MANNINGTON MEADOWS: A STUDY OF MARSH EROSION AND PLANS FOR RESTORATION

by

Nicholas Austin

(Under the Direction of C. Rhett Jackson)

Abstract

Globally, coastal marshlands are shrinking due to sediment loss caused by human activities. Mannington Meadows, in Salem County, New Jersey, was once a freshwater marsh but has been converted to an area of mudflats and open water due to agricultural land conversion, dredging of the Salem Shipping Channel and the Delaware River Channel, the installation of bypass dams on the Salem River that divert freshwater inflows and alluvial sediment, and sea-level rise. Ducks Unlimited has identified Mannington Meadows as an important area for restoration because the wetland provides essential habitat for wildlife and waterfowl. This study used sources such as current and historic aerial photos, maps, soil samples, hydrology data, and LiDAR to assess the current condition of the marsh, estimate the volume of sediment lost, and determine what is needed to restore the wetlands, including potential sediment sources and transport techniques, as well as methods for preventing further erosion.

INDEX WORDS: Mannington Meadows, Erosion, Restoration, Sediment, Wetlands

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1. INTRODUCTION

1.1 Purpose of This Study

Coastal wetlands, particularly in the mid-Atlantic region of the United States, have suffered from erosion due to human alterations of sediment sourcing and transport, compounded by the effects of sea-level rise. Mannington Meadows, formerly a freshwater marsh and now an expanding mudflat in Salem County, NJ, along the Delaware River, is emblematic of such sediment loss. Ducks Unlimited has identified Mannington Meadows as an important area in need of restoration because it provides crucial habitat for wildlife and waterfowl (New Jersey Audubon, 2024). Over 128 bird species have been reported in Mannington Meadows, including several common species such as Canadian Goose, Snow Goose, and American Coot (see Appendix). Without intervention, Mannington Meadows will continue to erode. The purpose of this study is to assess the sediment loss in Mannington Meadows, including documenting the historic changes in Mannington Meadows as it eroded in response to human made changes that affected sediment transport, estimating the quantity of sediment needed to restore the marsh platform, and proposing next steps for developing a restoration plan for the marsh.

1.2 Importance of Coastal Wetlands

Coastal marshes and wetlands provide important ecosystem functions and services. For example, they provide habitat and food for native species, filter pollutants, protect shorelines from storms, provide food and habitat for native species, and sequester carbon and store sediments (Costanza et al., 1997). These areas serve as habitat and food sources for migratory wading birds and waterfowl (McMullon, 2008), as well as fish (Rodriquez et al., 2017). Wetlands are effective in filtering pollutants such as nitrogen or phosphorus (Costanza et al., 1997). They act as buffers by absorbing these pollutants before they reach the water. Coastal marshes are important to protecting infrastructure from high winds, tidal surges, and sea-level rise (Delaware Estuary Regional Sediment Management Plan Workgroup, 2013). These regions reduce damage from storms by absorbing storm energy, which decreases storm surge and wave amplitude (Costanza et al., 2008). Marsh vegetation serves as a means of storm protection by reducing wave height during storms and flooding events (Rodriguez et al., 2017). According to a 2008 study, coastal marshlands, such as Mannington Meadows, provided an estimated value of over $5 million per square kilometer in storm protection (Costanza et al., 2008). Since marshes can store carbon as above-ground biomass in leaves and stems, belowground biomass in roots, and in carbon-dense soils to moderate organic matter remineralization, as marshland is lost, so is its ability to store carbon (Powell et al., 2020). In addition, coastal marshes and wetlands are important in nutrient processing (Dame et al., 1991). Other ecosystem services provided by marshlands include recreation, such as birdwatching opportunities and walking paths (Foster et al., 2013). Because of the ecosystem functions and services they provide, restoring and preserving coastal marshes and wetlands is essential.

1.3 Sediment and Erosion in Coastal Wetlands

Coastal marshlands exist in a state of dynamic response to sediment gains and losses from alluvial sedimentation, tidal deposition, tidal erosion, and sediment fluxes from strong wind and storm surge events (Mariotti & Fagherazzi, 2010; Liu et al., 2021). Sediment loss in coastal wetlands occurs through both horizontal and vertical erosion processes. Horizontal erosion occurs due to lateral erosive processes such as wind action and waves (Mariotti & Fagherazzi, 2010). Lateral erosion at marsh edges is thought to be the most common cause of marsh erosion worldwide (Marani et al., 2011). Marani et al. (2011) found edge erosion rates to be linearly related to wave power density. Vertical erosion occurs when there is a loss of vegetation in the marsh (Marani et al., 2011). For example, when areas of vegetation are submerged for longer periods of time, such as with sea-level rise, marsh vegetation is unable to survive, leaving the marsh vulnerable to erosion (Rodriquez et al., 2017). Any interventions to restore or protect coastal marshland must focus on supplying and maintaining sediment.

Since coastal marshes are constantly subjected to a pattern of constructive and destructive forces, any plan to restore the marsh ecosystem must also consider the sediment budget of the entire wetland system. Marshlands rely on sediment deposits from tides or freshwater inputs to maintain their elevation and stability (Christiansen et al., 2000). While constant flooding during high tides is needed to deliver sediment, the effectiveness of this flooding for depositing sediment depends on marsh elevation, tidal range, and vegetation properties (Donatelli et al., 2018). Marsh erosion and loss of vegetation affect the ability of the whole bay system to retain sediment (Donatelli et al., 2018). In addition, if wetlands have low sediment inputs, they cannot sustain elevation gain enough to prevent the wetland from drowning, because wetland vegetation cannot survive the extended hydroperiods (Rodriguez et al., 2017). Ultimately, the marsh becomes eroded without vegetation. Vegetation helps mitigate erosion by contributing to the buildup of organic material, which combats the destructive forces of wind, waves, and tides (D'Alpaos et al., 2012). However, vegetation alone cannot prevent marsh erosion from such destructive forces. The types of plants and soils used must be resistant to erosive forces both at the marsh edge and the marsh interior (Feagin et al., 2009). Any salt marsh restoration plan using coastal vegetation should focus on stabilizing sediment within the whole marsh system (Feagin et al., 2009). The health of tidal wetland systems depends on many factors, including sediment supply, tidal range, winds, and vegetation (D'Alpaos et al., 2012). A sound marsh restoration plan must account for all these factors to ensure marsh stability.

1.4 Threats to Coastal Wetlands

Coastal wetlands worldwide, including those in New Jersey, are endangered by factors such as sea-level rise and human disruptions of flows and sediment dynamics. Consequently, attributing marsh erosion to specific causes can be difficult. Globally, in the 20th century, sea level has risen approximately 0.5 ft, which is the greatest increase in 3,000 years (New Jersey Climate Change Resource Center, Rutgers University, 2020, May). In New Jersey, it is estimated that sea level will rise between 0.5 and 1.1 ft from 2000 to 2030, and between 0.9 and 2.1 ft from 2000 to 2050 (New Jersey Climate Change Resource Center, Rutgers University, 2020, May). Since coastal New Jersey wetlands are generally low-lying and are regularly affected by tides, waves, and storm surges, they are particularly susceptible to sea-level rise (Donatelli et al., 2018). Besides climate change, which is causing thermal expansion of oceans and melting of glaciers and ice sheets, New Jersey and the mid-Atlantic region are sinking due to human activity such as excessive pumping of aquifers (New Jersey Climate Change Resource Center, Rutgers University, 2020, May). Coastal marshes in the United States, including those in coastal New Jersey, were first altered by European settlers, who built dikes and sluice gates to drain the land for agricultural use (Sebold, 1992). Mosquito control was also a driver in altering marshes on the east coast of the United States during the early 1900s (Lathrop et al., 2000). Parallel grid ditching that drained the marsh surface and lowered the water table was used to reduce mosquito habitat (Lathrop et al., 2000). Nearly 90% of the tidewater marshland between Maine and Virginia in the United States had been ditched by 1938 (Bourn & Cottam, 1950). Later, methods of mosquito control involving open water ponding, which contributed to marsh erosion, replaced parallel grid ditching (Lathrop et al., 2000). Hydrologic changes due to man-made structures such as dams, levees, culverts, and bridges also affect water flow in coastal marsh areas (Rodriguez et al., 2017). This change in water flow can cause sediment to be washed out or diverted out of the marsh and further threaten wetland survival. In addition to changing the hydrology, human activity causes changes in vegetation, which threatens the stability of the wetlands. For example, coastal wetlands have deteriorated due to the use of agricultural chemicals, which have killed many plant species that once helped prevent erosion (Foster et al., 2013). An increase in nutrients from agricultural practices in coastal ecosystems can increase above-ground biomass but decrease the below-ground biomass of roots that provide bank stabilization (Deegan et al., 2012). Areas of decreased vegetation along with fewer roots and rhizomes, which hold the sediment in place, cannot withstand tidal currents that erode the marsh and creek banks (Terzaghi et al., 1996). In all cases, sediment transport due to climatic and anthropogenic factors threatens the stability of coastal wetlands (Ganju et al., 2013). Thus, to restore and preserve coastal wetlands it is necessary to understand sediment transport through a coastal wetland region and the factors that disrupt the natural sediment dynamics.

1.5 Goals and Objectives

The overall goal of this research is to assess sediment loss in Mannington Meadows. The specific objectives of this research are to 1) document the response of the marsh to human made changes to Mannington Meadows from the late 1800's to present day that have affected the sediment budget of the marsh, 2) estimate sediment loss in Mannington Meadows as the area of open water has increased over time, 3) determine the current state of the marsh, including elevation and soil composition, and 4) propose methods for restoring sediment and preventing further erosion of the marsh. Without intervention, erosive forces will continue to degrade the marsh. Completion of this research will provide Ducks Unlimited with the information needed to move forward with developing a restoration plan for Mannington Meadows.

2. STUDY SITE

2.1 Site Description and Possible Causes of Erosion

Mannington Meadows, an estuarine marsh at the former mouth of the Salem River in Salem County, New Jersey (Figure 1), is a tidal wetland complex surrounded by agricultural lands and grasslands, approximately 6,000 acres in size (New Jersey Conservation Foundation, 2024). Many migratory birds and waterfowl use Mannington Meadows for habitat. According to eBird (2025), from 1992 to 2025, 128 different species have been spotted near the Rt.540 Bridge on the east side of Mannington Meadows. Snow Geese, American Coot, Canadian Geese, Ring-billed Gulls, Mute Swan, and Gadwall have the greatest number of sightings (Table 1). In addition, there are several endangered, threatened, or species of special concern that use Mannington Meadows for habitat, including the Bald Eagle, King Rail, Least Bittern, and Pied-billed Grebe (New Jersey Audubon, 2024). Much of Mannington Meadows has invasive vegetation dominated by Phragmites, *Phragmites australis* (common reed), which can threaten bird habitat (New Jersey Audubon, 2024). It was thought that Phragmites became invasive in the marshland between the 1970s and 1980s, with the marsh being completely dominated by Phragmites in the 1990s and early 2000s. However, further research would be needed to support that claim. Migratory bird, and waterfowl usage of Mannington Meadows makes the restoration of habitat conditions important to many conservation groups and agencies, including Ducks Unlimited, Department of Environmental Protection [DEP], United States Fish & Wildlife Service [USFWS], New Jersey Fish & Wildlife Service [NJFWS], US Army Corps of Engineers [USACE], Partnership for the Delaware Estuary, New Jersey Conservation Foundation, and National Oceanic and Atmospheric Administration [NOAA].

Figure 1. General aerial overview of Mannington Meadows 2020 (NJ Office of Information Technology, Office of GIS [NJOGIS]).

Table 1. Rt. 540 Bridge Species Sightings 2014-2025 (eBird).

Canadian Goose	Snow Goose	Mute Swan	Gadwall	American Coot	Ring-Billed Gull
7,690	31,750	4,169	4,010	10,503	5,363

Mannington Meadows was originally freshwater marshland (Figure 2), but historic maps, aerial photographs, and satellite imagery indicate that a large portion of the marshland has been converted to its present state of mud flats and open water. Humans and climate change have altered sediment dynamics in a number of ways. In this analysis, we explored several hypotheses to explain the erosion of Mannington Meadows: 1) the oxidation and subsidence of marsh soils following agricultural diking and ditching in the late 1800s; 2) the acceleration of tidal flows due to the creation (dredging) of the Salem Shipping Channel in 1925; 3) the loss of river sediment inputs and freshwater flows due to the diversion of the Salem River to the Dupont (now Chemours) plant in 1935; 4) acceleration and amplification of tidal exchange by deepening the Delaware River channel, and 5) sea-level rise.

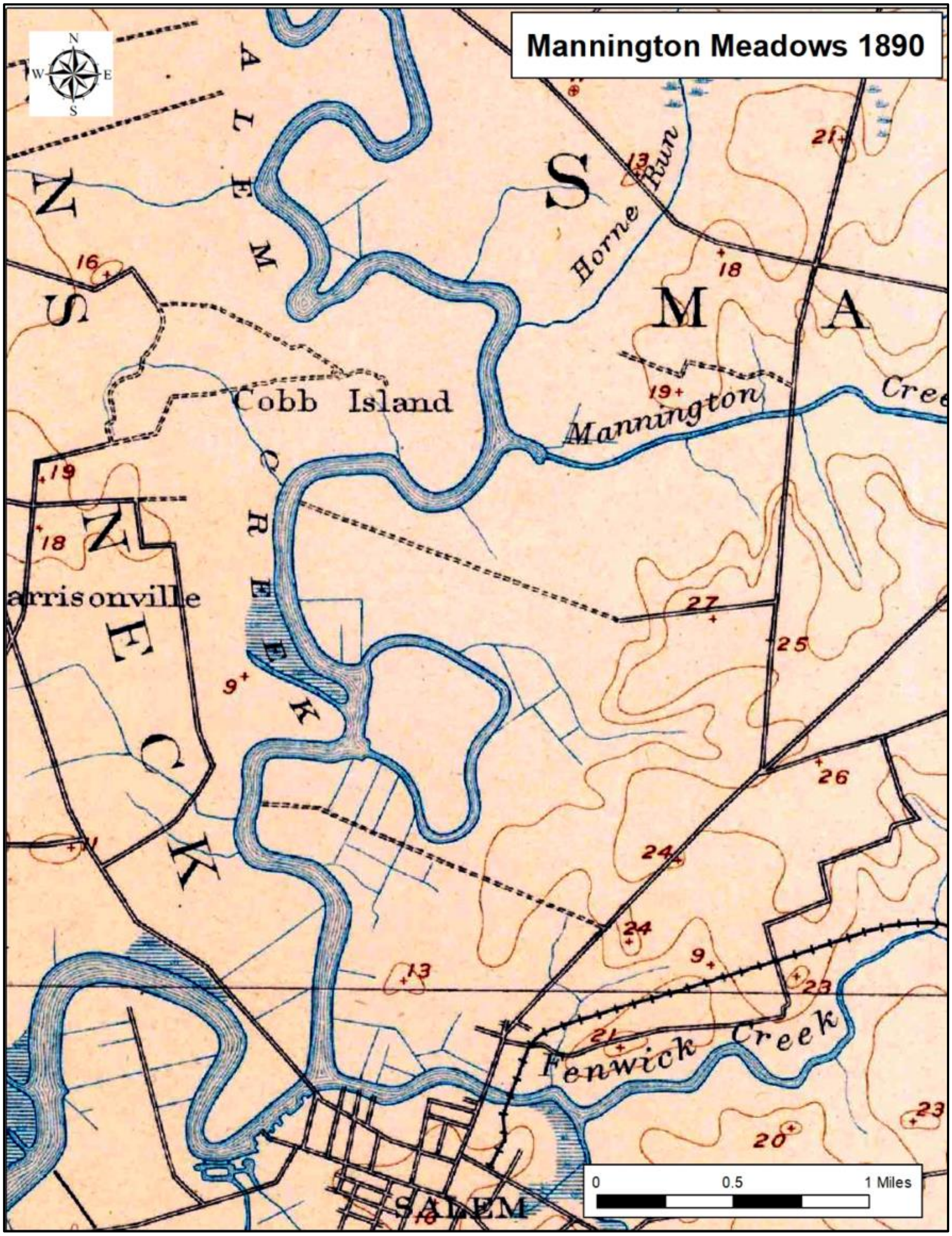


Figure 2. Topographic map of Mannington Meadows 1890 (provided by Ducks Unlimited). Marsh was directly fed by the Salem River.

2.2 Agricultural Ditching and Diking

In the late 1800s and early 1900s, much of the marsh was diked and drained for agricultural use, which blocked the tidal flow (Sebold, 1992). Banks were built to prevent the river or sea water from inundating the land, and drains were installed to allow water to escape the marsh (Sebold, 1992). This process allowed farmers to reclaim the land for crops or animals (Sebold, 1992). However, diking reduced sediment inputs, and drains increased sediment outflow, which left the marsh more vulnerable to erosion (Gebert, 2020).

2.3 Dredging of the Salem Shipping Channel

In 1925, the USACE dredged the Salem Shipping Channel, which cut off the long lower oxbow of the river and created a straight channel, connecting Salem and Mannington Meadows to the Delaware River (Figure 3) (Gebert, 2020). This channel greatly increased the velocity of tidal flows in the lower Meadows, which could allow more sediment to wash out of the marsh (Gebert, 2020). By 1930, erosion of the marsh was evident (figure 4). Estimates from USACE (2022) show that the average dredging volume to maintain navigation on the Salem River is expected to be 43,000 yd^3/yr. In 2024, approximately 200,000 yd^3 were removed and placed to restore the degraded marsh at Supawna Meadows (USACE, 2024). A deepening of the channel was completed in 1996, and O&M quantities have ranged from 100,000 yd^3 to 200,000 yd^3 (USACE, 2024). Another channel dredging was performed in 2012, and maintenance dredging of approximately 52,000 yd^3 in 2017 and 15,000 yd^3 in 2022 was performed (USACE, 2024). Dredging of the Salem Shipping Channel varies greatly from year to year (USACE, 2024).

Figure 3. Aerial view of the Salem Shipping Canal (Google Earth, 2024).

Figure 4. Aerial image of Mannington Meadows 1930 (NJOGIS). Lower marsh erosion begins to occur.

2.4 Installation of Salem River Dams

In 1935, the Brown and Munson Dams were constructed on the Salem River (Figure 5) (Spitz & DePaul, 2023). The Brown Dam (Figure 6) diverted the river flow to the Salem Canal, supporting the DuPont/Chemours chemical plant on the Delaware River to prevent water from the Salem River estuary from intruding on the freshwater supply to the plant (Spitz & DePaul, 2023). In addition, the Munson Dam, located at the downstream end of the Salem Canal, releases water into the Delaware River (Spitz & DePaul, 2023). The construction of the dams and canal resulted in the loss of river sediments and freshwater flows to Mannington Meadows (Spitz & DePaul, 2023).

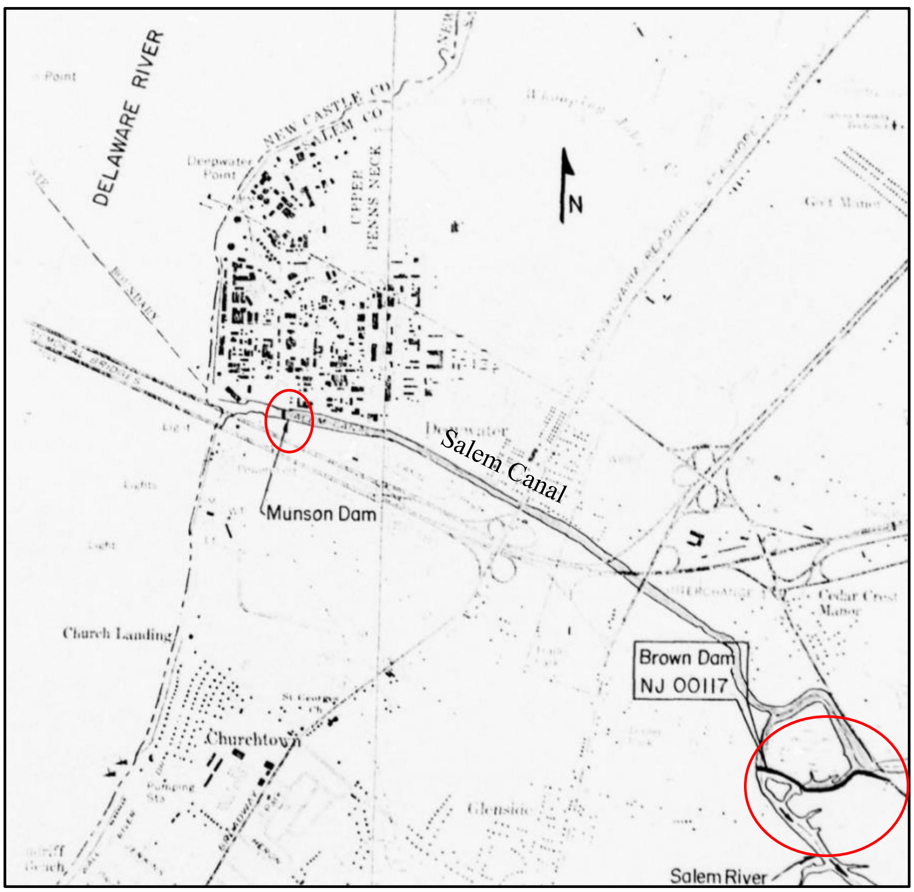


Figure 5. Topographic map showing the locations of the Brown and Munson Dams along the Salem Canal (USACE, 1979).

Figure 6. The Brown Dam (left: photo by Nicholas Austin, right: image from Google Earth, 2025).The Brown Dam can be seen across the middle of the right image.

2.5 Delaware River Channel Deepening

The dredging of the Delaware River Channel to allow for larger ships to travel up the river also may have contributed to the erosion of Mannington Meadows. The Delaware Estuary, which runs alongside Mannington Meadows, located along the Atlantic coast, is made up of three parts, the lower bay from Lewes, Delaware to Bombay Hook, the upper estuary from Bombay Hook to Wilmington, and tidal freshwater river that starts around Trenton, NJ (Pareja-Roman et al., 2020). The estuary's maximum depth near Philadelphia was only 6 m prior to 1890 (Blood, 1918). By the early 1900s, there was a need to deepen the shipping channel for Hog Island, which became the world's largest shipyard at the time (Blood, 1918). Dredging was completed by the USACE to allow ships access to ports in Wilmington and Philadelphia (Pareja-Roman et al., 2020). Channel depths in 1898 were 6.10 m, increased to 12.19 m in 1941, and increased again to 13.72 m in 2014 to accommodate larger ships. (Pareja-Roman et al., 2020). As a result, yearly average tidal elevation amplitudes increased as dredging increased channel depth (Figure 7), with recorded amplitudes of 0.66 m in 1898, 0.72 m in 1941, and 0.82 m in 2014 (Pareja-Roman et al., 2020). There were noticeable changes in the response of tidal currents to deepening of the channel from Bombay Hook to Trenton, at the upper part of the estuary in the area of Mannington Meadows, and extreme variability near Bombay Hook (Pareja-Roman et al., 2020). In general, patterns of increasing tidal current amplitude are related to depth-averaged friction (Pareja-Roman et al., 2020). As roughness is decreased from topographic features, tidal current amplitude is increased (Pareja-Roman et al., 2020). This increase in tidal current amplitude could lessen the amount of suspended sediment transported to the marsh in tidal rivers (Pareja-Roman et al., 2020). It is estimated that the volume of sediment dredged for maintenance from the Delaware Channel from 1990 through 2020 is approximately 3,000,000 yd^3 (USACE, 2022). In addition, deepening of the channel to 45 feet occurred in the 2010s, which removed approximately 16,000,000 yd^3 of sediment (USACE, 2022).

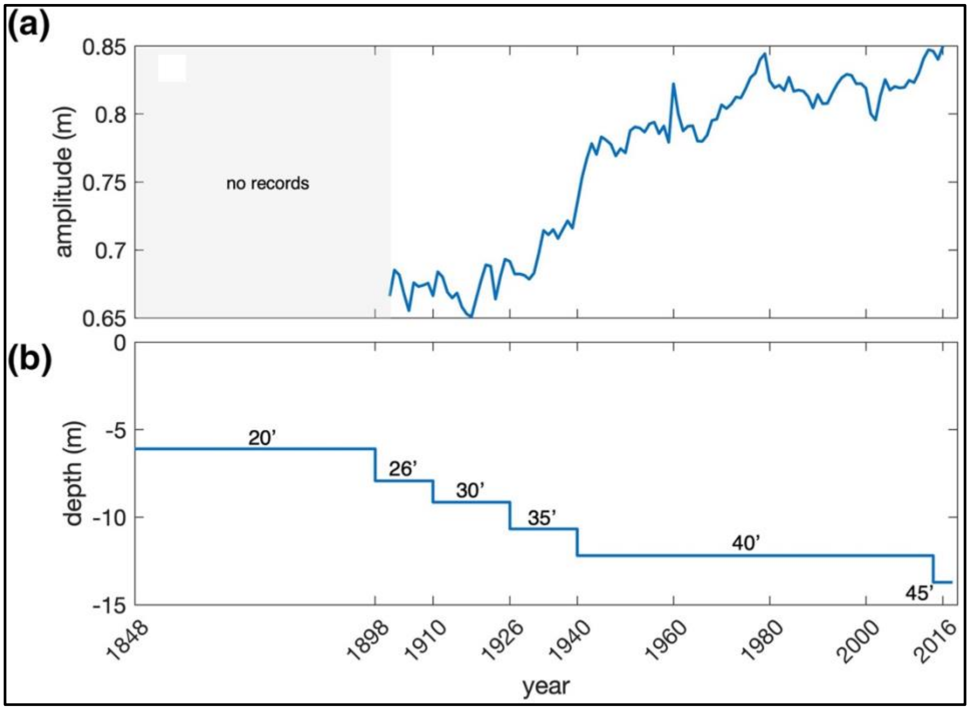


Figure 7. Timeline of Delaware River Channel depth increases. (a) Yearly averaged tidal elevation amplitude in Philadelphia from historical records at NOAA stations 8545530 and 8545240, and (b) shipping channel depth over time. Depth in feet is also shown in panel (b) for reference (Pareja-Roman et al., 2020).

2.6 Sea-level Rise

While there are no studies on sea-level rise specific to Mannington Meadows, findings on sea-level rise in the Delaware Estuary could be used to better understand the conditions in this region. The Delaware Estuary has experienced a 30 cm or 1 ft rise in sea level over the past century (Delaware Valley Regional Planning Commission [DVRPC], 2004). It is estimated by the International Panel on Climate Change that in the Delaware Estuary, sea-level will rise 1.5 mm/yr higher than the predicted global average of 914.4 mm (3 ft) that will occur during the twenty-first century (DVRPC, 2004). Since the majority of coastal wetlands in the Delaware Estuary are only less than a meter above sea level, a one-meter rise could be devastating to them (DVRPC, 2004). Active tidal gauges can be used to understand local relative sea level. The Reedy Point, Delaware tidal gauge, located across from Mannington Meadows, shows a local relative sea level trend of 3.99 mm/yr, based on monthly sea-level data collected from 1956 to 2024 (Figure 8) (NOAA, 2025). This data represents a change of 399.288 mm or (1.31 ft) in 100 years (NOAA, 2025). If current trends continue, sea-level rise will have a major impact on the erosion of Mannington Meadows.

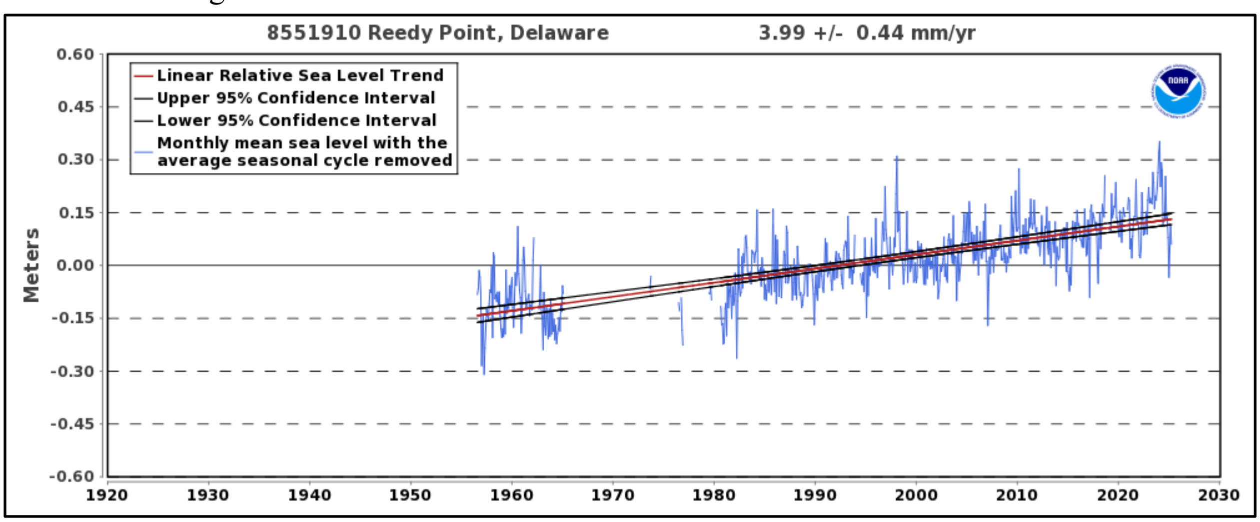


Figure 8. Reedy Point, Delaware relative sea-level trend timeline. (NOAA, 2025)

The changes made to Mannington Meadows over the last century have contributed to the erosion of the marsh. After the 1930s, the dike system was abandoned due to a shift in agricultural demand. As a result, agricultural fields became flooded as the dike system failed from disrepair, which released tidewater from the Salem River and allowed sediment to wash out (Gebert, 2020). Dredging of the Salem Shipping Channel and the Delaware River Channel, along with the installation of the dams, has limited sediment inputs to the marsh (Gebert, 2020). Furthermore, marsh erosion may have been exacerbated by sea-level rise (Delaware Estuary Regional Sediment Management Plan Workshop, 2013). Cumulatively, these changes have degraded important waterfowl and wildlife habitat in Mannington Meadows (New Jersey Audubon, 2024). Understanding the historic changes made to Mannington Meadows and how these changes have affected the sediment budget of the region is important in developing a restoration plan.

3. METHODS

After documenting the historic alterations that have been made to Mannington Meadows, this research involved several steps to track the erosion of the marsh over time, assess the current state of the marsh, including marsh elevation and soil composition, estimate total volume of sediment needed to restore marsh platform, and propose ways to restore sediment to the marsh.

3.1 Estimating Sediment Loss and Marsh Boundaries

First, I used the Salem Creek sediment load data from the results of the 1974 Sediment Report by Mansue & Commings to estimate the sediment loss from Mannington Meadows caused by the construction of the Brown Dam. I then assembled historic maps and aerial images of the area and used ArcGIS Pro to trace the open water boundaries of the marsh for maps dating from 1890 to 2024 (Figure 9). Years documented were based on available maps and images (Appendix). Using ArcGIS, the area of open water was calculated for each year documented (Table 2).

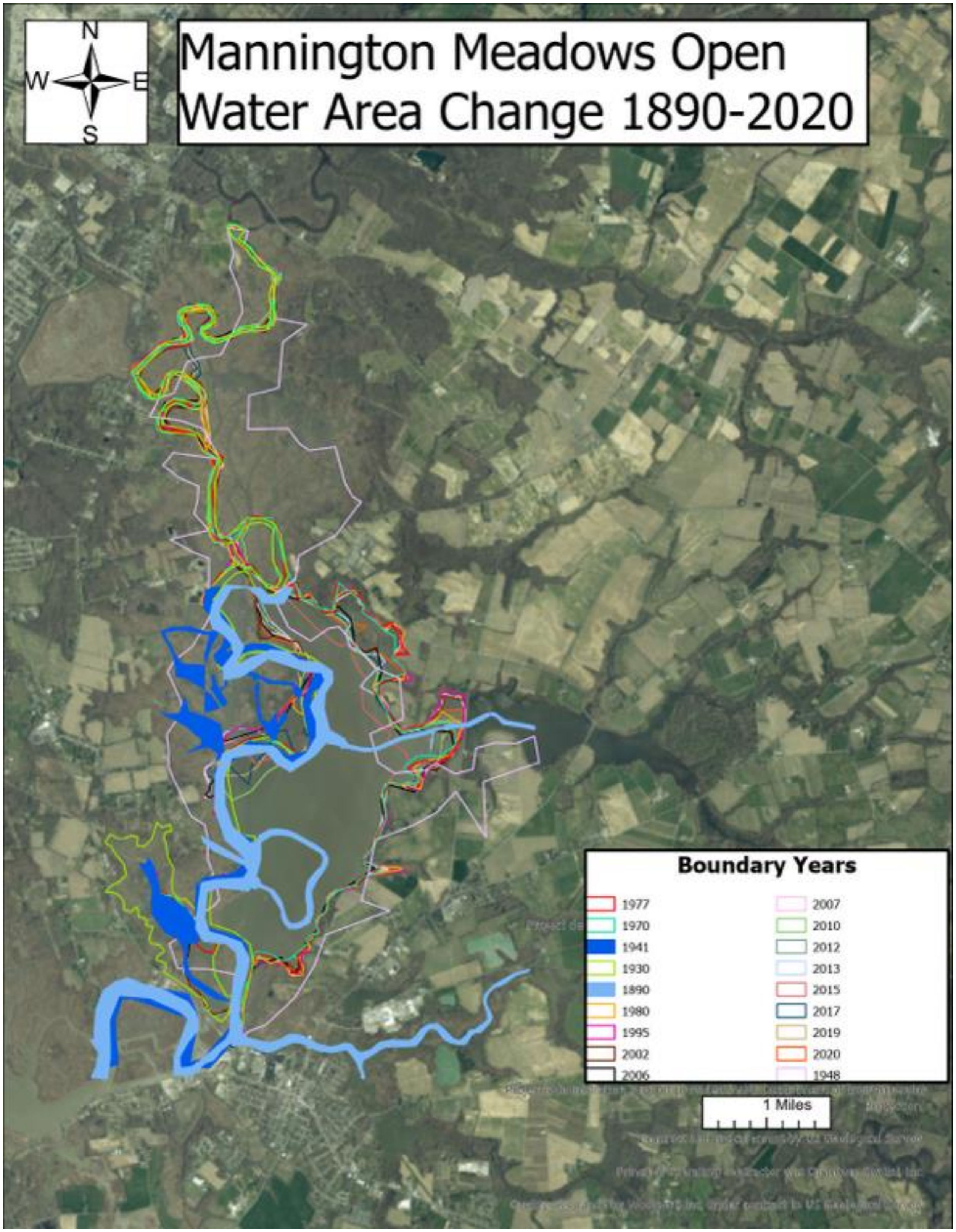


Figure 9. Mannington Meadows open water area boundaries 1890-2024 (NJOGIS, 2020).

Table 2. Mannington Meadows Boundary Area 1890-2020

Year	Area (km^2)
1890	2.5
1930	3.03
1941	2.6
1948	16.8
1970	85.2
1977	87.04
1980	87.8
1995	94.8
2002	89.4
2006	85.1
2007	91.9
2010	76.8
2012	81.4
2013	79.5
2015	71.6
2017	79.6
2019	78.2
2020	89.9

3.2 Assessing Ideal Marsh Elevation and Estimating Replacement Sediment Volume

Marsh elevation samples were taken using the most up-to-date LiDAR data (2020) from Boyd Maps (Figure 11). Samples were taken over areas of invasive vegetation (Phragmites), 23 samples (Table 3), and native vegetation (non-Phragmites), 19 samples (Table 4). The invasive Phragmites (common reed), which likely became established when tidal flows the marsh were restricted by human activity, are well-adapted to higher marsh, lower salinity conditions, while the desired native non-Phragmites, pickerel weed or wild rice are better adapted to wetter, higher salinity conditions (Chambers et al., 2012). The elevation samples were then averaged and compared to determine an ideal elevation for the new marsh platform based on the average elevation of the desired non-Phragmites. Phragmites (invasive vegetation) had an average elevation of 2.71 ft, and non-Phragmites (native vegetation) had an average elevation of 1.31 ft. The non-Phragmites elevation ranged from 1.3 to 1.6 ft. Using the elevation data for the non-Phragmites, an elevation of 1.5 ft was chosen as ideal for a new marsh platform. The total sediment volume needed to restore the marsh platform was calculated using bathymetry data provided by the USACE (Figure 10). Bathymetric data was collected by the USACE between February and May, 2020, per the Corps of Engineers Hydrographic Survey Manual EM1110-2-1003, dated November 30, 2013, for navigation and dredging support surveys. The horizontal reference is NAD83, New Jersey State Plane, Zone 2900, USFOOT. The vertical references are NAVD 88, GEOID 12B, and NOAA Tidal Epoch 1983-2001. Soundings refer to mean lower low water. NYPACK, Inc. Software was used to perform sounding selection. The bathymetry data indicated an arithmetic mean depth of 8.81 ft, a geometric mean depth of 6.22 ft, and a median depth of 5.7 ft from summarizing the data in ArcGIS Pro. For the purpose of finding an estimate, I chose to use the arithmetic mean. I then added the arithmetic mean depth (8.81 ft) to the ideal non-Phragmites elevation of 1.5 ft and then multiplied by the area of the marsh (3,000 acres). (8.81 ft+1.5 ft=10.3 ft x 3000 ac x 43560 ft^2/1 ac=1,346,000,000 ft^3) or (38,100,000 m^3)

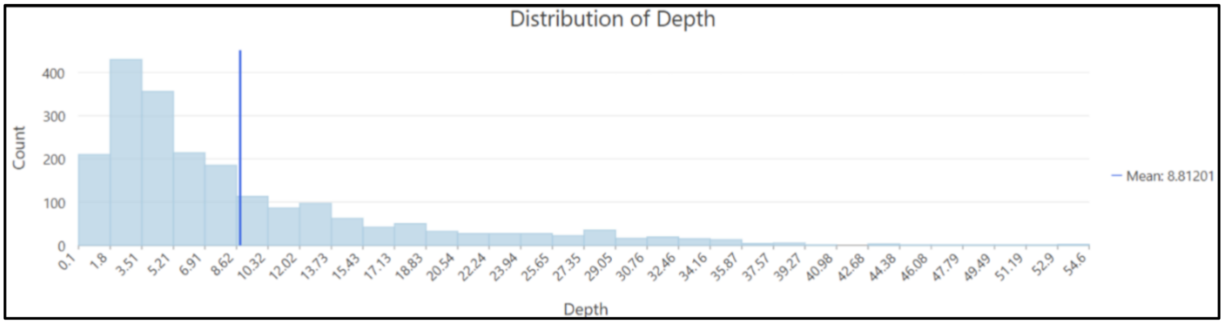


Figure 10. Distribution of Mannington Meadows Depth (ft) (USACE, 2020). The mean depth of Mannington Meadows (8.81 ft) was used to calculate the volume of sediment needed to restore the marsh platform.

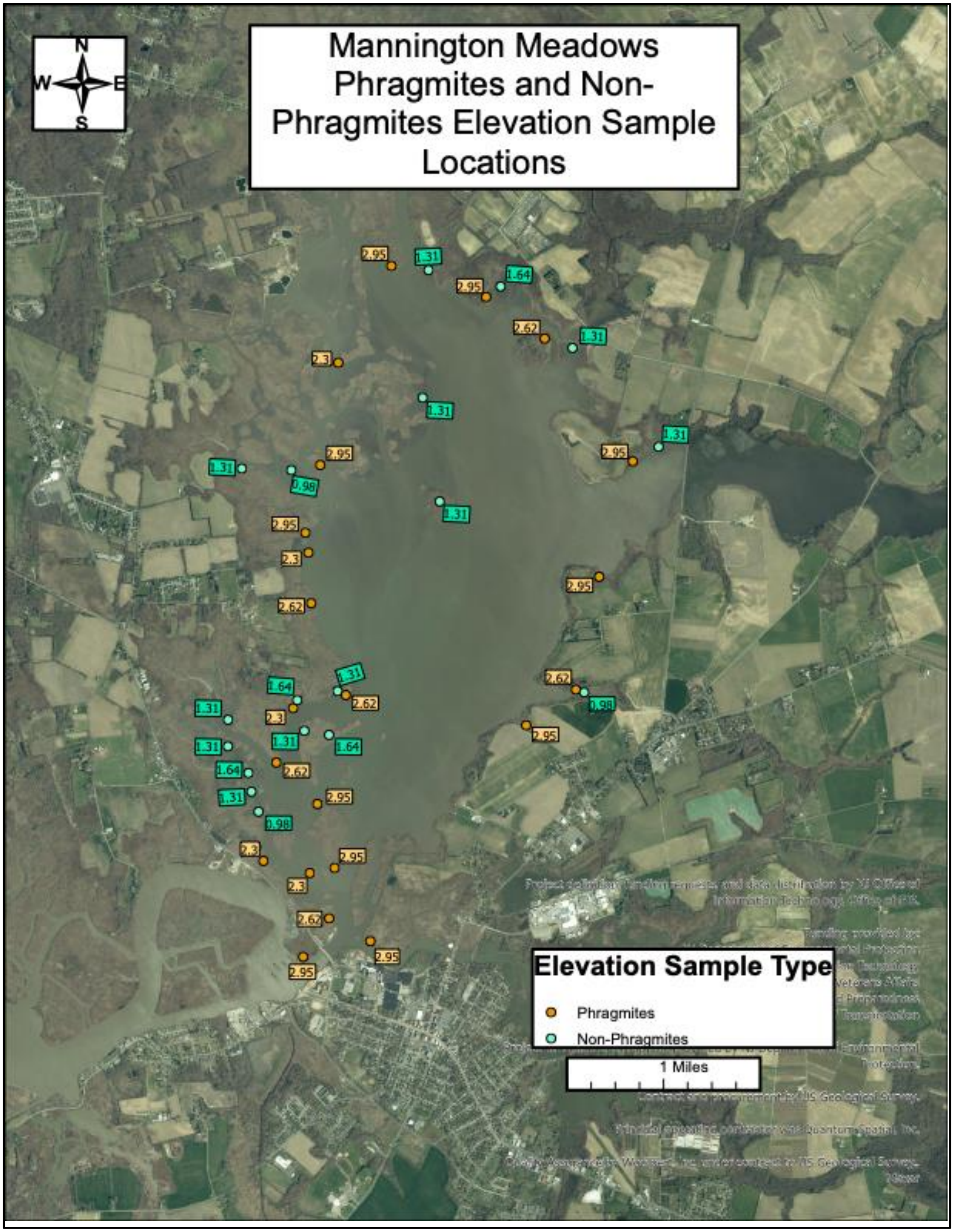


Figure 11. Map of Mannington Meadows Phragmites and non-Phragmites elevations. (NJOGIS).

Table 3. Phragmites Elevation Samples.

Sample	Latitude	Longitude	Elevation (ft)
PE1	39.5776	-75.4791	2.95
PE2	39.5805	-75.4766	2.62
PE3	39.5843	-75.4761	2.95
PE4	39.5839	-75.4785	2.3
PE5	39.5848	-75.483	2.3
PE6	39.5891	-75.4778	2.95
PE7	39.5922	-75.4818	2.62
PE8	39.5963	-75.4802	2.3
PE9	39.5973	-75.4751	2.62
PE10	39.6042	-75.4785	2.62
PE11	39.608	-75.4788	2.3
PE12	39.6095	-75.4791	2.95
PE13	39.6146	-75.4777	2.95
PE14	39.6223	-75.476	2.3
PE15	39.6296	-75.4709	2.95
PE16	39.6273	-75.4617	2.95
PE17	39.6242	-75.456	2.62
PE18	39.615	-75.4474	2.95
PE19	39.6063	-75.4506	2.95
PE20	39.5978	-75.4528	2.62
PE21	39.5951	-75.4576	2.95
PE22	39.6865	-75.4691	2.62
PE23	39.5788	-75.4726	2.95

Note: PE=Phragmites Elevation

Table 4. Non-Phragmites Elevation Samples.

Sample	Latitude	Longitude	Elevation (ft)
NPE1	39.5858	-75.4837	0.98
NPE2	39.5885	-75.4835	1.31
NPE3	39.59	-75.4842	1.64
NPE4	39.5914	-75.4845	1.31
NPE5	39.5934	-75.4865	1.31
NPE6	39.5954	-75.4865	1.31
NPE7	39.5946	-75.4791	1.31
NPE8	39.5969	-75.4798	1.64
NPE9	39.5976	-75.4759	1.31
NPE10	39.6143	-75.4853	1.31
NPE11	39.6142	-75.4805	0.98
NPE12	39.6119	-75.4661	1.31
NPE13	39.6197	-75.4678	1.31
NPE14	39.6293	-75.4673	1.31
NPE15	39.6281	-75.4603	1.64
NPE16	39.6235	-75.4533	1.31
NPE17	39.6161	-75.4449	0.98
NPE18	39.5976	-75.452	0.98
NPE19	39.5943	-75.4767	1.64

Note: NPE=Non-Phragmites Elevation.

3.3 Soil Composition

To assess the soil composition of Mannington Meadows, duplicate sediment samples were taken from Mannington Meadows in 8 different locations (16 total samples), representing the various areas of the marsh (Figure 12, Table 5). Samples were collected using a 2-inch ring core or auger placed into a PVC pipe. Samples were then examined for organic matter and placed into bags. Sediment samples were then oven-dried and weighed to calculate the bulk density.

Samples were then sieved using a 2 mm #10 sieve, weighed out, and pretreated using distilled water and hydrogen peroxide to burn off organic matter and carbon, and then underwent a laser particle size analysis [LPSA] to determine particle size distribution and soil texture. Samples were also analyzed for carbon and nitrogen content.

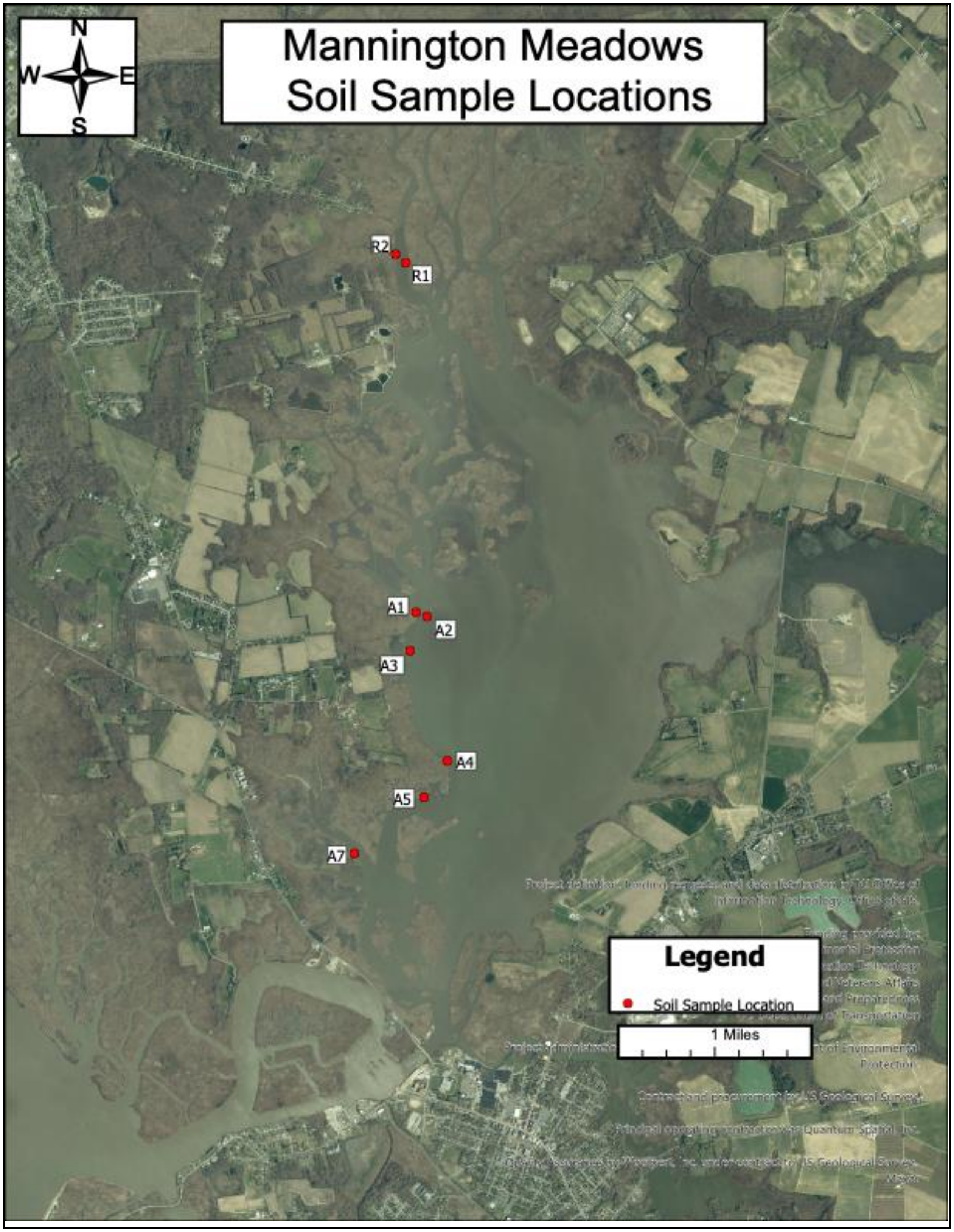


Figure 12. Soil sample locations (NJOGIS).

Table 5. Soil Sample Coordinates.

Sample	Latitude	Longitude
R1	39.63716667	-75.47902
R2	39.6378	-75.48002
A1	39.61088333	-75.47787
A2	39.61056667	-75.47678
A3	39.60798333	-75.47843
A4	39.59971667	-75.47472
A5	39.59696667	-75.47698
A7	39.59271667	-75.48372

Note: R=Ring core sample, A=Auger sample.

4. RESULTS

4.1 Previous Studies of Sediment Transport in Mannington Meadows

Estimating the sediment lost from Mannington Meadows is challenging because few studies have been done on sediment transport in this area. The 1974 study by Mansue and Commings estimated suspended-sediment yields, sediment transport to estuarine areas, particle-size, and sediment-discharge trends in the Delaware Estuary, by sampling sediment daily at four streamflow gaging stations, as well as collecting random samples at three other stations, over a several-year period. The researchers found that suspended sediment yields from streams draining into the Delaware estuary varied considerably from year to year due to precipitation and changes in land use, and it was estimated that an average of 5 to 1,000 tons per square mile, an estimated total of 1.6 million tons, of suspended-sediment are drained from streams into the Delaware Estuary annually (Mansue & Commings, 1974). There is nothing to indicate this estimated total of 1.6 million tons annually has changed significantly over the past 60 years, based on sediment load data at 3 gaged locations from the Delaware, Schuylkill and Brandywine Rivers collected from 1950 to 2010 (Gebert & Searfoss, 2017). Drainage from the Piedmont province in Pennsylvania, New Jersey, and Delaware, in which Mannington Meadows resides, had the greatest effect on sediment yields in the estuarine areas of the basins with average annual yields of 100 to 1,000 tons per square mile (Mansue & Commings, 1974). Another study tracked tidal and subtidal fluctuations in suspended sediment transport in the Upper Delaware Estuary in the spring season, the peak time for sediment delivery (Cook et al., 2006). It was evident that sediments deposited and stored in the upper estuary during low flow periods became a significant source of sediment in the lower estuary during the highest flow periods (Cook et al., 2006).

Significant dredging in the upper Delaware Estuary removed sediment that would have been naturally transported to lower areas of marshland, and these dredged materials were transported and stored in containment areas (Cook et al., 2006). An interagency collaboration, the Delaware Estuary Regional Sediment Management Plan Workgroup, was formed to study and manage sediment in the estuary (Delaware Estuary Regional Sediment Management Plan Workgroup, 2013). Much attention has been focused on sediment transport in the upper Delaware Estuary due to the need for maintaining navigation (Cook et al., 2006). However, little research has been done on sediment transport in the lower Delaware estuary, especially in the tidal marshes and wetlands (Delaware Estuary Regional Sediment Management Plan Workgroup, 2013).

Further study is needed to determine the mechanisms of sediment transport in the lower Delaware Estuary and to more accurately estimate how much sediment has been lost. However, using the 1974 Sediment Report, by Mansue and Commings, a rough estimate of sediment loss from Mannington Meadows could be calculated by using the Salem Creek load of 100 tons/mi^2/yr (Mansue & Commings, 1974), and the drainage area above the Brown Dam of 60 mi^2 (New Jersey Department of Environmental Protection, 1979). It is estimated that the missing sediment from the Salem Creek is approximately 484,000 metric tons over the 89 years after the Brown Dam was constructed. The total volume of sediment lost was calculated by dividing 484,000 metric tons by the bulk density of 1.6 tons/m^3 to get approximately 300,000 m^3 (10,700,000 ft^3) .

4.2 Increase in Open-water Area

The increase in open-water area was estimated by using ArcGIS Pro to compile aerial imagery maps of Mannington Meadows from 1890 to 2024. For each year available, an aerial imagery layer was used to outline the marsh boundary and projected into the New Jersey State

Plane Coordinate system. As the maps indicate, the area of open water in Mannington Meadows has expanded significantly over time (Figure 9). By plotting the open water boundary areas, it is evident that the greatest increases in area of open water in Mannington Meadows occurred between the 1930s and 1970s (Figure 13). Since the 1970s, erosion has slowed.

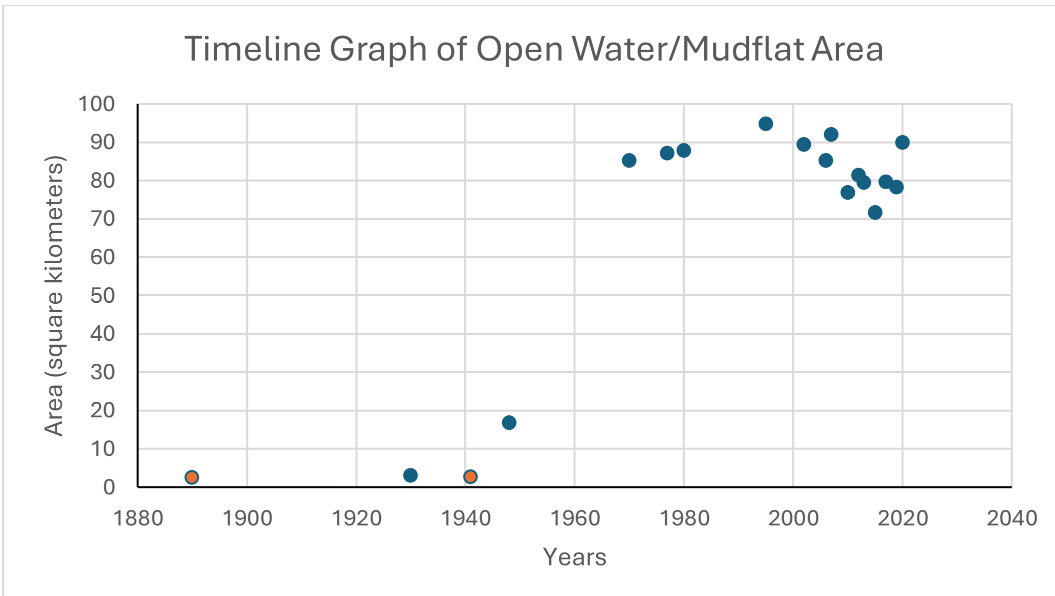


Figure 13. Calculated area (km^2) of open water in Mannington Meadows from 1890-2024. Orange markers are to indicate only the marsh ditching area boundaries for 1890 and 1941. Blue markers indicate the entire marsh boundary area for all the other years. Note that the 1948 topographic map used to trace the marsh boundary had limited quality.

4.3 Ideal Elevation Estimates Using Lidar

Calculations indicate that the total volume of sediment needed to restore the marsh platform to an ideal elevation to sustain native plant species of 1.5 ft is approximately 1,350,000,000 ft^3 (38,100,00 m^3), based on arithmetic mean bathymetry (8.81 ft) of the current open water area.

4.4 Soil Analysis

Average bulk density was calculated to be 1.57 g/cm^3 for the ring core samples and 0.56 g/cm^3 for the auger core samples. Results from the LPSA (Table 6) indicate that soil texture did not vary much from sample to sample. Using the USDA Soil Texture Calculator, R1, A1, A3, A4, A5, and A7 had a silty clay texture, and R2 and A2 had a silty clay loam texture (Figure 14).

Table 6. Average soil content of the samples taken for each location.

Sample	Average Clay %	Average Sand %	Average Silt %
R1	40.7	4.59	54.71
R2	30.25	5.015	64.735
A1	41.7	4.31	53.99
A2	35.85	0.905	63.245
A3	40.8	6.75	52.45
A4	41.6	3.935	54.465
A5	45.4	5.61	48.99
A7	43.85	3.84	52.31

Note: R=Ring core sample, A=Auger core sample.

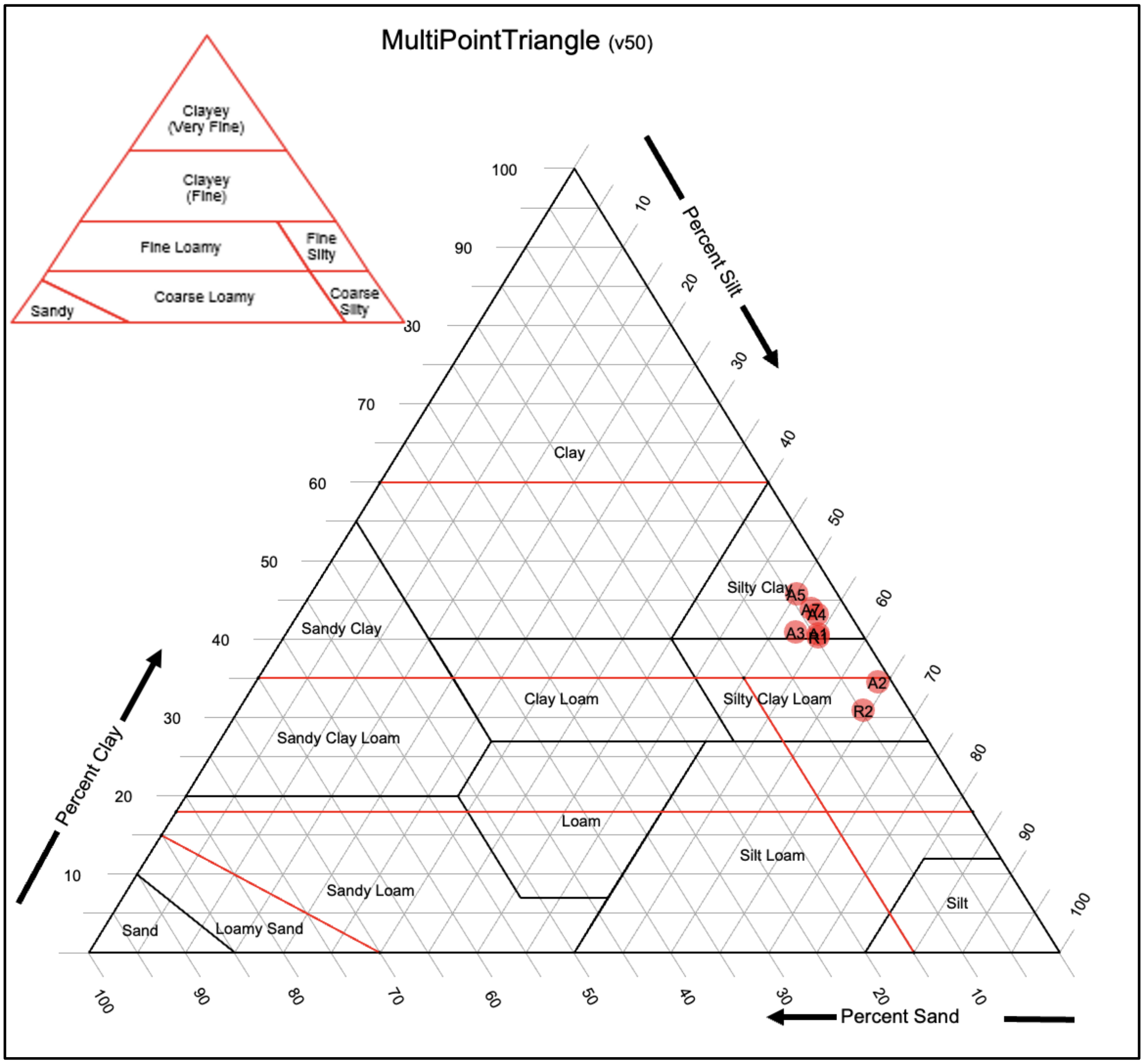


Figure 14. Multi-point Mannington Meadows Soil Triangle (USDA).

Results (Table 7) for the nitrogen and carbon analysis revealed N and C content did not vary much among samples. Nitrogen content ranged from 0.25% to 0.38% with an average of 0.34%. Carbon content ranged from 3.49% to 5.34% with an average of 4.14%.

Table 7. Total Nitrogen and Carbon content for soil samples.

Sample	Nitrogen %	Carbon %
R1	0.35	3.78
R2	0.25	3.51
A1	0.35	3.85
A2	0.37	5.34
A3	0.29	3.49
A4	0.37	4.39
A5	0.38	4.61
A7	0.36	4.17

Note: R=Ring core sample, A=Auger core sample.

5. DISCUSSION

5.1 Possible Restoration Strategies

After assessing of the current state of Mannington Meadows, it is evident that a restoration plan must incorporate ways to restore a great amount of sediment and include methods for retaining that sediment and preventing further erosion. It may be possible to restore lost sediment with sediment that has been dredged to maintain navigation channels. Dredged sediment can be used to help restore the marsh by increasing the sediment supply, improving the marsh platform geomorphology, and preventing shoreline erosion (Weinstein & Weishar, 2002). The dredged material can also help restore intertidal mudflats for foraging avian species (USACE, 2022). However, the process of using dredged sediment is subject to strict regulations, due to the possible presence of contaminants (Delaware Estuary Regional Sediment Management Plan Workgroup, 2013). In addition, the area surrounding Mannington Meadows is held by private landowners, making it difficult to obtain permission for the placement of dredged material (Gebert, 2020). Direct placement of dredged sediment can also be costly (Gailani et al., 2019). Strategic sediment placement can be used as a more cost-effective strategy (Gailani et al., 2019). This process involves placing fine-grained sediment into tidal channels where natural hydrodynamic processes move the sediment to the targeted location (Zapp & Mariotti, 2021). Because of the costs and potential environmental impacts involved in the direct or strategic placement of dredged sediment materials for sediment restoration, more research on these strategies is needed. Using a modeling approach, such as that proposed by Zapp and Mariotti (2021), could be a cost-effective way of evaluating and comparing strategies for restoring sediment to Mannington Meadows. When considering sediment restoration, it is important to have an estimate for how much sediment to restore. Because of the human alterations to the surrounding land and monetary constraints, it is unlikely that full-sediment restoration is possible. Whether full or partial sediment restoration is chosen, the goal should be to restore the marsh platform to a point that makes it more conducive for reestablishing bird habitat. Despite the constraints, direct or strategic placement of dredged sediment are strategies that should be explored.

In addition to restoring sediment, there are some nature-based concepts that can be applied to prevent the erosion of sediment in Mannington Meadows. One potential solution for preventing sediment loss is to reintroduce native plant species such as pickerel weed or wild rice, which can help reduce the erosive effects of tidal currents (Liu et al., 2021). In areas with some available sediment, planting marsh vegetation could trap additional sediments and prevent erosion, as well as promote further root growth, which can also help to retain sediment (Liu et al., 2021). Restoring the marsh platform along with tidal flows can make conditions favorable for native plant species (Chambers et al. 2012). Once established, the plants reduce tidal velocity and allow for longer periods of mineral sediment deposition, which encourages vegetation growth and allows for the accumulation of organic matter (Liu et al., 2021). In addition to trapping sediment, native vegetation provides the added benefit of providing essential bird habitat (Benoit & Askins, 1999). Planting pickerel weed or wild rice is a simple and cost-effective method to help prevent sediment loss and restore bird habitat.

Since the vegetation in Mannington Meadows is dominated by the invasive *Phragmites australis*, it may be necessary to remove or manage Phragmites before reintroducing native vegetation. The spread of Phragmites, which is often associated with marsh disturbance, can have negative impacts on migratory bird and waterfowl populations (Benoit & Askins, 1999). Phragmites grows densely to heights of 3 to 4 m and prevents native vegetation from growing (Windham & Meyerson, 2003; Meyerson et al., 2009). Such tall, dense stands of vegetation may make it difficult for many marsh birds to find prey (Benoit & Askins, 1999). However, Phragmites may provide stability to the marsh by trapping sediment and organic matter (Rooth et al., 2003). This stability is important to protect the marsh from the effects of sea-level rise (Chambers et al., 2012). Phragmites can also store large amounts of carbon in their roots (Chambers et al., 2012). Because of the benefits Phragmites provide, it may be better to control their spread rather than try to eliminate them.

Another erosion control method that can be used to retain sediment is fiber logs (or bio logs). Fiber logs can reduce wave amplitude in tidal marshes as well as keep soil contained (Duhring, 2008). They can be staked into areas of undercut bank where shading prevents marsh vegetation growth (Duhring, 2008). Fiber logs are temporary structures filled with sand that will last about 5 years before needing to be replaced (Duhring, 2008). They can keep soil in place until root systems are developed (Duhring, 2008). Fiber logs can be a temporary and cost-effective way to reduce wave amplitude, protecting the marsh from erosion.

Another possibility for preventing further sediment loss is blocking drainage ditches, which transport sediment out of the marsh and allow for too much variability in water level (Seabloom & Van der Valk, 2003). Creating more water level stability can also enhance vegetational growth, which helps retain sediment (Wiltermuth & Anteau, 2016). Earthen plugs, which function to promote surface storage while still allowing for drainage, can be used to plug ditches that were built to drain land for agricultural use (Jarzemzky et al., 2013). This method is a simple and cost-effective way to keep natural sediment from being washed away.

Cross vanes placed above the ship mooring on the Salem River can also be used as a possible restoration strategy. Cross vanes can be used to stabilize the channel by controlling grade, reducing energy, and correcting stream flow to the middle of the channel (Hickman & Thompson, 2025). This could prevent erosion by deflecting flow away from the river banks allowing for vegetation to take hold (Hickman & Thompson, 2025). One of the downsides of this method is that if the vane arms are placed larger than 30 degrees, additional erosion of the fine-grained sediment could occur immediately downstream of the vane due to the increased scour depth (Hickman & Thompson, 2025). Cross vanes could be an effective strategy for directing more sediment into the marsh.

5.2 Summary of Results

After reviewing historic sediment reports and outlining historic aerial images of the marsh boundary from 1890 to 2024, it is evident that the greatest increase in open water area of the marsh occurred between the 1930s and 1970s. This is largely associated with changes in agricultural use, the diversion of the Salem River, and the Delaware River Channel deepening. Restoring sediment to the marsh is essential for reestablishing bird habitat, which can be achieved by removing some of the Phragmites and replacing with native vegetation. LiDAR data indicates that a marsh elevation of 1.5 ft is most suitable to support non-Phragmites (native vegetation), which can also retain sediment, reduce erosion, and provide better habitat than the Phragmites. It is important to understand when assessing LiDAR data that the light pulses cannot get through dense vegetation when assessing the marsh surface (Medlock, 2020). Elevation can be overestimated between 9 and 25 cm (Medlock, 2020). It is possible that the 1.5 ft ideal marsh elevation is an underestimate, and the estimated volume of sediment (1,340,000,000 ft^3) needed to restore the entire marsh platform is actually greater. LPSA revealed that the soil samples taken were all similar in composition, with almost all being silty-clay. Carbon and nitrogen analyses for the soil samples were also very consistent.

5.3 Implications for Restoration of the Marsh

Finding ways to restore and retain sediment in the marsh is critical for preventing further erosion. Any restoration methods should also consider the effects of sea-level rise. One of the greatest contributors of sediment loss in Mannington Meadows after the agricultural ditching and diking of the late 1800s and early 1900s appears to be the diversion of the Salem River by the Brown and Munson dams. In an ideal situation, the dams could be removed, which would restore the freshwater sediment inputs, allowing Mannington Meadows to return to a more natural state. However, this is not a feasible solution, since the dams are privately owned and functioning. In addition, the creation of the Salem River Channel and the dredging of the Delaware River Channel enhanced tidal flows and increased velocity and sediment transport out of the marsh. Because of the availability of dredged materials from shipping channel maintenance, methods of direct or strategic placement of dredged sediment should be considered. In addition, restoring natural marsh vegetation and blocking drainage ditches can reduce erosion and keep sediment in place.

5.4 Limitations of This Study

One of the greatest limitations of this study was time and the lack of recent data available about sediment transport in Mannington Meadows. Estimating the sediment loss of the marsh was based on the 1974 sediment study and mapping the area of open water. A repeat of the 1974 sediment study would be helpful to see if sediment transport has changed over time, although it would be time-consuming. There was also no recent LiDAR data for Mannington Meadows, which made estimating the marsh elevation platform challenging. Documenting the changes in the area of open water in Mannington Meadows was also difficult due to the limited availability of maps and images. Only topographic maps were available for 1890, 1941, and 1948. Aerial imagery was first available in 1930, but there were large time gaps in imaging from 1930 to the present.

5.5 Recommendations for Further Study

Because of the limited research done on Mannington Meadows, there are several possibilities for further study, which would facilitate a plan for the restoration of the marsh. One recommendation is to perform a bird population assessment to document the birds and waterfowl that use Mannington Meadows as habitat, and to determine if erosion of the marsh has affected populations. Another recommendation would be to acquire higher-quality imagery of Mannington Meadows to trace the marshland boundary. Collecting new LiDAR data by drone to measure more accurate elevations of the marsh platform. A water quality assessment should be performed to detect contaminants that could cause concern. Collecting long-term tidal flow data is also necessary to monitor areas in the marsh that could be more susceptible to erosion. Further study on the methods of direct or strategic placement of sediment and their success and cost-effectiveness is needed. A new sediment transport study could also be conducted, but it would take some time to complete. Finally, further study on marsh vegetation that could be used to retain sediment and provide bird habitat could be beneficial.

6. CONCLUSIONS

Changes in the hydrology of Mannington Meadows due to agricultural use of the region, the diversion of the Salem River, dredging of the Salem Shipping Channel, the deepening of the Delaware River Channel, and the effects of sea-level rise have drastically affected the sediment of the area. It is important to restore lost sediment because it provides ecological vitality to the wetland region (Delaware Estuary Regional Sediment Management Plan Workgroup, 2013). Direct or strategic sediment placement coupled with erosion prevention strategies may be the most beneficial way to restore sediment to Mannington Meadows. However, this process is costly, requires large quantities, and is subject to many regulations. Current regulatory policies for sediment management are inconsistent in considering all stakeholders in the Delaware Estuary, as these policies must balance the needs of sediment management for navigation and commerce with the needs of wetland restoration and ecosystem health (Delaware Estuary Regional Sediment Management Plan Workgroup, 2013). If sediment loss continues in Mannington Meadows, the marshland will continue to deteriorate. Since the health of the marsh is dependent on the surrounding land as well as the use of the Delaware River and Salem River shipping channel, engagement with local landowners and other stakeholders is crucial. It is my hope that this study can serve as a catalyst for further research on Mannington Meadows and the development of a plan for the restoration of this important wetland habitat.

REFERENCES

Benoit, L.K., & Askins, R.A. (1999). Impact of the spread of *Phragmites* on the distribution of birds in Connecticut tidal marshes. *Wetlands,* 19, 194–208 https://doi.org/10.1007/BF03161749

Blood, W. (1918). *Hog Island: The greatest shipyard in the world.* Transactions of the Institute of Naval Architects and Marine Engineers. https://upload.wikimedia.org/wikipedia/commons/7/77/Transactions_-_The_Society_of_Naval_Architects_and_Marine_Engineers_%28IA_transactionssoci2618soci%29.pdf

Boyd Maps. (2020). https://boydsmaps.com/#11.00/39.428886/-75.463664/nj2020/0.00/0.00

Bourn, W. S. & Cottam, C. (1950). *Some biological effects of ditching tidewater marshes*. U.S. Fish and Wildlife Service Research Report 19. Washington, D.C. https://digital.library.unt.edu/ark:/67531/metadc100537/

Chambers, R., Meyerson, L. A., & Dibble, K. L. (2012). Ecology of *Phragmites australis* and responses to tidal restoration. In C. T. Roman & D. M. Burdick (Eds.), *Tidal Marsh Restoration: A Synthesis of Science and Management* (pp. 81-96). Island Press. https://scholarworks.wm.edu/asbookchapters/72

Christiansen, T., Wiberg, P. L., & Milligan, T. G. (2000). Flow and sediment transport on a tidal salt marsh surface, *Estuarine, Coastal and Shelf Science*, *50* (3), 315-331. https://doi.org/10.1006/ecss.2000.0548

Cook, T. L., Sommerfield, C. K., & Wong, K. (2006). Observations of tidal and springtime sediment transport in the upper Delaware Estuary*, Estuarine, Coastal and Shelf Science, 72,* 235-246. http://eclogite.geo.umass.edu/gradstud/cook/Cook_et_al_2007.pdf

Costanza, R., d'Arge, R., de Groot, R., Farber, S., Grasso, M., Hannon, B., Limburg, K., Naeem, S., O'Neill, R. V., Paruelo, J., Raskin, R. G., Sutton, P., & van den Belt, M. (1997). The value of the world's ecosystem services and natural capital. *Nature, 387*(6630), 253–260. https://doi.org/10.1038/387253a0

Costanza, R., Perez-Maqueo, O., Martinez, M. L., Sutton, P., Anderson, S. J., & Mulder, K. (2008). The value of coastal wetlands for hurricane protection. *Ambio*, 37(4), 241–248. 10.1579/0044-7447(2008)37[241:tvocwf]2.0.co;2

D'Alpaos, A., Da Lio, C., & Marani, M. (2012). Biogeomorphology of tidal landforms: Physical and biological processes shaping the tidal landscape. *Ecohydrology, 5,* 550-562. https://doi.org/10.1002/eco.279

Dame, R. F., Spurrier, J. D., Williams, T. M., Kjerfve, B., Zingmark, R. G., Wolaver, T. G., Chrzanowski, T. H., McKellar, H. N., & Vernberg, F. J. (1991). Annual material processing by a salt marsh-estuarine basin in South Carolina, USA. *Marine Ecology-progress Series*, *72,* 153-166. https://www.researchgate.net/publication/250214956_Annual_Material_Processing_by_a_Salt_Marsh-Estuarine_Basin_in_South_Carolina_USA

Deegan, L. A., Johnson, D. S., Warren, R. S., Peterson, B. J., Fleeger, J. W., Fagherazzi, S., & Wollheim, W. M. (2012). Coastal eutrophication as a driver of salt marsh loss. *Nature, 490*, 388–392. https://doi.org/10.1038/nature11533

Delaware Estuary Regional Sediment Management Plan Workgroup. (2013). *Delaware Estuary* *regional sediment management plan.* https://www.nj.gov/drbc/library/documents/RSMPaug2013final-report.pdf

Delaware Valley Regional Planning Commission. (2004). *Sea Level Rise in the Delaware Estuary.* https://www.dvrpc.org/reports/04037.pdf

Donatelli, C., Ganju, N. K., Zhang, X., Fagherazzi, S., & Leonardi, N. (2018). Salt marsh loss affects tides and the sediment budget in shallow bays. *Journal of Geophysical Research: Earth Surface*, *123*, 2647–2662. https://doi.org/10.1029/2018JF004617

Duhring, K. (2008). Overview of living shoreline design options for erosion protection on tidal shorelines (2008). In S. Y. Erdle, J. L. D. Davis, & K. G. Sellner (Eds.) *Management policy, science, and engineering of nonstructural erosion control in the Chesapeake Bay.* Chesapeake Research Consortium. https://scholarworks.wm.edu/vimsbooks/126

eBird. (2025). https://ebird.org/hotspot/L2066936

Feagin, R. A., Lozada-Bernard, S. M., Ravens, T. M., Möller, I., Yeager, K. M. & Baird, A. H. (2009). Does vegetation prevent wave erosion of salt marsh edges? *Proceedings of the National Academy of Sciences, 106* (25). https://www.pnas.org/doi/10.1073/pnas.0901297106

Foster, N. M., Hudson, M. D., Bray, S., & Nicholls, R. J. (2013). Intertidal mudflat and salt marsh conservation and sustainable use in the UK: A review. *Journal of Environmental Management, 126,* 96-104. https://doi.org/10.1016/j.jenvman.2013.04.015

Gailani, J. Z., Brutsche, K. E., Godsey, E. S., Wang, P., & Hartman, M. A. (2019). Strategic placement for beneficial use of dredged material. Report. *Coastal and Hydraulics Laboratory (U.S. Army Corp of Engineers).* https://apps.dtic.mil/sti/pdfs/AD1075332.pdf

Ganju, N. K., Nidzieko, N. J., & Kirwan, M. L. (2013). Inferring tidal wetland stability from channel sediment fluxes: Observations and a conceptual model. *Journal of Geophysical Research: Earth Surface*, *118*, 2045–2058. https://doi.org/10.1002/jgrf.20143

Gebert, J. A. (2020). *Introductory/Background information on sediments, sediment transport, and dredging in the vicinity of the Salem River, NJ navigation project* [White Paper]. U. S Army Corps of Engineers, Philadelphia District.

Gebert, J. A., & Searfoss, R. (2017). Sediments. In P. Cole, A. Padeletti, & D. Kreeger (Eds.) *Technical report for the Delaware Estuary and Basin.* (pp.146-159). Partnership for the Delaware Estuary. https://www.delawareestuary.org/wp-content/uploads/2018/01/Chp4-sediment.pdf

Hickman, E. L. & Thompson, T. M. (2025). *Stream restoration series cross vane*. https://cbtrust.org/wp-content/uploads/Cross-Vane-Fact-Sheet.pdf.

Jarzemsky, R. D., Burchell, M. R., & Evans, R. O. (2013). The impact of manipulating surface topography on the hydrologic restoration of a forested coastal wetland, Eco*logical Engineering, 58,* 35-43. https://doi.org/10.1016/j.ecoleng.2013.06.002

Lathrop, R., Cole, M. & Showalter, R. (2000). Quantifying the habitat structure and spatial pattern of New Jersey (U.S.A.) salt marshes under different management regimes. *Wetlands Ecology and Management, 8*, 163–172. https://doi.org/10.1023/A:1008492418788

Liu, Z., Fagherazzi, S., & Cui, B. (2021). Success of coastal wetlands restoration is driven by sediment availability. *Communications Earth & Environment, 2* (44). https://doi.org/10.1038/s43247-021-00117-7

Mansue, L. J., & Commings, A. B. (1974). *Sediment transport by streams draining into the*

Delaware Estuary: Hydrologic effects of land use. United States Department of the Interior Geological Survey. https://pubs.usgs.gov/wsp/1532h/report.pdf

Marani, M., D'Alpaos, A., Lanzoni, S., & Santalucia, M. (2011). Understanding and predicting wave erosion of marsh edges, *Geophysical Research Letters*, *38*. doi:10.1029/2011GL048995.

Mariotti, G., & Fagherazzi, S. (2010). A numerical model for the coupled long-term evolution of salt marshes and tidal flats, *Journal of Geophysical Research*, *115*. doi:10.1029/2009JF001326.

Medlock, C. (2020). *LiDAR Accuracy in Delaware's Salt Marshes*. https://wmap.blogs.delaware.gov/2020/03/06/lidar-accuracy-in-delawares-salt-marshes/

Meyerson, L., Saltonstall, K., & Chambers, R. (2009). Phragmites australis in Eastern North America: A historical and ecological perspective. In B. Silliman, M. Bertness & E. Grosholz (Eds.), Human Impacts on Salt Marshes: A Global Perspective (pp. 57-82). Berkeley: University of California Press. https://doi.org/10.1525/9780520943759-006

McMullon, C. (2008). The importance of salt marshes for biodiversity. In A. Inder, & K. Ansell (Eds.), *What future for the Solent's Saltmarshes?* Solent Protection Society, Beaulieu.

New Jersey Audubon. (2024). *Mannington Meadows*. https://njaudubon.org/wpcontent/ibba/www.njaudubon.org/SectionIBBA/IBBASiteGuide5108.html?sk=2962

New Jersey Climate Change Resource Center, Rutgers University. (2020, May). *Sea level rise in New Jersey: Projections and impacts.* https://njclimateresourcecenter.rutgers.edu/climate_change_101/sea-level-rise-in-new-jersey-projections-and-impacts/#:~:text=In%20addition%20to%20flooding%2C%20sea,disaster%20preparedness%2C%20and%20climate%20adaptation.

New Jersey Conservation Foundation. (2024). *Mannington Meadows Greenway.* https://www.njconservation.org/project/mannington-meadows-greenway/

New Jersey Department of Environmental Protection. (1979). *Brown Dam Phase I inspection report, National Dam Safety Program.* https://apps.dtic.mil/sti/tr/pdf/ADA068644.pdf

New Jersey Office of Information Technology. *New Jersey early 1930's aerial photography* [ArcGIS map]. Retrieved May 14, 2025, from newjersey.maps.arcgis.com/home/item.html?id=4e7de8d868

New Jersey Office of Information Technology. *New Jersey 1970 Wetlands Imagery* [ArcGIS map]. Retrieved May 14, 2025, 2025, from newjersey.maps.arcgis.com/home/item.html?id=

New Jersey Office of Information Technology. *New Jersey 1977 Tidelands Imagery* [ArcGIS map]. Retrieved May 14, 2025, from newjersey.maps.arcgis.com/home/item.html?id=

New Jersey Office of Information Technology. *New Jersey 2002 high resolution color infrared orthophotography* [ArcGIS map]. Retrieved May 14, 2025, from newjersey.maps.arcgis.com/home/item.html?id=fb3b62a2

New Jersey Office of Information Technology. *New Jersey 2006 Natural Color Imagery* [ArcGIS map]. Retrieved May 14, 2025, from newjersey.maps.arcgis.com/home/item.html?id=

New Jersey Office of Information Technology. *Office of Geographic Information Systems*

(OGIS) New Jersey 2007 - 2008 High Resolution Orthophotography, Natural Color Web Map Service (WMS) [ArcGIS map]. Retrieved May 14, 2025, from newjersey.maps.arcgis.com/home/item.html?id=1149a594

New Jersey Office of Information Technology. *New Jersey 2010 Natural Color Imagery* [ArcGIS map]. Retrieved May 14, 2025, from newjersey.maps.arcgis.com/home/item.html?id=

New Jersey Office of Information Technology. *New Jersey 2012 - 2013 High Resolution Orthophotography, Natural Color Web Map Service (WMS)* [ArcGIS map]. Retrieved May 14, 2025, from newjersey.maps.arcgis.com/home/item.html?id=153e2820ad454ffcbfddd9fda4ec3d7e

New Jersey Office of Information Technology. *New Jersey 2013 National Agricultural Imagery Program (NAIP) Orthophotography, Web Map Service (WMS)* [ArcGIS map]. Retrieved May 14, 2025, from https://njgin.nj.gov/njgin/edata/imagery

New Jersey Office of Information Technology. *New Jersey 2015 High Resolution Orthophotography, Natural Color Web Map Service (WMS)* [ArcGIS map]. Retrieved May 14, 2025, from https://njgin.nj.gov/njgin/edata/imagery

New Jersey Office of Information Technology. *NJ 2017 Natural Color Imagery* [ArcGIS map]. Retrieved May 14, 2025, from newjersey.maps.arcgis.com/home/item.html?id=

New Jersey Office of Information Technology. *New Jersey 2019 National Agricultural Imagery Program (NAIP) Orthophotography, Web Map Service (WMS)* [ArcGIS map]. Retrieved May 14, 2025, from https://njgin.nj.gov/njgin/edata/imagery/index.html#!/

New Jersey Office of Information Technology. *New Jersey 2020 High Resolution Orthophotography, Natural Color Web Map Service (WMS)* [ArcGIS map]. Retrieved May 14, 2025, from https://njgin.nj.gov/njgin/edata/imagery

New Jersey USGS. *1995-97 Digital Orthophoto Quadrangles (color infrared)* [ArcGIS map]. Retrieved May 14, 2025, from newjersey.maps.arcgis.com/home/item.html?id=

National Oceanic and Atmospheric Administration. (2025). *Relative sea level trends.* https://tidesandcurrents.noaa.gov/sltrends/

Pareja-Roman, L. F., Chant, R. J., & Sommerfield, C. K. (2020). Impact of historical channel deepening on tidal hydraulics in the Delaware Estuary. *Journal of Geophysical Research: Oceans*, *125*, e2020JC016256. https://doi.org/10.1029/2020JC016256

Powell, E. B., Krause, J. R., Martin, R. M., & Watson, E. B. (2020). Pond excavation reduces coastal wetland carbon dioxide assimilation. *Journal of Geophysical Research: Biogeosciences*, *12* (8). https://doi.org/10.1029/2019JG005187

Rodríguez, J. F., Saco, P. M, Sandi, S., Saintilan, N., & Riccardi, G. (2017). Potential increase in coastal wetland vulnerability to sea-level rise suggested by considering hydrodynamic attenuation effects. *Nature Communications*, *8* (16094). https://doi.org/10.1038/ncomms16094

Rooth, J. E., Stevenson, J. C., & Cornwell, J. C. (2003). Increased sediment accretion rates following Invasion by *Phragmites australis*: The role of litter. *Estuaries, 26*, 475–483. https://www.jstor.org/stable/1353362

Seabloom, E. W. & Van der Valk A. G. (2003). Plant diversity, composition, and invasion of restored and natural prairie pothole wetlands: Implications for restoration. *Wetlands, 23* (1) 1-12. https://link.springer.com/content/pdf/10.1672/0277-5212(2003)023%5B0001%3APDCAIO%5D2.0.CO%3B2.pdf

Sebold, K. (1992). *From marsh to farm, the landscape transformation of coastal New Jersey*. U.S. Department of the Interior, National Park Service, Historic American Buildings Survey/Historic American Engineering Record, Washington, D.C. https://www.nps.gov/parkhistory/online_books/nj3/index.htm

Spitz, F. J., & DePaul, V. T. (2023). Simulation of flow and eutrophication in the central Salem River, New Jersey. *U.S. Geological Survey Scientific Investigations Report 2022–5047*. https://pubs.usgs.gov/sir/2022/5047/sir20225047.pdf

Terzaghi, K., Peck, R. B., & Mesri, G. (1996). *Soil Mechanics in Engineering Practice (3rd ed.)*. Wiley-Interscience. https://cequcest.wordpress.com/wp-content/uploads/2015/09/terzaghi129883967-soil-mechanics-in-engineering-practice-3rd-edition-karl-terzaghi-ralph-b-peck-gholamreza-mesri-1996.pdf

United States Army Corps of Engineers. (1979). Phase 1 inspection report National Dam Safety Program. https://apps.dtic.mil/sti/tr/pdf/ADA068644.pdf

United States Army Corps of Engineers. (2020). *Distribution of Mannington Meadows Depth*. [White Paper].

United States Army Corps of Engineers. (2022). *Dredged Management Plan*. DMMP_PreliminaryAssessment_DPS_2022

United States Army Corps of Engineers. (2024). *Environmental assessment, Salem River federal navigation channel maintenance dredging and beneficial use of dredged material, Salem*

County, New Jersey, New Castle County, Delaware. https://hdl.handle.net/11681/49598

United States Army Corps of Engineers (2024, June 27). Army Corps shares update on Salem River dredging. https://www.nap.usace.army.mil/Media/News-Releases/Article/3820119/army-corps-shares-update-on-salem-river-dredging/

United States Department of Agriculture Farm Production and Conservation Business Center. (2025). *1980-1989 New York NHAP color infrared aerial imagery* [ArcGIS map]. Retrieved May 14, 2025, from apfo-usdaonline.opendata.arcgis.com/maps/c2aafa2

United States Department of Agriculture. (2025). *Soil texture calculator*. https://www.nrcs.usda.gov/resources/education-and-teaching-materials/soil-texture calculator

United States Geological Survey. (2025). 1948 Salem, NJ Topographic Map. https://ngmdb.usgs.gov/topoview/viewer/#14/39.6002/-75.4565

Weinstein, M.P., & Weishar, L. (2002). Beneficial use of dredged material to enhance the restoration trajectories of formerly diked lands. *Ecological Engineering*, *19* (3), 187-201. https://doi.org/10.1016/S0925-8574(02)00077-0.

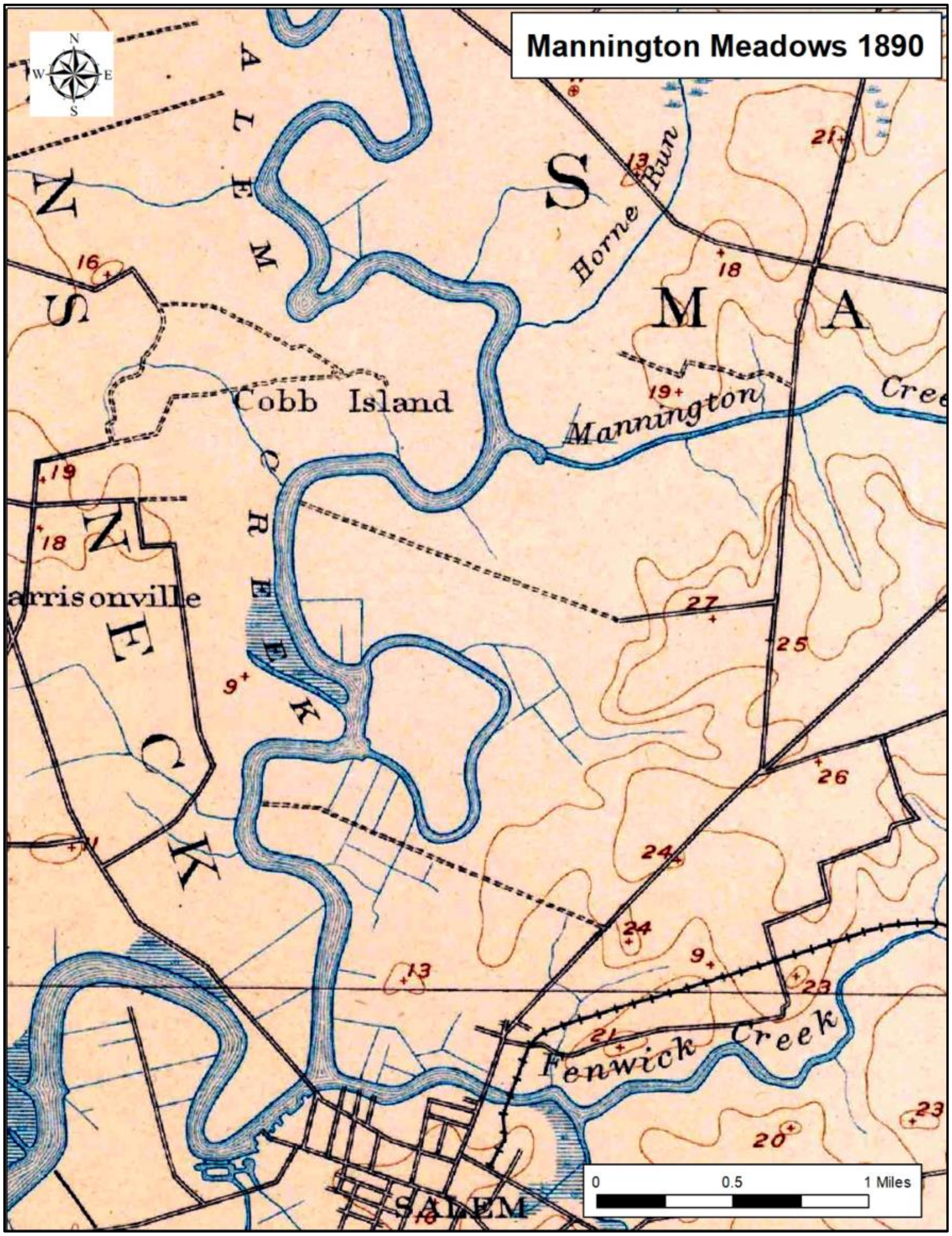
Windham, L. & Meyerson, L. A. (2003). Effects of common reed (*Phragmites australis*) expansions on nitrogen dynamics of tidal marshes of the northeastern U.S., *Estuaries, 26,* 452-464. https://www.jstor.org/stable/1353360

Wiltermuth, M.T., & Anteau, M. J. (2016). Is consolidation drainage an indirect mechanism for Increased abundance of cattail in northern prairie wetlands? *Wetlands Ecology Management, 24*, 533–544. https://doi.org/10.1007/s11273-016-9485-z

Zapp, S. M. & Mariotti, G. (2021). Evaluating direct and strategic placement of dredged material for marsh restoration through model simulations. *Shore & Beach*, *89*(4), 33-40. https://www.researchgate.net/publication/355962311_Evaluating_direct_and_strategic_placement_of_dredged_material_for_marsh_restoration_through_model_simulations

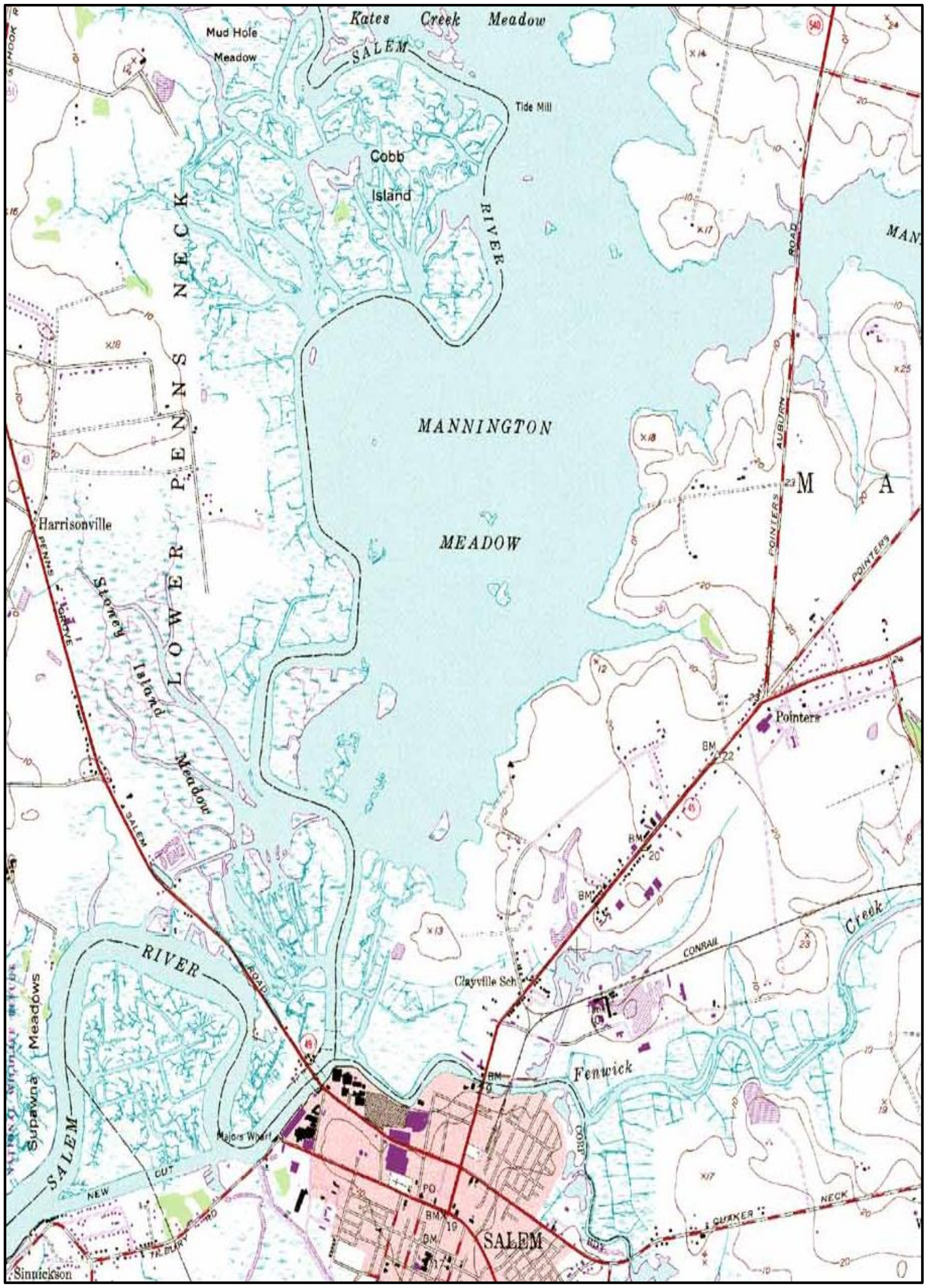
APPENDIX

Topographic map of Mannington Meadows 1839 (NJOGIS).



Topographic map of Mannington Meadows 1890 (NJOGIS).

Aerial image of Mannington Meadows 1930 (NJOGIS).



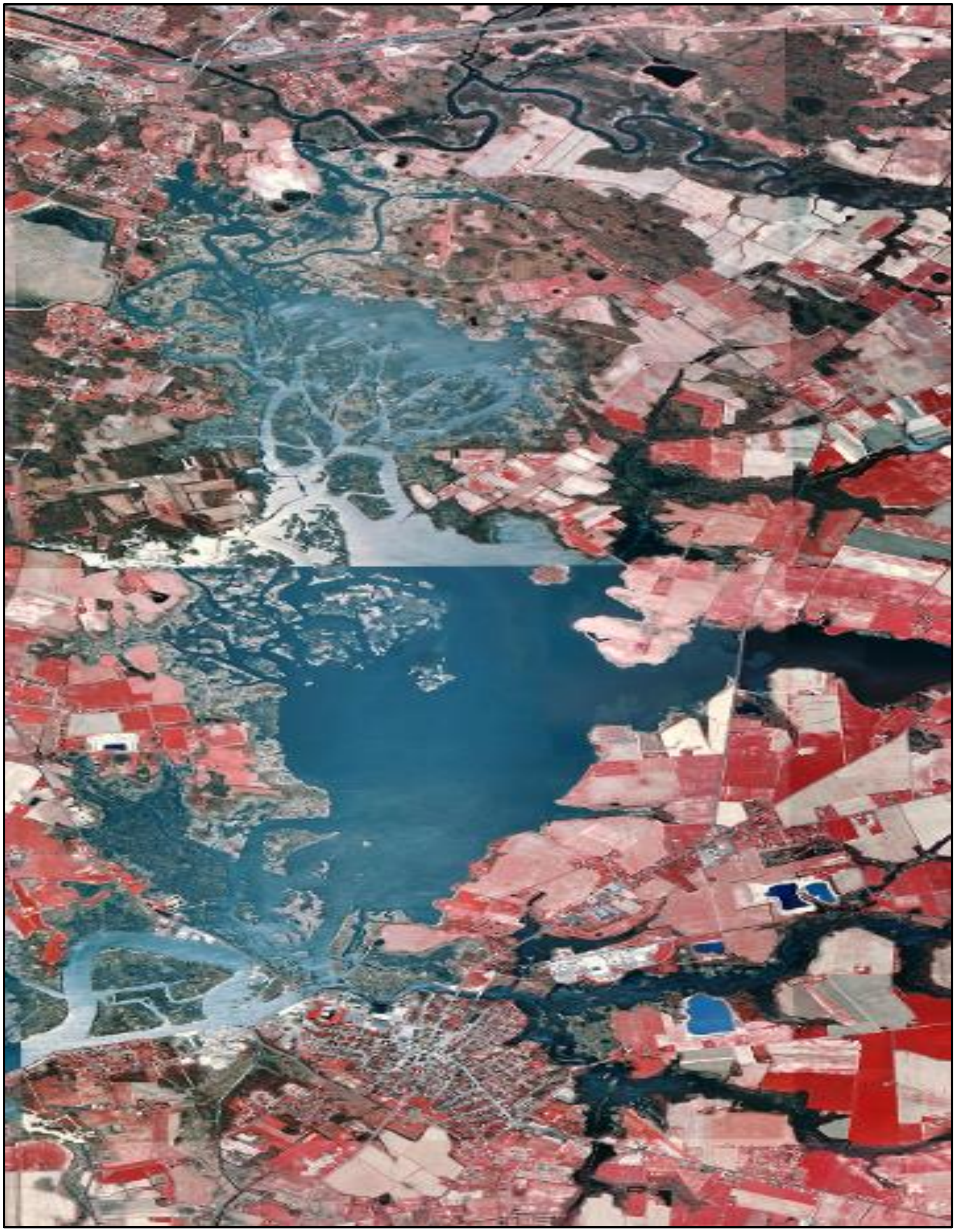
Topographic map of Mannington Meadows 1948 (USGS).

A

Aerial image of Mannington Meadows 1970 (NJOGIS).

Aerial Image of Mannington Meadows 1977 (NJOGIS).

Aerial image of Mannington Meadows 1980 (NJOGIS).



Aerial image of Mannington Meadows 1995 (NJOGIS).

Aerial image of Mannington Meadows 2002 (NJOGIS).

Aerial image of Mannington Meadows 2006 (NJOGIS).

Aerial image of Mannington Meadows 2007 (NJOGIS).

Aerial image of Mannington Meadows 2010 (NJOGIS).

Aerial image of Mannington Meadows 2012 (NJOGIS).

Aerial image of Mannington Meadows 2013 (NJOGIS).

Aerial image of Mannington Meadows 2015 (NJOGIS).

Aerial image of Mannington Meadows 2019 (NJOGIS).

Aerial image of Mannington Meadows 2020 (NJOGIS).

Aerial image of Mannington Meadows 2021 (Google Earth).

Aerial image of Mannington Meadows 2022 (Google Earth).

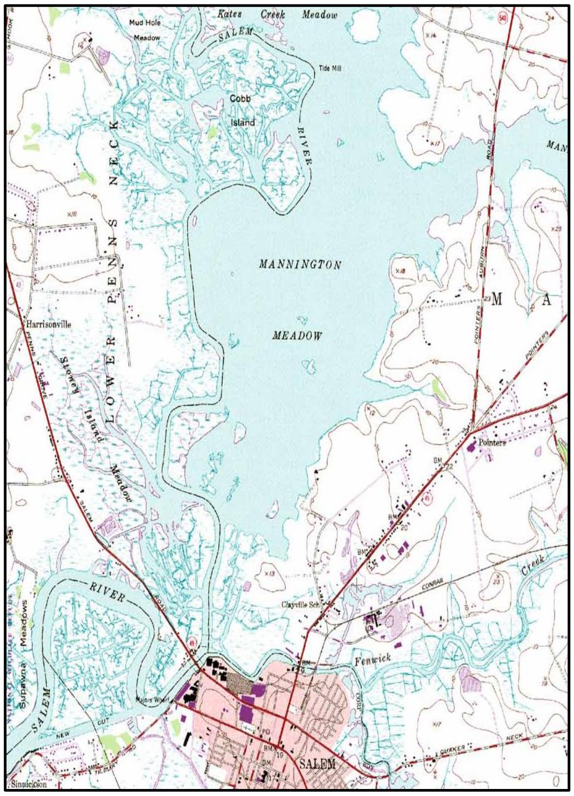
Aerial image of Mannington Meadows 2024 (Google Earth).

Mannington Meadows Fact Sheet

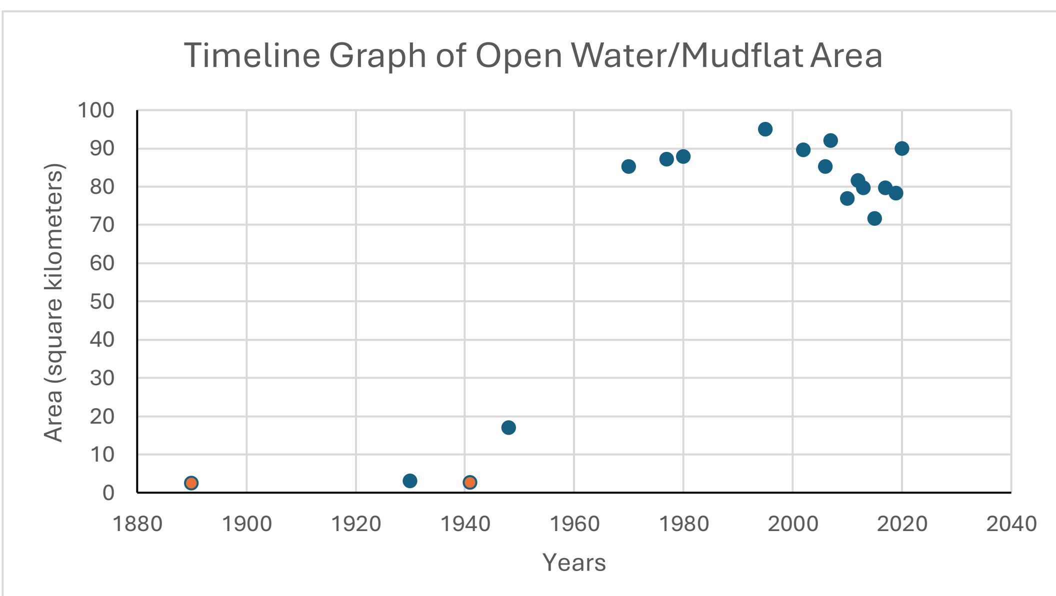
Prior to 1925, Mannington Meadows was a freshwater marsh approximately 6,000 acres in size and fed by the Salem River. Over 128 migratory birds/waterfowl species have been sighted in Mannington Meadows (ebird).

Aerial and Satellite photography show that the marsh eroded rapidly into open water/mudflats beginning around 1930 and continuing through 1970. The marsh has continued to erode since then but at a much lower rate. Between approximately 1970 and 1980, *Phragmites australis* invaded Mannington Meadows and now dominates the vegetation. Since the initial dredging, the total volume of sediment dredged is unspecified. Phragmites holds marsh sediments well, and Phragmites establishment may partly explain the slower erosion rate post-1970.

1930 Aerial Map. Lower marsh erosion begins to occur.



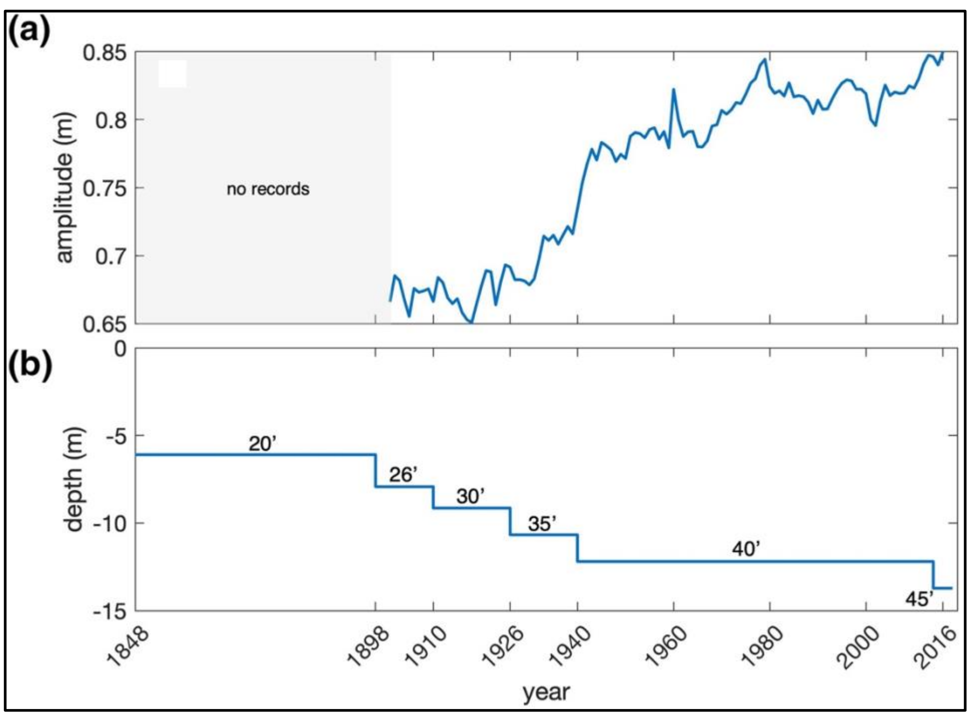
Left: 1948 USGS Map. Mannington Meadows is now all open-water. Right: Recent aerial view of Mannington Meadows (2020).



Calculated area (km^2) of open water in Mannington Meadows from 1890-2020. Orange markers are to indicate only the marsh ditching area boundaries for 1890 and 1941. Blue markers indicate the entire marsh boundary area for all the other years.

We identified five potential causes of the erosion of Mannington Meadows: 1) In the late 1800s and early 1900s, much of the marsh was diked and drained for agricultural use, which blocked the tidal flow; 2) In 1925, the USACE dredged the Salem Shipping Channel, increasing tidal velocities and amplitudes in the marsh; 3) In 1935, the Brown and Munson Dams were constructed on the Salem River, diverting all of the freshwater flows and river sediments from MM; 4) Sequential deepening of the Delaware River Channel and dredging of the Salem Shipping Channel to allow navigation for larger ships has increased tidal amplitudes in the Delaware estuary; and 5) Ongoing sea-level rise has exacerbated erosion in the marsh.

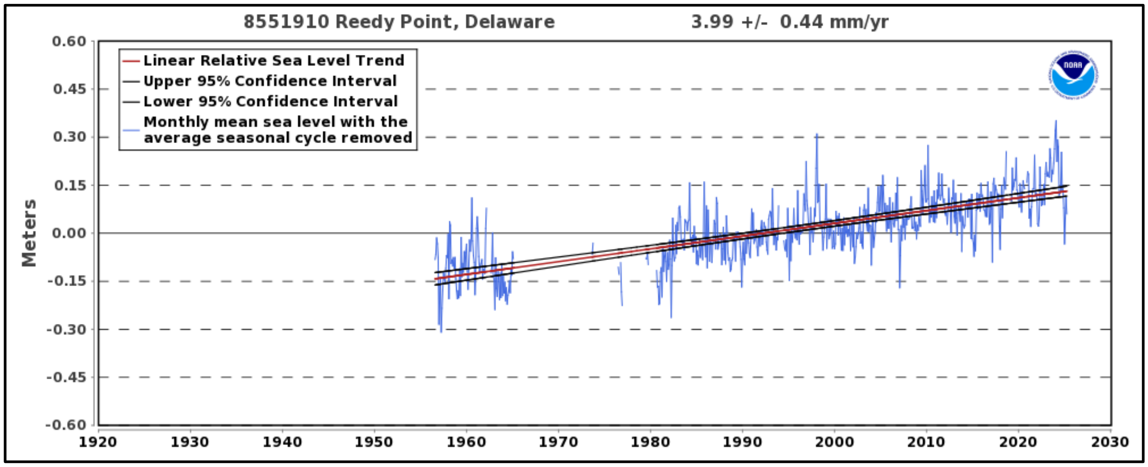
Aerial view of the Salem Shipping Canal (Google Earth, 2024).



Timeline of Delaware River Channel depth increases. (a) Yearly averaged tidal elevation amplitude in Philadelphia from historical records, NOAA stations 8545530 and 8545240, and (b) shipping channel depth over time.

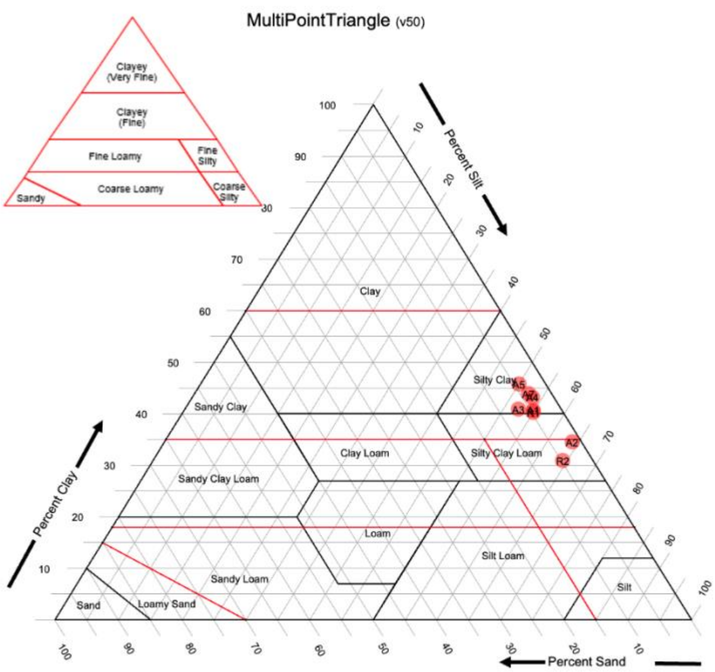
(Pareja-Roman et al., 2020)

Sea level in the Delaware estuary has risen by 30 cm or 1 ft over the past century. The majority of coastal wetlands in the Delaware Estuary are less than a meter above sea level.



Reedy Point, Delaware, relative sea-level trend timeline. (NOAA, 2025)

The Reedy Point, Delaware tidal gauge, located across from Mannington Meadows, shows a local relative sea level trend of 3.99 mm/yr, based on monthly sea-level data collected from 1956 to 2024 (NOAA, 2025). This data represents a change of 399 mm or (1.31 ft) in 100 years.



Sediment samples were taken from different locations representing the various areas of the marsh (16 total). All samples were silty clay and silty clay loam in texture. Carbon content ranged from 3.49% to 5.34% with an average of 4.14%.

Sediment volume estimation and number

The volume of sediment needed to bring Mannington Meadows marsh elevations to 1.5 feet above sea-level across the entire marsh area would be approximately 38,100,000 m^3. This compares to average dredging volumes in the local area of 32,900 m^3/yr.

Next Steps

An incoming hydrodynamics graduate student will take over the project to model tidal flow velocities around Mannington Meadows. The goal is to produce post-project tidal velocities that won't erode the sediment placed back into the marsh.

Mannington Meadows Restoration Design Trade-offs

Restoration Method	Pros	Cons
Widespread Sediment Placement	Can use sediment that has already been dredged, helps restore marsh platform and marsh habitat for avian species.	Costly, subject to environmental regulations, requires coordination with private landowners for placement.
Strategic Sediment Placement	Cost-effective, natural processes move sediment to target location.	Requires more research (modeling).
Control/Remove Phragmites (non-native vegetation)	Phragmites is invasive and provides poor avian habitat, removal would allow for restoration of native plants and provide better bird habitat.	Phragmites holds sediment well and is effective in minimizing erosion and it stores a large amount of carbon.
Restore Native Vegetation (Pickerel Weed and Wild Rice)	Effective in trapping sediment, prevents erosion, promote root growth, provides essential bird habitat, reduce tidal velocity, cost-effective.	Not as effective as phragmites in holding marsh sediments.
Removing Brown Dam	Restore sediment and freshwater inflows.	Need permission of the property owner to remove dam, currently used for industrial water supply.
Install cross vane above shipping mooring	Stabilize the river channel by correcting flow, prevents erosion.	Could cause local erosion where flows are redirected.

Mannington Meadows Rt. 540 Bridge Bird Species List 1992-2025 (eBird, 2025)

1. **Osprey** *Pandion haliaetus*
2. **Great Egret** *Ardea alba*
3. **Red-winged Blackbird** *Agelaius phoeniceus*
4. **Mute Swan** *Cygnus olor*
5. **Mourning Dove** *Zenaida macroura*
6. **Semipalmated Plover** *Charadrius semipalmatus*
7. **Double-crested Cormorant** *Nannopterum auritum*
8. **Glossy Ibis** *Plegadis falcinellus*
9. **Great Blue Heron** *Ardea herodias*
10. **Turkey Vulture** *Cathartes aura*
11. **Bald Eagle** *Haliaeetus leucocephalus*
12. **Red-tailed Hawk** *Buteo jamaicensis*
13. **American Kestrel** *Falco sparverius*
14. **Fish Crow** *Corvus ossifragus*
15. **Tree Swallow** *Tachycineta bicolor*
16. **Common Yellowthroat** *Geothlypis trichas*
17. **Yellow Warbler** *Setophaga petechia*
18. **Snow Goose** *Anser caerulescens*
19. **Carolina Chickadee** *Poecile carolinensis*
20. **Common Grackle** *Quiscalus quiscula*
21. **American Black Duck** *Anas rubripes*

22. **Northern Harrier** *Circus hudsonius*

23. **Sandhill Crane** *Antigone canadensis*

24. **American Robin** *Turdus migratorius*

25. **Song Sparrow** *Melospiza melodia*

26. **Swamp Sparrow** *Melospiza georgiana*

27. **Sharp-shinned Hawk** *Accipiter striatus*

28. **Belted Kingfisher** *Megaceryle alcyon*

29. **American Crow** *Corvus brachyrhynchos*

30. **Carolina Wren** *Thryothorus ludovicianus*

31. **Savannah Sparrow** *Passerculus sandwichensis*

32. **Canada Goose** *Branta canadensis*

33. **Gadwall** *Mareca strepera*

34. **Mallard** *Anas platyrhynchos*

35. **Northern Pintail** *Anas acuta*

36. **Ring-billed Gull** *Larus delawarensis*

37. **European Starling** *Sturnus vulgaris*

38. **Brown-headed Cowbird** *Molothrus ater*

39. **Black Vulture** *Coragyps atratus*

40. **Northern Mockingbird** *Mimus polyglottos*

41. **Northern Shoveler** *Spatula clypeata*

42. **American Coot** *Fulica americana*

43. **Tundra Swan** *Cygnus columbianus*

44. **Semipalmated Sandpiper** *Calidris pusilla*

45. **Caspian Tern** *Hydroprogne caspia*

46. **Little Blue Heron** *Egretta caerulea*

47. **Snowy Egret** *Egretta thula*

48. **Eastern Wood-Pewee** *Contopus virens*

49. **Lesser Yellowlegs** *Tringa flavipes*

50. **Forster's Tern** *Sterna forsteri*

51. **Marsh Wren** *Cistothorus palustris*

52. **Greater Yellowlegs** *Tringa melanoleuca*

53. **Field Sparrow** *Spizella pusilla*

54. **Green-winged Teal** *Anas crecca*

55. **Killdeer** *Charadrius vociferus*

56. **Dunlin** *Calidris alpina*

57. **Laughing Gull** *Leucophaeus atricilla*

58. **Eastern Phoebe** *Sayornis phoebe*

59. **Barn Swallow** *Hirundo rustica*

60. **White-throated Sparrow** *Zonotrichia albicollis*

61. **Blue-winged Teal** *Spatula discors*

62. **American Herring Gull** *Larus smithsonianus*

63. **Red-bellied Woodpecker** *Melanerpes carolinus*

64. **Northern Rough-winged Swallow** *Stelgidopteryx serripennis*

65. **Common Merganser** *Mergus merganser*

66. **Wilson's Snipe** *Gallinago delicata*

67. **Ruby-crowned Kinglet** *Corthylio calendula*

68. **Northern Cardinal** *Cardinalis cardinalis*

69. **Great Black-backed Gull** *Larus marinus*

70. **Northern Flicker** *Colaptes auratus*

71. **Pied-billed Grebe** *Podilymbus podiceps*

72. **Ruddy Duck** *Oxyura jamaicensis*

73. **Least Sandpiper** *Calidris minutilla*

74. **Ruby-throated Hummingbird** *Archilochus colubris*

75. **Pectoral Sandpiper** *Calidris melanotos*

76. **Gray Catbird***Dumetella carolinensis*

77. **Indigo Bunting** *Passerina cyanea*

78. **Chimney Swift** *Chaetura pelagica*

79. **Rock Pigeon** *Columba livia*

80. **Golden-crowned Kinglet** *Regulus satrapa*

81. **Cackling Goose** *Branta hutchinsii*

82. **Yellow-rumped Warbler** *Setophaga coronata*

83. **Blue Jay** *Cyanocitta cristata*

84. **American Wigeon** *Mareca americana*

85. **Brown Creeper** *Certhia americana*

86. **Greater White-fronted Goose** *Anser albifrons*

87. **Tufted Titmouse** *Baeolophus bicolor*

88. **Horned Lark** *Eremophila alpestris*

89. **Peregrine Falcon** *Falco peregrinus*

90. **Ring-necked Duck** *Aythya collaris*

91. **Wood Duck** *Aix sponsa*
92. **Canvasback** *Aythya valisineria*
93. **American Goldfinch** *Spinus tristis*
94. **Bank Swallow** *Riparia riparia*
95. **Cedar Waxwing** *Bombycilla cedrorum*
96. **House Sparrow** *Passer domesticus*
97. **House Finch** *Haemorhous mexicanus*
98. **Bufflehead** *Bucephala albeola*
99. **Black-bellied Plover** *Pluvialis squatarola*
100. **Western Cattle-Egret** *Ardea ibis*
101. **Downy Woodpecker** *Dryobates pubescens*
102. **Northern House Wren** *Troglodytes aedon*
103. **American Redstart** *Setophaga ruticilla*
104. **Palm Warbler** *Setophaga palmarum*
105. **Redhead** *Aythya americana*
106. **Lesser Scaup** *Aythya affinis*
107. **Greater Scaup** *Aythya marila*
108. **Eastern Bluebird** *Sialia sialis*
109. **Hooded Merganser** *Lophodytes cucullatus*
110. **Bonaparte's** *Chroicocephalus philadelphia*
111. **Brown Thrasher** *Toxostoma rufum*
112. **Cooper's Hawk** *Astur cooperii*
113. **Common Gallinule** *Gallinula galeata*

114. **Warbling Vireo** *Vireo gilvus*

115. **White-rumped Sandpiper** *Calidris fuscicollis*

116. **Eastern Kingbird** Tyrannus tyrannus

117. **White-breasted Nuthatch** *Sitta carolinensis*

118. **Dark-eyed Junco** *Junco hyemalis*

119. **Common Goldeneye** *Bucephala clangula*

120. **American White Pelican** *Pelecanus erythrorhynchos*

121. **Red-breasted Merganser** *Mergus serrator*

122. **Black-crowned Night Heron** *Nycticorax nycticorax*

123. **Great Cormorant** *Phalacrocorax carbo*

124. **Winter Wren** *Troglodytes hiemalis*

125. **Wild Turkey** *Meleagris gallopavo*

126. **Ruff** *Calidris pugnax*

127. **Green Heron** *Butorides virescens*

128. **Bobolink** *Dolichonyx oryzivorus*