Delaware Marsh Migration Suitability Analysis

A GUIDANCE TOOL FOR PROFESSIONALS AND LANDOWNERS ALIKE

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Acronyms

Acronym	Definition
BMP	Best Management Practice
CMI	Conservation Management Institute
DEM	Digital Elevation Model
DNREC	Department of Natural Resources and Environmental Control
FEMA	Federal Emergency Management Agency
GIS	Geographic Information Systems
HAT	Highest Astronomical Tide
LLWW	Landscape Position, Landform Type, Waterbody Type, Waterflow Path
LULC	Land Use and Land Cover
MHHW	Mean Higher High Water
MSL	Mean Sea Level
NCSS	National Cooperative Soil Survey
NOAA	National Oceanic and Atmospheric Administration
NRCS	Natural Resources Conservation Service
RASCL	Resilient and Sustainable Communities League
SLAMM	Sea Level Affecting Marshes Model
SLR	Sea Level Rise
SWMP	Statewide Wetland Mapping Project
TNC	The Nature Conservancy
UD	University of Delaware

Abstract

Tidal marshes of Delaware are uniquely situated to experience difficulties with changes in water levels from both sea level rise (SLR) and subsidence. In Delaware, estuarine vegetated wetlands have been lost overwhelmingly due to open water conversion. It is important to understand which areas of the state may be suitable for future marsh migration in order to inform management decisions to prevent a net loss in tidal wetlands. This study aimed to update the former marsh migration model and conduct a suitability analysis on land in Delaware that may have the potential for future marsh migration under different sea level rise scenarios. This was achieved through a simplistic model in ArcGIS combining the Delaware 2 ft, 4 ft, and 7 ft SLR future scenarios, soil type, slope, land use/land cover (LULC), and distance to current tidal wetlands. The model excluded areas of impervious surface, open water, and the current extent of tidal wetlands. The result is a layer for each SLR scenario showing the possible suitability of land for future marsh migration. The final layer includes five categories: areas receiving a score of zero are unsuitable for marsh migration, scores 1-3 are least suitable for migration, 4-6 are less suitable, 7-9 are suitable and 10-12 are highly suitable. Under the 4 ft SLR scenario, the model estimated that 21,449 acres of land in Delaware were highly suitable for marsh migration, a majority of which are on privately owned, unprotected lands (65%). More than a third of the highly suitable areas are currently agricultural lands (36%) or current non-tidal wetlands (34%).

Introduction

Tidal marshes of Delaware are uniquely situated to experience difficulties with changes in water levels from both sea level rise (SLR) and subsidence. The range of tidal marsh vegetation is dependent on many factors, including hydrology, and can typically exist between Mean Sea Level (MSL) and the Highest Astronomical Tide (HAT; Provost, 1976). As sea levels increase and/or land subsides, some marshes may be able to migrate inland to adjacent lands if sufficient conditions exist (Cahoon et al, 2009; Schwimer and Pizzuto, 2000). However, anthropogenic structures such as hardened shorelines, roads, and levees can act as barriers to migration (Bozek and Burdick, 2005). Despite some studies that suggest Delaware tidal marshes may be able to keep pace with SLR (Kirwan et al, 2016), there has been a gross loss of 818 acres of vegetated tidal wetlands between 1992 and 2017, 78% of which were lost due to the conversion to open water (DNREC, 2022; Tiner et al., 2011). However, Delaware had a gross gain of 136 acres of vegetated tidal wetlands between 2007 and 2017, 91% of which were due to marsh migration (DNREC, 2022). Migration models are critical for informing management decisions to ensure there is not a net loss in these important habitats.

Studies have been conducted to model marsh migration on local, regional, and national scales. These models vary in the amount of data they include and can take the form of simple elevation-based models, elevation and time-based models, or more complicated geomorphological models that include accretion, erosion, and geomorphic rules (see NROC, 2015 for a review). At the intermediate level of complexity, the National Oceanographic and Atmospheric Administration's Sea Level Rise Viewer in marsh mode provides an elevation and time-based model, which depicts the potential future extent of wetlands under 1-6 feet of SLR (NOAA, 2025). Because this is a national scale model, underlying data is on a greater 30m resolution scale. Moving up in complexity and down in geographic scale, the Sea Level Affecting Marshes Model (SLAMM) has been run on small project areas in Delaware, including the Prime Hook National Wildlife Refuge (Scarborough, 2009), Bombay Hook National Wildlife Refuge (Clough & Larson, 2010), portions of the Broadkill, Mispillion, and St. Jones watersheds (EPA, 2019), and Rehoboth Beach (NWF, 2008). SLAMM, and other increasingly complex models, require more data and subsequently introduce more assumptions into the analysis (NROC, 2015). Additionally, the large amount of input data makes the results difficult to apply to large areas in high resolution and may be more difficult to interpret, while simple models can be informative on a broader scale for informing management decisions (NROC, 2015). The 2017 Marsh Migration Model was created to fill the gap in Delaware-specific statewide modeling of potential areas for marsh migration.

This study aimed to update the former marsh migration model and conduct a suitability analysis on land in Delaware that may have the potential for future marsh migration under different sea level rise scenarios. The simplistic elevation-based GIS model incorporated elevation, the Delaware 2 ft, 4 ft, and 7 ft SLR scenarios, soil, slope, land use/land cover (LULC), and distance to tidal wetlands, while excluding areas of impervious surface, incompatible LULC, open water, and the current extent of tidal wetland areas. This model did not incorporate data on accretion, erosion, or hydrodynamic water flow. The final layer includes five categories: areas receiving a score of zero are unsuitable for marsh migration, scores between one and three are least suitable for migration, four to six are less suitable, seven to nine are suitable, and ten to twelve are highly suitable. It was beyond the scope of this study to predict the extent of tidal wetlands in any given time frame; the model only indicates which areas exhibit conditions suitable for migration.

Methods

This simplistic model was based primarily on the main characteristics of a wetland including hydric soils, hydrology, and hydrophytic plants (Cowardin et al, 1979; Mitsch and Gosselink, 2015). The presence of hydric soils was determined by the 'drainclass' attribute in the soils layer. The hydrology requirement was determined by the 2 ft, 4 ft, and 7 ft SLR scenarios. These SLR scenarios were used as the extent of the analysis, as an estimation of Mean Higher High Water (MHHW) under future SLR. The extent of tidal wetlands generally extends past MHHW to the Highest Astronomical Tide (HAT; Provost, 1976). However, the difference between MHHW and HAT in Delaware is much smaller than the mapping unit of 10m (NOAA, 2017), and MHHW has been widely used in marsh migration modeling (NROC, 2015). Distance to tidal wetlands was used as a proxy for hydrophytic plants and the potential for dispersal. Additional data such as impervious surfaces and LULC were included to account for anthropogenic development within the model.

Shapefiles and raster images based on data collected between 2014 and 2022 were obtained from the State of Delaware Department of Natural Resources and Environmental Control (DNREC). Files were acquired either directly from the State or through FirstMap Delaware, an online platform that provides Delaware's publicly available data. Data included the extent of tidal wetlands, impervious surface, 2 ft, 4 ft, and 7 ft SLR scenarios, soil, Digital Elevation Model (DEM), LULC, as well as aerial imagery (Table 1). Using the DEM, a slope layer was also created for inclusion in the model.

Table 1: Data layers used in model creation.

Data Layer	File Type	Source
2017 Statewide Wetland Mapping Project: Tidal Wetlands	Shapefile	State of Delaware Wetland Assessment
2022 Impervious Surface	Raster	Delaware FirstMap
Delaware Updated SLR Scenarios 2 ft., 4 ft., 7 ft.	Shapefile	Delaware FirstMap
DE Soils	Shapefile	Delaware FirstMap
DEM (2014)	Raster	Delaware FirstMap
Slope (2014)	Raster	Created from DEM
2022 Land Use/ Land Cover (LULC)	Shapefile	Delaware FirstMap
2022 Aerial Imagery	Raster	Delaware FirstMap

What's New in the 2025 Marsh Migration Model?

The 2025 update of the Marsh Migration Model includes three new changes from the 2017 Marsh Migration Model: 1) the most up-to-date versions of model inputs were used, 2) there was a slight change in the category names for the model output, and 3) the 4 ft SLR output layer was made available on FirstMap.

The 2025 Marsh Migration Model includes multiple upgrades of previous versions of model inputs. All updated layers are listed here:

- **Statewide Wetland Mapping Project - Tidal Wetlands:** Previously, tidal wetland maps were created for Delaware based on 2007 aerial imagery. The updated wetland layer was created based on 2017 aerial imagery. In addition to newer imagery, mapping techniques have also advanced and improved over time, which helps increase the accuracy of mapped wetlands.
- **Impervious Surface:** The previous version of the Marsh Migration Model used a collection of four impervious surface layers from 2012. This included Sussex County East, Sussex County West, Kent County, and New Castle County. These were merged into a single layer and supplemented by hand where coverage was lacking in order to cover the entirety of Delaware. These layers have since been replace by a single impervious surface layer from 2022.
- **Land Use / Land Cover:** The LULC data layer was updated from the previous 2012 version to the most recent 2022 version. The 2022 LULC layer included some minor modifications to land use classification and was created using updated imagery from 2022.
- **Aerial Imagery:** The previous version of the Marsh Migration Model used aerial imagery from 2012. The updated imagery from 2022 was used in this current version of the model.

Changes in category names for the model output are as listed below in the table:

Suitability Score	2017 Category Name	2025 Category Name
0	Unsuitable	Unsuitable
1-3	Unlikely Suitable	Least Suitable
4-6	Moderately Suitable	Less Suitable
7-9	Suitable	Suitable
10-12	Highly Suitable	Highly Suitable

The 2025 Marsh Migration Model 4 ft SLR output layer is publicly accessible here.

Model Assumptions

Every model inherently has assumptions, as they are an estimation based on current data, and this information is never a perfect reflection of the synergistic in situ processes and natural variability. As such, every model contains different assumptions that must be considered during the interpretation of results. The results of the model should be used as a screening level tool for coastal land managers to determine which areas may be suitable for marsh migration, and where subsequent studies should be focused. It should be noted that other factors, beyond the inputs to this model, could affect marsh migration potential, such as unknown impacts from coastal storms. This model does not predict the extent of tidal wetlands at any given time period, only where conditions may exist for marsh migration.

While many factors influence the extent of tidal wetlands and future marsh migration, this model only included sea level rise, soil, slope, LULC, distance to tidal wetlands, impervious surface, and current wetland extent. Those areas currently classified as tidal wetlands were excluded from the analysis because it was assumed that marshes could not migrate to areas that are already tidal wetlands. Tidally influenced open water was also excluded from the analysis; however, it is possible that some of these areas may be available for marsh migration if significant accretion occurs. This model does not incorporate estimates of sediment accretion or hydrologic flow.

Additionally, certain LULC categories were considered incompatible with marsh migration including airports, highways, and industrial areas. It was assumed that in some of these instances that the infrastructure would either directly thwart marsh establishment or would be subject to human intervention to prevent these areas from being inundated with water. While impervious surfaces are not compatible with tidal wetlands, it is possible that the current extent of impervious surfaces could change. For example, new development could occur or impervious surfaces could be removed. Further, the scoring of land uses was based on physical parameters and suitability for marsh migration regardless of ownership. Although some LULC categories were classified as suitable for marsh migration, property owners may take measures to stop marshes from migrating onto their land.

Lastly, the 2 ft, 4 ft, and 7 ft SLR scenarios were used as the extent of the analysis, as an estimation of MHHW under future projected SLR. The extent of tidal wetlands generally extends past MHHW and therefore the SLR layers provide a conservative estimation of future migration potential. Additionally, the SLR layer was created from a bathtub model and as such did not include hydrodynamic water flow.

Data Preparation

The data obtained required additional preparation for input into the final analysis. Some data required merging several layers into one contiguous layer, and subsequent conversion to a raster layer for analysis. Additionally, all layers were converted to a 10m raster (due to the larger scale of the soil and impervious surface data), although some data layers were initially on a 1m or 3m scale. This was done by setting the ‘model properties’ to a cell size of 10m.

All layers required reclassification before input into the final analysis. Where no data was present and/or data were intentionally excluded from the analysis (tidal wetlands, impervious surfaces, and areas not inundated by SLR), the raster value was assigned a zero. The remaining data and data layers used to determine suitability were classified between zero and three (Table 2). The higher scores signified a larger likelihood for suitability for marsh migration.

Table 2: Reclassification of data layers for input into the final analysis.

Raster Value	0	1	2	3
Tidal Wetlands	Tidal wetlands, Open water	Not classified as tidal wetlands or open water		
Impervious Surface	No Data, Impervious surfaces	Pervious surfaces		
Sea Level Rise (SLR)	Not inundated under SLR	Inundated under SLR		
Soil	No Data	Well drained	Moderately well drained	Poorly drained
Slope	No Data	Steep = >5.886	Moderate = 1.438-5.886	Flat = 0-1.438
Land Use / Land Cover (LULC)	No Data, Classifications incompatible with marsh migration	Unlikely compatible	Somewhat compatible	Likely compatible
Distance to Nearest Tidal Wetland	No Data	Distant = 400.01-4,717.05m	Intermediate = 200-400m	Proximate = 0-200m

Tidal Wetlands

The 2017 tidal wetlands layer was obtained from the State of Delaware DNREC Wetlands Assessment (Table 1). This layer was created by the Conservation Management Institute (CMI) for the Delaware Statewide Wetland Mapping Project (SWMP). This layer included the Cowardin classification code (Cowardin et al, 1979; ex PFO1T), and the LLWW code (landscape position, landform, water flow path, and water body; Tiner, 2003), and an attribute indicating if the area was open water. The tidal wetlands data layer was joined with a table describing the Cowardin classification. To create a layer of tidal wetlands in Delaware that excluded open water systems, the 'select layer by attribute' tool was used to only select areas that were not classified as 'open water' and a new feature class was made using the 'copy features' tool. A separate layer of current tidal wetlands was created in order to exclude current tidal wetlands from the analysis, because marshes were not considered eligible areas for new marsh migration. This raster was categorized with areas considered tidal wetlands and open water areas equal to zero and areas not categorized as tidal wetlands equal to one (Table 2).

Impervious Surface

The 2022 Impervious Surface layer was obtained from the State of Delaware FirstMap (Table 1). The raster layer was set to a 10m cell size and masked. To exclude impervious surfaces, all impervious data and 'No Data' were reclassified to zero while pervious surfaces were reclassified to one (Table 2).

Delaware SLR Scenarios

The 2 ft, 4 ft, and 7 ft SLR scenario data layers were obtained from Delaware FirstMap (Table 1). Developed by the Delaware Geological Survey, these data were based on a 1m DEM and represented the future extent of MHHW estimated via a bathtub model. The 'polygon to raster' tool was used to convert the SLR layers into 10m raster layers for the analysis. Areas inundated under SLR scenarios were reclassified to one, and all other areas were set equal to zero (Table 2).

Soils

Soil data were obtained from Delaware FirstMap for each county in Delaware (Table 1). Those layers were prepared by soil scientists as part of the National Cooperative Soil Survey (NCSS). The soil data for all three counties was projected into the NAD_1983_StatePlane_Delaware_FIPS_0700. These three layers were merged into a single layer, and a new field was added for later reclassification. The resulting layer was converted to a 10m raster and reclassified from seven categories to three (Table 3). The layer was subsequently reclassified so that well drained soils were set equal to one, moderately well drained soils set to two, poorly drained to three, and 'No Data' to zero (Table 2).

Table 3: Reclassification of soil drainclass.

Original Drainclass	Reclassified Drainclass	Value
Excessively Drained	Well Drained	1
Somewhat Excessively Drained	Well Drained	1
Well Drained	Well Drained	1
Moderately Well Drained	Moderately Well Drained	2
Somewhat Poorly Drained	Moderately Well Drained	2
Poorly Drained	Poorly Drained	3
Very Poorly Drained	Poorly Drained	3
Subaqueous	Poorly Drained	3

Slope

A one-meter Digital Elevation Model (DEM) was obtained from Delaware FirstMap, which was created using LiDAR data from 2014 (Table 1). A slope layer was created from the DEM by using the 'slope' tool. First, to identify the slope range for existing tidal wetlands, the values of slope were extracted for areas of the tidal wetland layer. For the current extent of tidal wetlands, slope ranged from 0-33.36°, while the entire area of interest (area within the interim mask of 7 ft SLR plus 1000m) ranged from 0-76.24°. Outside of the model, Jenks with natural breaks were used to determine the classification thresholds based on the current extent of wetlands using 3 categories: steep, moderate, and flat. The flat category included slopes between 0 and 1.44°, the moderate category between 1.44 and 5.89°, and steep between 5.89 and 33.37°. Slopes greater than those found in current tidal wetlands (33.367624°) were added to the steep category because these areas were considered to be unlikely candidates for marsh migration. These values were then used to reclassify the original slope layer with steep lands equal to one, moderate slopes equal to two, and flat areas equal to three (Table 2).

Land Use / Land Cover (LULC)

The land use/land cover (LULC) layer was updated to 2022 imagery and reclassified by the University of Vermont Spatial Analysis Laboratory and was obtained from Delaware FirstMap (Table 1). Using the same classification schema as the 2017 Marsh Migration Model, a table was created for LULC categories with corresponding reclassifications and joined to the LULC layer (Table 4). Each LULC category was reclassified into one of the following categories: heavy development, mixed development, urban mixed development, water, open space, natural areas, and agriculture. The reclassified categories were then considered on a scale from zero to three, where zero represented areas that were not compatible with marsh migration and three represented areas that were most compatible (Table 2). Areas of heavy development and water were determined incompatible and classified as zero. Urban mixed development and maintained buffers (ex: communication lines) were classified as one, mixed development as two, and open space, agriculture, and natural areas were classified as a three. The layer was subsequently converted from a polygon to a 10m raster, and masked.

Table 4: Reclassification of land use / land cover (LULC) data.

LULC_CATEGORY2022	Reclass	Value
Airports	Heavy Development / Industrial	0
Bays and Covers (Tidal)	Water	0
Bays and Coves (Tidal)	Water	0
Confined Feeding Operations/Feedlots/Holding	Heavy Development / Industrial	0
Extraction	Heavy Development / Industrial	0
Highways/Roads/Access Roads/Freeways/ Interstates	Heavy Development / Industrial	0
Industrial	Heavy Development / Industrial	0
Junk/Salvage Yards	Heavy Development / Industrial	0
Man-made Reservoirs and Impoundments	Water	0
Man-made Reservoirs and Impoundments	Water	0
Marinas/Port Facilities/Docks	Heavy Development / Industrial	0
Natural Lakes and Ponds	Water	0
Other Transportation/Utilities	Heavy Development / Industrial	0

Parking Lots	Heavy Development / Industrial	0
Railroads	Heavy Development / Industrial	0
Retail Sales/Wholesale/Professional Services	Heavy Development / Industrial	0
Vehicle Related Activities	Heavy Development / Industrial	0
Warehouses and Temporary Storage	Heavy Development / Industrial	0
Waterways/Streams/Canals	Water	0
Open Water	Water	0
Communication Antennas	Maintained Buffer	1
Mixed Single and Multi-Family Residential	Urban Mixed Development	1
Mixed Urban or Built-up Land	Urban Mixed Development	1
Multi-Family Dwellings	Urban Mixed Development	1
Other Commercial	Urban Mixed Development	1
Single Family Dwellings	Urban Mixed Development	1
Institutional/Governmental	Mixed Development	2
Mobile home Parks/Courts	Mixed Development	2
Mobile Home Parks/Courts	Mixed Development	2
Other Urban or Built-up Land	Mixed Development	2
Transitional (includes cleared, filled, and gravel)	Mixed Development	2
Transitional (Includes cleared, filled, and gravel)	Mixed Development	2
Utilities	Mixed Development	2
Beaches and Riverbanks	Natural	3
Clear-cut	Open Space	3
Cropland	Agriculture	3
Deciduous Forest	Natural	3
Evergreen Forest	Natural	3
Farmsteads and Farm Related Buildings	Farmsteads	3
Herbaceous Rangeland	Agriculture	3
Idle Fields	Agriculture	3
Inland Natural Sandy Areas	Natural	3
Mixed Forest	Natural	3
Mixed Rangeland	Open Space	3
Non-Tidal Emergent Wetland	Natural / Non-tidal Wetlands	3
Non-tidal Forested Wetland	Natural / Non-tidal Wetlands	3
Non-Tidal Forested Wetland	Natural / Non-tidal Wetlands	3
Non-tidal Open Water	Natural / Non-tidal Wetlands	3
Non-Tidal Scrub/Shrub Wetland	Natural / Non-tidal Wetlands	3
Non-Tidal Shoreline	Natural / Non-tidal Wetlands	3
Orchards/Nurseries/Horticulture	Agriculture	3
Other Agriculture	Agriculture	3
Pasture	Agriculture	3
Recreational	Open Space	3

Shrub/Brush Rangeland	Natural	3
Tidal Emergent Wetland	Natural	3
Tidal Forested Wetland	Natural	3
Tidal Scrub/Shrub Wetland	Natural	3
Tidal Shoreline	Natural	3

Distance to Tidal Wetlands

Distance to tidal wetlands was determined by using the 'Euclidean distance' tool to create a new feature layer based on the tidal wetland layer, including open water. To our knowledge, distance to nearest tidal wetland has not been used in previous marsh migration studies, although distance has been used to estimate accretion in SLAMM (Warren Pinnacle, 2016), therefore cutoff values for distance to the nearest tidal wetlands could not be identified in the literature. The average Euclidean distance (μ = 426m) from tidal wetlands was therefore used as a cutoff for lands that were considered 'distant' from tidal wetlands. The layer was reclassified with areas of 'No Data' equal to zero, 400.01-4717.05m were considered 'distant' and set equal to one, 200.01-400m were considered 'intermediate' and set equal to two, and 0-200m were considered 'proximate' and set equal to three (Table 2). This layer was then converted to a 10m raster layer.

Mask

All interim layers were masked to a 10m raster within 1000m of the 7 ft Delaware SLR scenarios intersected with the state boundary to reduce processing time of extraneous data. Final layers were masked to the 2 ft, 4 ft, and 7 ft Delaware SLR scenarios.

Final Inputs & Final Outputs

The soil, slope, LULC, and distance to tidal wetland layers were each classified from zero to three (Figure 1). Zero represented areas that were not considered compatible with marsh migration, and three represented areas that were likely very suitable for marsh migration in the future. Using the 'raster calculator' tool, these four layers were combined into a single layer. This layer was then multiplied by the tidal wetlands masking layer and impervious surface layer in the 'raster calculator,' where areas incompatible with migration were set equal to zero (and thus excluded from the output) and those compatible set equal to one. This output layer resulted in values from zero to twelve, with zero being unsuitable and twelve being the most suitable for marsh migration. For ease of geospatial interpretation, this layer was reclassified into five categories: areas receiving a score of zero are unsuitable for marsh migration, scores between one and three are least suitable for migration, four to six are less suitable, seven to nine are suitable, and ten to twelve are highly suitable. Finally, the reclassified layer was masked to the 2 ft, 4 ft, and 7 ft SLR scenarios, where areas not inundated under the SLR scenario were set equal to zero (and thus excluded from the output) and those areas inundated set equal to one (Figure 2). While three outputs were produced from the model, one for each SLR scenario, the results are only presented for the 4 ft SLR scenario within the report. This stays consistent with previous reporting and provides analysis for a middle-of-the-ground SLR scenario.

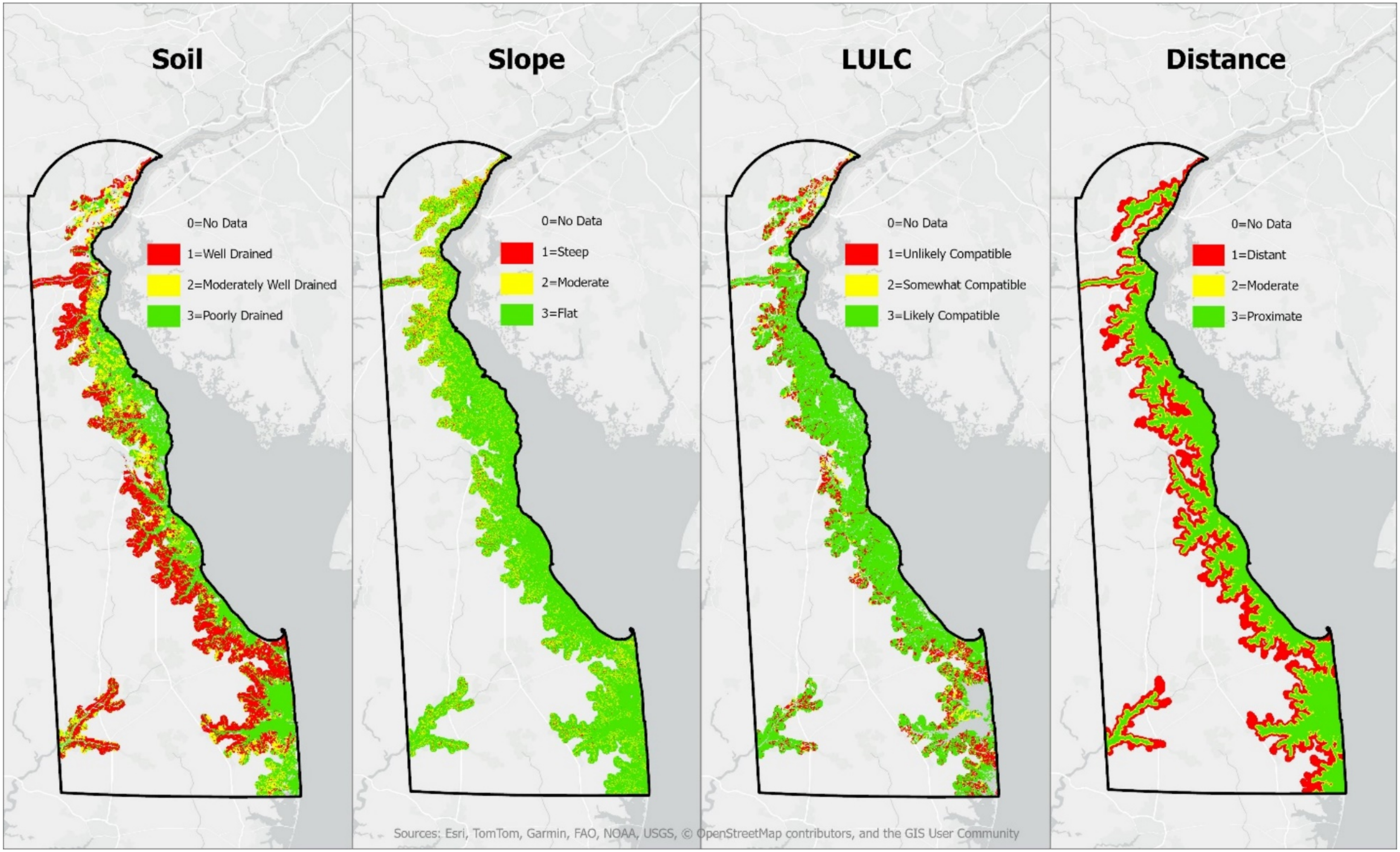

Figure 1: Final inputs used in the marsh migration model. Soil, slope, land use / land cover (LULC), and distance from tidal wetlands were re-classified into four numeric categories, where a higher number identifies a cell that is more suitable for marsh migration and vice versa.

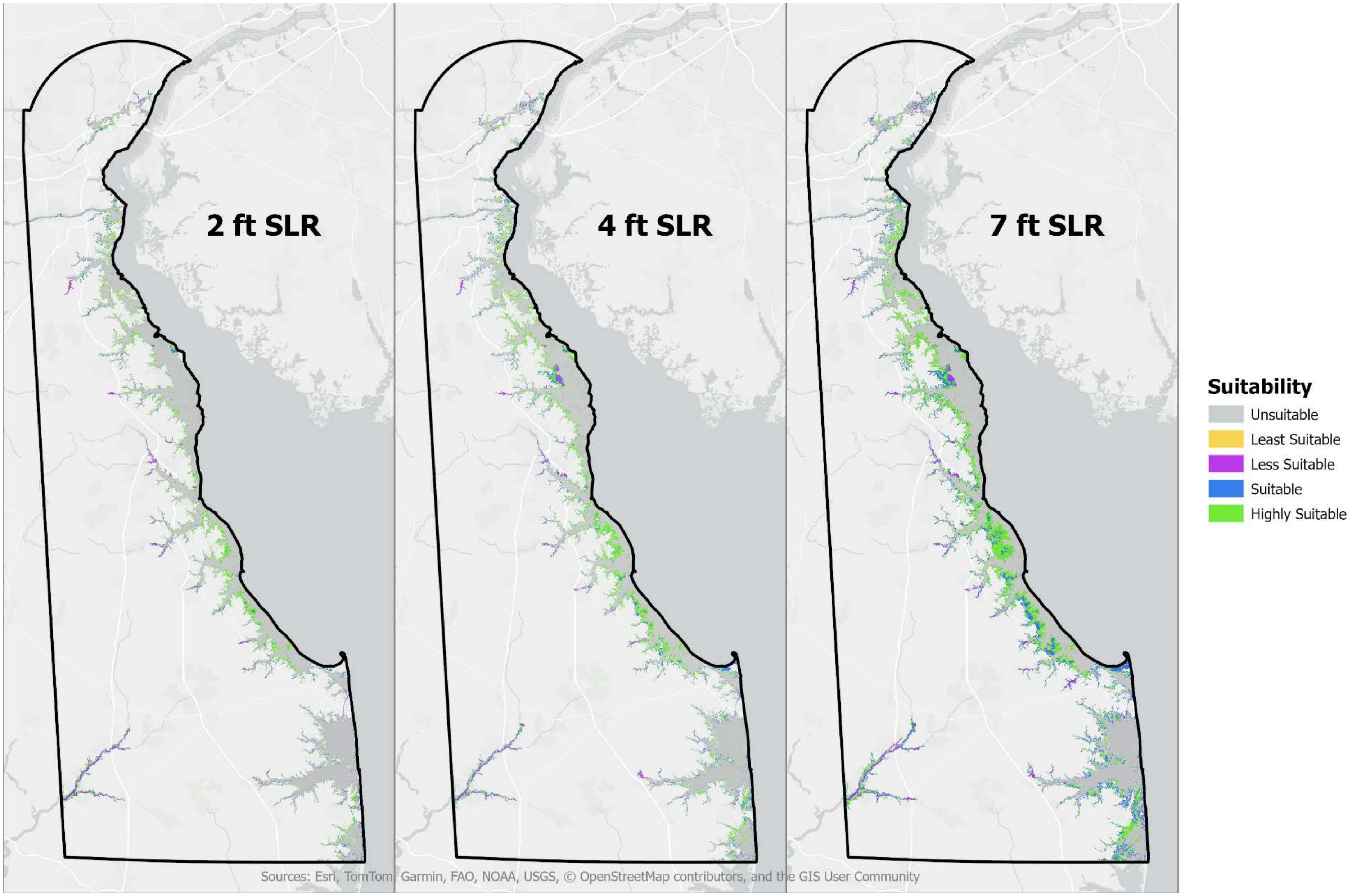

Figure 2: Final outputs from the marsh migration model. Suitability is shown for 2 ft, 4 ft, and 7 ft SLR scenarios. The scores are classified as follows: Unsuitable = 0, Least Suitable = 1-3, Less Suitable = 4-6, Suitable = 7-9, and Highly Suitable = 10-12. Unsuitable includes water and the current tidal wetland extent.

Analysis

Ownership analyses were performed on the 4 ft SLR Scenario, specifically focusing on highly suitable areas for marsh migration. For this analysis the final marsh migration raster was converted to a polygon layer and a new output layer was created that contained only areas highly suitable for marsh migration (score 10-12). The 'intersect' tool was used to isolate areas that had both high suitability for migration and were protected lands. The 'calculate geometry' tool was then used to calculate the area of each polygon. This was further divided by public and private ownership. The final 4 ft SLR marsh migration layer was also compared to the 2022 LULC dataset for Delaware[1] from which separate layers for agriculture, forestry, rangeland, and wetlands[2] were created. The 'intersect' tool was used to create four new layers that isolated areas that had both high suitability for marsh migration and contained the respective LULC categories. The 'calculate geometry' tool was then used to determine the area of each polygon.

Suitability Analysis & Case Studies

Intersection of Suitable Areas with Ownership & Land Use

Under the 4 ft SLR scenario, the model estimated that 21,449 acres of land in Delaware were highly suitable for marsh migration (score of 10-12; Table 5). A majority of these areas were found in Sussex (9,418 ac) and Kent Counties (8,482 ac), followed by New Castle County (3,549 ac). Although these areas showed a high suitability for migration, the ability for marshes to migrate is a complex interaction between a multitude of variables and it does not indicate that these areas will be tidal wetlands in the future. Similarly, areas that received a lower suitability score may still have the potential to convert to tidal wetlands.

Table 5: Acreage of highly suitable land by county and protection status under 4 ft SLR migration model.

County	Protected (public)	Protected (private)	Unprotected (private)	Total
Sussex	2,944.87	340.52	6,096.19	9,417.68
Kent	2,451.96	853.88	5,169.43	8,482.07
New Castle	704.36	86.12	2,759.10	3,549.58
Total	**6,101.19**	**1,323.42**	**14,024.72**	**21,449.33**

[1] It should be noted that LULC was part of the model input, so artifacts of the model may be present in the LULC breakdown of model results.

[2] Wetlands that were highly suitable for marsh migration only consisted of non-tidal wetlands because the current extent of tidal wetlands was excluded from the analysis.

Of the highly suitable land, only 29% occurred on public protected land, a majority of which was in Sussex (2,945 ac) and Kent Counties (2,452 ac), followed by New Castle County (704 ac). Publicly protected lands are those that are owned by federal, state, and county governments. An additional 6% of highly suitable lands were found within privately owned protected lands, of which the majority was in Kent County (861 ac), followed by Sussex County (377 ac) and New Castle County (86 ac), respectively. Privately protected lands are those that are owned by conservation partners or are part of an easement. The remaining 65% (14,025 acres) of highly suitable land for marsh migration was located on privately owned land that is not protected (Figure 3).

Looking at land use, highly suitable lands were classified as 36% agriculture, 34% current non-tidal wetlands, 14% forested, 7% rangeland, 5% developed, 3% shoreline, and <1% open water (Figure 4). It is important to note that developed lands were areas designated 'developed' in the LULC but are a pervious cover, such as lawns, natural buffer strips, and green areas of neighborhoods. While these areas are not impervious cover, like homes or roads, they are still maintained and are unlikely to sustain migration. The distribution of land uses susceptible to marsh migration indicates that agricultural property may be impacted the most in a 4 ft SLR scenario, which aligns with field observations of inundated fields and saltwater intrusion on crops which are already occurring throughout Delaware. With 85% of highly suitable agricultural lands being privately owned, this could lead to property becoming unprofitable (Table 6). Following agriculture, existing non-tidal wetlands and forested areas may be at risk in a 4 ft SLR scenario. The impact that tidal wetland migration on existing non-tidal wetlands is a field of study that is gaining momentum, and these results support this movement. Further, slightly more than half of the non-tidal wetlands and the forested areas that were highly suitable for marsh migration are unprotected currently (Table 6). Although agriculture, non-tidal wetlands, and forests have the chance to become tidal wetlands through migration with sea level rise, there is a prime opportunity to work with stakeholders on these lands to facilitate migration because they have not yet been developed and can still be managed for present and future wetland migration.

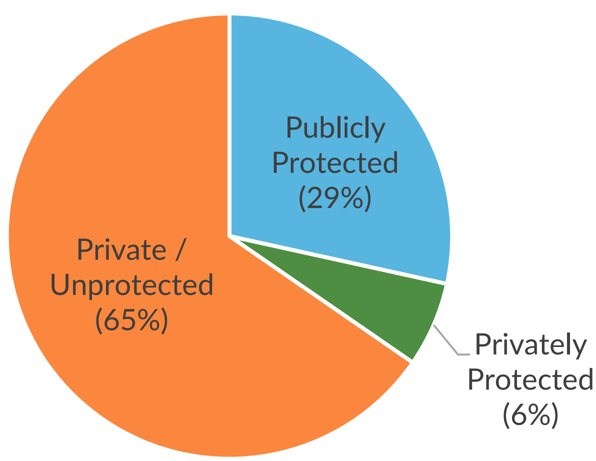

Figure 3: Ownership and protection status of highly suitable lands.

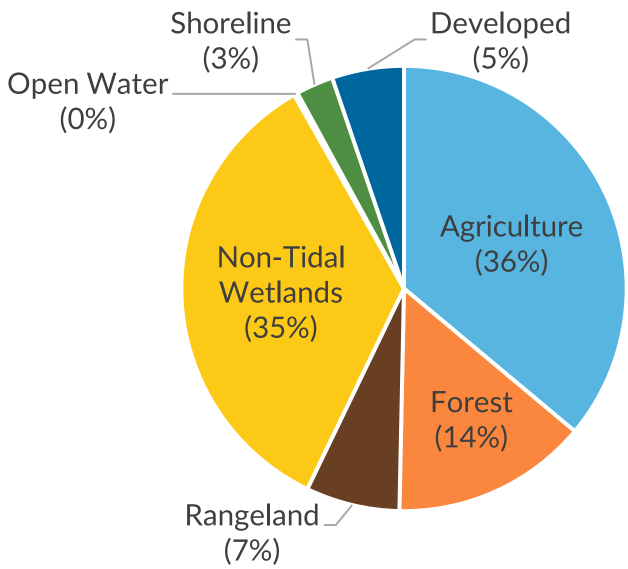

Figure 4: Land use and land cover of highly suitable lands.

Table 6: Acreage of highly suitable land by LULC under 4 ft SLR marsh migration model. The percent of total highly suitable land is the total acreage of each LULC category divided by the total acreage of all highly suitable lands.

LULC	Protected (public)	Protected (private)	Unprotected (private)	Total (% of Total Highly Suitable Land)
Wetland	2,733.35	675.74	4,019.87	7,428.96 (34.63%)
Agriculture	864.09	294.78	6,579.88	7,739.39 (36.08%)
Forest	1,143.54	175.46	1,736.73	3,055.73 (14.25%)
Rangeland	920.72	172.63	369.58	1,462.93 (6.82%)
Developed	120.60	7.95	992.36	1,120.91 (5.23%)
Shoreline	302.27	6.10	273.36	581.73 (2.71%)
Open Water	15.93	6.72	36.89	59.54 (0.28%)
TOTAL	**6,100.50**	**1,339.38**	**14,008.67**	**21,449.33**

Example: St. Jones River Watershed

A case study of a portion of the St. Jones River watershed was included in the report to showcase land preserved by the St. Jones National Estuarine Research Reserve, a component of Delaware Coastal Program, and how the final layers from the model may be used to plan for marsh migration on these protected lands. The 4 ft SLR scenario model highlights a number of 'highly suitable' (score of 10-12) areas, as well as some 'less suitable' areas (score 4-6), for marsh migration adjacent to the current extent of tidal wetlands (Figure 5). Presently, these lands are mostly classified as non-tidal wetlands and agriculture. Many of the agricultural lands within the reserve boundary are in an agricultural lease, and thus could be a future option for tidal wetland migration if leasing is discontinued. The model also shows that the unincorporated community of Kitts Hummock and the Dover Air Force Base are less suited for marsh migration due to areas categorized as impervious surfaces. A majority of the remaining land falls into the 'suitable' category.

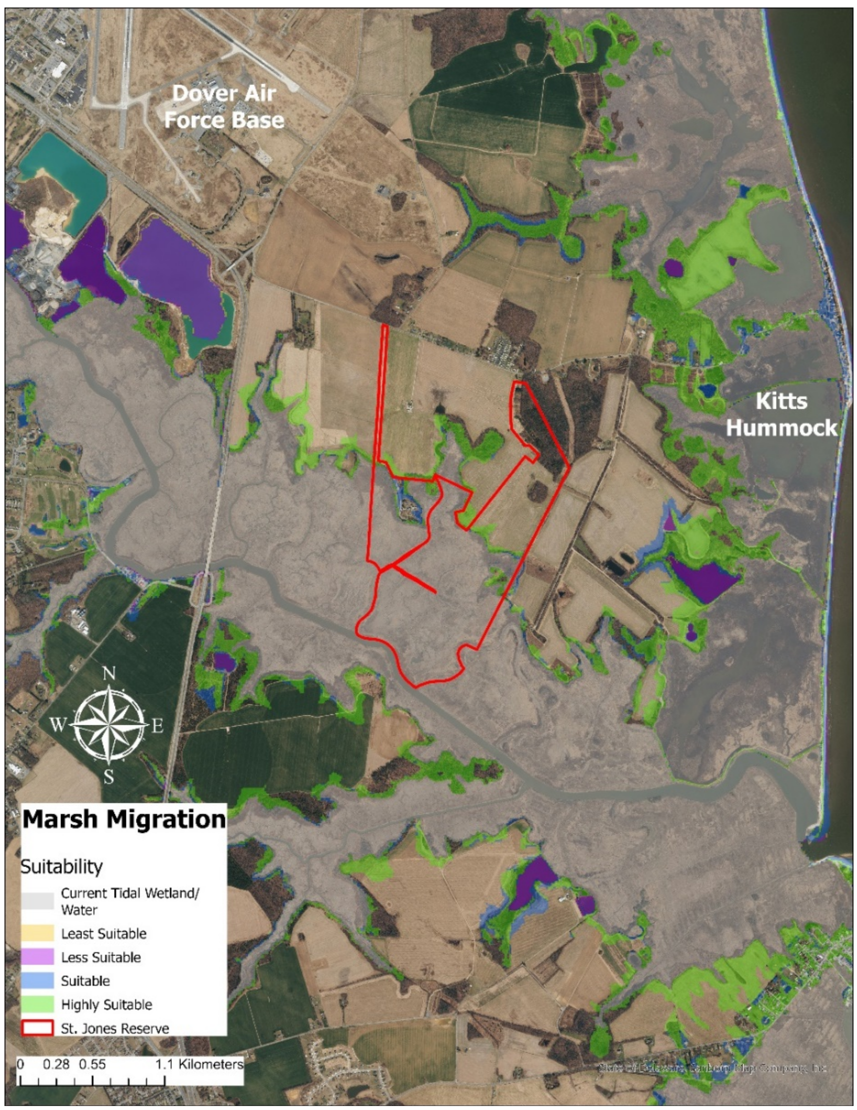

Figure 5: Case study of marsh migration model under 4 ft SLR in the St. Jones Watershed near Dover, DE.

Example: East of Milford Neck Wildlife Area

Some areas of the state exhibited larger potential for marsh migration, including the area east of the Milford Neck Wildlife Area (Figure 6). The larger expanse of areas highly suitable (score of 10-12) or suitable (score of 7-9) for marsh migration is due partially to the low elevation in this area, making the future extent of MHHW reach further inland. The areas identified for potential marsh migration include current areas of agriculture and forest, as well as large tracts of natural public protected lands in the Milford Neck Wildlife Area. Efforts to facilitate marsh migration might focus on these publicly protected lands, which are managed by Delaware Fish and Wildlife, as they are already protected from future development, exist in a natural state, and can be incorporated into land management plans. This case study also provides an example of some roads that may prohibit marshes from migrating depending on hydrology at the site, and if culverts exist to allow water to flow under the road. Further investigation should be conducted on these areas when planning for marsh migration.

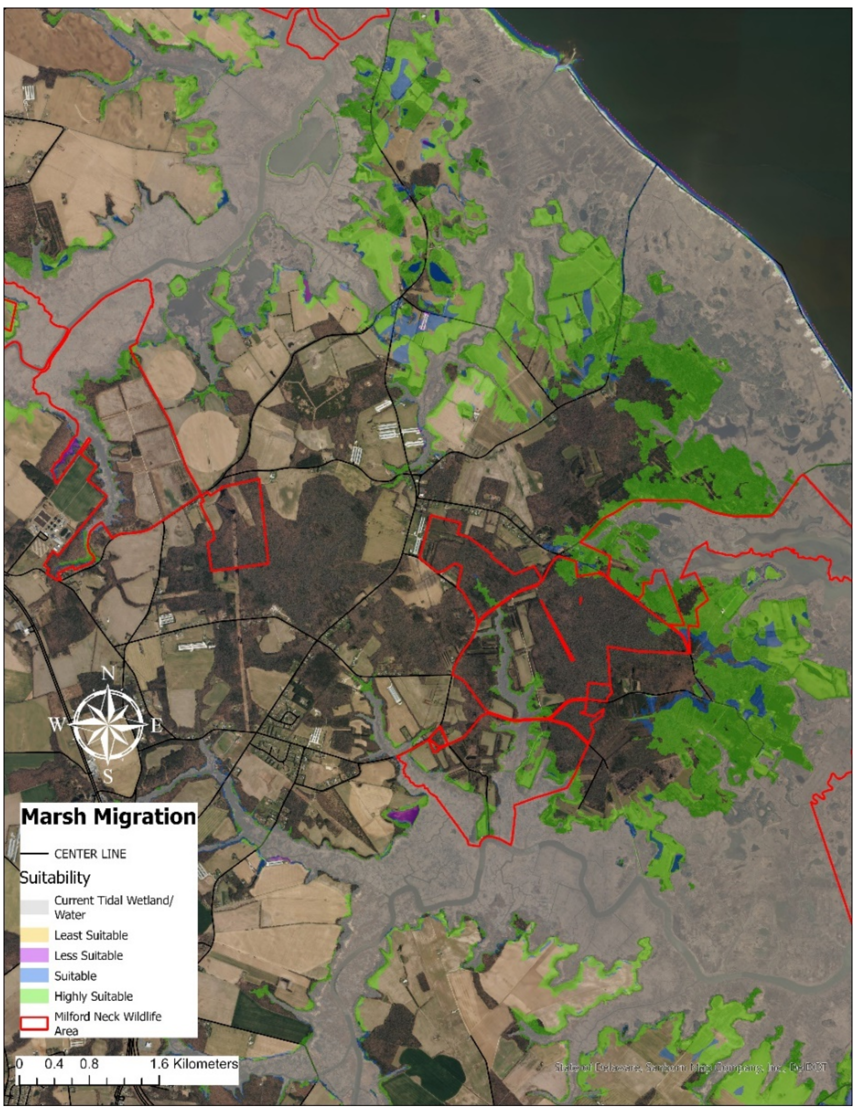

Figure 6: Case study of marsh migration model under 4 ft SLR east of the Milford Neck Wildlife Area near Milford, DE.

Example: Bombay Hook Wildlife Refuge

National Wildlife Refuges are some of the largest natural areas found throughout the state. One such refuge is Bombay Hook, which has an extensive spread of highly suitable land for marsh migration (Figure 7). The combination of low elevations and natural land uses has resulted in much of the refuge being predicted to have suitable to highly suitable land; very little area was found to be unsuitable or least suitable for migration. Managed by the US Fish and Wildlife Service as a wildlife hotspot, Bombay Hook exists in a largely natural state and has multiple freshwater impoundments that were created as habitat for waterfowl and shorebirds. Similar to the prior example, efforts to facilitate marsh migration can easily be incorporated into land management plans for this location. This is especially important for this case study as any migration into the freshwater impoundments could result in a salinity change and loss of intended functionality. Refuge-wide management planning would be beneficial for promoting future marsh migration in conjunction with current land use goals.

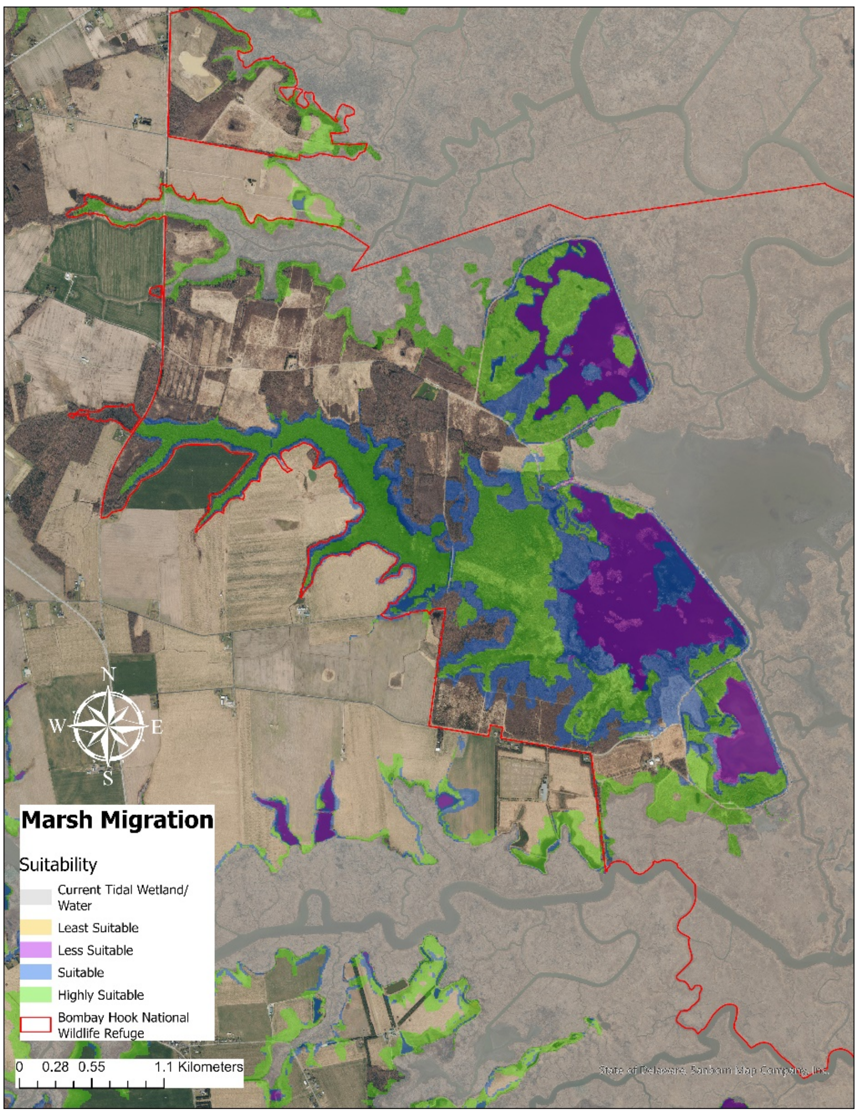

Figure 7: Case study of marsh migration model under 4 ft SLR within the Bombay Hook National Wildlife Refuge near Smyrna, DE.

Example: South Bethany, Sussex County, DE

Compared to previous case study locations, the Delaware Inland Bays provides a unique example of future marsh migration, where expansive open water areas and existing tidal wetlands are largely surrounded by development. As a result, potential areas of marsh migration are limited, held back by hardened structures and impermeable surfaces. South Bethany provides an example of marsh migration potential common for many communities surrounding the Inland Bays, where less suitable and suitable lands pepper nearly every green space and yard within the canal-lined community (Figure 8). Despite the predicted suitability, these areas are very unlikely to actually experience marsh migration as the green spaces and yards are maintained by the neighborhood and residents. Further, the model highlights areas of suitable and highly suitable migration potential that, since the creation of the 2022 LULC layer, are already being developed for future residential development. Therefore, the most productive management for marsh migration around the Inland Bays is the conservation of any remaining natural or agricultural areas to protect against future development.

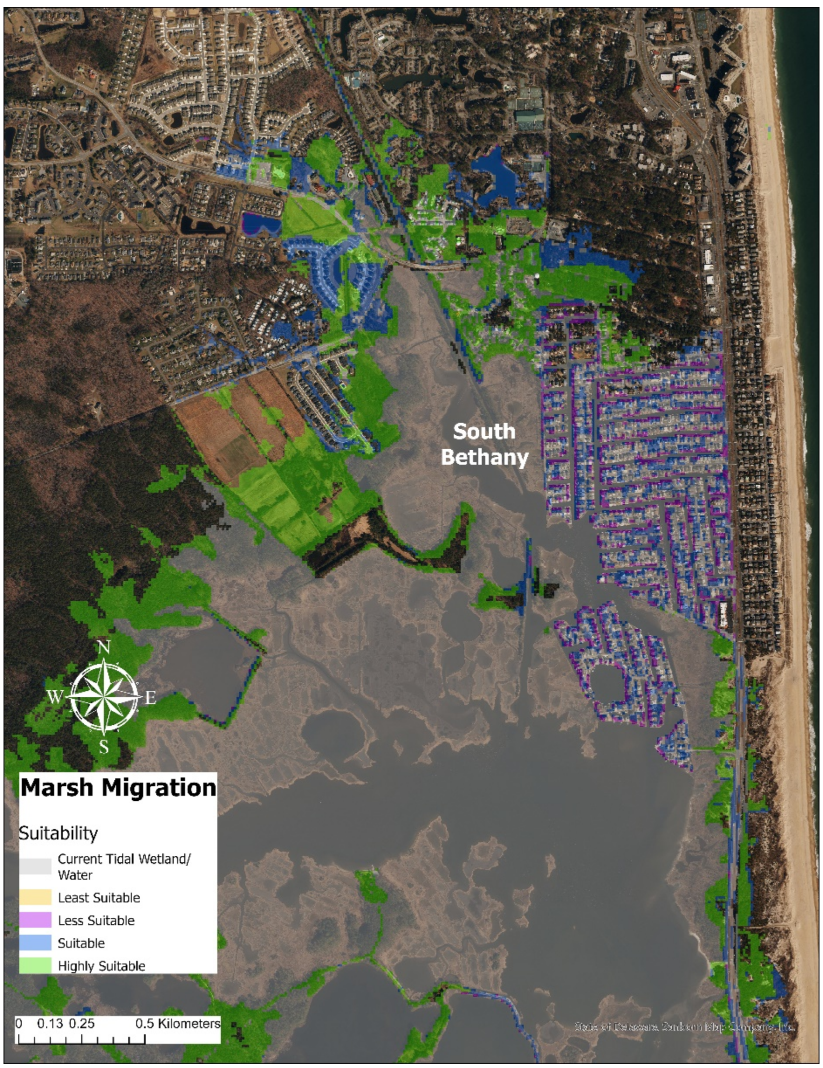

Figure 8: Case study of marsh migration model under 4 ft SLR within and around the residential communities of South Bethany in Sussex County, DE.

Example: Wilmington, New Castle County, DE

Wilmington, the largest and most populous city in Delaware, contains extensive residential, professional, and industrial development. As such, impervious surfaces, like buildings and roads, cover the city and act as a barrier to marsh migration. Yet, the Christina River, lined by wetlands along its banks, runs through the southern end of Wilmington. These wetlands have very little room to migrate, especially considering highly suitable areas of migration fall within areas of freshwater wetland restoration and stormwater retention ponds. As these natural areas are created for a particular purpose, it is unlikely they will be allowed to convert to tidal wetlands. Further, suitable areas of migration fall largely within upland pervious surfaces, which are unlikely to be converted as they are associated with development in the area. Therefore, migration along the riverfront may cause issues to roads, buildings, and could increase existing stormwater management requirements.

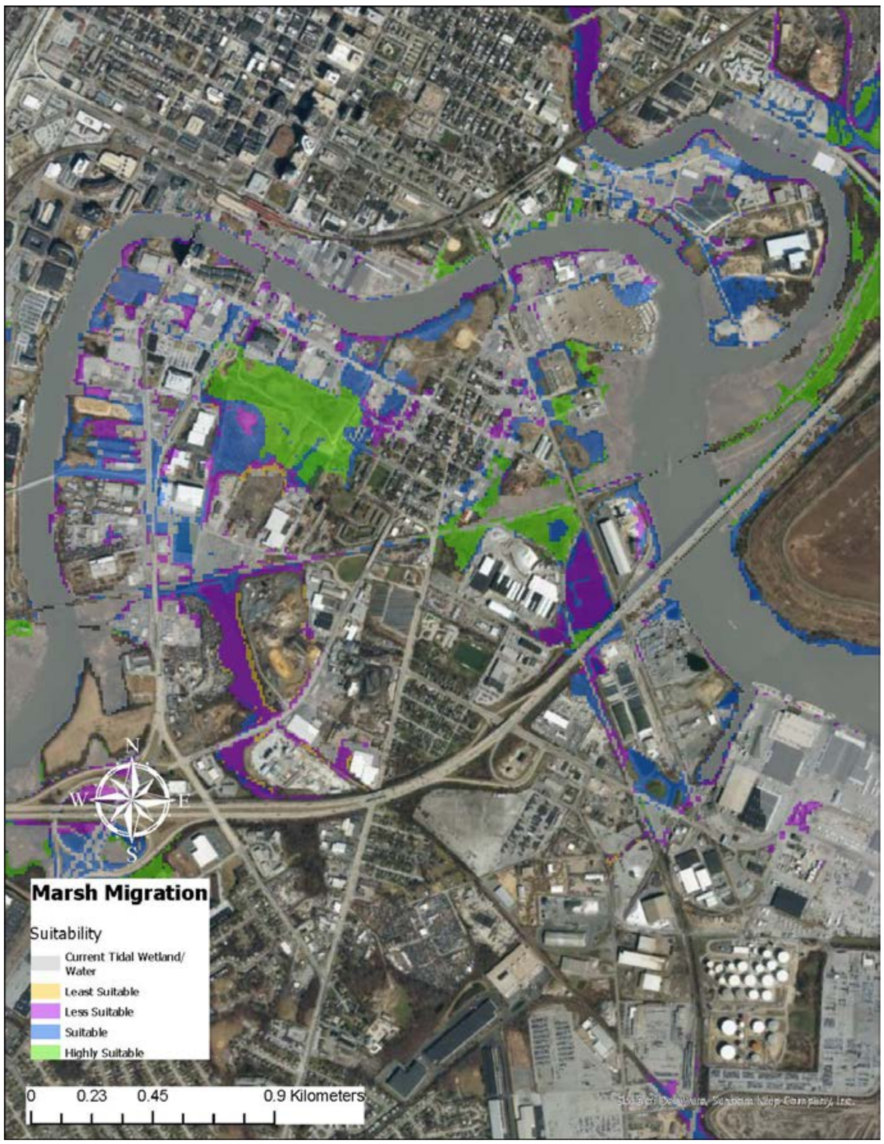

Figure 9: Case study of marsh migration model under 4 ft SLR within and around the Christina Riverfront in Wilmington, DE.

Model Use

The results of this model can be used as a screening level tool for coastal land managers to determine which areas may be suitable for future marsh migration, and where subsequent studies should be focused. The final layer does not show what areas should definitively be managed for marsh migration but act as one of many resources for land managers to consider when developing their management plans. This model does not predict the extent of tidal wetlands at any given time period, only where conditions may exist for marsh migration.

Overall, the model performed well in identifying areas with suitability for marsh migration. However, caution should be exercised when interpreting results as some model abnormalities exist. For example, the non-tidal extent of rivers and streams were included as having some level of suitability despite being open water. While the open water LULC category was excluded from the model, open water within the wetland layer was not excluded. Therefore, there are a handful of areas where a stream or river has a clear line between being excluded from the model and having some level of suitability, usually at the point where the waterbody shifts from tidal to non-tidal. Other model abnormalities include migration far beyond open water or existing tidal wetlands, migration past impervious surfaces, and migration into shoreline and beach areas. Thus, extra care should be given to interpreting results from the model and other resources and local knowledge should be considered in conjunction when making management decisions.

Because the resulting layers are meant to be screening level tools, several next steps should be considered. For example, these layers, in combination with other geospatial and scientific data, may be used to inform decisions on facilitating marsh migration within management plans for publicly owned lands. This may include a prioritization of areas for conservation or identifying locations where barriers to migration may exist due to disconnections in hydrology. Additionally, with the majority of highly suitable land being privately owned, future stakeholder engagement should be considered to determine options for facilitating marsh migration on these properties, including utilizing current conservation initiatives, incentive programs, wetland easements, and potential policy changes, among others. Finally, because a majority of highly suitable lands are non-tidal wetlands, future impacts to these areas and the potential for their migration should also be considered.

Additional Resources

	Technical Assistance	Land Acquisition / Easements	Mapping Tools	Flooding & SLR Information	Community Resilience Support	Adaptations
Resilient and Sustainable Communities League (RASCL)	X				X	
Delaware Sea Grant	X				X	
Delaware Open Space Program		X				
Delaware Land Protection Coalition		X				
NRCS Agricultural Conservation Easement Program		X				
UD Cooperative Extension	X					
New Castle Conservation District	X					
Kent Conservation District	X					
Sussex Conservation District	X					
Federal Emergency Management Agency (FEMA) Flood Maps			X	X		
The Nature Conservancy (TNC) Flood Adaptation Hierarchy				X		
NOAA Sea Level Rise Viewer			X	X		
The Delaware Conservation Blueprint			X			
Assisted Marsh Migration Fact Sheet						X
ADAPT VA						X

* Click on the name of the resource to be directed to the resource's webpage for additional information.

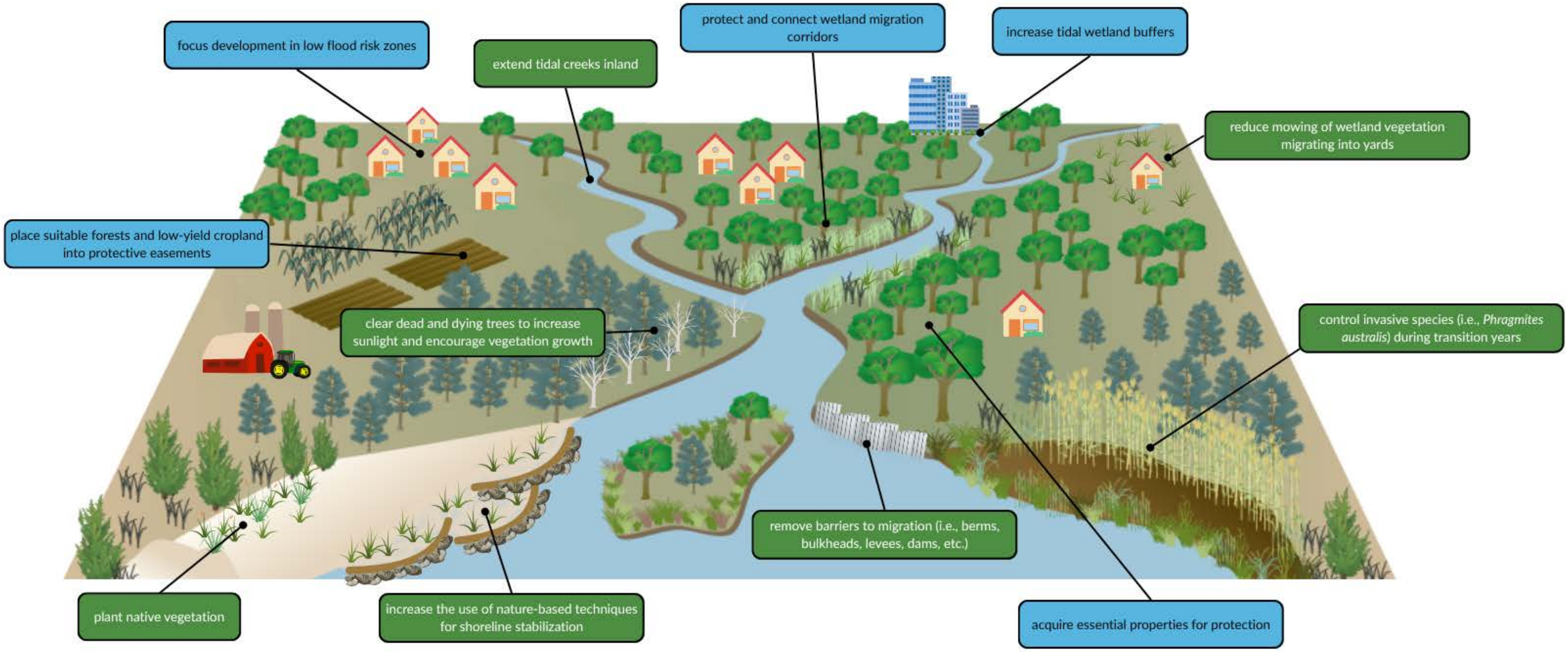

Figure 10: Example adaptations that can be implemented to help facilitate marsh migration. Green text bubbles represent actions that actively promote marsh migration. Blue text bubbles represent actions that passively promote marsh migration. Graphic is adapted from an image produced by the Integration and Application Network (ian.umces.edu), University of Maryland Center for Environmental Science.

Links from Additional Resources Table

All links from the Additional Resources table are provided below in the order in which they are given within the table.

- https://www.derascl.org/
- https://www.udel.edu/academics/colleges/ceoe/delaware-sea-grant/extension/resilient-communities-and-economies/hazards/
- https://dnrec.delaware.gov/parks/open-space/
- https://inlandbays.org/projects_issues/delaware-land-protection-coalition/
- https://www.nrcs.usda.gov/programs-initiatives/acep-agricultural-conservation-easement-program
- https://www.udel.edu/academics/colleges/canr/cooperative-extension/about/
- https://www.newcastlecd.org/
- https://www.kentcd.org/
- https://www.sussexconservation.org/
- https://msc.fema.gov/portal/home
- https://www.nature.org/content/dam/tnc/nature/en/documents/Flood_Hierarchy_Executive_Summary_FINAL_v2.pdf
- https://coast.noaa.gov/slr/
- https://www.nature.org/content/dam/tnc/nature/en/documents/DE_Conservation_Blueprint_2024.pdf
- https://nicholasinstitute.duke.edu/sites/default/files/project/nature-based-solutions-roadmap/strategy/doi-nbs-roadmap-strategy_assisted-marsh-migration_fact-sheet.pdf
- https://www.adaptva.org/info/adaptations.html

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[DNREC] Department of Natural Resources and Environmental Control. (2022). *Delaware wetlands: Status and trends from 2007 to 2017*. 38pp. https://www.nawm.org/pdf_lib/status_and_trends_reports/status_and_trends_from_2007_2017.pdf.

[EPA] United States Environmental Protection Agency. (2019). *Application of the sea-level affecting marshes model (SLAMM) to the lower Delaware Bay, with a focus on salt marsh habitat*. 74pp. EPA/600/R-18/385.

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