Effects of Storm Surge and Sea Level Rise on "Eight Towns by the Bay"

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December 16, 2009 - Salem State College - GGR 903

Abstract

The eight coastal communities from Salisbury to Rockport, the "8 Towns by the Bay," are exposed to varying degrees to coastal flooding resulting from sea level rise and storm surges. Elevation analysis of this region identifies those areas at risk of inundation at flood levels of 3 meters, 3.5 meters, and 4 meters above current sea levels. Although built infrastructure is affected to a degree, especially in the northern portion of this region, the major impacts of flooding are on sensitive ecological areas such as saltwater marshes. Residential flooding is greatest in the Gloucester area.

Introduction

Climate scientists estimate that the next 100 years could see global temperatures rise by 2 to 11.5 degrees Fahrenheit. (1) Among the effects of this climate change are an increase in the frequency and severity of heat waves, more storms of greater severity, and rising sea levels. Coastal areas are particularly at risk from sea level rise associated with climate change. More specifically, sea levels are expected to rise about 1 meter over the next 100 years, permanently inundating many low-lying areas. (1) In addition, more frequent and more severe storms are expected to cause short-term flooding of coastal areas above and beyond the level of flooding caused by rising sea levels. This study considers the impact of sea level rise and storm surge flooding on the built and natural environments of 8 coastal towns along the northern portion of the Massachusetts coastline, Salisbury, Newburyport, Newbury, Rowley, Ipswich, Essex, Gloucester, and Rockport, the "8 Towns by the Bay." Of 388 sq. km. included in the eight towns, 83 sq. km. will be flooded under the 3 meter scenario, 94 sq. km. under the 3.5 meter scenario, and 102 meters under the 4 meter scenario, or 21%, 24%, and 26%, respectively.

Methods

In order to model the effects of climate change-related flooding on the 8 Towns by the Bay, we first used elevation data collected by MassGIS to develop an elevation map of the 8 community region. We then used this elevation map to identify areas that would be inundated under three different scenarios. The first scenario represents flooding caused by a major storm surge of 3 meters at the present sea level, that is, without any sea level rise. Another scenario models a 1 meter rise in the sea level, a climate change outcome widely considered by climate scientists as likely within the next 100 years, along with a 3 meter storm surge. The third scenario, 3.5 meters of flooding, represents a 3 meter storm surge along with a 0.5 meter rise in the sea level. We then combined the areas found to be flooded under the three scenarios with maps showing the location of critical infrastructure, land use, vulnerable ecology, etc. to determine the effects of climate change -related flooding on the region.

Conclusions and Recommendations

There are positives and negatives associated with the fact that the 8 Town region has a natural "buffer area" along the coast. The positive effect is that people and the built environment are largely, though not completely, protected from major storm surges. The negative effect is that this protection of built environments comes at the expense of natural areas along the coast. Although some degree of change in natural environments is normal, a storm surge that causes extensive flooding could alter or damage these areas for years to come.

Efforts to mitigate the damage to wetlands, coastal forests, and other critical habitats should include the prevention of encroachment of development. This would keep current natural areas natural, and would maintain a mass of land as a buffer against storms and as a habitat for rare species. Also important for the rapid recovery of wetlands *after* a major flood is the health of the wetlands *before* flooding. Efforts to reduce pollutants and environmental stress would increase the resilience of wetlands and other affected areas to a flood. Finally, endangered wildlife and humans would both benefit from a deliberate *increase* in designated "natural" areas along the existing buffer zone. Increasing the natural land area would result in more habitat for endangered species, and greater buffer from humans from major storm surges.

Efforts to prepare for flooding of the magnitude analyzed here should include development of detailed evacuation plans for affected populations and public education about flooding.

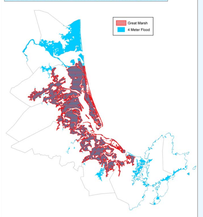
Possible Improvements to the Analysis

ArcGIS allows us to look at elevation, but not at how bodies of water and flooding are connected. For example, a low-lying area could be shielded on all sides by tall hills, as a "bowl," but would still show up as flooded due to its low elevation. This leads to an over-estimate of flooded area. Up-to-date Census data would allow for better analysis of populations affected by flooding. Analysis of levels of flooding over critical infrastructure such as roads requires elevation data at a resolution greater than what is currently available.

Further lines of research

While this analysis shows which major roads are free of any flooding, there are some areas which may be difficult to access by major roads alone. Further research could include an analysis on which minor roads in each town will remain flood-free. This is an important component of developing evacuation routes for the approximately 30,000 residents of the area whose homes might be inundated in a 3 to 4 meter flood.

Areas of Critical Environmental Concern

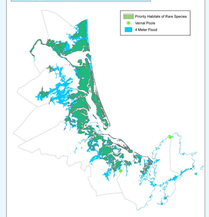


Great Marsh

The "8 Towns on the Bay" region includes Great Marsh, a 25,500 acre (79 million square meter) marsh spanning Newbury, Rowley, Ipswich, Essex, and Gloucester. Included in this *Area of Critical Environmental Concern* (as designated by the Massachusetts Executive Office of Environmental Affairs) is the 2,900 acre Parker River National Wildlife Refuge, a stop-over on the Atlantic Fly-way Migration route for more than 300 species of birds, including 75 rare species. This area is also a breeding ground for 60 bird species, including such rarities such as the Seaside Sparrow and the Least Tern. The Great Marsh also includes Plum Island, breeding ground for Piping Plovers and home to over 490 species of vascular plants. The surrounding waters host the largest anadromous fish runs of alewives and smelt on the North Shore. The area is also important for fishing, shell-fishing, tourism, and recreation. (2)

Inundation analysis reveals that approximately 54 million square meters, or 69% of the total area of the Great Marsh, would be affected by a 3 meter storm surge, the lower limit of the current analysis. The medium-level flood would affect about 78% of the area; the upper-level flood estimate of flooding, 4 meters above current sea level, would cover about 83% of the Great Marsh. Although the storm-surge-related flooding would not be permanent, it is likely that the violence of the surges would cause serious damage to the ecology of the area, and may disrupt or destroy important habitats.

Priority Habitats and Vernal Pools



Priority Habitat for Rare Species

Massachusetts Department of Fish and Game's Natural Heritage & Endangered Species Program (NHESP) identifies areas critical to endangered species in Massachusetts. NHESP's "Priority Habitat of Rare Species" is a designation based on the known geographical extent of habitat for state-listed rare species, both plants and animals. The 8 Towns on the Bay is home to Priority Habitats for 74 rare species of birds, plants, reptiles, and crustaceans. (3)

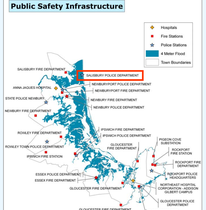
Of the 89 million square meters of Priority Habitat in the 8 Town region, about 54 million square meters, or 61% of the total, would be inundated by a 3 meter storm surge. A flood of 3.5 meters above current sea level would cover about 65% of the Priority Habitat area. The maximum flood scenario, 4 meters above current sea level, would inundate about 68% of Priority Habitat. This flooding has the potential to disrupt and cause stress for the rare species located in flooded areas, and may destroy important habitat.

Vernal Pools

According to Mass Wildlife, Vernal pools are "unique wildlife habitats best known for the amphibians and invertebrate animals that use them to breed. Vernal pools, also known as ephemeral pools, autumnal pools, and temporary woodland ponds, typically fill with water in the autumn or winter due to rising ground water and rainfall and remain ponded through the spring and into summer. Vernal pools dry completely by the middle or end of summer each year, or at least every few years. Occasional drying prevents fish from establishing permanent populations. Many amphibian and invertebrate species rely on breeding habitat that is free of fish predators." Mass Wildlife confers protection from encroachment to those vernal pools it designates as "Certified Vernal Pools." (2)

Of the 192 Certified Vernal Pools in the 8 Town region, 2 would be affected by floods of 3 to 4 meters above current sea level. This flooding could introduce salt water, debris, or predatory fishes, and thus diminish the vitality of these vernal pools.

Public Safety Infrastructure



Public Safety Infrastructure

The region from Salisbury to Rockport contains public safety infrastructure that will be of critical importance during a natural disaster. Any flooding of this infrastructure would further exacerbate the disaster by depriving the local population of emergency resources.

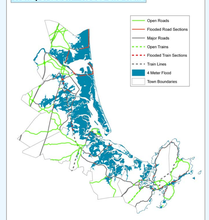
This area contains 22 buildings that we've classified as public safety infrastructure: 11 fire stations, 9 police stations, and 2 acute care hospitals (defined as having an emergency room or trauma center). This does not include environmental police, and various state and federal law enforcement agencies.

In the event of a 3m, 3.5m, or 4m flood, only 1 of the 22 (4.50%) public safety infrastructure buildings would be affected by flooding. This is the Salisbury Police Department, and is highlighted in red on the accompanying map. This building lies at an elevation of 1.32m above sea level, and depending on the depth of flooding will be inundated by the following amounts:

Elevation	1.32 m	1.32 m	1.32 m
Flooding height	3.0 m	3.5 m	4.0 m
Inundation (Elevation - Flood height)	-1.68 m	-2.18 m	-2.68 m

The next building of lowest elevation is the Essex Fire Department, and lies at an elevation of 6.04m. This is greater than 2 meters above the worst-case scenario outlined in this poster (4m flood), so it is not in immediate danger of inundation.

Transportation - Roads and Rails



Transportation – Roads and Rails

During a flood, some people will be unable to evacuate before a storm surge moves inland. Maintaining open transportation routes is important to get these people out of the region after flooding has occurred.

The lengths of roads inundated by flooding increases as higher flood heights occur, according to the following table. Note that only major roads (state and federal highways) are included in this analysis.

Major Roads	Total (km)	3m	3.5m	4m
	270.64 km	11.98 km	16.65 km	21.98 km
% inundated		4.43%	6.15%	8.12%

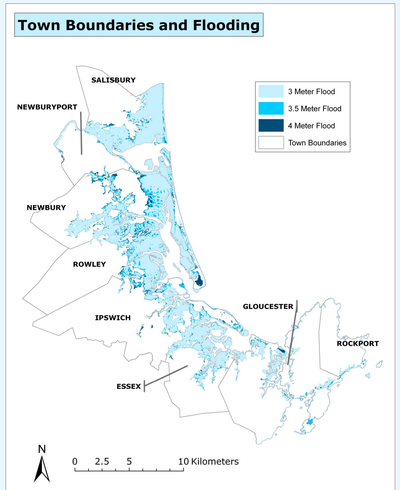
During a 3m flood, ~81% of major roads in the region remain completely clear of flooding. This number decreases to ~76%, and ~70% during a 3.5m and 4m flood, respectively.

Similar to roads, the length of inundated train lines increases with higher flooding. Only rails with active service are included in this analysis.

Train lines	Total (km)	3m	3.5m	4m
	29.41 km	0.2 km	0.82 km	2.86 km
% inundated		0.85%	2.80%	9.72%

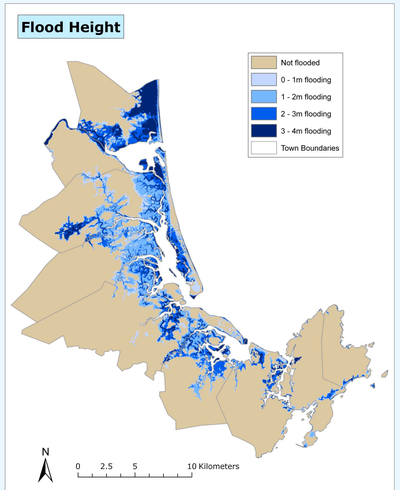
Both active train lines in this region experience some form of inundation in all three flooding scenarios.

Town Boundaries and Flooding



Projected Coordinate System: NAD_1983_StatePlane_Massachusetts_Mainland_FIPS_2001

Flood Height



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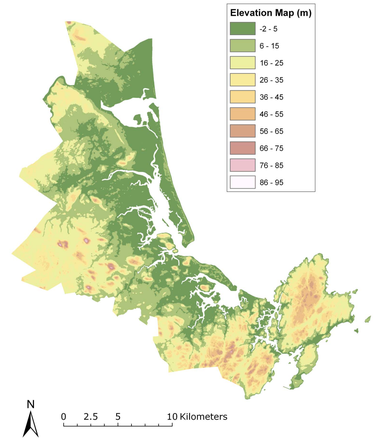
Digital Elevation Map



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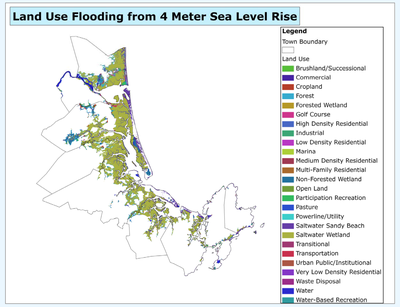
Land Use Flooding from 4 Meter Sea Level Rise



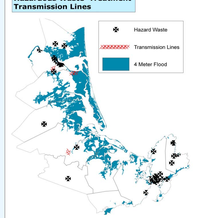
Land Use

The effect of 4m flooding on Land Use is shown for each town in the "8 Towns and a Bay" region. There are 31 land use classes for the region but these classes are not found in uniform amounts throughout each town. The accompanying table summarizes inundated percentage values of impacted land use since detail is lost on the map. Orchards, Nursery, Mining, Junkyard, and Cemetery land uses were not included in the map since there was minimal flooding of 1% or less at each flooding scenario.

Areas of greater impact include:

- Saltwater Wetland and Saltwater Sandy Beach land uses are heavily inundated by a 4m flood in most of the eight town region, ranging from 25–100% inundation depending on the town and flood height.
- Forest and Forested Wetland in Salisbury is inundated in all three scenarios from 13–35%.
- The high-density residential areas for Salisbury are heavily flooded in all three scenarios varying from 40% at 3m flooding, to 48% at 4m flooding. Essex experiences a range of 11–25% depending on the flood height.
- The industrial area in Newbury experiences 8% inundation during a 3m flood, which increases dramatically for a 3.5m (65%) and 4m (96%) flood.
- Multi-family residential land use in Salisbury and Newbury are inundated in all three flooding scenarios, ranging from 20–49% throughout the two towns.
- Non-forested wetland in Salisbury, Newbury, and Rowley are inundated at all three flood heights, ranging from 25-68%. Likewise, non-forested wetland in Ipswich will experience 30% inundation during a 4m flood
- Transportation land area in Salisbury and Newbury are impacted in all three flooding scenarios, from 10-23% depending on the town.
- Waste disposal areas in Newburyport and Essex will be flooded, both experiencing a dramatic rise from 24-49% and 8-41% respectively.
- The commercial areas of Salisbury, Newburyport, Newbury, Essex, and Gloucester are impacted in varying degrees, ranging from 4-22% depending on the town and flood height.

Hazardous Waste Treatment Transmission Lines

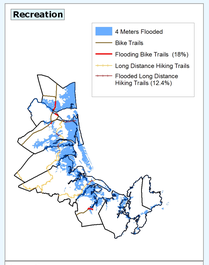


Hazardous Waste and Transmission Lines

The 8 Towns by the Bay in Essex county are home to 25 hazardous waste storage and treatment facilities. 75% of these facilities will be affected by flooding at the 3 meter to 4 meter levels. Flooding near these facilities could be dangerous due to the potential for power outages, security system outages, and the inability of essential workers to reach the facilities.

There are 7.4 kilometers of power transmission lines and one substation located in areas that would be flooded under the 4 meter scenario. Although this flooding may not directly disturb the power generation over these facilities, the violence of floodwaters could weaken and damage this vital infrastructure.

Recreation



Recreation

Flooding affects the ability of residents to enjoy some recreation areas. Because use of recreational spaces might also stimulate spending in the area, for example, for transportation, food, and lodging, local economies might be affected via damage to these areas.

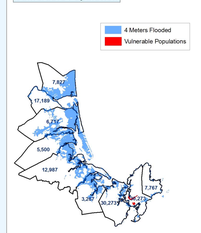
Bicycle Trails

The total of length of bicycling trails in this region is 26.7 kilometers. Of these trails, about 12.5% will be flooded under the 3 meter flood scenario. However, 15.7% will be flooded by a 3.5 meter flood, and 18% will be flooded by a 4 meter flood.

Hiking Trails

The total length of the long distance hiking trails in this region is 48.9 kilometers. Of these trails, about 6.4% will be flooded by a 3 meter flood. However, 8.9 % will be flooded by a 3.5 meter flood, 12.4% will be flooded by a 4 meter flood.

Vulnerable Population

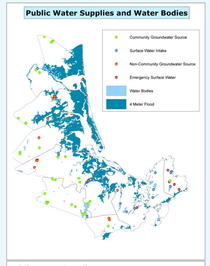


Demographics

Town Populations The map shows the total population for each town. Data at the census-block level allows us to estimate the number of residents directly affected by flooding. Of the 91,527 residents in the 8 town area, approximately 28,833, or 31.5% will be directly affected by a 4 meter flood. The town with the largest number of flood-affected residents is Gloucester, with 10,629. Rowley has the fewest number of people with flooded homes, at 151.

Vulnerable Populations Three red areas on the map indicate vulnerable populations. Specifically, these areas meet the following four conditions: the percentage of minorities making up the population is greater than 25%, the median household income in the area is less than $30,515 (or 65% of the statewide household median income of $46,947), the percentage of English-proficient households is less than 75%, and the percentage of residents who are foreign-born is greater than 25%. The three neighborhoods with vulnerable populations totaling 2,527 persons are located in Gloucester. However, all of these three areas are located away form the areas that would be flooded under the scenarios discussed here.

Public Water Supplies and Water Bodies



Public Water Supplies

In the case of a flood 4 meters above current sea levels, 35% of the *Community Groundwater Sources*, 55% of the *Surface Water Intake* areas, and 25% of the *Emergency Surface Water* sources will be inundated. In addition, 7,935 square meters of water bodies which feed the fresh groundwater will be affected. The biggest problem with the 4 meter flood is that it can contaminate the sweet, drinkable water, which could take weeks to return to normal.

	Salisbury		Newburyport		Newbury		Rowley		Ipswich		Essex		Gloucester		Rockport	
Land Use Flood Scenarios (m)	3	4	3	4	3	4	3	4	3	4	3	4	3	4	3	4
Brushland/ Successional	5	6	12	12	37	63	0	0	14	31	13	26	4	8	1	4
Commercial	17	22	6	15	5	11	0	0	1	4	4	13	6	14	3	7
Cropland	3	5	2	4	3	14	1	7	0	1	2	9	0	0	0	0
Forest	13	18	2	3	3	8	1	3	2	4	1	3	1	1	0	0
Forested Wetland	29	35	2	8	2	9	1	3	0	2	0	0	2	3	1	2
Golf Course	0	0	0	0	5	14	0	0	0	0	2	10	0	0	0	0
High Density Residential	40	48	1	2	0	0	0	0	1	2	11	25	3	6	0	1
Industrial	7	8	2	11	8	96	0	0	0	1	1	2	10	18	0	0
Low Density Residential	4	7	2	4	1	2	0	0	1	1	2	1	3	2	4	4
Marina	48	80	55	79	11	26	40	79	0	0	32	89	45	84	92	97
Medium Density Residential	8	16	1	2	0	2	0	0	0	1	0	2	1	3	1	1
Multi-Family Residential	36	49	1	3	20	22	0	1	0	0	0	2	1	3	1	2
Non-Forested Wetland	62	68	9	12	38	49	25	28	5	30	3	8	12	19	7	8
Open Land	13	17	6	19	11	24	9	14	6	9	1	5	4	12	9	11
Participation Recreation	64	71	14	18	17	22	0	0	0	0	3	21	8	13	0	0
Pasture	9	14	2	4	2	9	1	3	1	3	2	7	3	9	0	0
Powerline/ Utility	0	0	0	5	0	0	0	0	0	0	0	0	0	1	0	0
Saltwater Sandy Beach	77	86	92	97	28	46	44	65	18	32	77	86	51	69	60	73
Saltwater Wetland	100	100	95	98	81	99	82	98	87	99	94	99	96	99	99	100
Transitional	4	19	0	0	0	3	0	0	0	2	0	0	2	7	23	26
Transportation	16	17	3	5	10	23	0	1	2	11	0	0	2	4	2	3
Urban Public/Institutional	8	10	2	5	1	3	0	0	0	1	0	0	4	8	0	0
Very Low Density Residential	5	8	6	12	0	2	1	4	1	3	1	4	1	4	0	0
Waste Disposal	0	0	24	49	0	0	0	0	0	0	8	41	1	3	0	0
Water	98	98	84	88	90	91	86	86	51	58	58	58	14	21	14	14
Water-Based Recreation	89	100	76	100	2	13	0	0	0	0	0	0	54	77	18	27
Total Land Use Flooding	41	45	14	17	30	40	18	23	20	26	25	28	9	12	5	6

References

1. *Global Climate Change Impacts in the United States*, U.S. Global Change Research Program, Cambridge University Press, 2009, at 24-25.
2. Massachusetts Department of Conservation and Recreation, ACEC Program. (http://www.mass.gov/dcr/stewardship/acec/acecs/i-parriv.htm, visited 12/2/2009)
3. Massachusetts Department of Fish and Game, Division of Wildlife and Fisheries, Natural Heritage and Endangered Species Program Database. (http://www.mass.gov/dfwele/dfw, visited 12/2/2009)
4. "During a Flood?" http://www.fema.gov/hazard/flood/fl_during.shtm, Retrieved December 2, 2009.

Note: All data layers used to make these maps were obtained from the commonwealth of Massachusetts Executive Office of Energy and Environmental Affairs, Office of Geographic and Environmental Information (MassGIS)