Mapping the potential impact of sea level rise on agricultural land in Virginia Beach, Virginia

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Abstract

The Hampton Roads region of southeastern Virginia is experiencing the highest rates of sea level rise (SLR) along the Atlantic Coast due to the combined effects of climate change and local land subsidence. While sea levels have been rising globally at a rate of 1.8 mm/year, sea levels in Norfolk, Virginia have been rising at a rate of 4.4 mm/year (Zervas, 2009). This study focused on the southern rural sector of the City of Virginia Beach, where agriculture is a major land use, with the primary objective of determining how SLR may impact the agricultural land of the city by the year 2100. To forecast the percentage of agricultural land that will potentially be inundated and subjected to increases in salinity, the United States Army Corps of Engineers Sea Level Change Curve Calculator was utilized to determine the projected SLR for the area of interest. The intermediate-high projection for the year 2100 was determined to be approximately 1.5 meters of SLR. ArcMap 10 was used to correlate 1.5 meters of SLR using a LiDAR DEM to agricultural land use data. It was determined that about 72% of the agricultural land units and 42% of agricultural land area in Virginia Beach would be affected by 1.5 meters of sea level rise. A literature review also examined the potential impacts of increased salinity due to salt water transgression.

Introduction

Along the East Coast of the United States the area experiencing the highest rates of sea level rise is the Hampton Roads region of southeastern Virginia (Connolly, 2015). This is due to the fact that, in addition to rising water levels, the region is undergoing land subsidence which has been observed at an average rate of 2.8 mm/year since the 1940s (Eggleston & Pope, 2013). This land subsidence can likely be attributed to two factors, glacial isostatic adjustment and rigorous groundwater withdrawals. While global average sea levels have been rising at a rate of about 1.8 mm/year, sea level at the Sewells Point tidal station in Norfolk, Virginia has risen at an average of 4.4 mm/year from 1927-2006 (Zervas, 2009).

The northern sector of Virginia Beach is intensely developed, whereas the southern sector is largely rural, with agriculture being a primary land use (City of Virginia Beach, ©2016). In 1979, the City of Virginia Beach established an urban-growth boundary, known as the green line (fig.2), to concentrate development to the north and protect its agricultural heritage to the south (City of Virginia Beach, ©2016). City policies strictly limit development south of the green line; therefore, it is assumed that agricultural land use in Virginia Beach will not undergo any significant changes in the near future. Furthermore, 193 of Virginia Beach's agricultural land units are enrolled in a permanent easement program with the city, ensuring they will remain in agricultural production and avoid development (City of Virginia Beach, ©2016).

In 2011, the total economic impact of agriculture in Virginia Beach was about $250 million, and agriculture employed 2,555 people in the city (Rephann, 2013). City planners intend to put forth efforts to protect the northern, intensely developed portion of the city from rising seas, but the southern portion of the city will likely remain unprotected based on current city planning (Titus, et al., 2009).

Much of this agricultural land is located alongside waterbodies such as the North Landing River and Back Bay. This study aimed to determine how sea level rise may impact the unprotected agricultural lands of southern Virginia Beach by the year 2100 in terms of potential inundation and includes a discussion on the impacts of a potential increase in soil salinity prior to inundation.

Rationale and Significance

Sea level rise is a significant issue globally, and southeastern Virginia is expected to experience the impacts of sea level rise sooner than most coastal localities in the United States due to the fact that it is also subsiding (Eggleston & Pope, 2013). It has been reported that in the city of Virginia Beach, funding for protecting shorelines will be concentrated to the northern portion of the city, which is densely populated, leaving the southern, rural portion of the city unprotected from rising seas (Titus, et al., 2010). This will undoubtedly have a detrimental impact on agricultural production in the city. Anyone involved either directly or indirectly with agriculture in the city of Virginia Beach should be aware of the potential implications of sea-level rise to the agricultural lands of the city.

Objectives

The objective of this project was to utilize sea level rise projections to determine the potential impact of rising seas on the agricultural land of southern Virginia Beach. The project sought to establish what percentage of the current agricultural land in Virginia Beach will be impacted by sea-level rise by the year 2100. The study also investigated which local soil series will be most affected and the potential impacts of increased salinity.

Materials & Methods

Study Site

Hampton Roads is located at the mouth of the Chesapeake Bay, where its brackish waters are discharged into the Atlantic Ocean (fig. 1). The region is currently the 2nd largest population center at risk from sea level rise in the country, behind only New Orleans, LA (Connolly, 2015). The City of Virginia Beach, the largest city in Hampton Roads and most populous city in the state of Virginia, is located in the southeastern most corner of Virginia, bordering the Atlantic Ocean to the east and the Chesapeake Bay to the north. It is one of the most popular tourist destinations on the east coast and is home to four military installations. The city covers 307 square miles: 248 miles of land, 59 miles of water and 38 miles of beaches and has an elevation of 3.7 m above sea level (Hall, 2015).

Sea Level Rise Prediction

Due to local variability, rather than utilizing the generalized estimate of 1 meter of sea-level rise predicted by 2100 by the Intergovernmental Panel on Climate Change (2007), this study utilized the U.S. Army Corps of Engineers Sea Level Change Curve Calculator (USACE SLCCC) v2015.46 to determine the rate at which sea levels may rise in Virginia Beach by 2100. The SLCCC is a web-based tool which allows user input such as project start date, preference for an applicable NOAA long term tide gauge, and project life span, to generate a graph and table of the projected sea level rise for a particular area (Huber & White, 2015). For this project, the Sewells Point tide gauge in Norfolk, Virginia was used. The formula used by the USACE SLCCC to compute sea level change is as follows:

$$E(t) = Mt + bt_2 \text{ where:}$$

E = the change in global mean sea level between project start and end dates

t = time in years between start and end date

M = the generally accepted eustatic sea level rise rate 1.7 mm/yr plus the Vertical Land Movement (VLM) rate at selected tide gauge

b = Constants for low, intermediate or high rate curves from Engineering Report 1100-2-8162

The USACE SLCCC produced a variety of sea level rise projections using the Sewells Point tide gauge and the NOAA and USACE estimates from low to high ranges of sea level rise as well as high tide projections. The projections range from low to high based on a variety of climatic variables and models. It has been reported that many scientific communities, including NASA and the IPCC, have been underestimating the current and projected rates of sea level rise (Lewis, 2015; Scherer, 2012), therefore this study utilized the result between the NOAA intermediate high and the USACE high projections.

Projecting Sea Level Rise Implications in Virginia Beach

ArcMap 10.0 was used to analyze data and create various maps predicting the impact of sea level rise on agricultural land in Virginia Beach by the year 2100. A LiDAR DEM, city boundary shape file and soils data for Virginia Beach were obtained from the U.S. Department of Agriculture Natural Resources Conservation Service (USDA NRCS) field office in Chesapeake, Virginia. Agricultural land use data was obtained from a *Parcels* shapefile on the city of Virginia Beach's Open GIS Data website (©2014). All data sources are cited at the conclusion of this report.

The LiDAR DEM, which is a high resolution digital elevation model obtained from light detection and ranging, initially encompassed the cities of Virginia Beach, Chesapeake, Norfolk and Portsmouth. For this study it was clipped using the city boundary of Virginia Beach. The raster was then reclassified to indicate up to 1.5 m of sea level rise (as determined by the USACE SLCCC, to be discussed in the results) by removing data that falls above 1.5 m in elevation (fig. 4), resulting in the *projected sea level rise* raster. The inverse Cyan-Light to Blue-Dark color ramp was selected to indicate gradual sea level rise impact in 1 foot increments for display purposes.

To obtain agricultural land units, the agricultural land uses from the City of Virginia Beach's *Parcels* shapefile were selected to create a new layer named *Agriculture*. The *projected sea level rise* raster was then converted to a polygon feature using the conversion tool so that it could be used to clip the *Agriculture* layer, indicating which tracts would be impacted by 1.5 m of sea level rise by 2100. The resulting feature was named *Affected Ag*. The number of land units in the *Agriculture* layer was then compared to that of the *Affected Ag* layer. The *Agriculture* and *Affected Ag* polygons were then converted to rasters and the area of each layer was calculated and compared to determine what percentage of farmland acres would be affected. Then, the Virginia Beach *Soils* layer was then converted to a raster and clipped using the *Affected Ag* feature to indicate which soils types will be most impacted by sea level rise. The *Affected Soils* layer pixels, which are at a scale of 1 acre each, were then quantified to indicate which soil types will be most affected by sea level rise. The raster was then reclassified to display the top five affected agricultural soils.

Results

Sea Level Rise Prediction

A projection of 1.5 meters of sea level rise for Virginia Beach by the year 2100 was determined based on the values calculated between the NOAA intermediate high and the USACE high projections (table 1).

Projecting Sea Level Rise Implications in Virginia Beach

Figure 6 displays the projected impact of 1.5 m of sea level rise on southern Virginia Beach. Analysis of the *Affected Ag* layer indicates that 842 out of 1171 parcels will be affected by 1.5 m of sea level rise, which is about 72% of the agricultural land units in Virginia Beach (fig. 7). In terms of area, about 10,500 acres of agricultural land out of 25,300 acres will be affected, which is 42%. Out of 44 soil map units in Virginia Beach, 23 are located within the *Agriculture* layer and 22 are located within the *Affected Ag* layer. Of the affected soils, the predominant soil series are included in table 2 and displayed in figure 8.

Discussion

This study is the first to utilize relative sea level rise models to determine potential impacts to the agricultural land in the city of Virginia Beach, Virginia. There are many different scenarios and variables, both globally and locally, to consider when projecting sea level rise and its possible implications. This study utilized a tool developed by the Army Corps of Engineers to project local sea level rise for the city of Virginia Beach based on measurements from the Sewells Point tide gauge in Norfolk, Virginia. Based on the USACE SLCCC, a projection of 1.5 m of sea level rise by 2100 was predicted for the city of Virginia Beach. A LiDAR DEM was then reclassified to indicate all land which falls within 0-1.5 m of elevation within the southern sector of Virginia Beach. This methodology gives us a generalization of the impact of 1.5 m of sea level rise. It does not account for loss of wetland buffers, increased storm surges or increased tidal ranges, which should also be considered in land management planning. Further studies should discuss planning for worst case scenarios and which environmental factors and climate models should be considered.

The 1.5 m reclassified DEM was then used to indicate which land parcels classified as agriculture would likely be impacted by rising sea levels by the year 2100 as well as what soil series within the agricultural land would be affected. It was found that nearly ¾ of the agricultural land units in Virginia Beach will be affected by 1.5 m of sea level rise which could occur over the next 85 years. The majority of the affected agricultural soils are poorly drained and hydric, which will further subject them to the detrimental impacts of sea level rise and salt water transgression.

A literature review of the effects of increased salinity in the soil due to saltwater transgression and storm surge indicated that salinity may be an issue prior to inundation. Soil salinity can be defined as the occurrence of excessive concentrations of soluble salts located within the soil (van Mensvoort, et al., 1985). The salinity in Back Bay ranges from 0-4 ppt, following a north to south trend of increasing salinity (USFWS, 2010). The process of saltwater intrusion due to SLR is expected to result in an overall permanent increase in the salinity of the Bay, as is the case with the Chesapeake Bay to the north (Leatherman, et al., 1995). Saltwater intrusion in the soil on land adjacent to Back Bay will not immediately result in soil salinization because water-soluble salts are highly mobile and the salts may be diluted or removed laterally and vertically by rain. Virginia Beach's climate is humid subtropical and the city receives an average of 115 cm of rain per year (City of Virginia Beach, 2012). However, the majority of the affected agricultural soils are poorly drained with slow surface runoff so dilution and runoff from rain may not be very effective at preventing soil salinization for long (USDA NRCS, 2008).

Furthermore, in soils where the water table is high and saline, water rises via capillarity resulting in an increase in salt concentration and EC in the soil surface strata (USDA NRCS, 2011).

An increase in salinity in the soils will have detrimental impacts to soil fertility and overall soil quality. The majority of soil microorganisms are sensitive to salt, therefore, microbial processes such as respiration and nitrification decline as salinity increases (USDA NRCS, 2011). Actinomycetes and fungi are less sensitive to salinity than baceteria (USDA NRCS 2011). Weston et al. (2011) studied the impact of saltwater intrusion on tidal freshwater marsh soils and found that flux rates of CO2 and CH4 increased significantly after saltwater intrusion and remained higher in comparison to freshwater cores for up to 6 months. They also found significantly increased rates of sulfate reduction which persisted and significant decreases in soil organic carbon content following saltwater intrusion. Increases in soil salinity and submergence can result in oxygen depletion, an accumulation of toxic compounds and an overall shift in nutrient cycling which can alter metabolic functioning in plants and result in reduced survival, growth and productivity (DeLaune, et al. 1987).

Soil salinity impedes crop growth by preventing plants water uptake (USDA NRCS, 2011). Crops may also suffer adverse effects due to salinity-induced nutritional disorders, primarily reducing uptake and accumulation of nutrients such as phosphate, calcium, potassium and nitrate, resulting in reduced yield and/or quality (Grattan & Grieve, 1999). The primary cash crops in Virginia Beach are soybeans, with low tolerance for salinity, and corn, with moderate tolerance for salinity. The soils are poorly drained and will become inundated over time, so reclamation by leaching is not a viable option for preventing an accumulation of salts in these soils.

Conclusion

The data and results from this project can help city planners, land owners and farmers plan for the future. Agriculture is an important industry in Virginia Beach, one which nearly 3,000 individuals rely on for their livelihood. They should be aware of the potential impact of sea level rise on their land and their industry in the years to come. Further discussion is needed to determine whose responsibility it is to inform the citizens who will be impacted as well as what options are available to them. Local and/or federal programs may need to be developed to offer assistance. One federal option already in existence is a Wetland Reserve Easement, which is part of a conservation easement program offered by the U.S. Department of Agriculture Natural Resources Conservation Service (USDA NRCS). In this program, land owners may receive funding to restore wetlands on agricultural land which was historically a wetland and contains hydric soils. The top four most affected soil series in this study all meet hydric criteria (USDA NRCS, 2008).

Overall, it is clear that sea level rise has the potential to pose a great threat to the agricultural lands of Virginia Beach and this risk should be a topic of discussion among city planners and those working in, or affected by, the local agricultural industry. Further studies are needed to indicate which agricultural parcels are at the greatest risk and how soon they may be affected to allow for prioritization of resources and adequate planning time. The data utilized in this study could be used for such projections. The City of Virginia Beach has long cherished its rural heritage and put forth efforts to preserve it, but if those efforts don’t soon address sea level rise in the southern sector of the city, that cultural heritage will be washed away along with a $250 million dollar industry.

Figures & Tables

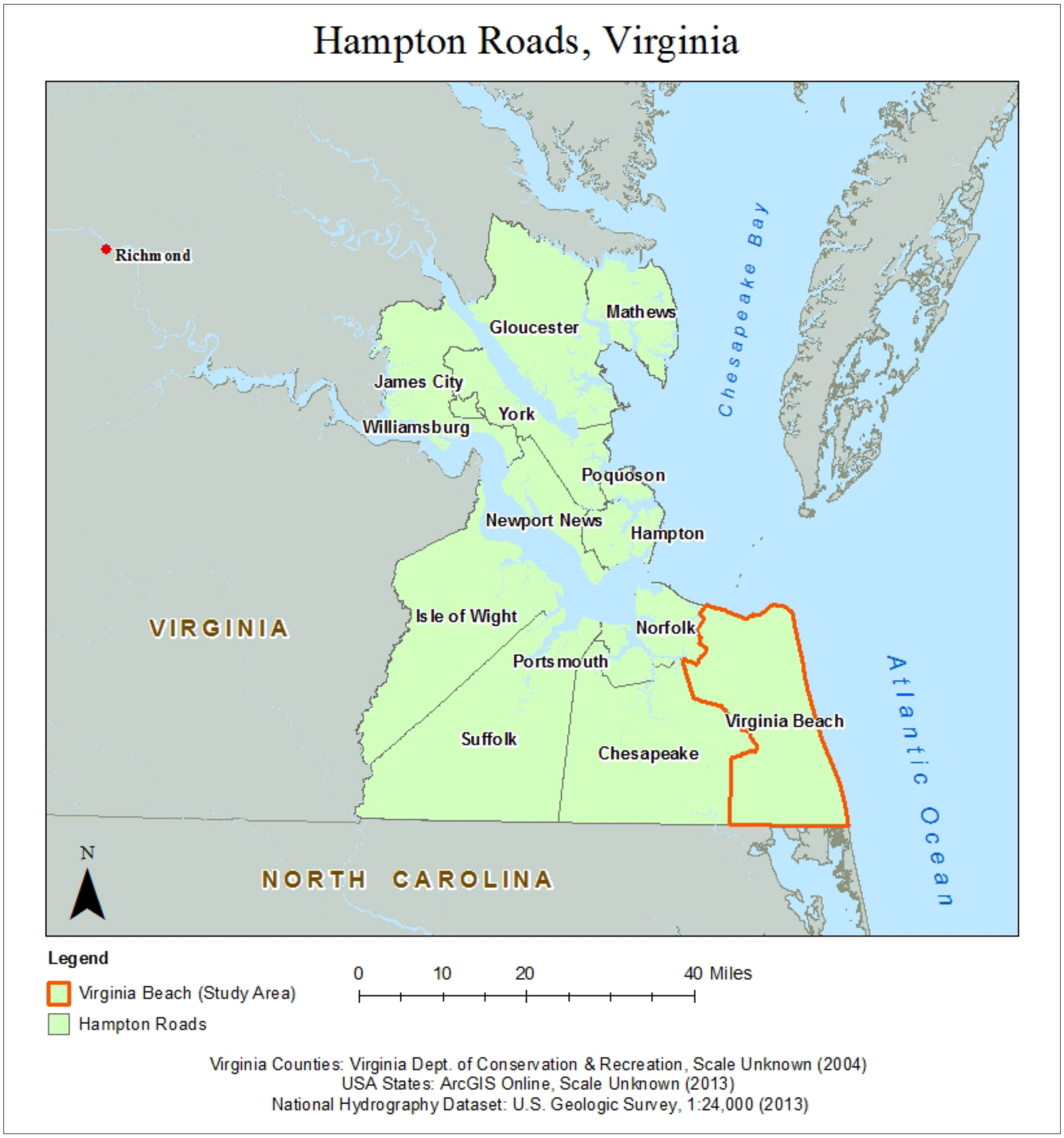

Figure 1: Map depicting the Hampton Roads area of Virginia.

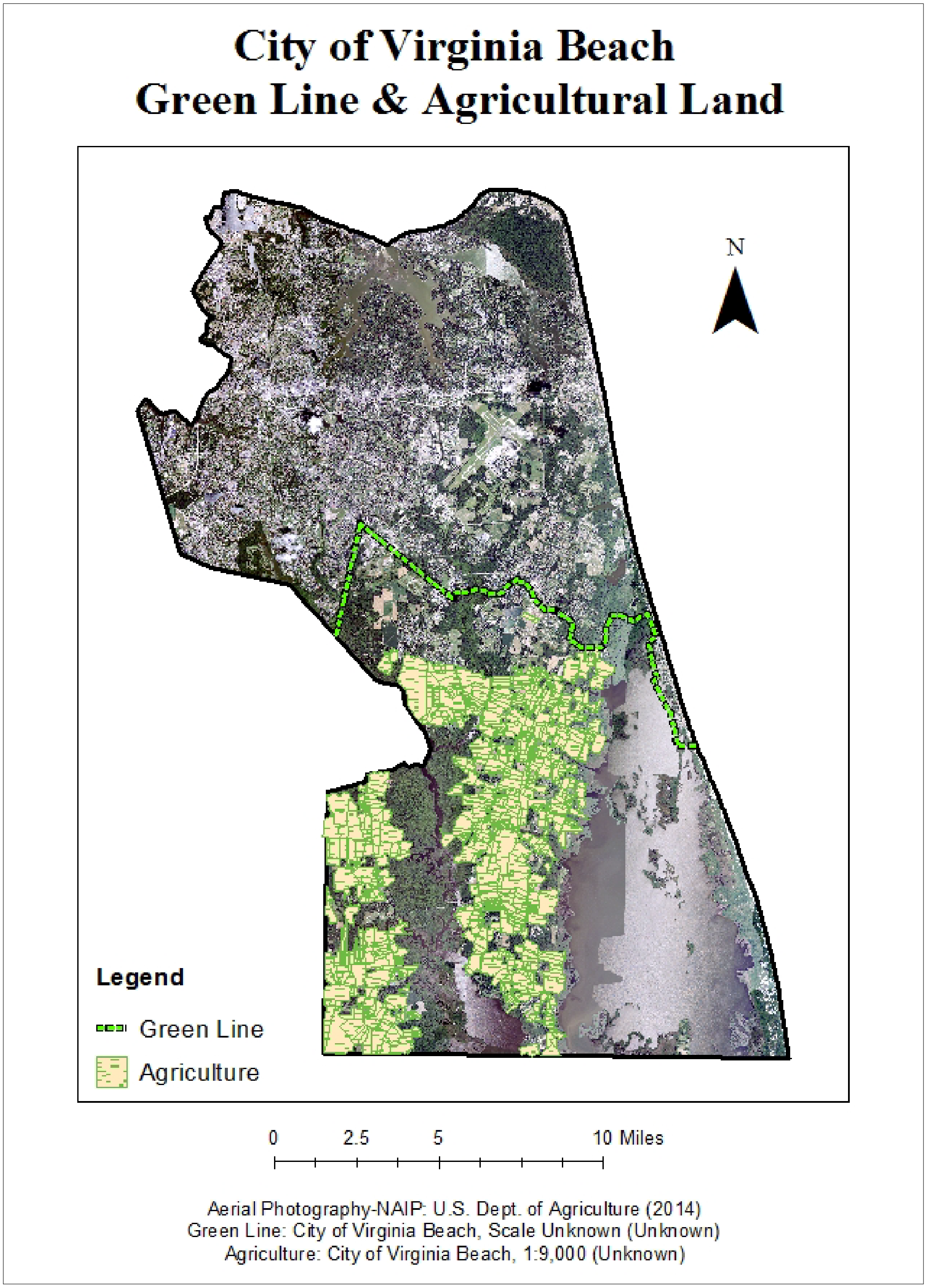

Figure 2: Map of Virginia Beach depicting the green line and agricultural land.

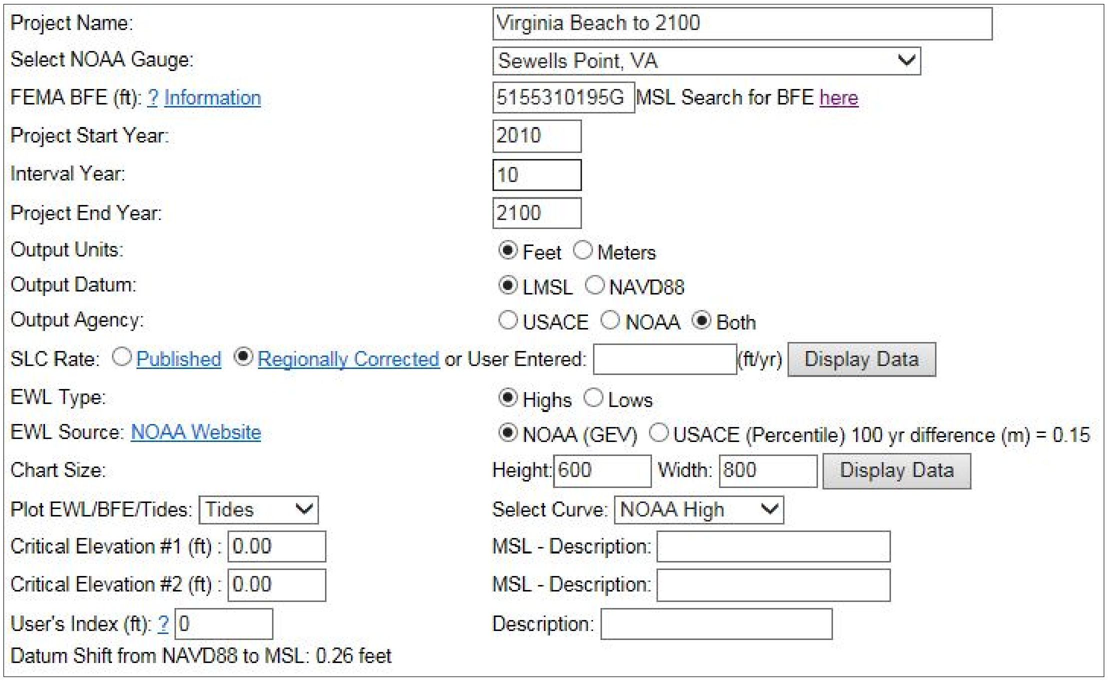

Figure 3: USACE SLCCC input for projecting sea level rise in Virginia Beach, VA from 2010-2100.

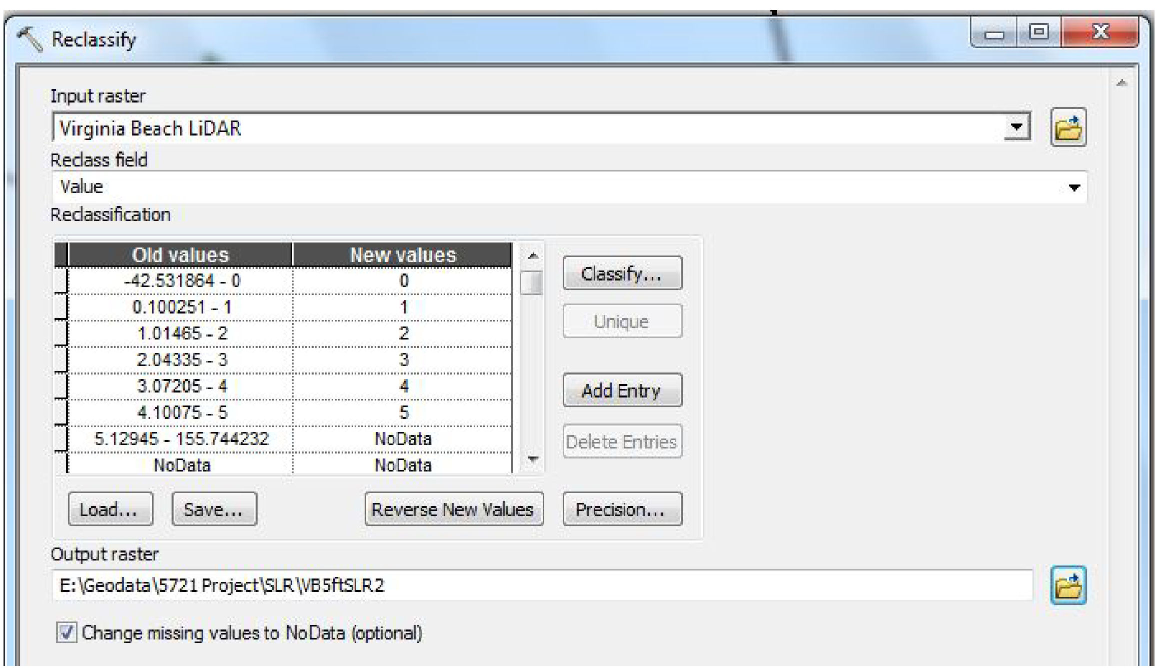

Figure 4: Reclassification of LiDAR DEM to indicate 1.5 m of sea level rise.

Virginia Beach to 2100
8638610, Sewells Point, VA
NOAA's Regional Rate: 0.01414 feet/yr
All values are expressed in feet relative to LMSL

Year	USACE Low NOAA Low	USACE Int NOAA Int Low	NOAA Int High	USACE High	NOAA High	NOAA High + EWL (Tides)
2010	0.26	0.28	0.35	0.38	0.42	1.824
2020	0.40	0.47	0.62	0.69	0.80	2.2
2030	0.54	0.67	0.95	1.07	1.27	2.679
2040	0.68	0.88	1.34	1.53	1.86	3.26
2050	0.82	1.12	1.78	2.07	2.54	3.943
2060	0.96	1.37	2.28	2.68	3.32	4.728
2070	1.10	1.64	2.84	3.36	4.21	5.615
2080	1.24	1.93	3.46	4.12	5.20	6.604
2090	1.39	2.24	4.13	4.95	6.29	7.696
2100	1.53	2.56	4.86	5.85	7.49	8.889

Table 1: USACE SLCCC sea level rise projections from 2010-2100 using the Sewells Point tide gauge.

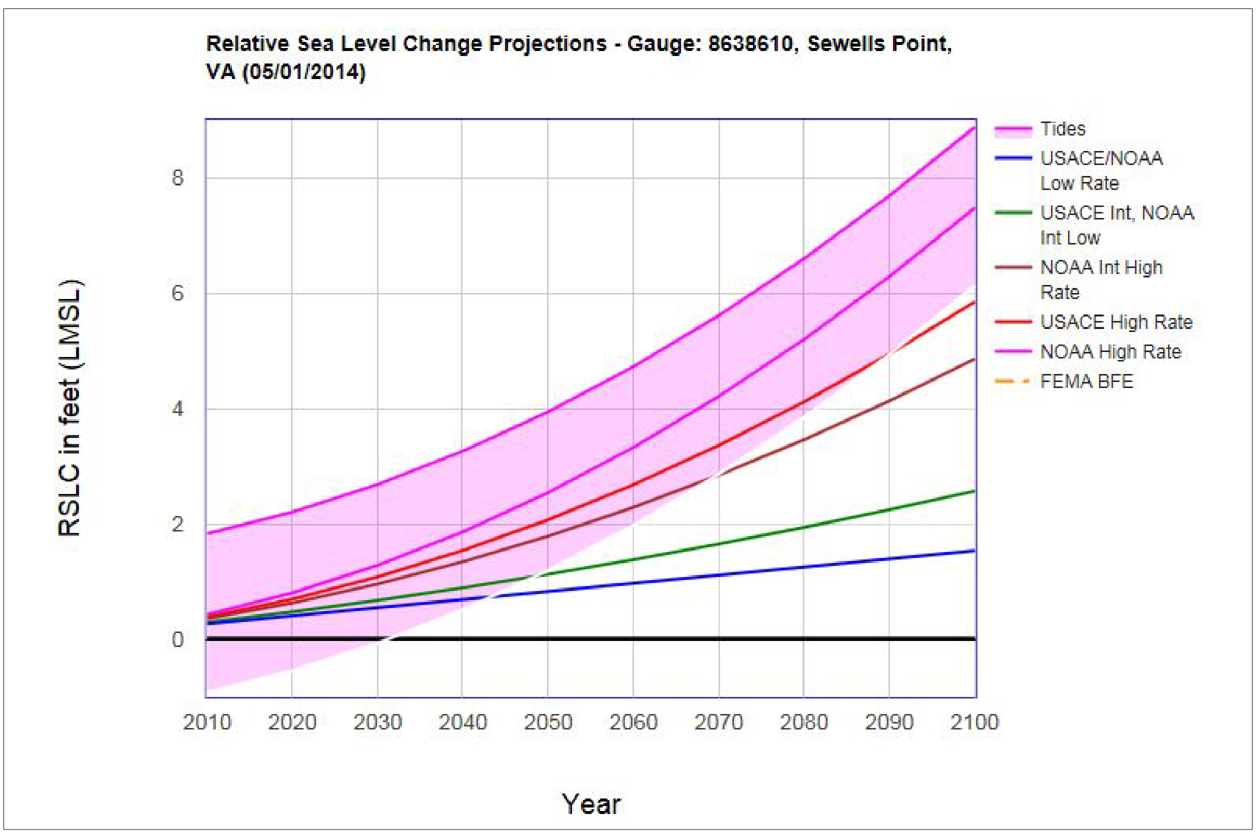

Figure 5: Graph of projected sea level rise scenarios for Virginia Beach produced by the USACE SLCCC using the Sewells Point Tide Gauge from 2010-2100.

Soil Series Name	**% of Affected Soil**	**Drainage Class**
Nimmo Loam (Hydric)	22%	Poorly Drained
Tomotley Loam (Hydric)	19%	Poorly Drained
Dorovan Mucky Peat (Hydric)	13%	Very Poorly Drained
Acredale Silt Loam (Hydric)	11%	Poorly Drained
Dragston Fine Sandy Loam (Non-hydric)	6%	Somewhat Poorly Drained

Table 2: Predominate soil series affected by 1.5 m of sea level rise in agricultural land in Virginia Beach and their drainage classes as defined by the Soil Survey of the City of Virginia Beach, VA.

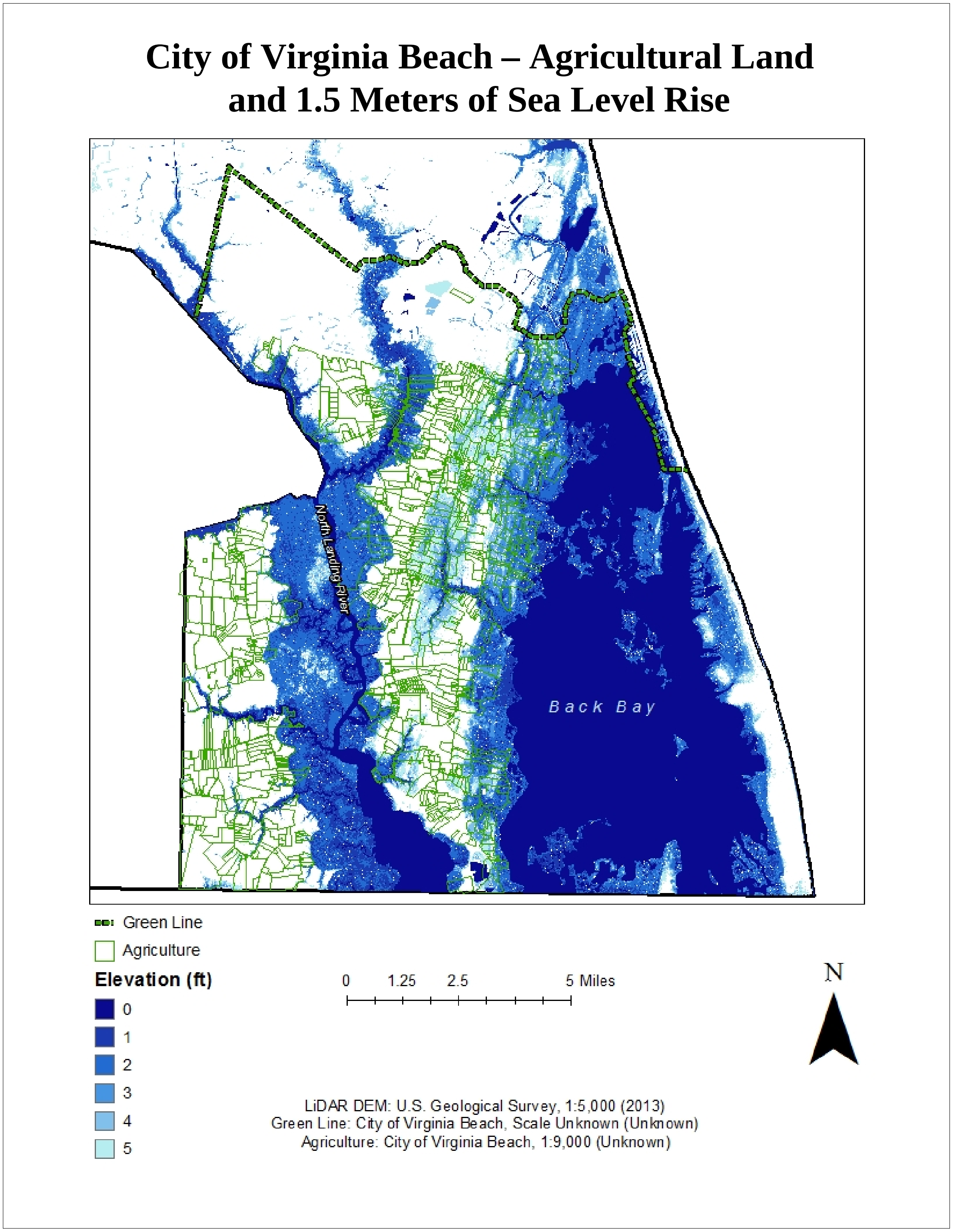

Figure 6: Map depicting 1.5 m of sea level rise in the southern portion of Virginia Beach and the agricultural land units.

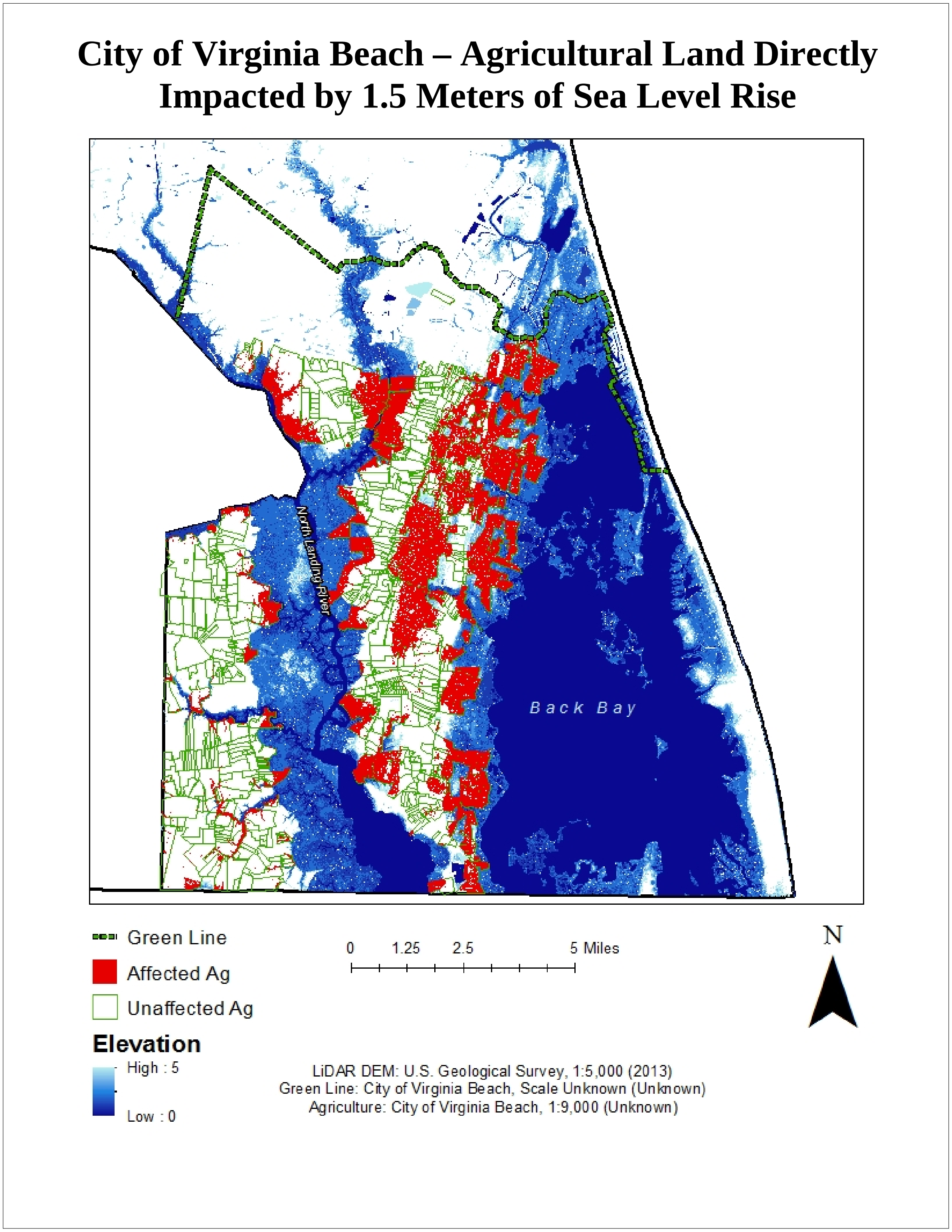

Figure 7: Map depicting 1.5 m of sea level rise in Virginia Beach and the affected and unaffected agricultural land units.

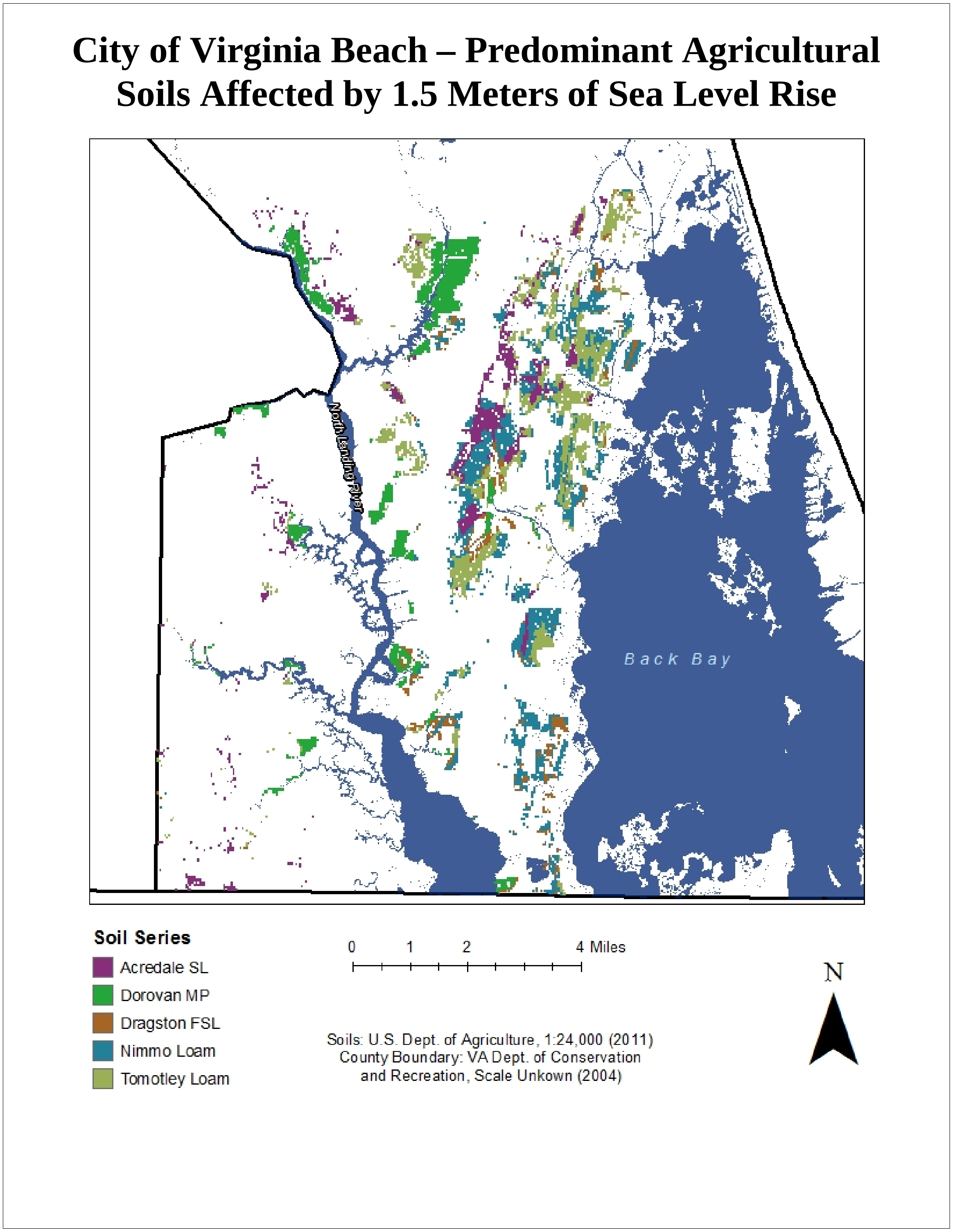

Figure 8: Map displaying the agricultural soils which will be most affected by 1.5 m of sea level rise in Virginia Beach. Soil Series include Acredale sandy loam, Dorovan mucky peat, Dragston fine sandy loam, Nimmo loam and Tomotley loam.

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Data Sources

Analyzed Data

LiDAR DEM: U.S. Geologic Survey, 1:5,000 (2013)

Parcels (Agriculture): City of Virginia Beach, 1:9,000 (Unknown)

Virginia Beach Soils: U.S. Dept. of Agriculture Natural Resources Conservation Service, 1:24,000 (2011)

Visual Data

Aerial Photography (NAIP): U.S. Dept. of Agriculture (2014)

Virginia Beach Green Line: City of Virginia Beach (Unknown)

National Hydrography Dataset: U.S. Geologic Survey, 1:24,000 (2013)

USA States: ArcGIS Online (2013)

Virginia Counties: Virginia Dept. of Conservation & Recreation (2004)