogunquit Sewage Treatment Plant


Ogunquit Sewage Treatment Plant

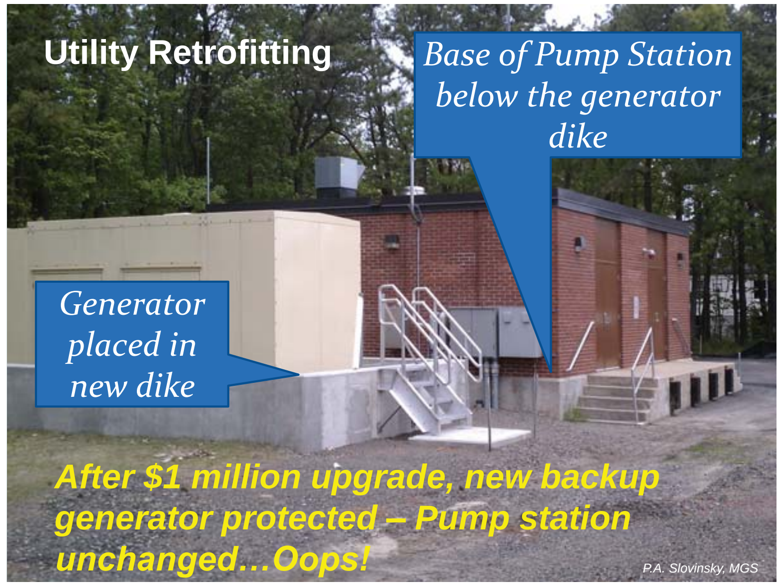

Implementation Steps
LiDAR Based Zoning Lines – Highest Annual Tide
Old Orchard Beach – East Grand Avenue Area
Shoreline Position
Highest Ann. Tide (HAT)
6.3 Feet Elev.- NAVD 88
As Measured by LIDAR
2000
2004
2005-7
Old SLZ
New SLZ
Marsh
Atlantic Ocean

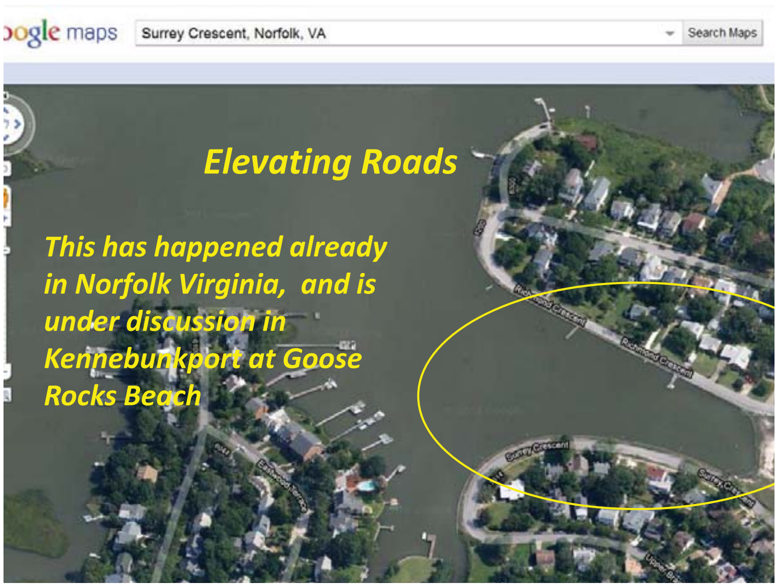

Implementation Steps
Jones Creek
Removing tidal
restrictions
Depot Street and Route 9
- Add Two 12' x 7' Culverts
- Add Tide Gate on Existing
and Proposed Culvert
- Lower Invert to Elevation -2.0
- Add Overflow Channel
- Retain Existing Culvert
Bayley Dam
- Remove or Modify
Dam
Storage Areas
- Enhance School Street
Storage
- Restore Cascade Road
Storage
Railroad Culvert
- Add Two 8' H x 7' W
bypass culverts
Walnut Street
- Install 12' wide x 3' high
Box Culvert
- Raise Road by 1'
Railroad
From OOB's "Milone
McBroom" report


N
Improving Tidal Connections
Pine Point Road - Amtrak
100 50 0 100 Meters



Implementation Steps Not Considered Yet?





Considerations for the Town of York Comprehensive Plan Sea Level Rise Chapter

Peter Slovinsky, Marine Geologist
Maine Geological Survey, Department of Conservation
peter.a.slovinsky@maine.gov
207-287-7173

Jonathan T. Lockman, Planning Director
Southern Maine Regional Planning Commission
jlockman@smrpc.org
207-324-2952