Vulnerability of New Jersey's Coastal Habitats to Sea Level Rise

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1. Introduction

Sea level rise is a well documented physical reality that is impacting New Jersey's coastline. The recent historical levels of sea level rise along the New Jersey coast is generally thought to be about 3-4 mm/yr, while predicted future rates are expected to increase to 6 mm/yr (Cooper et al., 2005; Psuty and Ofiara, 2002). The hazards posed by sea level rise and severe coastal storms has instigated a number of studies examining the issue here in New Jersey as well as elsewhere in the Mid-Atlantic region (Cooper et al., 2005; Psuty and Ofiara, 2002; Gornitz et al., 2002; Rosenwieg and Solecki, 2001; Field et al., 2000; Najjar et al., 2000). The developed nature of New Jersey's coastline makes it vulnerable to flooding and inundation and cause for concern by both government officials and the public alike.

New Jersey's sandy barrier beaches are dynamic features that respond in a generally predictable manner, migrating landward by storm overwash as the shoreline is also retreating due to erosion (Psuty and Ofiara, 2002; Phillips, 1986). Historically, societal response to sea level rise has been one of trying to short-circuit this natural process and to "hold the line." Along the New Jersey coastline, as elsewhere in the Mid-Atlantic region, shoreline protection activities such as shoreline armoring (e.g., bulkheading, riprap or other solid beach fill) and/or beach nourishment have been extensively employed to halt shoreline erosion and maintain the coastline in place. With the predicted acceleration of sea level rise, the demand for additional shoreline protection structures and/or beach nourishment is expected to increase (Field et al. 2000; Najjar et al., 2000). However, there is a downside to this strategy, in that shoreline stabilization projects can either completely eliminate intertidal sand beach and shallow water littoral habitats (as in the case of bulkheading) (Able et al., 1996; Clark, 1974) or sufficiently alter the habitat such that is loses some of its natural functions. For example, beach stabilization practices in Delaware Bay have been documented to alter sediment quality and beach morphology negatively affecting the suitability of the remaining beach as horseshoe crab spawning habitat (Botton et al., 1988).

In this report, we revisit the issue of sea level rise and its potential impact to New Jerseys' coastal development and ecosystems. Increasingly it is being recognized that engineered shoreline stabilization (sometimes labeled "hard" approaches) is expensive and ultimately only a short term solution. Instead, flexible adaptation strategies (sometimes labeled "soft" approaches) that recognize and plan for the dynamic nature of our coastlines are being promoted (Psuty and Ofiara, 2002; Field, 2000). In this light, we undertook a geographic information system-based approach to identify vulnerable development and where this development is constricting the natural dynamics of coastline migration. This study was part of a broader assessment of New Jersey's coastal environmental resources conducted by the Walton Center for Remote Sensing & Spatial Analysis (CRSSA) of Rutgers University and the American Littoral Society. The objective of the New Jersey Coastal Assessment was to compile and synthesize a diversity of mapped information to provide a fuller picture of New Jersey's coastal resources and habitats to assist in land and conservation planning.

2. Objectives

We did not set out to do a comprehensive study on the impact of sea level rise on New Jersey's coastal zone but rather focus on several components that pertain to the long term sustainability of coastal habitats. Our study expands upon the recent work of Cooper et al. (2005) to more closely examine vulnerable development and where this development is constricting the natural dynamics of coastline migration. In this report, we examine six specific issues related to coastal vulnerability and future adaptability:

- to map near shore development;
- to map the land use/land cover that is vulnerable to tidal surge inundation and flooding;
- to map the distance from coastal waters to the first developed obstruction (i.e. how far removed is existing development from the surging coastal waters);
- to map the degree of shoreline alteration due to coastal protection structures;
- to map where coastal beach and dune habitats are relatively undisturbed; and
- delineate those portions of our coastal wetland complex that are free to retreat inland as part of the natural landward migration process (i.e., where are coastal wetlands bordered by undeveloped vs. developed uplands).

3. Study Area

The study area includes all or part of eight New Jersey coastal watershed management areas, as well as the near shore waters, extending from Raritan Bay southward along the Atlantic coastline and westward along Delaware Bay (Figure 1). This analysis included portions of Middlesex, Monmouth, Ocean, Burlington, Atlantic, Cape May, Cumberland and Salem counties.

Figure 1. Map of study area – all watersheds coastward of red boundary line.

4a. Coastal Land Use/Land Cover

To examine the influence of human altered land uses that are directly adjacent to coastal waters, we tabulated the upland land use/land cover within 500 m (0.5 km) from coastal waters or salt marshes. The majority of this coastal buffer is in some form of human dominated land use: 42% urban, transitional or mining; and, 14% in agriculture. The remaining 44% is in natural land covers such as forest/scrub, freshwater wetland, freshwater lakes/streams or beaches. The comparatively undeveloped nature of the Delaware Bay shore stands out in stark contrast to the mainland shores of Middlesex and Monmouth and northern Ocean counties, as well as the barrier islands of Ocean, Atlantic and Cape May counties (Figure 2).

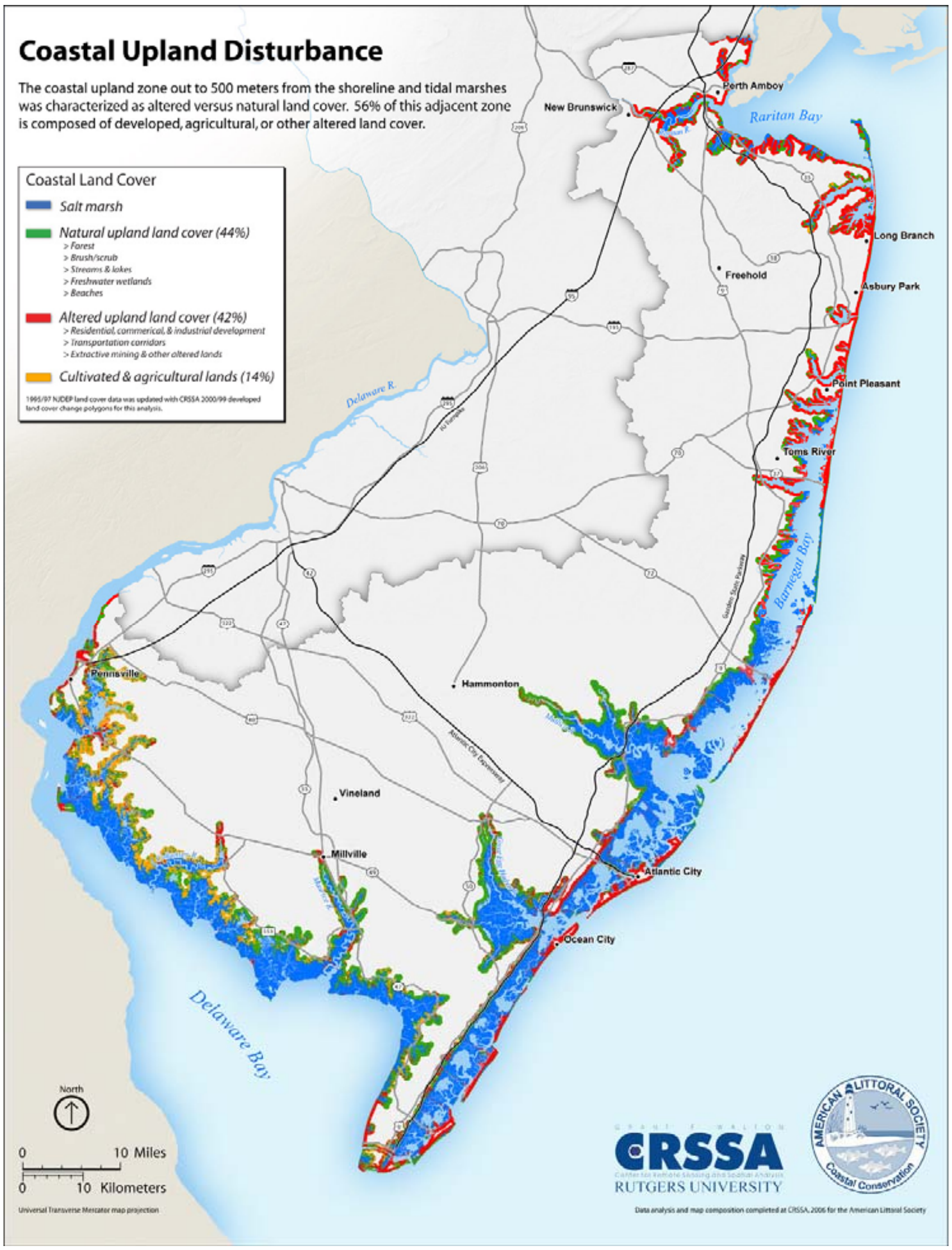

Figure 2. Map of upland land use/land cover directly adjacent to coastal waters.

4b. 100-year (3 meter) Tidal Surge Inundation Area

The Federal Emergency management Agency (FEMA) estimates a 100-year storm tidal surge (1% yearly likelihood) of approximately 2.89 meters above National Geodetic Vertical Datum (NGVD) for the Atlantic coast of New Jersey (Psuty and Ofiara, 2002). Similarly, the 30-year FEMA tidal surge is estimated at 2.34 m. Cooper et al. (2005) used a projected median sea level rise by 2100 of 0.61m and a high end projection of 1.22 m. Following a 0.61 m rise in sea level, they go on to estimate that the current 30-year storm will produce a flood water level of 2.96 m and a 100-year storm will produce a flood water level of 3.5m. Based on these analyses, we choose a 3m threshold elevation value to represent the coastal land area that would be affected by the approximately 3 meter tidal surge that is estimated for a present day 100-year storm surge or future sea level rise-augmented 30-year storm.

Using geographic information system (GIS) software and readily available public domain data sets, we mapped the potential 100-year tidal surge inundation area as any land area 3.0 meters or lower in elevation. We then cross-tabulated the flood zone map with land use/land cover (lu/lc) data derived from the New Jersey Department of Environmental Protection (NJDEP) 1995/97 LU/LC data (NJDEP, 2000) updated with 2000/1999 developed land cover change from CRSSA (2004). The source elevation data were U.S. Geological Survey 10 meter ground cell resolution digital elevation models (DEMs) (USGS). While the published vertical resolution of the data is 0.1 meters there are inconsistencies in the 1 and 2 meter elevation contours between adjacent DEMs, resulting in many edge artifacts. At 3 meters, the approximate elevation of a 100-year storm surge, these inconsistencies were deemed to be minimal. To aid more detailed mapping and analysis of tidal surge inundation zones, higher spatial resolution (in both horizontal as well as vertical dimensions) mapping of elevation is needed. FEMA and the state of New Jersey have instituted high resolution floodplain mapping using LiDAR remote sensing technology in several inland areas. NOAA likewise has used LiDAR to map a narrow swath of the Atlantic shoreline leaving a majority of New Jersey's coastal zone unmapped.

The area estimated to be inundated by a 100-year (3m) storm tidal surge is displayed in Figure 3. Note that all of New Jersey's barrier island communities, as well as significant sections of the Barnegat, Delaware and Raritan Bays' are within the inundation zone. Approximately 16% of the predicted flood zone (240 km^2 or 90 $mi.^2$) is in developed land uses, primarily residential development (9%). 79% of the inundation area (1,200 km^2 or 460 $mi.^2$) is in natural land cover, primarily tidal salt marshes and freshwater wetlands. The remaining 6% of the flood zone (90 km^2 or 35 $mi.^2$) is in agricultural land covers.

While the 500 m coastal buffer analysis (from Section 4a) and the 100-year tidal surge inundation zones closely overlap with approximately 61.4% of the adjacent upland zone (500 m buffer from 4a above) within 3m tidal surge inundation zone. One region where there is a significant difference is the Monmouth county coastline where the mainland is at greater elevation (e.g., Atlantic Highlands) and slopes more steeply to the shoreline, thus limiting tidal surge inundation.

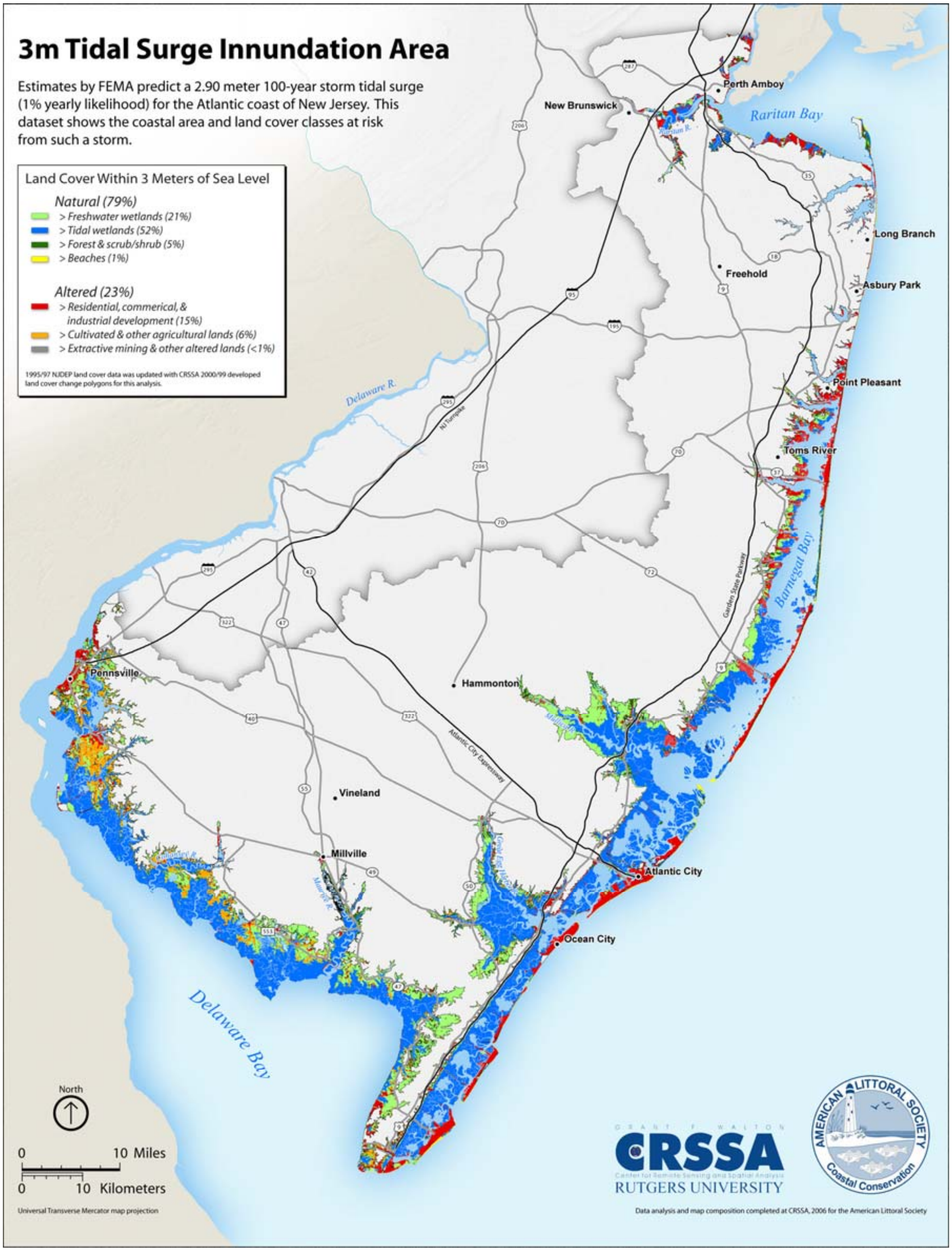

Figure 3. Map of land use/land cover within the estimated 100-year (3m) storm surge zone. Note: only areas within the potential storm surge zone are displayed.

4c. Distance to First Developed Infrastructure

To more closely examine the vulnerability of coastal development to sea level rise and tidal surges, we mapped the Euclidean (straight line) distance from tidal waters to the first developed land uses or road infrastructure. Developed features included residential, commercial, and industrial land uses as well as all county level and larger roads. The spatial analysis was limited to developed features within 3 m tidal surge inundation zone. New Jersey Department of Transportation digital roads data (NJDOT, 2005) was used to extract county level (500 and 500 level) and larger (state and federal highways) roads. Figure 4 shows the concentration of development in close proximity (<100 m) to tidal water in the Shrewsbury/Navesink rivers, northern Barnegat Bay, the barrier islands and associated causeways.

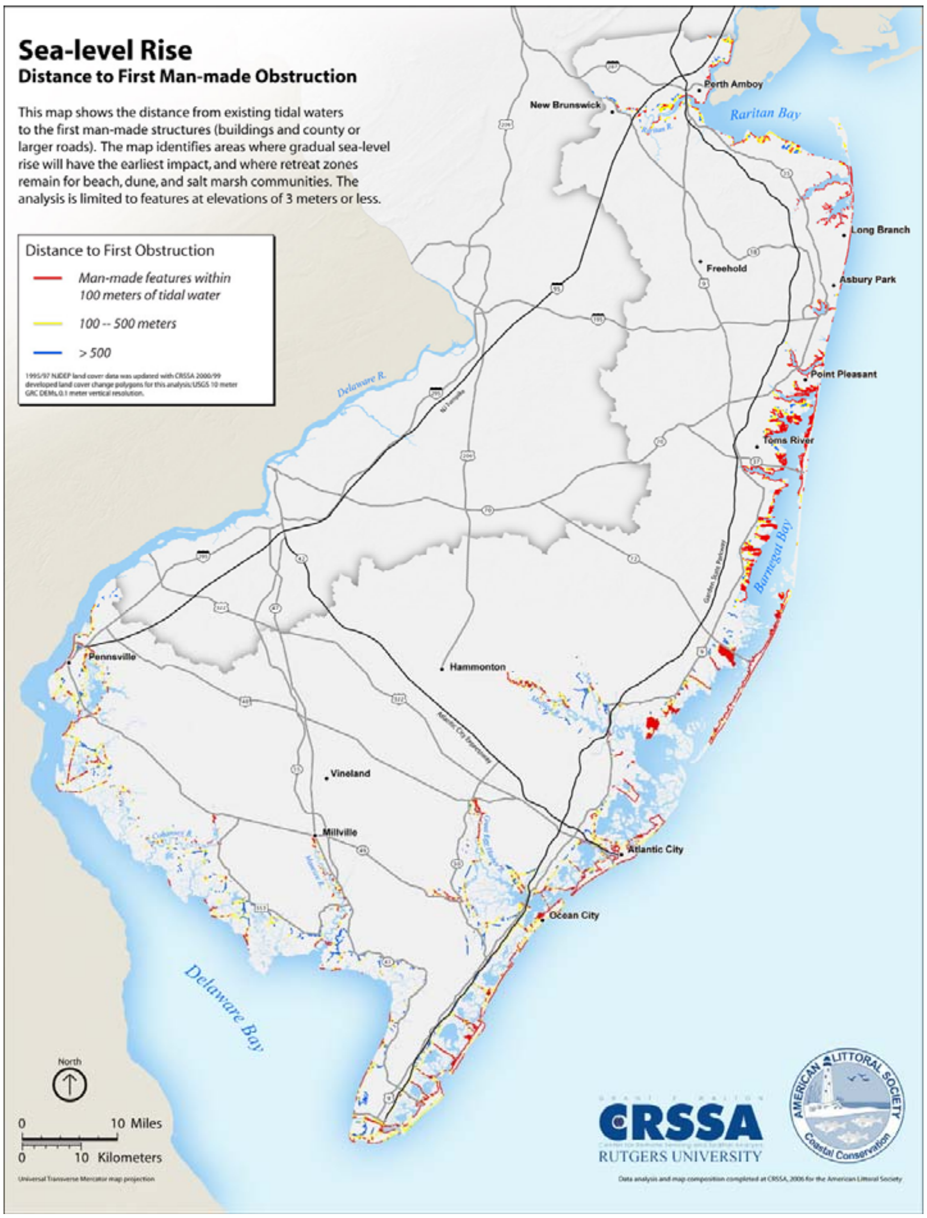

Figure 4. Map of distance to first developed obstruction.

4d. Altered Shorelines

As past of the larger New Jersey Coastal assessment we compiled and synthesized existing mapped data on coastal land cover and habitats. In particular, we were interested in identifying and mapping the spatial location of shorelines that have been altered by some form of armoring or other engineered coastal protection structures and thus represent potential impediments to future beach migration. The National Oceanographic and Atmospheric Administration (NOAA) Environmental Sensitivity Index (NOAA 2002, 2000) map series provided information on composition of the Atlantic, Delaware, Raritan and other coastal bays shorelines (Figure 5). While sand beaches dominate the Atlantic shoreline, a vast majority (over 75%) of New Jersey's coastal shoreline is made up of convoluted bay, lagoon and tidal creek shorelines bordered by salt marsh or other vegetation. Approximately 17% of the mapped shoreline has been altered due to bulkheading, rip-rap or other coastal protection structures.

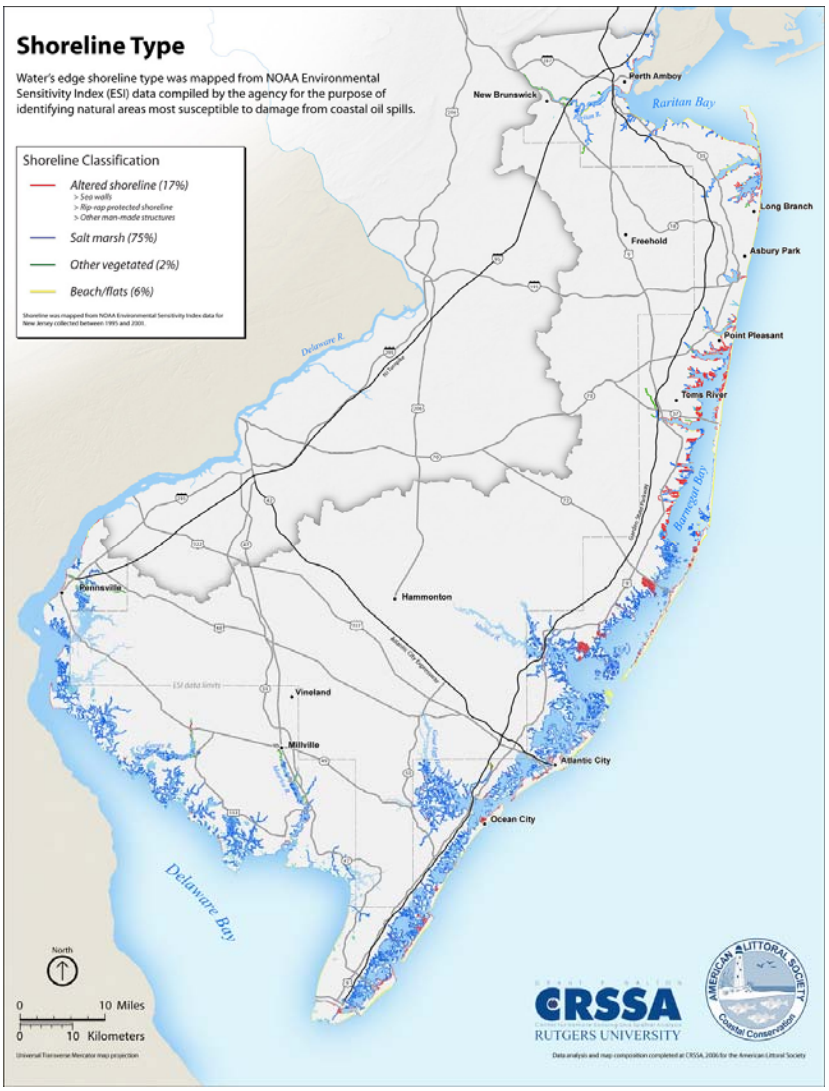

Figure 5. Map of New Jersey shoreline type.

4e. Proximity of Coastal Beach and Dune Habitats to Development

Sand beaches and vegetated dunes provide an important buffer between coastal waters and human development. However, adjacent development may compromise some of the natural functions of the beach (e.g., its utility as wildlife habitat, e.g., Burger (1986)) and inhibit future movement or migration of these features. We mapped the proximity of developed land uses (residential/ commercial/ industrial development and altered/ transitional land uses) to all beach/dune areas to provide an index of present disturbance, as well as future limitations, to beach and dune habitats (as mapped from NJDEP 1995/97 lu/lc data). Examination of the entire coastline shows that 48% of the beach and dune habitats are within 100m of development. When only Atlantic and Raritan Bayshore beaches and dunes are considered, this figure increases to 60%. Only comparatively short stretches of Atlantic coastal beach/dune systems are relatively undisturbed by adjacent development (e.g., Sandy Hook, Island Beach, Holgate and Pullen Island and some isolated sections of Avalon, Stone Harbor and the Wildwoods) (Figure 6). This contrasts strongly with the Delaware Bayshore's comparatively undeveloped shoreline.

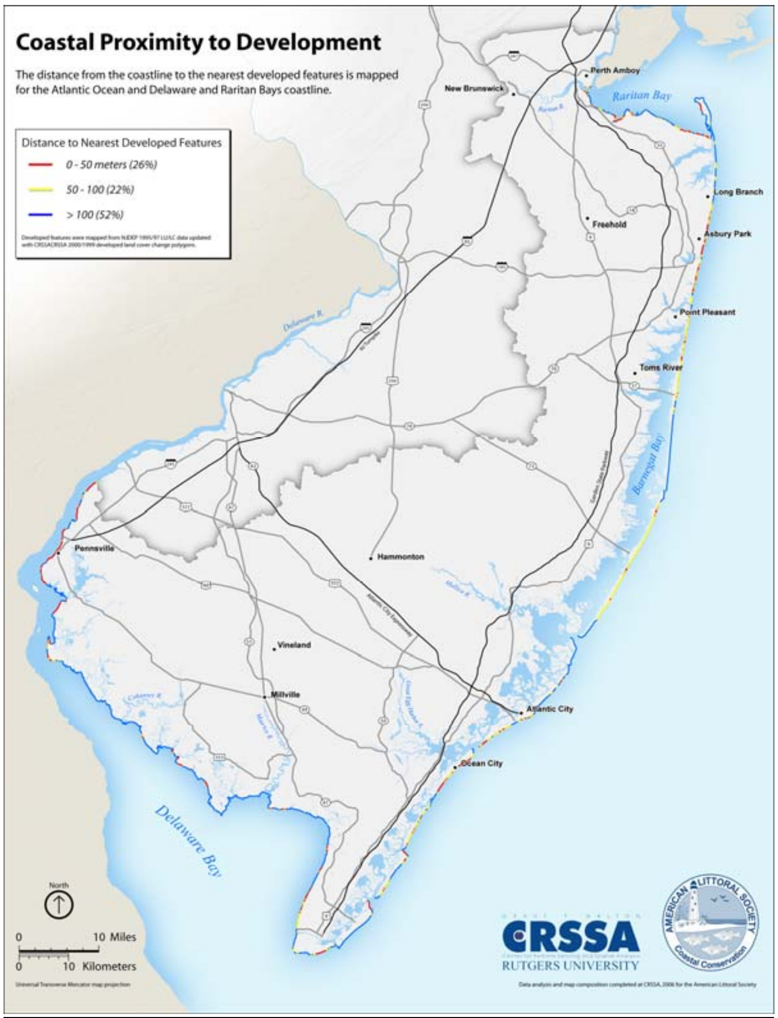

Figure 6. Map of relative proximity of coastal beaches and dunes to development

4f. Coastal Wetland Retreat Zones

Tidal salt marshes are and have been a characteristic landscape feature of New Jersey's coastal bays, fringing both the back side of the barrier islands, as well as the mainland. Through the process of vertical accretion of sediment and organic matter, the tidal salt marsh surface will rise in relation to sea level, i.e., the marsh can continue to grow "up" into a rising sea (Warren and Niering, 1993; Redfield, 1972). New Jersey salt marshes appear to have been able to keep pace with historical rates of sea level rise (Kana et al., 1988). When sea level rises faster than marsh accretion, tidal marshes are eventually drowned and replaced by open water.

Galbraith et al (2002) examined several different scenarios of future sea level rise as a consequence of global climate change and projected major losses of intertidal habitat (i.e., exposed sand and mud flats) due to continued sea level rise. Under the 50% probability scenario (i.e., the most likely scenario), Delaware Bay is predicted to lose 60% or more of the shorebird intertidal feeding habitats by 2100. Under more extreme sea level rise, Delaware Bay may actually have a net gain of intertidal flats as the coastline migrates further inland converting marsh or upland to intertidal habitat. However, this prediction assumes that the coastal protection structures do not constrain the ability of shorelines to migrate landward. Tidal marshes can also retreat landward through a process of 'creative destruction.' If there is only a gradual rise in elevation, the adjacent uplands will be periodically flooded by rising tidal inundation. The more sensitive upland vegetation will be stressed by the flooding and higher salinity and be replaced by emergent marsh vegetation. However, in most areas, the slope above the coastal marsh is steeper than the marsh; so a rise in sea level will cause a net loss of marsh acreage (Titus, 1988). Development or other 'hard" obstructions (i.e. levees or bulkheads) in the upland fringe adjacent to coastal wetlands will further impinge on the landward migration process, effectively squeezing out the marshes (Cooper et al., 1995; Kana et al., 1988).

To examine this issue we modeled buffer areas within 500 meters up-gradient of existing tidal marshes and to elevations of 3 meters or less that could potentially serve as retreat zones as sea levels rise (Figure 7). In some respects, using a 3 m elevation threshold overestimates the projected Year 2100 sea level rise by a factor of 2 to 3 (i.e., Cooper et al. (2005) used a 0.6 to 1.2 m rise, while Kana et al. (1988) used a 0.9 to 1.5 m rise). We employ this more conservative threshold to ensure that there is space to maintain a non-developed vegetated upland buffer along with a marsh retreat zone. As such, we have undertaken this analysis more as a planning tool than as a prediction of future conditions. For the purposes of this model salt marsh retreat is limited by existing developed features, including major roads (600-level county roads and larger). The buffer zones were calculated with and without the developed features and roads constraints to determine the difference between the available (with development) and potential (without) retreat zones.

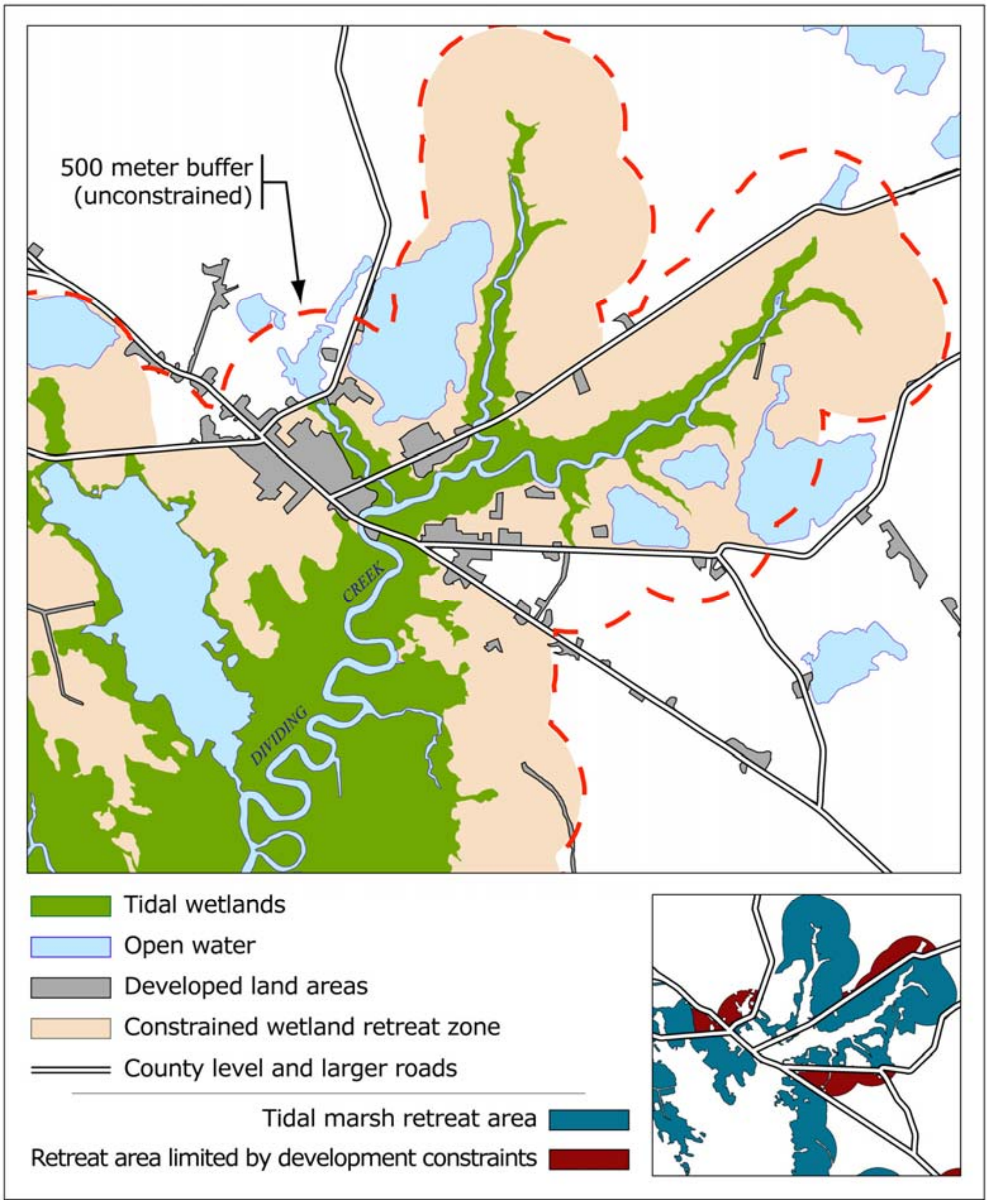

Figure 7. Example illustration of the method to determine potential tidal marsh retreat zones using development constraint factors.

Our analysis reveals that approximately 29% of potential tidal marsh retreat area is presently limited by developed features and roads. Tidal marshes along Raritan Bay, northern/central Barnegat Bay and the backsides of the barrier islands have limited retreat zones (Figure 8). However, extensive areas in southern Barnegat Bay/Little Egg Harbor, Great Bay, Reed Bay, Great Egg Harbor and Delaware Bay have comparatively unrestricted retreat zones due to the extensive amounts of federal and state wildlife refuge and management lands that have protect both the coastal wetlands as well as the adjacent uplands.

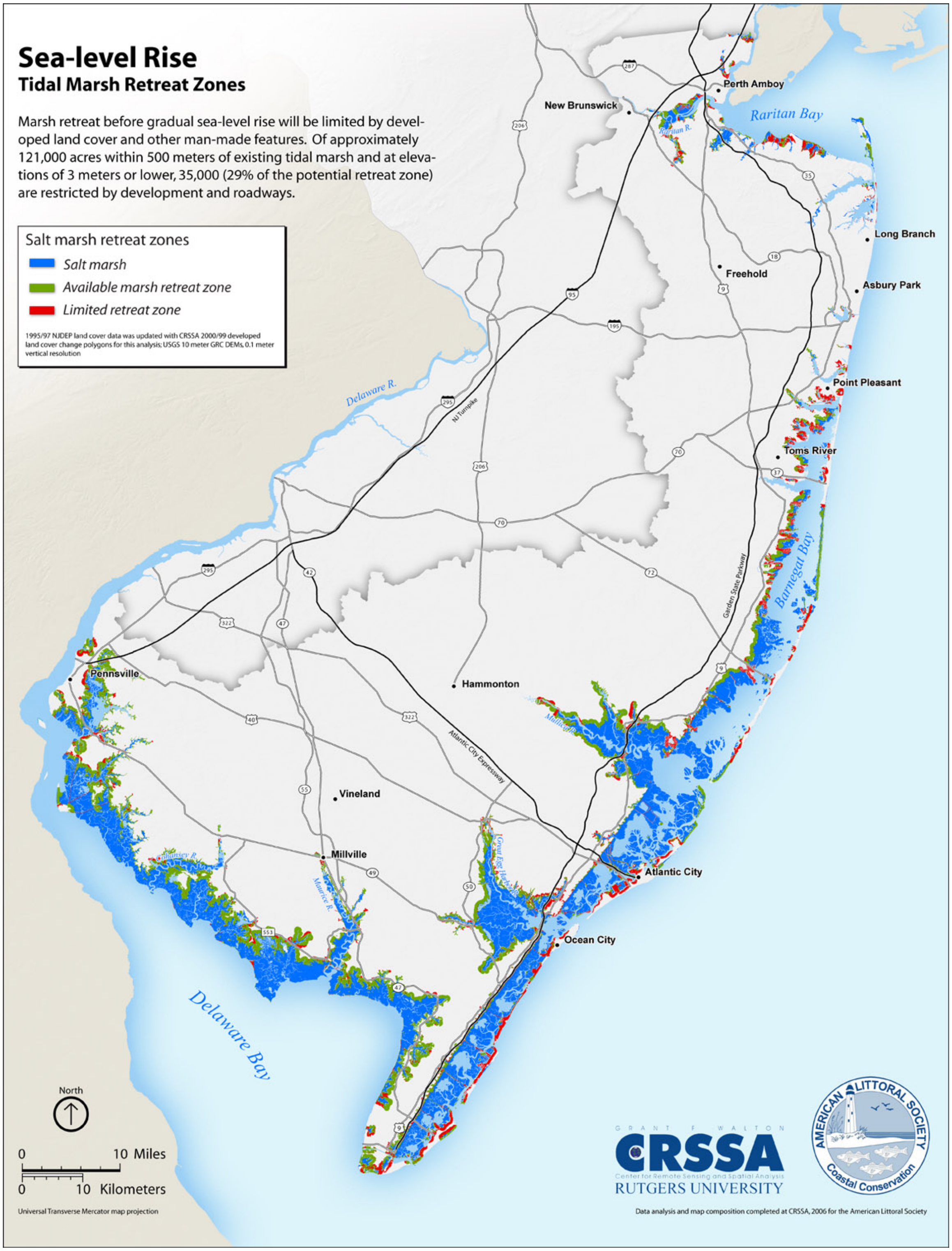

Figure 8. Map of potential tidal marsh retreat zones.

5. Summary and Conclusions

In this report, we revisit the issue of sea level rise and its potential impact to New Jerseys' coastal development and ecosystems. New Jersey's coastal zone is heavily impacted by development with a high degree of developed land uses in close proximity to the tidal waters and thereby vulnerable to future sea level rise:

- The majority of near-shore coastal zone (<500 m from tidal water) is in some form of human dominated land use: 42% urban, transitional or mining; and, 14% in agriculture.

To model the potential hazard posed by future sea level rise and storm surge, we mapped the predicted inundation zone for a 100-year tidal surge, which also equates very closely to a 30-yr storm under a 2100 sea level rise scenario:

- Approximately 16% of the predicted 100-yr tidal surge inundation zone is in developed land uses including all of New Jersey's barrier island communities, as well as significant sections of the Barnegat, Delaware and Raritan Bays.

Near shore development and other infrastructure such as shoreline armoring limits the future flexibility in adapting to predicted sea level rise and coastal storm surges.

- 17% of New Jersey's shoreline is altered due to bulkheading or rip-rap or other coastal protection structures;
- 60% of New Jersey's Atlantic shore beaches and dunes are in close proximity (< 100 m) to developed land uses; and,
- 29% of tidal marsh retreat area is presently limited by development and roads.

The detail and specificity of the sea level rise/storm surge analysis reported on this study was limited by the vertical and horizontal resolution (1.0 m in the vertical and 10 m in the horizontal) of the digital elevation model used. Higher spatial resolution (in both horizontal as well as vertical dimensions) mapping of elevation using LiDAR or other remote sensing technologies is needed to support more detailed mapping and analysis of coastal hazards. There are several ongoing missions to map New Jersey's river floodplains using LiDAR. A similar effort to undertake a "wall-to-wall" mapping of New Jersey's coastal zone from the tidal shoreline to the upper reaches of potential tidal surge inundation zones is critical.

While reductions in the emission of greenhouse gas and other climate change mitigation strategies may slow the rate of sea level rise, sea level rise is an ongoing process that that will not go away (Nicholls and Lowe, 2004). If we are to sustain functioning coastal ecosystems, then we need to maintain our beaches, tidal flats and bars, seagrass beds and tidal wetlands. To ensure vitality of these coastal habitats for the long term then we need to plan for and design flexible adaptation strategies that recognize the dynamic nature of our coastlines. Sea level rise and associated problems of shoreline erosion and storm surges have been primarily addressed through "hard" structural approaches to protect existing developed infrastructure. We suggest that future adaptation to sea level rise is not just an engineering issue but rather primarily a **land use** issue.

New development should be minimized in beach, dune and coastal wetland retreat zones to provide for future shoreline retreat and minimize the need for future investment in structural protection (USEPA, 1988). Present state regulations limit development in proscribed buffer zones adjacent to coastal wetlands and waters to limit the impact associated with runoff, sedimentation, and non-point source pollution. As such these presently regulated buffer zones serve the dual purpose of also serving as coastal "retreat" zones. These buffer zones should to be "rolling" to reflect changes as sea levels rise and the water/wetland boundary retreats landward (Titus, 1988). Where existing beach or bayfront development is threatened by shoreline erosion, "soft" approaches such as dune protection/stabilization or salt marsh restoration should be used rather than shoreline armoring.

New Jersey is presently engaged in an expensive experiment involving beach nourishment as a buffer against sea level rise and shoreline erosion. The efficacy of beach nourishment as a viable policy option/approach for the long term (i.e., the next 100 years) remains to be proven. Alternatively, a policy of "strategic adjustment" where developed properties in high hazard erosion and storm inundation zones are acquired and removed should receive careful consideration (Psuty and Ofiara, 2002). Such a Coastal Blue Acres program would mirror the approach that New Jersey has successfully used in removing vulnerable development in river floodplains. Future work is needed to identify "high hazard conflict" zones where "strategic adjustment" may serve as the preferred policy option/approach.

The map graphics produced as part of this study, are available at
http://www.crssa.rutgers.edu/projects/coastal/sealevel/index.html

6. Acknowledgements

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