Section 145
Climate Change and Sea Level Rise

A. Definitions

1. **Climate** is the long-term weather average observed within a geographic region, and **climate change** refers to fluctuations in the Earth's climate system as a result of both natural and anthropogenic causes. Currently the long term climate change trend is evidenced by rising global temperatures; increasing extremes within the hydrologic cycle resulting in more frequent floods and droughts; and rising sea level.

~~a.~~2. **Sea level** is the height of the sea with respect to a horizontal control point or benchmark such as the National Geodetic Vertical Datum of 1929 (NGVD 29) or the North American Vertical Datum of 1988 (NAVD 88).**Sea level rise** refers to the ~~change~~ net increase in mean sea level over time in response to global climate, ~~and~~ local tectonic changes, glacial isostatic adjustment, and ocean dynamics. ~~Sea level is the height of the sea with respect to a horizontal control point, or benchmark (e.g., The National Geodetic Vertical Datum of 1929 or NGVD 29; The North American Vertical Datum of 1988 or NAVD 88)~~. Sea level rise indicates a positive trend, thus an increase in sea level as compared to historic measurements. **Global sea level rise** is the worldwide variations in sea level due to eustatic contributions such as thermal expansion of seawater and melting glacial ice sheets. **Relative sea level rise** is a regional change in sea level relative to land surface elevations. Relative sea level rise is influenced by tectonic response to ice or sediment loading, land subsidence due to extraction of water or oil, dynamic effects of ocean currents or the gravitational pull of ice sheets on ocean waters. Sea levels are rising along most of the world's coastlines including Rhode Island. However, in places that are experiencing rapid uplift due to tectonic plate movement or glacial isostatic adjustment the relative sea level trends are falling because the land is rising faster than the sea (http://tidesandcurrents.noaa.gov/sltrends/sltrends.shtml).

~~b.~~3. **Vertical datums** are either fixed benchmarks such as NGVD 29 and NAVD 88 or site specific tidal datums such as mean high water, mean low water and mean sea level. NGVD 29 is based on the local mean sea level in 1929, which has changed over time. NAVD 88 is now the official civilian vertical datum for surveying and mapping activities in the United States. The conversion to NAVD 88 should be accomplished on a project-by-project basis. It should be noted, however, that NAVD 88 is not synonymous with mean sea level nor does it correct for sea level changes that have occurred since the establishment of NGVD 29. Tidal datums, such as mean sea level (MSL) or mean high water (MHW) vary according to the specific location, and represent the mean heights observed over the National Tidal Datum Epoch. Datum ~~C~~conversions ~~between the datums can be made~~ for NOAA tide gauges at www.tidesandcurrents.noaa.gov or can be calculated ~~through~~ using the NOAA VDatum software available at http://vdatum.noaa.gov or the US Army Corps of Engineers CORPSCON software available at ~~http://crunch.tec.army.mil/software/corpscon/corpscon.html~~http://www.agc.army.mil/corpscon/.

~~c.~~4. ~~Sea level rise includes *eustatic* contributions - global changes responsible for worldwide variations in sea level (e.g., thermal expansion of seawater, melting glacial ice sheets), and *isostatic* effects - regional changes in land surface elevations that are related to the tectonic response to ice or sediment loading, and land subsidence due to extraction of water or oil. The combination of eustatic and isostatic effects at a particular location is known as relative sea level rise.~~ **Horizontal datums** are either fixed benchmarks or site-specific control points that establish location for a point on a map consistent with a coordinate system. The North American Datum of 1983 (NAD 83) is the official horizontal datum for the United States based on a geocentric origin and the Geodetic Reference System 1980. Conversions between the datums can be made using software such as NADCON available from the National Geodetic Survey at http://www.ngs.noaa.gov/PC_PROD/pc_prod.shtml or the US Army Corps of Engineers CORPSCON software at http://www.agc.army.mil/corpscon/.

B. Findings

1. On very long (geologic) time scales, sea level naturally fluctuates in response to variations in astronomical configurations that cause changes in the Earth's climate system. Since the Last Glacial Maximum (approximately ~~20,000~~26,000 years ago), global sea level has risen by over 390 feet (120 meters), as water that was previously trapped in continental ice sheets has made its way into the global ocean.

2. Sea level rise is a direct consequence of global climate change. Greenhouse gas emissions to the atmosphere increase surface warming, which in turn increases the volume of ocean waters due to thermal expansion, and accelerates the melting of glacial ice. Atmospheric greenhouse gas concentrations are already higher than levels at the last interglacial period, when sea levels were 13 to 19 feet (4 to 6 meters) higher than at present (Overpeck *et al*., 2006). Greenhouse gas concentrations are expected to continue to increase through 2100.

3. Human activities and increased concentrations of greenhouse gasses in the atmosphere have *accelerated* the historic rate of eustatic sea level rise. Over the last 100 years, sea levels have risen 0.56 feet (0.17 m) globally. The average rate of rise during the years between 1961 and 2003 was 0.071 inches per year (1.8 mm/yr), and between 1993 and 2003 the rate nearly doubled to 0.12 inches per year (3.1 mm/yr) (IPCC, 2007).

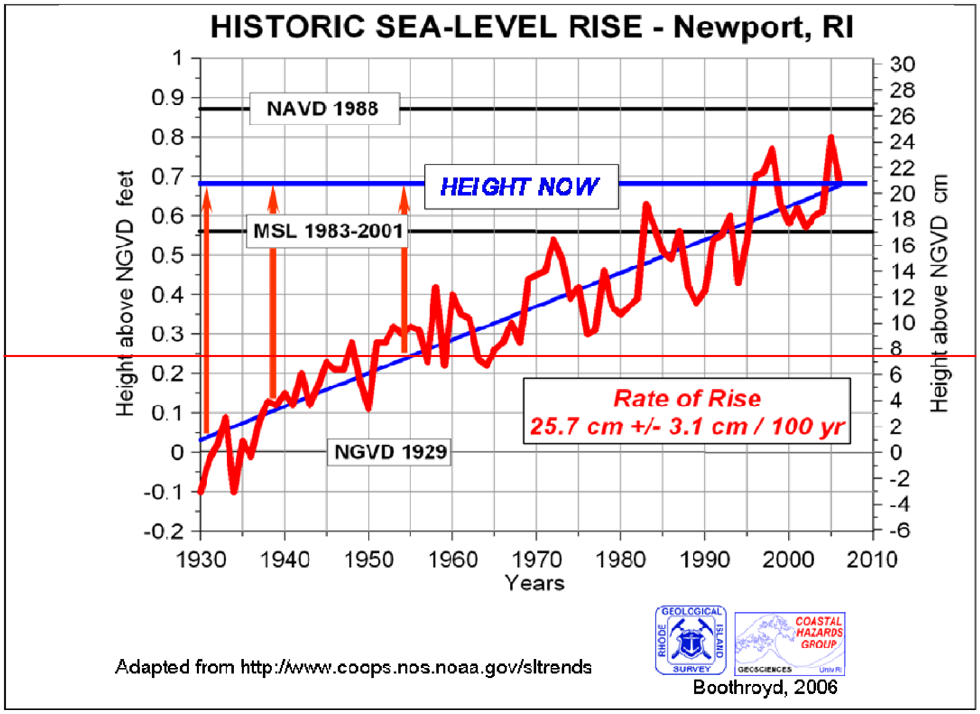
4. In addition to rising global sea levels, the land surface in Rhode Island was believed to be subsiding at a rate of approximately 6 inches (15 cm) per century (Douglas, 1991). More recent studies indicate that many more factors, including changes in ocean circulation, contribute to Rhode Island's relative sea level rise that subsidence alone. The combination of these effects is evident from the long-term trend recorded by the Newport tide gauge (Figure 1), which indicates a rate of 10.6 inches (26.9 cm) of relative sea level rise per century or 2.69 mm per year.

~~4.In addition to rising global sea levels, the land surface in Rhode Island is was believed to be subsiding at a rate of approximately 6 inches (15 cm) per century (Douglas, 1991). The combination of these two effects is evident from the long-term trend recorded by the Newport tide gauge (Figure 1), which indicates a rate of 10.110.6 inches +/- 1.2 in (25.726.9 cm +/- 3.1 cm) of relative sea level rise over the last per century or 2.69 mm per year.~~

5. The rate of sea level rise is accelerating. Future sea level rise, like the recent rise, is not expected to be globally uniform or linear. Some regions will become more substantially inundated than the global average, and others less. Of foremost concern is the trend in eustatic rise as observed from tide-gauge records over the past century. The rate of rise globally during the past 20 years is 25% faster than the rate of rise in any 20 year period that exists in the instrumental record (Church and White, 2006; Rahmstorf *et al*., 2007, Vermeer and Rahmstorf, 2009 and Rahmstorf *et al*., 2011).

6. Model-simulated projections of global sea level over the 21st century also clearly demonstrate accelerated progression. Predictions have ranged from 4 inches (10 cm) to several feet above current levels by the year 2100. As a rule, sea level estimates are increasing as the science of modeling becomes more developed.

Note: Delete Figure 1 below (2006 graph) and replace with updated Figure 1 (2012 graph)



~~Figure 1. Historic Sea level Rise in Newport, RI shows an increase of approximately 0.64 feet between 1930 and 2006~~

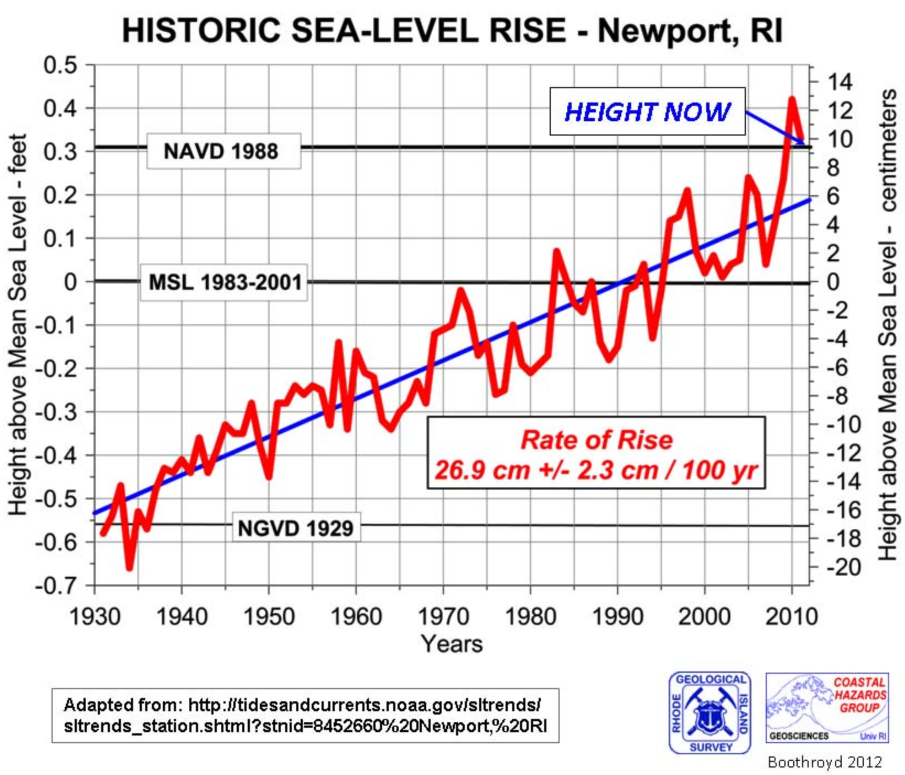


Figure 1. Sea level has risen 8.5 inches since 1931 based on the long-term trend at Newport.

7. When compared with actual observations, modeling scenarios can be quite conservative, as recently observed rates of continental ice melt are greater than those used to generate estimates of sea level rise over the coming century. Since 1990, sea level has been rising faster than the rate predicted by models used to generate IPCC (2001) estimates (Rahmstorf *et al*., 2007).

8. Higher global temperatures indicate a greater risk of destabilizing the Greenland and West Antarctic ice sheets, yet a great amount of uncertainty remains as to the overall contribution from ice sheet melting. The recent and much publicized Fourth Assessment Report of the Intergovernmental Panel on Climate Change (IPCC 2007) projects 7 to 23 in (18 to 59 cm) of eustatic sea level rise in the coming century. These estimates do not include contributions of ice flow dynamics or local subsidence.

9. ~~The most recent science (~~Rahmstorf (2007) and Rahmstorf *et al.* (2011) correlate~~s~~ global sea level rise to global mean surface temperature, which is a good approximation for observations of the 20th century. When this relationship is applied to 21st century warming scenarios, eustatic rise is projected between 1.6 to 4.6 feet (50 to 140 cm) above 1990 levels. Accounting for regional isostatic effects, this estimate suggests that by 2100 sea level in Rhode Island could rise approximately 2 to 5 feet (65 to 155 cm).

10. More recent scientific observations and refined climate models support previous projections and indicate that globally a range of sea level rise of between 2 to 6 feet (0.6 to 1.9 m) above 1990 levels is expected by the year 2100 (Jevrejeva *et al*., 2010; Vermeer and Rahmstorf, 2009 and Rahmstorf *et al*., 2011).

11. Regional rates of sea level rise will differ across the globe. The dynamic effects of ocean currents and the diminishing gravitational pull of dwindling ice sheets on ocean waters, have the potential to increase sea level rise rates at a particular location. Model projections indicate that a slowdown in the Atlantic Meridional Overturning Circulation (AMOC) may lead to a rapid rise in sea level on the northeast coast of the United States (Yin *et al*., 2009, Yin *et al*., 2011, Kuhlbrodt *et al*., 2009, Hu *et al*., 2009, Bingham and Hughes, 2009 and Kopp *et al*., 2010). Changes in static equilibrium of ocean and ice mass distribution will have an impact on relative sea levels depending on the rate of melt (Kopp *et al*., 2010).

12. U.S. Geological Survey scientists detail in their study (Sallenger *et al*., 2012) that recently accelerated sea level rise along the Atlantic Coast will result in sea levels 8 to 11 inches (20-29 cm) higher than the global average from Cape Hatteras, NC to Boston, MA by 2100. They present evidence that the rate of sea level rise increase in the study area was 3-4 times higher than the global average during the last two tidal epochs of 1950-1979 and 1980-2009. Sea level rise combined with storm surge, wave run-up and set-up will increase the vulnerability of near-shore areas to flooding, beach erosion and coastal wetland degradation.

13. A study by Strauss *et al.* (2012) examines topographic vulnerability of low-lying coastal land in the continental United States to sea level rise and flooding. The researchers found that there are presently 2705 housing units along the Rhode Island shoreline that are located less than 1 meter (39 inches) above local mean high water (MHW). These housing units are most at risk for increased flooding and eventual submersion as a result of sea level rise.

14. Tibaldi *et al.* (2012) investigated the historic patterns of extreme high tide events at 55 coastal locations of the contiguous United States using a detailed analysis of the NOAA tide gauge station data from 1979-2008 coupled with anticipated relative sea level rise. They calculate an increase of 5.1 inches (0.13m) by 2030 and 12.2 inches (0.31) by 2050 above the 2008 mean high water level as measured at the Newport tide gauge. The study indicates that the frequency of extreme high tide levels will increase significantly in the coming years.

~~10~~15. Climate change will result in wide scale systematic changes in the terrestrial and marine environments. These changes will result in ecosystem shifts that will challenge natural resource managers' efforts to cope and adapt to the new regime.

~~11.~~16. Future increases in relative sea level will displace coastal populations, threaten infrastructure, intensify coastal flooding and ultimately lead to the loss of recreation areas, public space, and coastal wetlands.

~~12.~~17. Coastal infrastructure will become increasingly susceptible to complications from rising sea levels, as the upward trend continues. Residential and commercial structures, roads, and bridges will be more prone to flooding. Sea level rise will also reduce the effectiveness and integrity of existing seawalls and revetments, designed for historically lower water levels.

~~13.~~18. Higher sea levels will result in changes in surface water and groundwater characteristics. Salt intrusion into aquifers will contaminate drinking water supplies and higher water tables will compromise wastewater treatment systems in the coastal zone.

~~14.~~19. Future increase in relative sea level will increase the extent of flood damage over time. Lower elevations will become increasingly susceptible to flooding as storm surge reaches further inland due to ~~both~~ sea level rise in concert with a probable increase in the ~~frequency and~~ intensity of storms predicted from climate change. As a result, more coastal lands will be susceptible to erosion.

~~15.~~20. At historic rates of sea level rise, the relative surface elevation of a salt marsh may be maintained through the process of accretion (the build-up of live and decaying plant parts and inorganic sediments). Yet, at high rates of relative sea level rise as predicted by Rahmstorf (2007), accretive processes in coastal wetlands will not keep pace. These habitats can become submerged resulting in a loss of salt marsh vegetation and an alteration of habitat types. This has been demonstrated by the rapid salt marsh loss in coastal Louisiana. Observations by environmental reseachers here in Rhode Island indicate that salt marshes are losing high marsh habitat as a result of more frequent inundation and possibly a consequence of accretion rates that are unable to keep pace with increased rates of sea level rise. As salt marshes and other coastal habitats become submerged, they migrate inland. However, coastal development has decreased the amount of upland open space adjacent to these habitats limiting their ability to migrate landward. Thus, an increase in the rate of relative sea level rise will likely result in significant losses of coastal saltmarsh habitats.

~~16~~21. The average annual temperature of southern New England coastal waters, including Narragansett Bay, has risen approximately two (2) degrees Fahrenheit since the 1960's. This warming trend is implicated in the change of species composition and abundance in Narragansett Bay waters (Nixon, *et al*., 2003).

~~17~~22. Increased water temperatures due to climate change will work synergistically with high nutrient levels to stress eelgrass beds. Eelgrass grows best in cool, clean waters. Even as nutrient levels in the Bay are reduced from wastewater treatment plants, if Bay and coastal waters continue to warm due to climate change, it will adversely impact eelgrass beds (Bintz, *et al*., 2003).

~~18~~23. Barrier islands are forced landward with rising sea levels. Increased frontal erosion and retreat of the barriers will cause Rhode Island's south shore to migrate continuously landward with rising sea levels.

~~19~~24. Due to the timescales associated with climate processes and feedbacks, anthropogenic warming and sea level rise will continue for centuries regardless of steps taken to curb greenhouse gas emissions (IPCC, 2007).

25. Flooding is a destructive natural hazard and results in economic loss to the citizens of Rhode Island. Approximately 154 square miles (14%) of the State's 1100 square miles of land area are mapped as Special Flood Hazard Areas by the National Flood Insurance Program (NFIP) where there is a 1% chance of flooding in any given year. (RIEMA, 2011). More than 16,000 buildings are located within these flood

prone areas with an additional 12,000 buildings located in areas mapped as 0.2% chance of flooding (based on CRMC GIS assessment of E911 data and flood zones).

26. All 39 communities within the State participate in the National Flood Insurance Program, yet only about half of Rhode Island property owners located within Special Flood Hazard Areas carry flood insurance (RIEMA and E911 data assessment).

2027. Pursuant to R.I.G.L. § 46-23-6, the Council is authorized to develop and adopt policies and regulations necessary to manage the coastal resources of the state and protect life and property from coastal hazards resulting from projected sea level rise and probable increased frequency and intensity of coastal storms due to climate change. The Council is also authorized to collaborate with the State Building Commissioner and adopt freeboard calculations (a factor of added safety above the anticipated flood level), in accordance with R.I.G.L. § 23-27.3-100.1.5.5.

28. The U.S. Army Corps of Engineers (USACE) has released a revised circular dated October 1, 2011 detailing its methodologies for assessing the impacts of sea level rise in the planning, design, engineering, construction, operation and maintenance of USACE civil works projects in coastal areas. The required project analyses determine how sea level rise scenarios may affect risk levels to the surrounding area and identify the design or operations and maintenance measures that will minimize adverse consequences while maximizing the beneficial effects of the project. See: http://publications.usace.army.mil/publications/eng-circulars/EC_1165-2-212.pdf.

29. According to a USGS report (Titus et al., 2009), preparing in advance for expected sea level rise is justifiable for several types of impacts, as it may be less costly to react now than to react to an adverse condition in the future. Some examples:

- *Coastal wetland protection*. Preserving undeveloped lands abutting coastal wetlands allows wetland migration, but once developed, it is very difficult to make land available for wetland migration. Therefore, it is far more practicable to promote wetland migration by setting aside land before it is developed and preserving coastal buffer zones, than to require development to be removed as sea level rises.
- *Some long-term infrastructure*. Whether it is beneficial to design coastal infrastructure to anticipate rising sea level depends on economic analysis of the incremental cost of designing for a higher sea level now, and the retrofit cost of modifying the structure at some point in the future. Most long-lived infrastructure in the threatened areas is sufficiently sensitive to rising sea level to warrant at least an assessment of the costs and benefits of preparing for rising sea level.
- *Floodplain management*. Rising sea level increases the potential disparity between rates and risk. Even without considering the possibility of accelerated sea level rise, the National Academy of Sciences and a Federal Emergency Management Agency (FEMA)-supported study by the Heinz Center recommended to Congress that insurance rates should reflect the changing risks resulting from coastal erosion.

(Titus et al., 2009)

C. Policies

1. The Council will review its policies, plans and regulations to proactively plan for and adapt to climate change and sea level rise. The Council will integrate climate change and sea level rise scenarios into its ~~operations~~ programs to prepare Rhode Island for these new, evolving conditions and make our coastal areas more resilient.

2. The Council's sea level rise policies are based upon the CRMC's legislative mandate to preserve, protect, and where possible, restore the coastal resources of the state through comprehensive and coordinated long-range planning.

3. The Council recognizes that sea level rise is ongoing and its foremost concern is the accelerated rate of rise and the associated risks to Rhode Island coastal areas today and in the future. Accordingly, for planning and management purposes, it is the Council's policy to accommodate a base rate of expected 3 to 5 foot rise in sea level by 2100 in the siting, design, and implementation of public and private coastal activities and to insure proactive stewardship of coastal ecosystems under these changing conditions. It should be noted that the 3-5 ft. rate of sea level rise assumption embedded in this policy is relatively narrow and low. The Council recognizes that the lower the sea level rise estimate used, the greater the risk that policies and efforts to adapt sea level rise and climate change will prove to be inadequate. Therefore, the policies of the Council may take into account different risk tolerances for differing types of public and private coastal activities. In addition, this long term sea level change base rate will be revisited by the Council periodically to address new scientific evidence.

E. References

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