York River - Smelt Brook Salt Marsh Restoration Project

York, Maine

Site Assessment and Preliminary Design Final Report

Edkins Parcel Photo by G.Wilson

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SPECIALIZING IN THE RESTORATION OF SENSITIVE ECOSYSTEMS

Acknowledgments

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Reclamation embankment - Edkins Parcel Photo by G.Wilson

York River - Smelt Brook Salt Marsh Restoration

Project Background and Overview

The York River Watershed Stewardship Plan, developed with extensive community input around the designation of the York River and its major tributaries into the National Wild and Scenic Rivers System, identifies improving coastal resilience, restoring salt marshes, conserving land, and proactive planning to support marsh migration as priorities for the preservation of critical habitats, water quality, and healthy coastal river systems. The York River Stewardship Committee (YRSC), which formed in 2023 after river designation, prioritized salt marsh restoration as its first area of focus, with the aim of increasing the pace and scale of salt marsh restoration in the York River watershed. The YRSC, in coordination with landowners, initiated this project in 2024 to develop a restoration plan for 132 acres of degraded salt marshes owned by the York Land Trust and the USFWS Rachel Carson National Wildlife Refuge. The Stewardship Committee hired Northeast Wetland Restoration to assess the marsh systems, identify and document agricultural infrastructure, and design restoration plans for the project area. The YRSC also organized a local project team consisting of individuals and organizations experienced with salt marsh and coastal river restoration to help guide this design phase.

The primary purpose of the York River - Smelt Brook Salt Marsh Restoration Project is to prepare restoration designs to address historic ditching and other marsh alterations that have changed marsh hydrology within these salt marsh systems. All of the project areas included in the restoration project display extensive agricultural impairment that includes the use of agricultural embankments and ditching infrastructures believed to date back to the early and late agricultural periods. The dominant wetland habitat classification for these parcels is Estuarine Intertidal Emergent Persistent Irregularly Flooded (E2EM1P) wetland.

The York Land Trust's properties included in this restoration project are within the Near Point Preserve, Smelt Brook Preserve, and First Parish parcels on the York River and Smelt Brook, with a total area of approximately 104 acres. In the lower extents of the Smelt Brook Preserve, along the York River, two large mega-pools with a combined area of ten acres can be identified as existing prior to the 1973 air photo series. Upon further investigations in these areas, soil probing along transects suggests the presence of clay-cored embankments, which may have stalled the secondary successional trajectory. Follow-up investigations throughout the Smelt Brook Preserve revealed indications that clay-cored embankments were likely used in six locations. More extensive site investigations into the use of clay-cored embankments could prove to be a valuable contribution to the State of Maine's agricultural history.

The USFWS Rachel Carson National Wildlife Refuge's Edkins Parcel contains approximately 28 acres of tidal marshes directly adjacent to the York River. The initial site analysis identified extensive agricultural impairment due to the use of earthen embankment and ditching infrastructure believed to date back to early and late agricultural periods. Due to the extensive agricultural use of the site, approximately five acres are in the Late Decline stage of salt marsh secondary succession. These areas are at extreme risk of advancing into the subsidence stage of secondary succession, which is often referred to as marsh collapse.

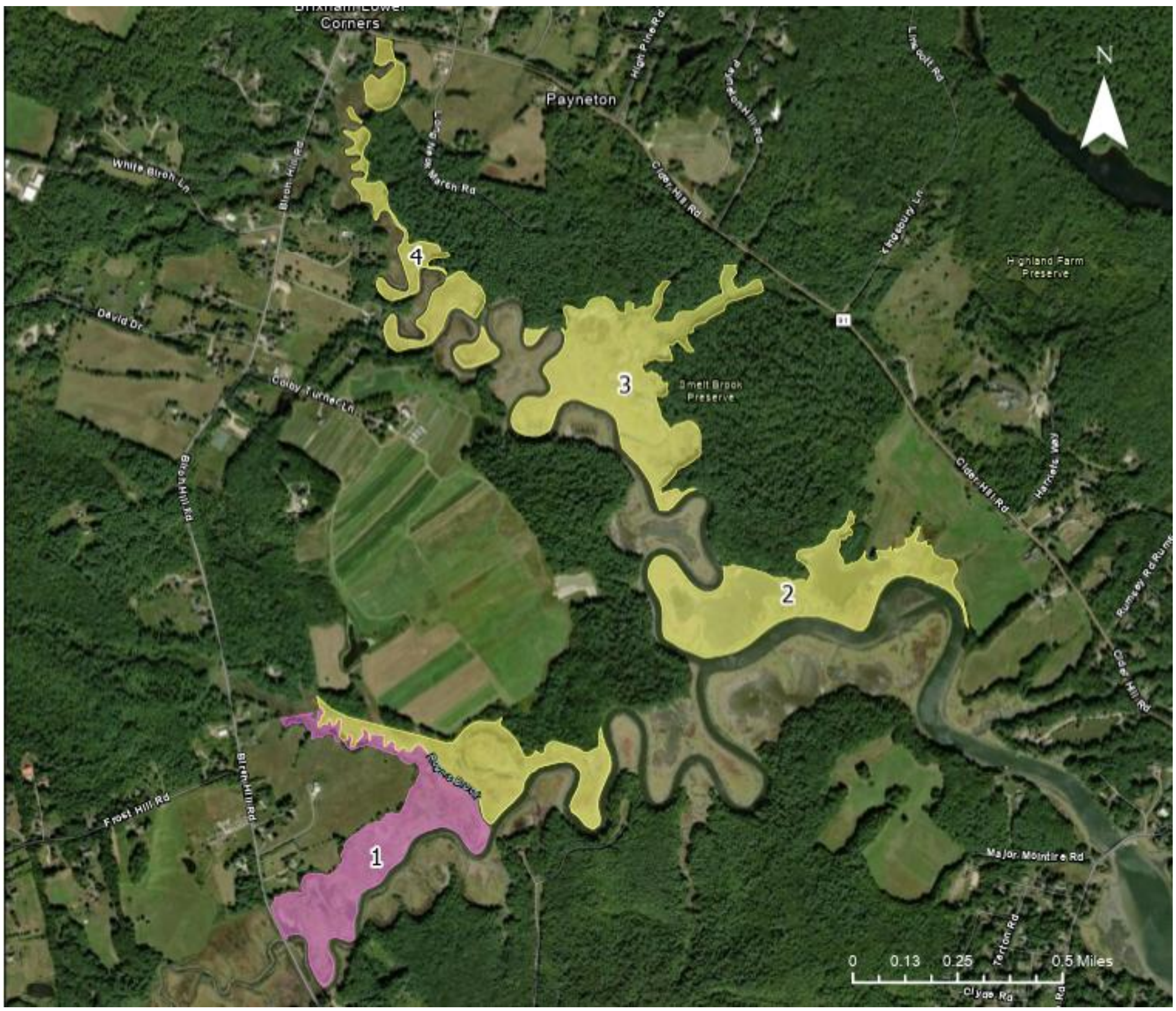
Northeast Wetland Restoration's project work spanned from September 2024 to September 2025, during which time it met with the Project Team in person three times, conducted two site walks with project team members, and presented project details at two public meetings. Project Team meetings included a kick-off meeting in September 2024 to share site information and general approaches; a second meeting in November 2024 to discuss initial findings and seek landowner input on restoration goals and stewardship priorities (marsh migration, invasive species, mega-pool habitat, wildlife species management, etc.) to inform design plans and approaches for the sites; and a third meeting in April 2025 to discuss the preliminary restoration plan. A preliminary project report was shared with the Project Team for review in May 2025, with the team's input incorporated into this final report.

Findings, Proposed Actions, and Proposed Conditions

NWR used a combination of field verification and aerial imagery interpretation of available agriculture infrastructure databases to identify agricultural infrastructure and assess marsh health. The aerial imagery utilized is from Google Earth Pro and the series of images are included within the supplemental KMZ files.

Data sets for the attributes of the salt marsh agriculture infrastructure, proposed restoration approaches, and proposed conditions are provided in a separate electronic database file. This includes early and late period embankments, tidal channel networks, tidal channel restoration (early/late successional, brackish and phragmites) and ditch remediation (linear and point treatment). A summary of the statistics for the full project area is provided in Appendix A. NWR has provided the data sets in KMZ, PDF (created using GIS data), and Excel formats, all of which were made available to the Project Team.

Appendix A includes a plan sheets directory, a coding system for the data sets, descriptive information summarizing the data for each project sub-area, and the series of sheets for each of the four areas.



The project area is divided into four sub-areas: 1 – USFWS Edkins parcel (pink) and YLT First Parish parcels (yellow); 2 & 3 – YLT Smelt Brook Preserve; and 4 – YLT Smelt Brook Preserve and Near Point Preserve

The series of plan sheets for each sub-area found in Appendix A shows mapped features as follows:

- Sheet 1 – Parcel identification, topography, and project area
- Sheet 2 – Existing conditions / agricultural infrastructure
  - Early period embankments: low earthen agricultural embankment systems, from the 1600s-1700s, incorporated into ditching infrastructural networks to improve soil drainage
  - Late period embankments: high terraced agricultural embankment systems, from the 1800s-1900s, overlaid on existing ditching infrastructural networks to improve yields
  - Clay-cored embankments: agricultural embankments with clay cores that serve as a low permeability barrier, allowing freshwater groundwater to accumulate and create brackish growing conditions
- Sheet 3 – Proposed restoration actions
  - Ditch remediation: a measured process for restoring the single channel hydrology necessary for tideshed equilibrium with the use of natural processes that govern salt marsh peat formation; includes mowing and secure placement of braided salt marsh hay in ditches over several seasons
    - Linear treatment: remediation of ditches with continuous ditch voids along their entire length
    - Point treatment: remediation of ditches with intermittent ditch voids and consisting of variable length treatment segments
  - Tidal channel restoration: restoring small channel hydrology through the use of micro-runnels; includes digging shallow runnels, approximately 20 cm deep by 30-45 cm wide, to reconnect pooled or degraded areas to tidal channels
    - Early successional: when a subsidence basin exists and requires immediate intervention prior to advancing into the mega-pool stage of salt marsh secondary succession
    - Late successional: within the existing ditching infrastructure where the ditch has self-remediated (i.e. it has vegetated over) and lateral hydrology is necessary to centralize the flow, increase marsh productivity and prepare the marsh to be more resilient to sea level rise
  - Phragmites control
    - Brackish ditch: future extension of single channel hydrology network to facilitate a transition from brackish to salt marsh vegetation species, while minimizing Phragmites encroachment
    - Marginal ditch: ditch between salt marsh and upland; to be restored where Phragmites has established in order to control (drain) freshwater groundwater and raise salinity levels to decrease Phragmites persistence and expansion in salt marsh
- Sheet 4 – Proposed conditions plan for single channel hydrology
  - Restored tidal channel network
  - Phragmites control areas with marginal ditches; these areas may require adaptive management

Restoration Plan Summary

Implementation of the restoration plan will improve salt marsh resiliency in the high marsh of the York River and Smelt Brook systems, where there is the greatest potential to maintain populations of the endangered Saltmarsh Sparrow (*Ammospiza caudacuta*) in the landscape and improve other beneficial marsh functions. It will facilitate marsh migration into adjacent brackish marsh areas, and it addresses Phragmites (*Phragmites australis*) expansion and encroachment into areas of the salt marsh. Restoration will be accomplished through the application of the Salt Marsh Adaptation and Resiliency Teams' 4-Tiered Restoration Model (SMARTeams/4TRM) as described in this report.

The first steps in the restoration process are to stop the loss of marsh surface elevations while improving productivity rates in the existing vegetative communities. By preventing additional elevation losses, in combination with increasing salt marsh productivity, the marsh platform will be preserved to serve as a stable base that will allow for the natural accretion processes to increase marsh surface elevations. Following stabilization of the marsh platform and the increase of accretion rates, wildlife management considerations are able to be included in the restoration plan.

Improvements to salt marsh growing conditions and tidal exchange will stabilize subsidence trajectories, enhance native plant productivity and re-colonization, restore additional salt marsh functions and values, and provide long-term marsh resilience. The first two tiers of SMARTeams/4TRM directly contribute to stabilizing subsidence losses of ancient blue carbon stores within the marsh platform and increasing carbon sequestration through the optimization of the primary production rates required in the formation of salt marsh peat.

To achieve these goals, the SMARTeams/4TRM combines the use of ditch remediation and micro-runnel restoration techniques to stabilize salt marsh subsidence trajectories and increase primary production within the vegetated plane. The framework for the restoration model is to identify and document the agricultural infrastructure, which is performed in the field and with the use of aerial imagery, and then use this infrastructure to improve the hydrological pathways that will restore single channel hydrology and sustain the salt marsh. As part of this process, tidesheds are identified and, within each tideshed, tidal flows are directed into the primary channels with the combined use of ditch remediation and micro-runnels, which improve surface hydrology and focus tidal exchange into a single sustainable tidal channel network (see *Salt Marsh Functions to be Restored* section below for more details). The improved surface hydrology provides a better overall growing condition that increases marsh primary productivity for the marsh vegetation to restore an elevation building trajectory.

All ditch remediation ditches will be vegetated to reduce their impact on the sustainability of the single channel hydrology networks and to raise groundwater elevations in the peat soil column in order to slow the loss of elevation through oxidative subsidence. The ditch remediation technique uses layers of adjacent aboveground biomass (mowed marsh grass) placed within the ditch to serve as an organic growing medium that slows tidal flow, allowing for the infiltration of sediments and the colonization of vegetation. The belowground biomass inputs from the colonizing vegetation will then regenerate salt marsh peat within the ditch void that will closely match the soil texture and characteristics of peat soil columns on either side of the ditch.

To restore the single channel network across the landscape, select ditches within the existing ditching infrastructure will be maintained using a micro-runnel profile to reconnect segments of former hydrological pathways and create a single channel network for each tideshed. Single channel hydrology will promote better connectivity within each tideshed and the natural conservation of tidal energy necessary to maintain tidal velocities that are conducive to transporting greater sediment loads onto the salt marsh vegetated plane. All work will be done within the existing ditch infrastructure and there will not be any new hydrological pathways created. Ditch remediation can take 3 to 5 seasons to complete, and single channel hydrology establishment will be completed in one season.

Two successional distinctions have been established for runnel types within the York River and Smelt Brook salt marshes. Early Successional is when a subsidence basin exists and requires immediate intervention prior to advancing into the mega-pool stage of salt marsh secondary succession. Late Successional is within the existing ditching infrastructure where the ditch has self-remediated (i.e. it has vegetated over) and lateral hydrology is necessary to centralize the flow, increase marsh productivity and prepare the marsh to be more resilient to sea level rise. See the *Vegetation Management* section below for brackish conditions and Phragmites control.

Once the marsh platform is stabilized and the primary production rate has increased, the marsh surface elevation will start to increase. Sedimentation and accretion rates will affect the timeline for marsh stability; however, the elevation will eventually level off as it stabilizes on a parallel trajectory with localized sea levels. Once the marsh surface elevations have stabilized relative to localized sea levels, it should be a more reliable breeding area for birds such as the Saltmarsh Sparrow. As part of the third tier of SMARTeams/4TRM, nesting islands will be created using the structured micro-topography technique to create more areas suitable as nesting habitat throughout the landscape.

The use of structured micro-topography to create marsh bird nesting islands is a beneficial reuse of materials generated during the implementation of small channel hydrology. The best location for the reuse of peat soils generated is directly adjacent to a restored flow path and avoids secondary impacts that would result from transporting those materials across the marsh for removal. These higher areas will also provide better growing conditions for high marsh plants while the marsh is recovering, which will then spread through rhizomes into the marsh. The micro-topography creation methods designed and described for this project area are based on approaches and techniques used in recent restoration projects throughout New England, as developed and implemented at the Rachel Carson National Wildlife Refuge in coordination with other SMARTeams partners.

Phragmites, the invasive plant species also known as common reed, is present at various locations within the brackish marsh interface of the York River and Smelt Brook salt marsh systems. As part of the fourth tier of SMARTeams/4TRM, long-term management strategies are proposed to address the presence of Phragmites, to reduce future encroachments into the salt marsh, as well as to plan for marsh migration.

The Maine Natural Areas Program (MNAP) marsh monitoring program includes RSET sites and vegetation transects within the Smelt Brook Preserve marshes. Proposed restoration activities will not occur within five meters of these sites and no impacts will affect the vegetation transect plots. Additionally, any identified threatened or endangered plant species locations will be avoided.

The restoration implementation timeline depends on capacity, funding, permits and other approvals, and other factors. The proposed timeline presented here is to illustrate possible timing, the multiyear or iterative approach inherent in the methods:

- Year 1 (Sept-May): ditch remediation and runnels implementation, including micro-topography and marginal ditch maintenance
- Years 2 through 5 (Sept-May): additional ditch remediation as needed

A monitoring plan should be developed to ensure the success of the marsh restoration; see Appendix B for a potential approach for monitoring vegetation changes and adapting short and long-term management actions as needed.

Subsequent report sections more fully describe historic salt marsh agriculture and its lasting impacts on marsh health; marsh degradation and subsidence trajectories; salt marsh functions and hydrologic conditions to be restored; and restoration approaches developed by the Salt Marsh Adaptation and Resiliency Teams that are the basis for this restoration plan for upper York River and Smelt Brook marshes.

Historical Salt Marsh Land Usage in New England

Salt marshes have always played an important role in providing for the needs of people. Middens, fish weirs and other archeological findings show that indigenous people benefited from salt marshes for more than 5,000 years. Once early colonists settled in New England they used the marshes for salt hay, thereby starting an agricultural tradition that lasted for more than 300 years.[1]

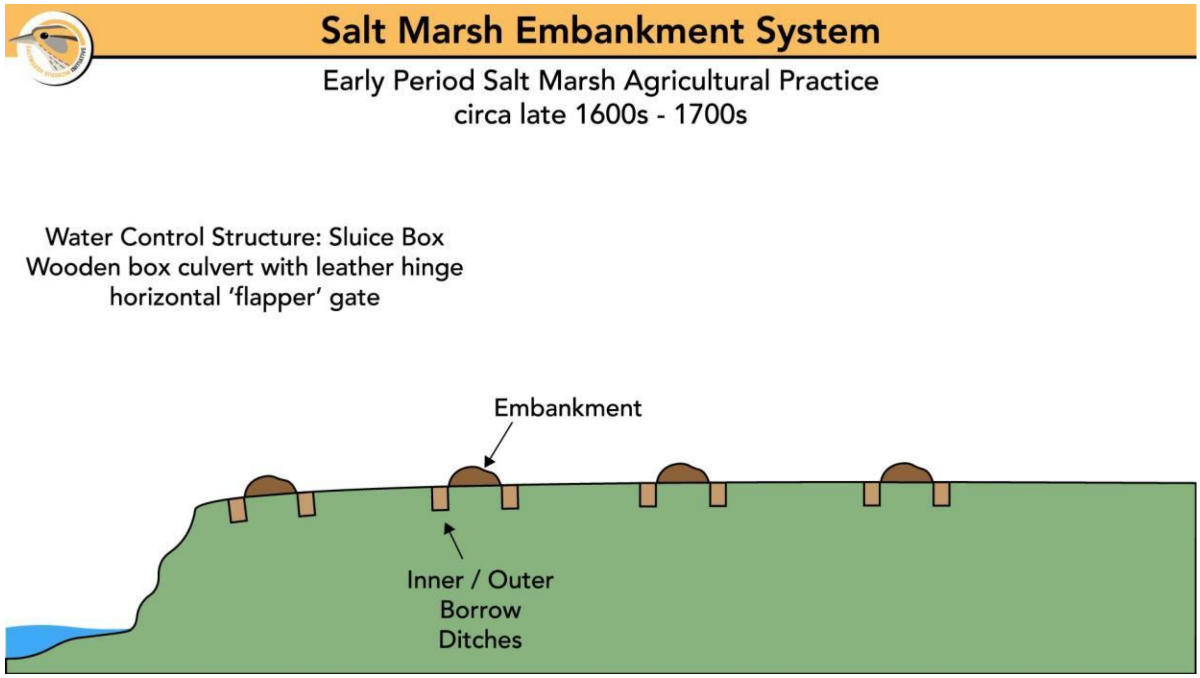
The historical impacts in New England salt marshes date as far back as the 17th century, when early colonial salt marsh hay farmers altered a pre-colonial equilibrium with their ditching practices. Prior to that time, an area of salt marsh would receive tidal waters from a single natural tidal channel network, and channel proportions were maintained naturally by the volume of water required to sustain the corresponding area of salt marsh. As time passed, these ditching practices continued and agricultural impacts were further exacerbated by embankment enclosures designed to reduce or prevent tidal waters from entering some of the salt marsh areas. Salt marsh management eras that followed maintained these ditching traditions and, in some cases, worsened these impacts by increasing the hydroperiod of large sections of the marsh. The 350-year tradition of managing salt marshes by maintaining ditches is now thought to have interrupted natural secondary successional patterns, and that these patterns would have had the potential to restore the marsh equilibrium.[2]

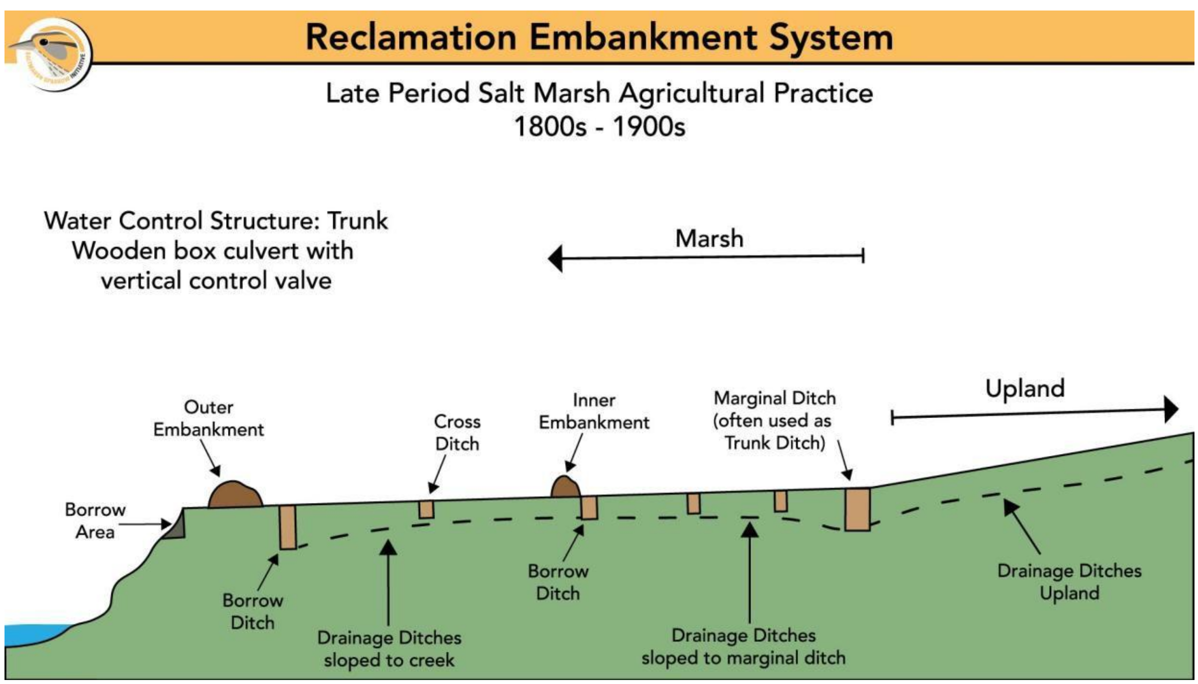
During the 1600's, the early colonists regarded the salt marsh as a readily available source for much of their agricultural needs. Salt marsh hay provided an instant source of fodder and bedding products used in animal husbandry, and was historically comprised of saltmeadow cordgrass (*Spartina patens*) and black grass (*Juncus gerardi*). After composting, the salt marsh peat served as one of the best sources of enrichment materials for depleted upland fields. In the long cold New England winters, the thatch that grew along creek banks would be used to insulate around drafty stone foundations and was then repurposed as fertilizer for upland fields in the spring.[3]

To promote the best salt hay grasses and to increase their yield three-fold, early colonial farmers improved the soil drainage with the use of ditching infrastructural networks. Based on a simple ditching formula used by salt marsh hay farmers until the 20th century, farmers would determine the ditching density needed to increase the grasses most favorable for the products that they were producing. According to this formula, it is estimated that the current ditching density is approximately 50 to 75% greater than the pre-colonial tidal channel density. This increase in channel density is what caused the alteration of the pre-colonial hydrology, by inserting multiple oversized channels across the entire landscape.

During the 1700's, early period salt marsh hay farmers incorporated low earthen embankment systems with sluice box structures into the existing ditching infrastructural networks. This change increased the hay yield by limiting the number and the duration of tides flooding a given section of the salt marsh. In most New England salt marshes, three to four layers of early period infrastructural networks can be identified.

During the 1800's, late period salt marsh hay farmers completely reworked the marshes by overlaying a new agricultural practice called Marsh Reclamation. This modern systematic agricultural practice utilized high embankment systems with more advanced water control box valves (called "trunks") to reclaim large portions of the salt marsh high meadow zone into upland fields. A "properly" banked marsh could produce four tons per acre of English Hay (an upland cultivated hay, sometimes referred to as Timothy or Herds grass), 1600 bushels per acre of a slightly salt tolerant fodder beet called Mangel-Wurzel, and common vegetables such as Indian Corn and potatoes.[4]

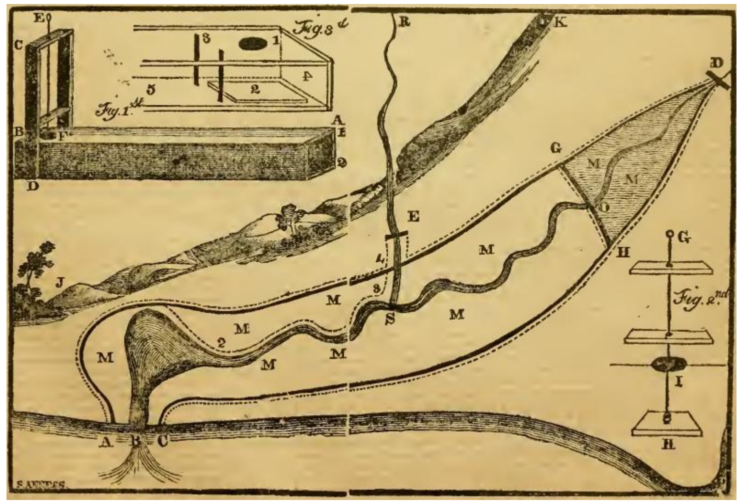




Reclamation embankments systematically terraced the marsh platform. The terracing embankment systems worked to exclude tides from entering large portions of the marsh. In all reclamation embankment systems, groundwater was drained from the interior through a complex drainage system consisting of *drainage ditches* and *cross ditches*, to a deep *marginal ditch* along the upland transition zone. The legacy ditches of the late period reclamation embankment ditching patterns form the first framework for the distinctive rectangular ditching infrastructure that dominates the marsh landscape today.

The plan proposed is, that the marginal ditch, from D to G, should be continued thence along the dotted lines to E, where a mound should be erected to turn the waters of the run, R, S, into the ditch which would thence be continued along the marsh to the river at A; a similar ditch would be continued from H to C on the river; and the tide trunk would be placed at the creek's mouth at B, and an embankment made along the river shore, from A to C, of sufficient height and strength to exclude the highest tide. It is estimated, upon apparently very reasonable grounds, that the draining of the whole marsh, might in this way, be effected with greater certainty, and, proportionably, much less expense than the reclaiming of any part of it; because, to prevent the embankment from being bored through with innumerable holes, by those indefatigable and sagacious little animals, the otters and muskrats, it must be made entirely of sandy or gravelly earth from the high-lands. The mound from G to H. was the most expensive part of the operation of draining the marsh G, H, D; and is made thus; stakes are driven down, and a wattling is made on them a foot or two high, to sustain the earth from the washing of the tide; the upper surface, or turf of the marsh is then removed near and parallel to the wattling, a few feet wide, to let the sandy earth sink into and incorporate with the marsh mud. Sandy, or gravelly earth is then carted on to this line, thus stripped of its turf, and the mound raised so high as to shut out the highest tides.

If the reclaiming of the marsh, on the one side of the creek only, were undertaken, a similar embankment must be made immediately along the water's edge; thus, suppose it was intended to reclaim the piece on the right side of this creek 1, 2, 3, 4. the embankment, such as I have described, must be carried along, or near the water's edge, designated by the dotted line, 1, 2, 3, 4; and the tide trunk be placed at the lowest and most convenient point along that line; at the same time, not neglecting in any case the marginal ditch for conducting the high land water



During the early 1900's, the increasing popularity of the 'horseless carriage' resulted in a decline for animal husbandry. As horses and oxen became less common, fodder crops required to feed them fell out of demand. As a result, the labor-intensive salt marsh systems of agriculture were largely abandoned. After abandonment, lack of maintenance caused widespread failure of the embankment systems and ditching networks.[5]

The resulting flooded conditions in the salt marsh increased mosquito populations. To address the mosquito problem, ditching was again used to drain salt marshes. The re-ditching of the marsh management era peaked in the late-1930's with the Works Progress Administration's (WPA) campaign to drain the salt marshes along the North Atlantic coast.

During the late 1930's to the 1980's, the ditches required regular maintenance to remove sediments and debris deposited by storms and tides. As hand labor gave way to mechanization, new ways to ditch the marsh evolved. One such method was a tracked machine with wooden treads, affectionately known as a 'Marsh Molly'. The Marsh Molly pushed a wedge-shaped V-plow down the ditch. As the plow proceeded, materials removed from the ditch were deposited adjacent to each side of the ditch, where the Marsh Molly's tracks would then compact the materials in place. Over time, the repeated ditching created dense ditch maintenance embankments along both sides of the ditch.

From circa 1960's to the present, two similar salt marsh mosquito management methods slowly began to replace ditch maintenance to reduce mosquito populations in the salt marsh. The first, Open Water Marsh Management (OWMM), addressed mosquito production by facilitating fish access to open water areas with high concentrations of mosquito larvae. Fish access was created by digging a series of shallow radial ditches extending from an existing salt marsh pool out into the surrounding marsh with mosquito larva habitat (shallow water).

Digging drainage ditches in the Meadows Courtesy of Frank DeCerbo

The second, Open Marsh Water Management (OMWM), addressed mosquito breeding locations by facilitating mosquito larval predation by fish through a series of radial ditch segments that extend out from excavated pools within the breeding location. Eventually, OMWM started incorporating short embankment segments over existing ditches, called ditch plugs with wing dams, to increase flooding and ensure that the zone of saturation remained at the surface of the marsh. This modification was done to minimize the amount of exposed mud which mosquitos could use for egg laying, and to maintain predatory fish populations on the marsh for longer periods of time.

[1] Sebold, 1992; Hawes, 1986

[2] Clift, 1862; Sebold, 1992; Hawes, 1986; Mora & Burdick, 2013

[3] Clift, 1862; Sebold, 1992; Hawes, 1986

[4] Farmer, 1820; Fessenden & Sheppard, 1823; Clift, 1862; Sebold, 1992; Hawes, 1986

[5] Sebold, 1992

Soil probing along transects indicates use of clay-cored embankments at Smelt Brook Preserve

Photo by G.Wilson

Socioeconomic Value of Salt Marshes

New England's coastal communities can attribute much of the region's prosperity to healthy salt marshes. Community benefits supplied by healthy salt marshes extend into segments of larger socioeconomic drivers, provide protection against storm impacts, and contribute to a desirable way of life.

New England is synonymous with its seafood industry. Menu choices like Maine lobster, Ipswich clams and New England clam chowder can be found throughout the region. However, few patrons realize that the local seafood industry is entirely dependent on healthy salt marshes and the natural services that they provide as a nursery ground for two-thirds of the region's commercially valued fish populations.[6]

Salt marshes provide only a small segment of the region's tourism appeal, however all of New England's major coastal tourism attractions are in many ways dependent on salt marshes. The beautiful white sand beaches, clean harbors, charming vistas and water dependent recreational opportunities are all directly related to the water quality of the nearshore environment. Salt marshes help keep the coastline clean by providing ecosystem services that filter out and trap pollution, pesticides and sediments that make their way into coastal waters.[7]

During major coastal storms, salt marshes decrease overall storm impacts by absorbing both wave energy and floodwaters. There is a direct positive correlation between the width of a salt marsh and wave energy absorption of the waves that batter the shores. As a floodplain, salt marshes receive and store the stormwater runoff and tidal surges that would inundate local neighborhoods in their absence, while trapping contaminants and debris the floodwaters often carry with them.[8]

In addition to species that support our economy, salt marshes support a wide range of other plants and wildlife that are important to maintaining the state's biodiversity. Many of the plants and animals that call salt marshes "home" depend on this habitat and are not found anywhere else, such as saltmarsh false foxglove (*Agalinas maritima*), a rare plant type in Maine. Salt marshes provide important habitat for numerous resident and migrating birds in the spring through fall, including herons, egrets, ospreys, terns, seaside sparrows and shorebirds (including willets). In winter, these marshes provide forage for numerous species of waterfowl, as well as snowy owls from far north.

Rare bird species also use salt marshes, including Least Tern, an endangered bird in Maine. The Saltmarsh Sparrow, listed as a Special Concern species in New Hampshire/Massachusetts and Endangered in Maine, nests exclusively in salt marshes, especially high marsh areas, and is declining by nine percent annually throughout its range. This species is an endemic species restricted to salt marshes along the North Atlantic coast and has been projected to be extinct from much of its range in less than 50 years because of more intense storms and higher sea levels associated with climate change that flood their nests and drown their young.[9]

[6] Dionne, Bonebakker & Grant, 2003; Boesch, 1984

[7] Nelson & Zavaleta, 2012

[8] King & Lester, 1995; Shepard, Crain & Beck, 2011; Nelson & Zavaleta, 2012

[9] MassWildlife NHESP; SHARP (https://www.tidalmarshbirds.org); Field, et al., 2016

Impacts of Sea Level Rise on the Salt Marsh

Sea level rise impacts on salt marshes come primarily from effects associated with our changing climate, consisting of the increasing volume of water in the world's oceans along with an increased frequency and intensity of storm events. The most recent estimate for the global sea level rise rate since 1993 is 3.3 mm per year, representing a total increase of about 9 cm between 1993 and 2021. When sea level rise is presented in this context, it may be difficult to visualize how that will impact salt marshes directly. In a simple model, an annual 3.3 mm increase in sea level for an average salt marsh means the marsh will be wetter for longer periods of time (i.e. the hydroperiod will increase). The net mean tide increase is approximately one acre-foot (43,560 cu.ft.) of additional water for every 92 acres of tidal marsh.[10]

Researchers studying these effects have observed a number of changes in salt marshes over the past two-plus decades. Some visual cues are obvious, such as severe bank erosion that has occurred as tidal creeks expand to accommodate an increasing volume of water. The most impacting changes, however, are the negative impacts on marsh vegetation caused by longer hydroperiods in salt marshes that are wetter for greater periods of time. In many cases, the increasing hydroperiods are compounded by legacy land use impairments, which result in large shallow open water bodies forming on the surface of the marsh.

Salt Marsh Migration

Salt marshes have developed in sheltered locations in the upper reaches of the tidal range. Tidal range is defined as the height difference between low and high tide, and varies by geographic location. Portions of the tidal range within which salt marsh vascular plants can survive, the "salt marsh vegetated plane", extend from approximately mean sea level (MSL) landward to the upland edge. In New England, the salt marsh vegetated plane fluctuates based on local variations and the plant species used to define the range. Typically, the range is 4 to 6 vertical feet and is located between 2.0 - 8.0 feet NGVD. This spatial relationship is changing, however, due to the 3.3 mm annual increase in tidal volume defined above. As a result, the salt marsh vegetated plane is moving landward in a process known as "salt marsh migration".

The current rise in sea level is not the first time that sea levels have changed. In the past, the salt marsh vegetated plane migrated relative to sea level as it changed position along the coast. With rising sea levels, the landward edges of salt marshes migrated up river systems into upland areas, a process known as marine transgression, while the seaward and middle marshes increased in elevation through the combined effects of plant growth and organic/inorganic sediment assimilation called salt marsh accretion. This conventional salt marsh migration model for a rising sea level is, however, not a 21st century option. Current conditions are very different in many parts of the world, as the marshes cannot move inland due to being blocked by surrounding human development. Expensive shoreline developments, civil infrastructure and industrial era dams, common along most shorelines, prohibit the horizontal salt marsh migration path. As a result, in developed regions around the world, coastal resources are dependent on an existing marsh's ability to migrate vertically at a faster pace than rising sea levels.[11]

While the rate of sea level rise due to the changing climate is exceptionally fast, it is possible that vertical salt marsh growth (i.e. salt marsh accretion) can keep pace. A growing body of evidence shows that the common salt marsh plant smooth cordgrass (*Spartina alterniflora*) has the ability to accrete at a rate much more quickly than the current sea level rise estimates of 3.3 mm/year. The potential accretion rate for saltmeadow cordgrass (*S. patens*) is +/- 4.5 mm per year, and for smooth cordgrass (*S. alterniflora*) the potential rate is within a range of 5.5 to 18.0 mm/yr. Unfortunately, legacy impairments from the marsh management eras, described in the *Historical Salt Marsh Land Usage in New England* section above, have left many large areas of marsh unable to adapt to the accelerating rate of sea level rise.[12]

[10] Kirshen, et al., 2014; CMEMS Ocean Monitoring Indicator based on C3S sea level product (C3S/ECMWF/CMEMS), 2022.

[11] Redfield 1972; Kelly, Dickson & Belknap, 1996

[12] Gonneea, et al., 2018; Members of SMARTeams/DR observations at Awcomin Marsh in Rye, NH

Salt Marsh Functions to be Restored

Salt marshes are located in tidal floodplains that flood and ebb every 12 hours and 25 minutes. The volume of water that flows in (flood) and out (ebb) of a salt marsh on each tide corresponds with the earth's orientation to the sun and the moon. When the three celestial bodies are aligned, the strong pull of gravity transfers large volumes of sea water into and out of the salt marsh. When the three bodies form at opposing angles to each other, the gravitational forces counteract one another and a smaller volume of sea water is transferred.[13]

When large tides flood over the surface of a salt marsh, they are referred to as "flood tides" or "spring tides", because the tide is springing forth onto the marsh surface. Smaller tides that do not flood over the salt marsh surface are referred to as "neap tides", which has a nautical origin established prior to the 12th century possibly referring to a scant or lacking tide. During each month, there will be flood/spring tide cycles and neap tide cycles. As the moon orbits the earth, the three celestial objects align, then become opposed, then align again, and finally become opposed for a second time. The changing orientation of the objects occurs slowly, over the course of about a week's time. The corresponding transition from spring tides to neap tides occurs over a series of daily tide cycles that are said to be trending either up or down.[14]

Tideshed Equilibrium

The past four centuries of ditching practices within our salt marshes have dramatically upset the marsh area to channel capacity balance. Prior to agricultural disturbance, the marsh landscape was formed by coastal waters being pulled into the vegetated plane by gravity, and ebb tides draining out as gravity is released. Sediments carried in by the tide filtered into the grassy surfaces to form gentle plains with smooth edges. A "tideshed" is an area of tidal marsh that receives channelized tidal flow via a single channel, often referred to as single channel hydrology. Each tideshed of the marsh was supplied with salt water through a single tidal channel, sized to correspond to the volume of water required to fill that section of marsh. The daily movement of tides creates a balance between channel size and the area of the marsh that the channel services, which can be expressed as a ratio (marsh area: channel capacity). If the ratio changes, natural processes will attempt to restore it. This balance between marsh area and channel capacity is referred to as "tideshed equilibrium".[15]

Fracturing of the Tidesheds

Beginning with agricultural land use, single channels that once serviced formerly balanced tidesheds were modified into multiple channels (via ditching) of similar dimensions (i.e. multi-channel hydrology). The new multi-channel hydrology patterns significantly increased the ratio of channel volume to the corresponding salt marsh area, which in turn divided the flow between the channels/ditches, eventually leading to reduced connectivity within the tideshed. The lower velocity rates in each channel resulted in a reduction of the tidewater's ability to entrain (draw in and transport) sediments and carry them onto the salt marsh vegetated plane. Over time, these sediments fill the channels and further reduce the flow volume and velocity within the tideshed, causing isolation of portions of the tideshed from channelized flow.

Salt Marsh Subsidence Trajectories

The soil in a salt marsh is a peatland soil type consisting of organic and non-organic sediments, referred to as salt marsh peat. With the exception of sediments deposited by an overwash event in a coastal storm, the majority of sediments are carried into the marsh suspended in the water column. Each tide carries small amounts of sediments that settle out of the water column during the 'slack' period at high tide. Occasionally, storm events will suspend a great deal of sediments and a large layer, up to a millimeter thick, can quickly coat the marsh. Plant stems and leaves also factor significantly in drawing sediments out of the water column. As aboveground biomass density increases, so does sediment deposition.

The organic content in salt marsh peat is mostly supplied by the marsh's perennial grasses. The majority of the organic content in salt marsh peat, up to 80 percent, is supplied by belowground biomass consisting of roots and rhizomes of the marsh plants. Aboveground biomass contributes the remaining portion of the organic content at the end of each growing season, as the senescent leaves and stems mat together to form a thatch layer or detach and drift to a new location in the marsh. Season by season, these layers of organic and inorganic sediments bound together with the organic matter inputs supplied by the vegetation, build-up the soil surface elevation in the process called "salt marsh accretion".

Oxidative Subsidence Trajectory

Like all wetland soils, salt marsh peat has an interesting self-regulation process. When the soil is saturated, and the voids between the soil particles are filled with water, the resulting low oxygen environment limits the amount of organic matter that can be consumed by soil microbes. Lignin, the portions of the organic matter that are more resistant to decomposition, then build up in the soil layer. Over time, both the surface elevation and density of the salt marsh peat increase as the layers of organic matter and fine sediments accumulate.

However, marsh soil formation has a limit. When salt marsh elevations rise above frequent tidal flooding and soil voids no longer fill with water, another process takes over. The dry conditions at the soil surface provide air-filled voids in the upper soil horizon, which supply the microbes with enough oxygen to consume all of the organic matter in the soil. When this occurs, the soil microbes switch from anaerobic respiration (respiration without oxygen) in the saturated soil, to aerobic respiration (respiration with oxygen) in the air-filled soil. This process creates a balance with the surface of the marsh and sea level. As the surface elevation builds-up beyond the sustained saturated condition, natural microbial processes maintain a marsh surface elevation that is in balance with sea level, through the decomposition of the organic matter in the oxygen-rich upper portions of the soil column.

Ditching infrastructures upset the marsh surface/sea level balance by draining the water out of the pore spaces deep in the soil column. When the water drains from deep in the soil column, void spaces fill with air. When oxygen becomes available deep in the soil column, microbes switch to aerobic respiration and decompose organic matter in positions of the soil column that are no longer in a saturated condition. Aerobic respiration deep in the soil column reduces the organic content throughout the aerated portion of the soil column, resulting in an accelerated loss of surface elevation. This process is one of many factors that can lead to a lowering of the surface of the salt marsh, known as the "oxidative subsidence trajectory" (OST). This process is also one of the ways that the ancient blue carbon stored in the salt marsh peat soil column is released back into the atmosphere, contributing to increases in greenhouse gases.

Waterlogged Subsidence Trajectory

Waterlogged subsidence trajectory (WST) describes the cycle of coastal processes involved in the creation of subsidence basins and "mega-pools", as a result of anthropogenic alterations of the salt marsh due primarily to historic farming practices. Unlike a natural pool cycle, the waterlogged subsidence trajectory is a direct result of past management, including over-ditching and embankment agricultural practices.

Four main stages of WST have been identified: Decline, Mega-pool, Mega-pool Breach and Single Channel Hydrology. These terms and stages have been developed by the Salt Marsh Adaptation and Resiliency Teams' Design Review (SMARTeams/DR)*, a collection of regional federal, state and local government scientists, private scientists, and practitioners dedicated to salt marsh restoration. The various stages of WST have been individually recognized and observed by scientists and salt marsh managers, though the identification of a specific sequence of stages had not previously been clarified.

While there are other causes of subsidence of marsh peat, including the oxidative subsidence trajectory (OST), WST describes the subsidence that occurs as a result of the entrapment of water behind low embankments, as well as other historic structures, which form individual tidesheds and prevent full tidal exchange, particularly draining on the ebb tide. This reduced connectivity and accumulation of water behind the embankment structure causes changes to soil chemistry and soil structure that result in the loss of vertical marsh elevation (subsidence). The combined subsidence and inundated conditions result initially in a shift towards plant species tolerant of the new conditions, then a gradual loss of vegetation as conditions become unsuitable for all salt marsh plants. The progression of this over-saturation results in the development of a series of salt pannes. If unchecked, the process continues to accelerate the widening and deepening of the pannes into pools that, in time, expand until they intersect and create large mega-pools. Mega-pools will persist until sufficient hydraulic head causes a breach that incises a low point in the basin, allowing the pool to drain and the process of revegetation to begin. The breach will gradually expand to accommodate the new tidal flow of the subsidence basin.

[13, 14] Hicks, 2006

[15] Redfield, 1972

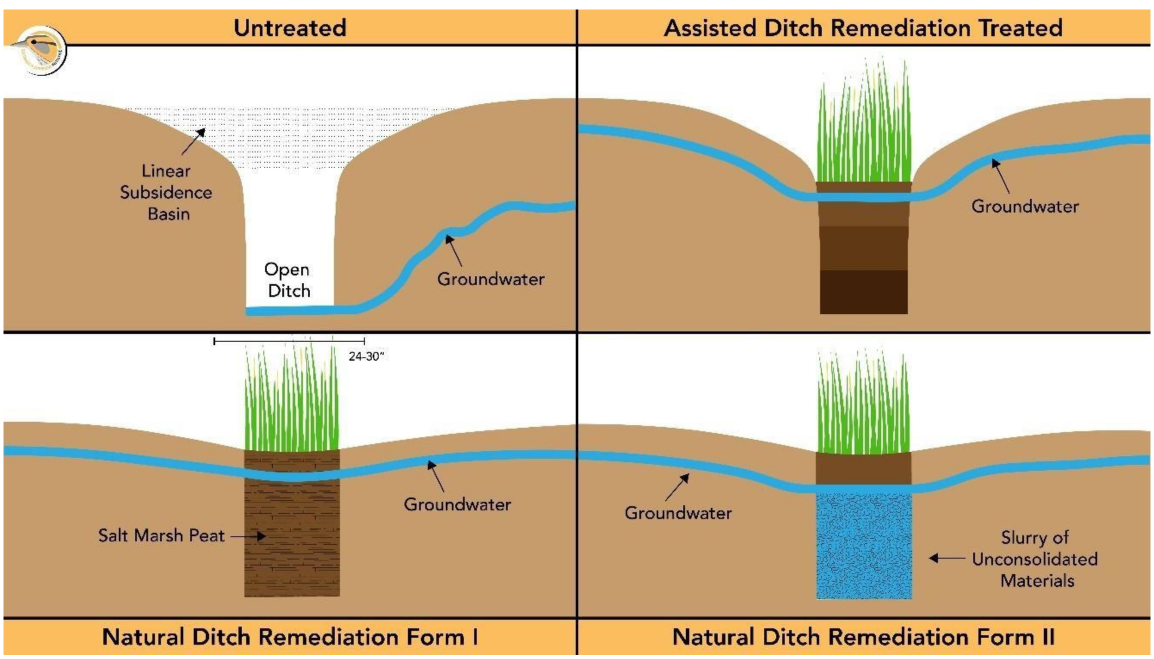
*The SMARTeams' Design Review (SMARTeams/DR) consists of project partners: U.S. Fish and Wildlife Service National Wildlife Refuge System, U.S. Fish and Wildlife Service Land Management Research and Demonstration, University of New Hampshire, Connecticut Department of Energy and Environmental Protection, Save the Bay - Narragansett Bay, University of Maryland Center for Environmental Science, The Nature Conservancy Long Island Chapter, Narragansett Bay National Estuarine Research Reserve, and Bear Creek Wildlife Sanctuary. The team was established to develop management strategies that address salt marsh subsidence and improve vital habitats for tidal marsh dependent species identified as Endangered, Threatened or At-Risk by the U.S. Fish and Wildlife Service.

Reclamation embankment – Smelt Brook Preserve Photo by G.Wilson

Addressing the Current Impairment Created by Ditches in the Salt Marsh

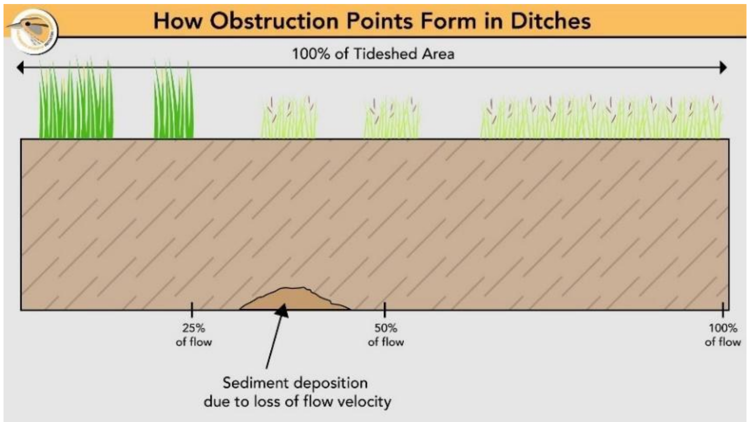
Salt marsh secondary succession (SMSS) is a natural process that establishes single channel hydrology back into a marsh over great lengths of time. As part of this process, ditches slowly self-remediate. The two most common forms of natural remediation are described below. In order to intersect the oxidative subsidence trajectory, and advance the SMSS process by restoring single channel hydrology, it is necessary to understand both the natural pathways and how assisted ditch remediation will accelerate the remediation process.

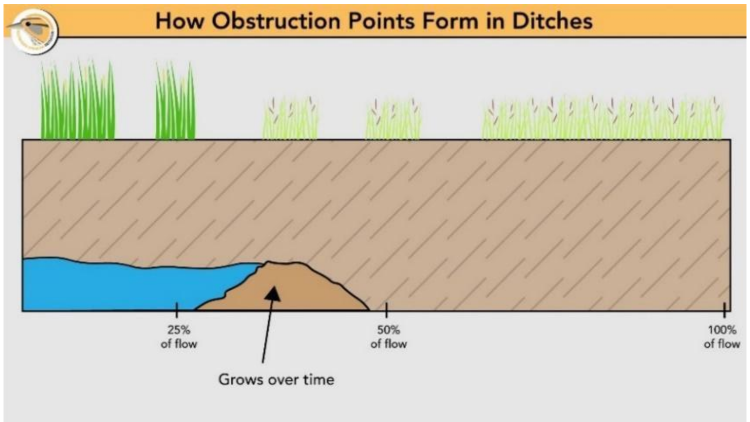
The most common ditches observed today in New England salt marshes are the result of historical single wide borrow ditches made by farmers to create embankments. These ditches tend to be approximately 18 inches wide and three feet deep, and their current condition is one of three types. The first type is an open ditch that has been maintained or has not gone through a process of natural remediation. These ditches were generally maintained during mosquito control periods, though are currently untreated. A linear subsidence basin, where the OST has lowered the marsh surface, is present along the length of the ditch. This lowering of the marsh surface along the ditch path is a direct result of microbes decomposing organic matter that accumulated in the marsh soil column before the increased drainage, caused by the ditch, lowered the groundwater level. The linear subsidence basin varies in depth depending on numerous factors, including soil characteristics. There is no vegetation in the ditch and the groundwater level remains close to the ditch bottom.



The other two types reflect the most common forms of natural (unassisted) ditch remediation. The first of these unassisted types, Form I, is the less common of the two and has salt marsh peat regenerating on its own. This occurs through the natural accumulation of sediment materials over a significant amount of time (decades). The ditch is mostly filled in and the groundwater level is close to the top of the peat soil column. A shallow swale, approximately 24 to 30 inches wide, is formed on top with salt marsh vegetation present.

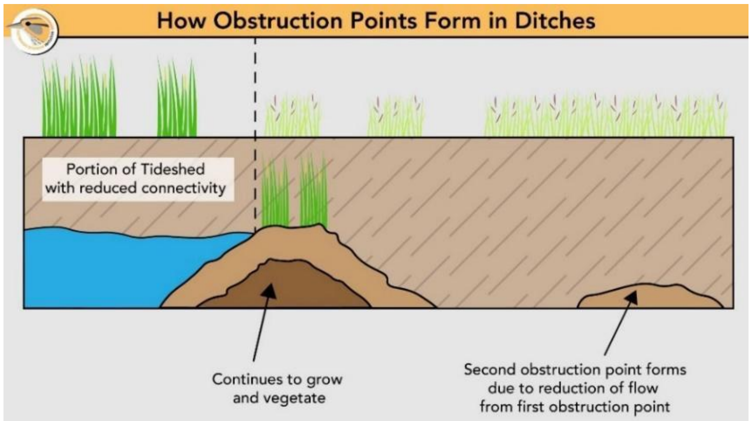
The second of the unassisted types, Form II, is the more common form and occurs due to the formation of obstruction points within the ditch. An obstruction point forms as a result of sediment deposition taking place where the loss of flow velocity allows suspended sediment to fall from the water column.

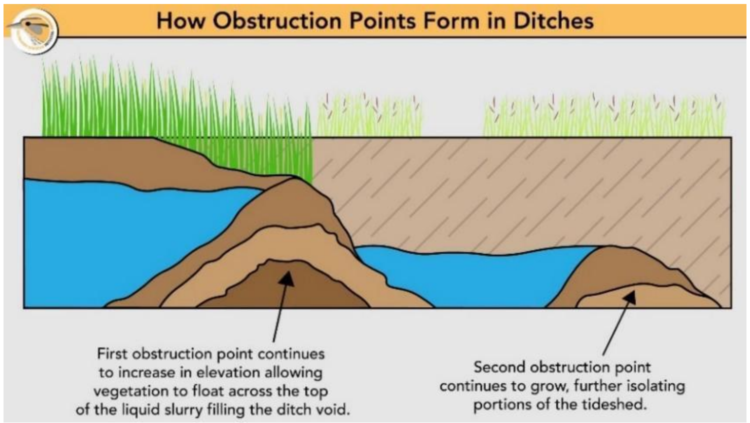




The growing obstruction point continues to reduce flow, isolating upstream portions of the tideshed, and results in reduced connectivity. As the sediment deposition accumulates it forms a blockage, which holds water behind it and eventually grows smooth cordgrass (*S. alterniflora*), accelerating sediment deposition.

As the obstruction point formation process accelerates, smooth cordgrass (*S. alterniflora*) can float roots across a slurry of unconsolidated materials, filling the ditch's surface and covering the ditch. The slurry remains in an unconsolidated liquid state that is not dense peat for an extended period of time. During this time, the center of the ditch stays liquid and can pipe water.





The first obstruction point isolates the upstream portions of the tideshed, reducing flow velocity and causing additional obstruction point(s) to form in the ditch. As a result, the reduction of flow from the initial obstruction point is further compounded. As multiple ditches within a tideshed fail, the adjacent marsh area can enter into the WST described above.

In order to restore a salt marsh to single channel hydrology, the ideal model to use for assisted ditch remediation is natural ditch remediation Form I, which regenerates salt marsh peat in the ditch void, as depicted above. In the assisted ditch remediation approach, an open ditch is treated by inserting layers of organic growing medium over three successive seasons. This approach allows time to filter suspended sediments transported by tidal waters, improving the growing medium for smooth cordgrass (*S. alterniflora*) and allowing the belowground biomass to regenerate salt marsh peat that is as similar in composition to the adjacent soil texture and composition as possible. The biological process of regenerating salt marsh peat within the ditch void creates a uniform bond and a nearly seamless restoration of the peatland soil structure between each side of the ditch void. This reduces the groundwater discharge surface area found along the untreated ditch walls and brings the zone of saturation closer to the surface of the marsh. Raising the groundwater level to just below the active root zone of salt marsh plants decreases the depth of aerated soils, reducing the loss of elevation by the OST without impacting the productivity of the adjacent salt marsh vegetative community. After reducing the number of channels across the landscape, lateral hydrology is established to provide pathways for tidal waters to reach the primary ditch, which will increase flow velocity and prevent future obstruction points from developing.

Marsh bank calving caused by low small channel hydrology frequency - Smelt Brook Preserve   Photo by G.Wilson

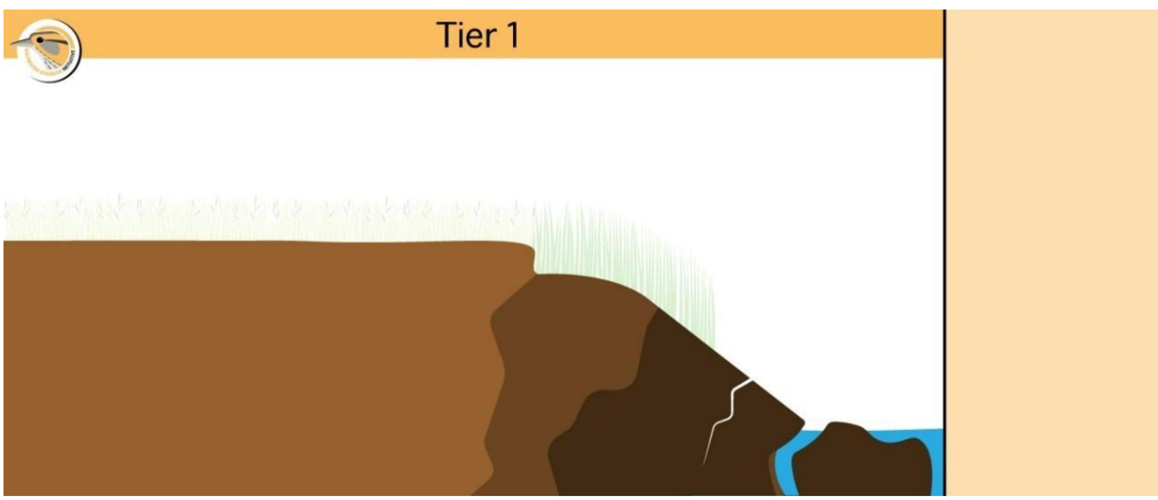
Salt Marsh Adaptation and Resiliency Teams' 4-Tiered Restoration Model

The Salt Marsh Adaptation and Resiliency Teams' 4-Tiered Restoration Model (SMARTeams/4TRM) is a structured restoration design process that focuses on restoring salt marsh resiliency by addressing the legacy land use impairment found throughout salt marshes. The primary focus of the restoration model is to intersect a salt marsh's position in salt marsh secondary succession (SMSS) and advance the successional stage to single channel hydrology, thus avoiding the subsidence trajectories often associated with natural unassisted SMSS.

Tier 1

Stabilizing the Marsh Platform

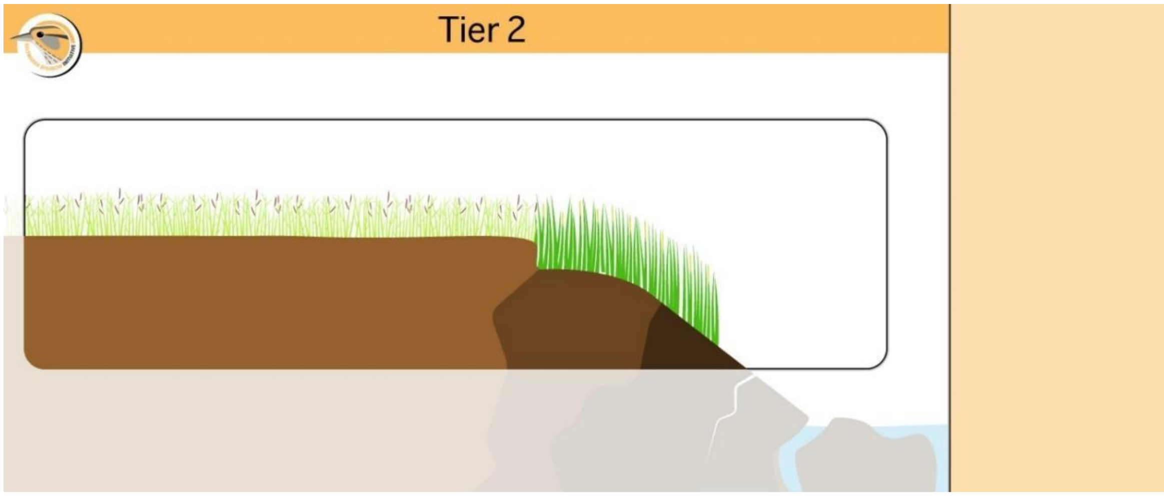
The two most common forms of salt marsh subsidence are both related to agricultural practices that were once used along the North Atlantic coast. The recovery trajectories from historical agricultural impairments are predictable and, like secondary succession in other ecosystems, can be identified and advanced to accelerate the recovery period. In the first tier of the restoration model, the agricultural infrastructure is identified and used to address hydrology impairments in the upper meter of the peat soil column. By preventing further elevation losses in the marsh platform, the existing peat soil column then provides a stable base for accretion to restore the marsh elevation relative to sea levels and preserve the ancient carbon stores found in salt marsh peat. Tier 1 design/project goals are to identify where each tideshed is in the SMSS trajectory and to intersect the identified successional trajectory with the appropriate technique to stabilize the platform hydrology and restore single channel hydrology. By stabilizing the trajectory through restored single channel hydrology, the marsh platform is preserved to form the foundation of a salt marsh that can more readily adapt to sea level rise.



Tier 2

Increasing Salt Marsh Productivity Rates

For millennia, salt marsh elevation and sea level evolved on a parallel pathway. However, due to a recent (in geological time) 350-year tradition of ditch maintenance, salt marsh subsidence has lowered, and continues to lower, the surface elevation of most salt marshes. This continued loss of salt marsh surface elevation is causing the relationship between salt marsh elevations and sea level to change. To preserve an impaired salt marsh area, the salt marsh platform needs to be stabilized in combination with increasing surface elevations relative to the increasing rate of sea level rise. One method for increasing surface elevations over large areas of the marsh is to address marsh surface impairments to increase primary production rates. Increased plant productivity will allow existing salt marsh plants more opportunities to store the net fixed energy remaining after cell respiration and reproduction in the soil, as belowground biomass that will increase the surface elevation of the marsh.

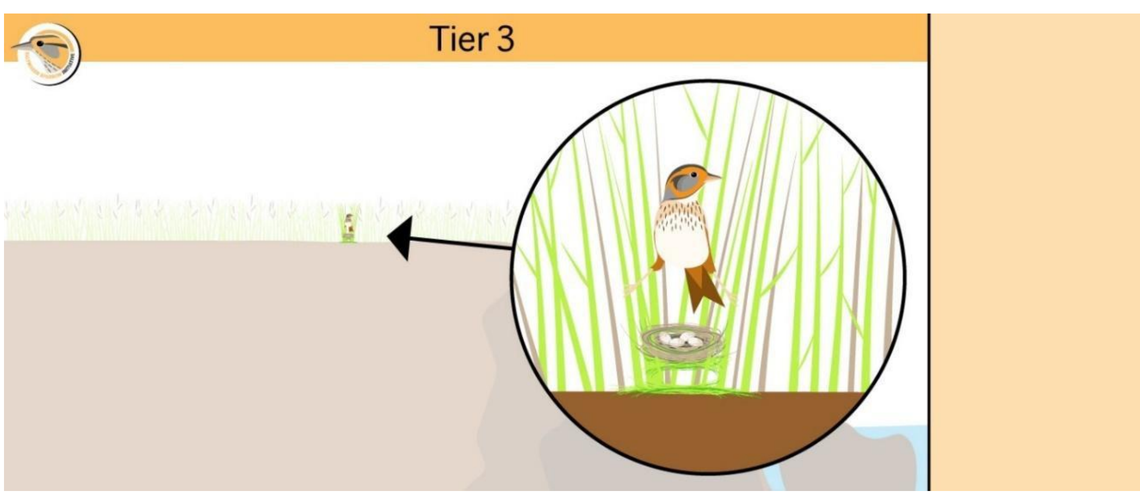


In general, salt marsh surface elevations are closely tied to plant productivity. Productivity in salt marsh plants can vary based on their growing conditions. Improving the growing conditions in a location will stimulate an increase in the productivity of the salt marsh plant community. The increase in productivity will result in an increase of above and belowground biomass that can be stored in the peat soil column. As a result of this natural process, the salt marsh surface elevation will increase in elevation commensurate with the plant community composition and prevailing growing conditions. The potential accretion rate for saltmeadow cordgrass (*S. patens*) is +/- 4.5 mm per year, and for smooth cordgrass (*S. alterniflora*) the potential rate is within a range of +/- 5.5 to 18.0 mm/yr. After the salt marsh soil column has been stabilized by Tier 1 treatments, the salt marsh surface elevation can be restored by increasing primary production rates to recover the lost elevation relative to current sea level.

Tier 3

<u>Tune for Wildlife</u>

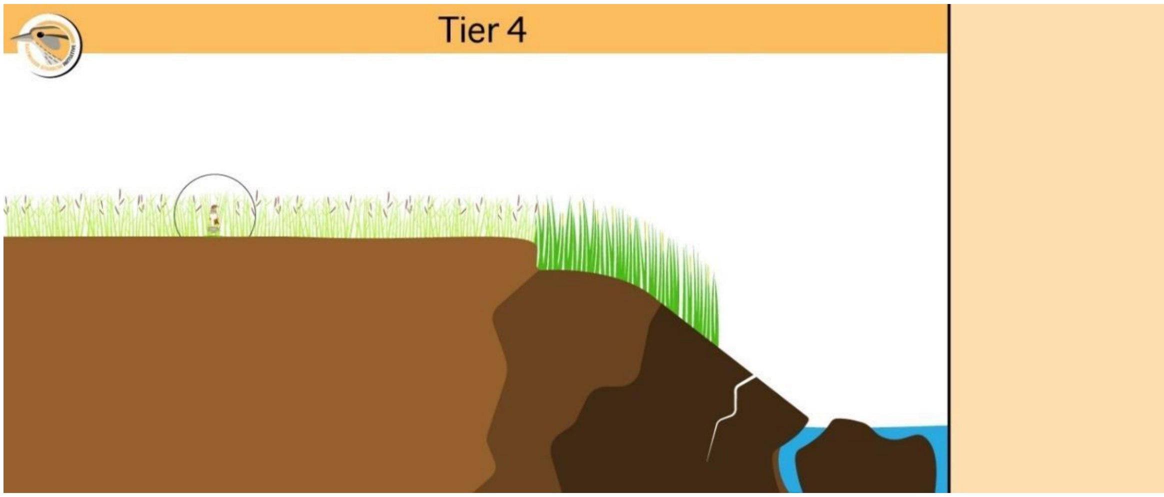
Many tidal marsh dependent species are being negatively affected by salt marsh subsidence compounded by sea level rise. After the salt marsh platform has been stabilized and the rate of primary production has been increased, additional management measures can be included in the project design/goals, such as structured micro-topography for Saltmarsh Sparrows. The idea is based largely on increasing nest success to extend the extirpation horizon beyond the marsh surface elevation recovery period.



Tier 4

<u>Salt Marsh Adaptive Management</u>

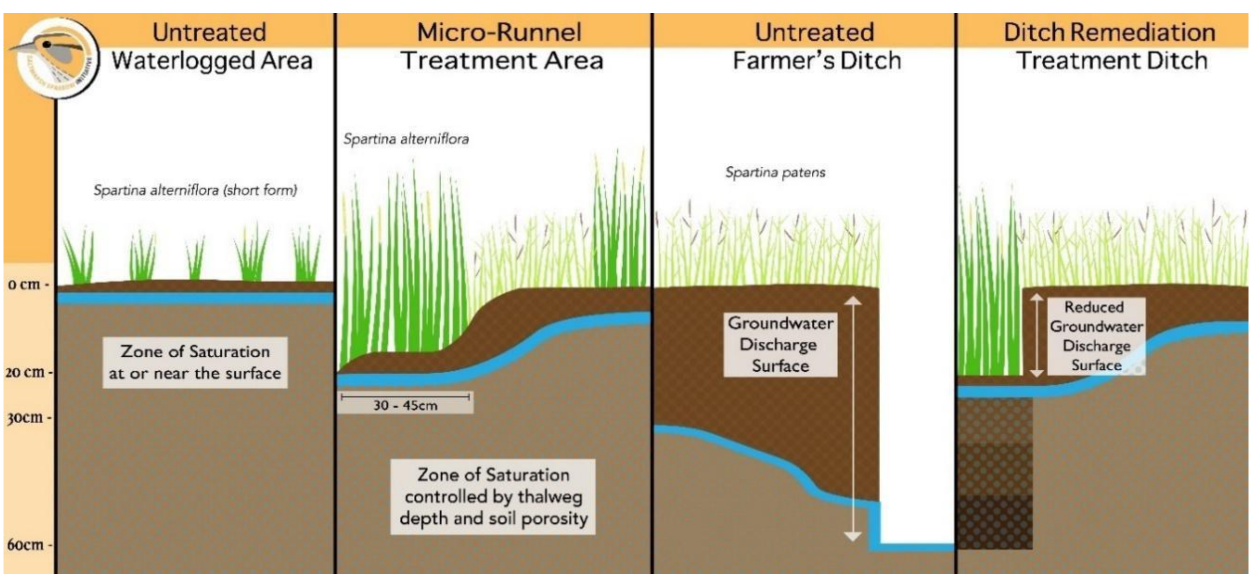
Project stewardship is focused on adaptive management and prescribing objective-based adaptive measures, such as modified accretion cycles, invasive species management, and marsh migration adaptations. These are based on long-term monitoring results to achieve the project goals and to facilitate marsh migration over longer project periods.



Addressing Platform Hydrology

The Waterlogged Subsidence Trajectory (WST) occurs when the zone of saturation is positioned at the surface to within 10 cm of the surface of the peat soil column where it can negatively affect plant productivity, including killing the plants or preventing revegetation of bare soils. This condition has many forms, from stunted plants with low productivity to large, shallow, firm-bottomed open water bodies on the surface of the marsh (mega-pools). The appropriate technique to stabilize the platform hydrology for WST is micro-runnel (see *Small Channel Hydrology* section below).

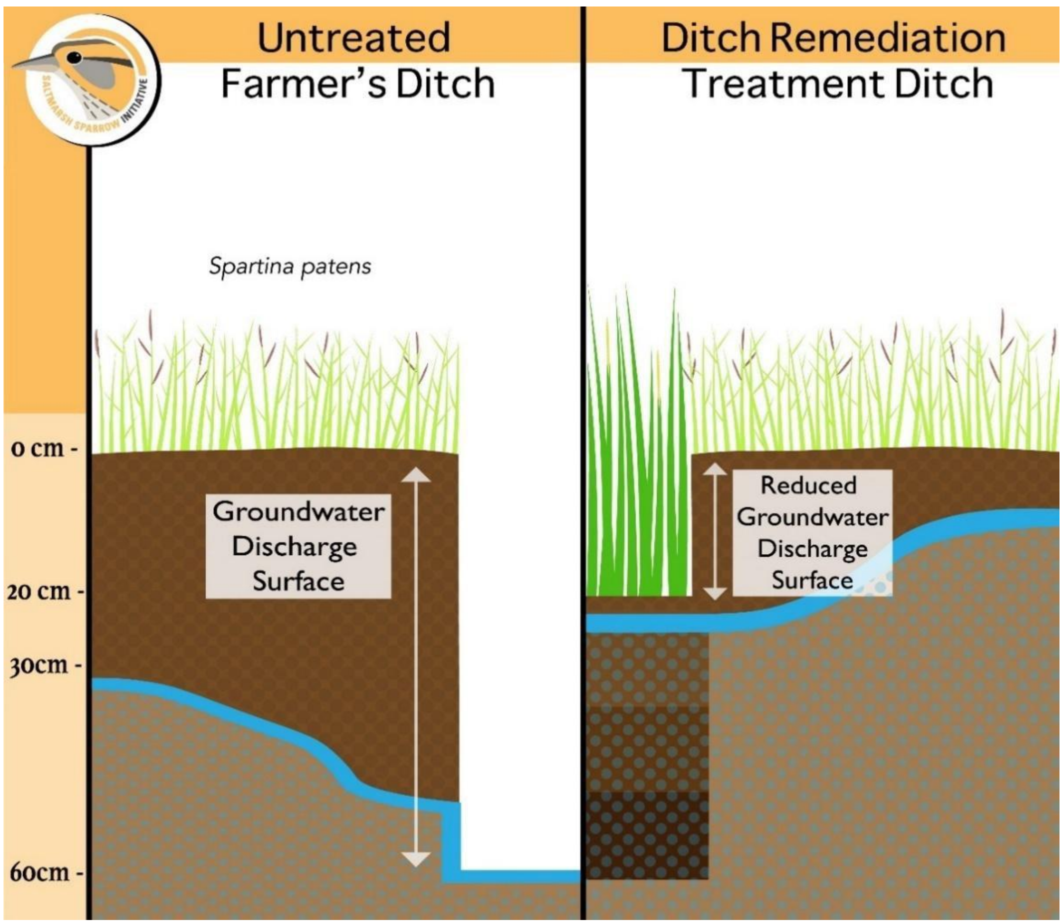
The Oxidative Subsidence Trajectory (OST) occurs when too much oxygen enters the peat soil column and organic matter is decomposing at a rate faster than primary production can replace. The appropriate technique to stabilize the platform hydrology for OST is ditch remediation.



The Ditch Remediation Technique

The appropriate technique to stabilize the platform hydrology for the oxidative subsidence trajectory is ditch remediation, which is one of a suite of restoration techniques that are part of SMARTeams/4TRM projects. SMARTeams/4TRM projects focus on increasing tidal marsh resiliency by advancing natural processes that facilitate a marsh's ability to adapt to sea level rise.

Ditch remediation is a measured process for restoring the single channel hydrology necessary for tideshed equilibrium with the use of natural processes that govern salt marsh peat formation. Auxiliary channels within a tideshed are thinly layered with salt marsh hay to reduce tidal flow potential, while flow potential in the primary channel is increased correspondingly. Naturally occurring sediments within the water column filter into thin layers of salt marsh hay, increasing the ditch floor elevation with naturally-formed salt marsh peat made of the same components as the surrounding peat soil column. Once the ditch floor reaches a sufficient elevation to receive approximately 6 hours of full sunlight within the vascular plant inhabitable zone, rooting structures of smooth cordgrass (*S. alterniflora*) regenerate salt marsh peat in the open void of the ditch trench. The ditch remediation process uses salt marsh vegetation as a growing medium to facilitate belowground biomass that regenerates salt marsh peat. This restoration process matches the peat soils on either side of the ditch void as closely as possible.



The ditch remediation process begins with tideshed boundary delineation and tideshed channel classification. The tideshed boundary delineation is determined over multiple spring tide field surveys in combination with microtopography field observations. Field surveying is a hands-on process where careful observation of the historical agricultural structures is made and used to determine tideshed boundaries and channelized flow patterns.

After the tideshed delineation is complete, careful observation of the tidal channels servicing each tideshed is used to identify the primary and auxiliary tidal channel pattern. In some locations, channel hierarchy is readily observable in the field. In other locations, where the existing ditching infrastructure has clogged, the identification of channel hierarchy is more difficult and multiple observations of the existing flood and ebb patterns are required to determine channel hierarchy. In the locations where the ditching infrastructure has clogged, it may be necessary to use the micro-runnel technique in combination with the ditch remediation technique to re-establish single channel hydrology (see *Small Channel Hydrology* section below).

Ditch Remediation Treatment Ditch Types

Ditches with continuous ditch voids in need of remediation treatment along their entire length have been categorized as Linear Treatment ditches. Ditches were selected as needing linear treatment if they had a ditch void present that was visible from a height of 1,000 to 1,500 feet, along at least 50 percent of their length. Ditches were excluded from being selected for linear treatment if they had intermittent ditch voids visible from a height of 1,000 to 1,500 feet, the visible ditch void made up less than 50 percent of the ditch length, or the ditch being considered was in deep standing water.

Ditches with intermittent ditch voids and consisting of variable length treatment segments have been categorized as Point Treatment ditches. Ditches were selected as needing point treatment if a discernable ditch void or void segment was visible from a height of 1,000 to 1,500 feet.

Ditch Remediation Implementation

Step 1: Salt Marsh Hay Harvest

The existing salt marsh hay adjacent to the remediation ditch is mowed with a walk-behind mower during the neap tide cycle. The use of a walk-behind mower during the neap tide cycle will not impact the salt marsh hay harvest area.

<u>Step 2: Salt Marsh Hay Placement</u>

The harvested salt marsh hay is braided and placed in the remediation ditch. The braiding process is an integral step to prevent translocation of the organic growing medium during the salt marsh peat regeneration process.

<u>Step 3: Salt Marsh Hay Securement</u>

After placement, the harvested salt marsh hay is secured in place with natural sisal twine and softwood-grade stakes before the next high tide. The sisal twine is pre-soaked in vegetable oil, for a minimum of 24 hours prior to use, to extend its usable lifespan.

<u>Step 4: Repeat Treatments</u>

Steps 1 through 3 should be repeated for several years, until the ditch floor elevation is 20 cm below the surface of the marsh.

<u>Step 5: Sediment Deposition & Plant Recruitment</u>

During the course of a season, sediments filter into the organic growing medium. Smooth cordgrass (*S. alterniflora*) seedlings introduce belowground vegetative structures that regenerate a close match to the salt marsh peat of the surrounding soils.

Ditch Remediation Examples

Goose Rocks Marsh, Rachel Carson National Wildlife Refuge - Kennebunk ME: Remediation Ditch A
The “before” photograph, taken in 2010, shows a deep ditch with crowned slopes adjacent to the ditch.

Goose Rocks Marsh, Rachel Carson National Wildlife Refuge - Kennebunk ME: Remediation Ditch A

This photograph was taken at the end of the second application season. The ditch is fully vegetated and difficult to discern from the surrounding setting.

Goose Rocks Marsh, Rachel Carson National Wildlife Refuge - Kennebunk ME: Remediation Ditch A

This photograph was taken immediately after the third application of braided salt marsh hay was placed in the remediation ditch, prior to securement. The remediation medium is nearing the proposed finish grade. Due to the pronounced slope of the linear subsidence basin, the proposed finish grade is within 10 cm of the marsh ditch edge elevation. Natural plant growth and peat accretion will self-regulate the final grade based on the site-specific growing conditions.

Recommended Equipment for Ditch Remediation

Mowing: Self-propelled Mower

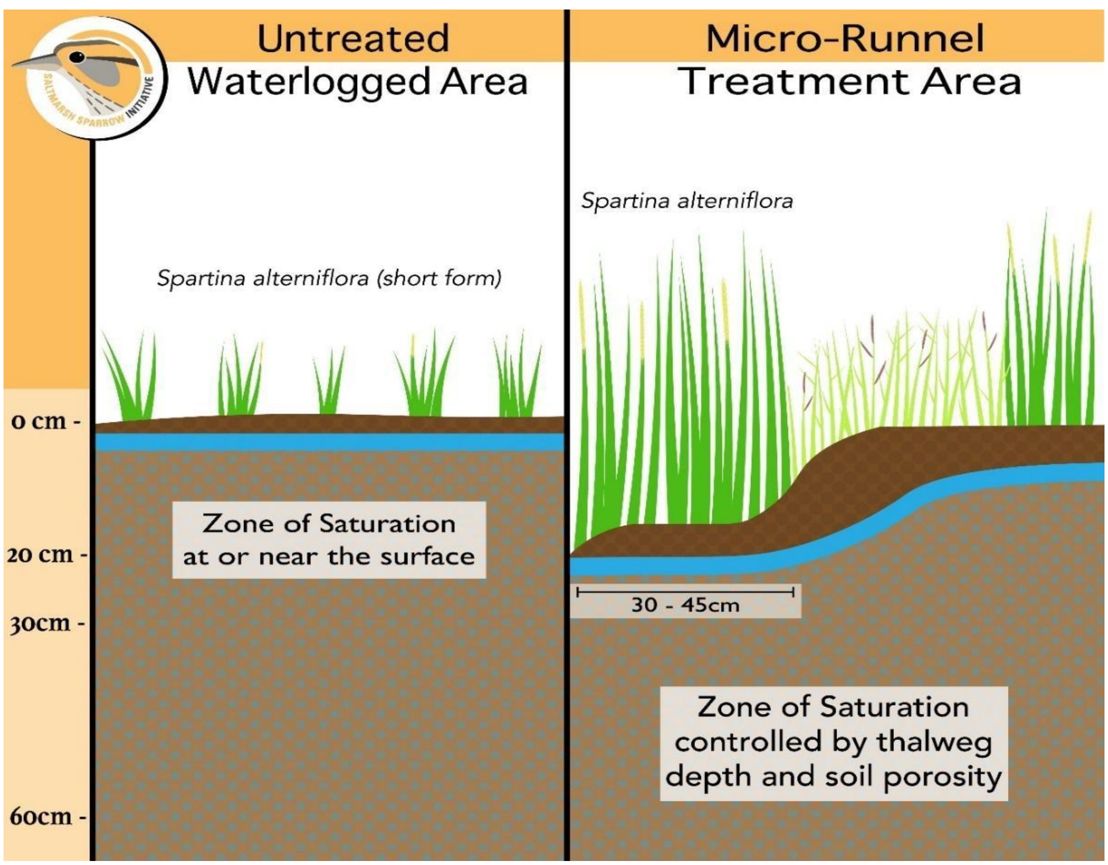
Placement: Hand Rake, Backpack Blower or Hay Rake

Securement: Natural Fiber Sissel Twine and 3- to 4-foot Grade Stakes

Small Channel Hydrology

Tidal channel restoration (TCR) for small channel hydrology is another restoration approach that is part of SMARTeams/4TRM projects. It is a nature-based solution that utilizes the underlying agricultural infrastructure to address the waterlogged subsidence trajectory (WST) in portions of a salt marsh where the existing tidal channel network is not functional. The WST is typically associated with portions of a salt marsh where the sustainable tidal flow is divided between impaired drainage paths. The persistent saturated conditions reduce primary production rates causing a loss of function and vegetative cover, which results in a decline in marsh vegetation, persistent bare soils, and large shallow open waterbodies on the surface of the marsh.

Micro-runnel treatment is the primary focus that is used to restore first order channels, which can re-establish single channel hydrology to portions of a salt marsh that are displaying the WST. This approach results in improved growing conditions and tidal signaling, which intersects and stabilizes the marsh subsidence trajectory, allowing for increased primary production rates and restored function. Typical applications of the micro-runnel technique necessitate the restoration of low order tidal channels, in order to restore connectivity to isolated portions of micro- and sub-tidesheds, as part of an overarching larger tidal channel network. Sustainable profiles and channel capacity for restored channel segments are dependent on spatial variation within the tidal channel network.



Potential tidal channels identified for the restoration of single channel hydrology were located by using aerial images and confirmed during the field verification process. Tidal channels were considered and marked for restoration if there was no clear visible indication of a ditch void present when viewed from a height of 1,000 to 1,500 feet. Tidal channels were excluded from being considered for restoration if there were signs of a ditch void visible from 1,000 to 1,500 feet, or if they were completely within deep standing water with no connection to non-flooded marsh areas (either directly or by connection to another tidal channel). Tidal channels in need of restoration were marked along the sections that had no visible ditch void, in most cases. If an area with no visible ditch void contained segments of small areas with visible ditch voids, the hydrological pathway was considered impaired and the whole length of the tidal channel was marked as in need of restoration.

Agricultural Embankments with Clay Cores

A series of agricultural embankments with clay cores was located within the Smelt Brook project area. The use of clay, tree boughs and 'high land' soils are mentioned frequently in historical journals, as a means of increasing the volume of material available to complete the embankment enclosure process and as a means of increasing the durability of the exterior of the embankment.

In the salt marsh secondary successional process, after a water control structure has failed and the enclosure enters the WST, the clay-cored embankment serves as a low permeability barrier that allows freshwater groundwater to accumulate within the enclosure. The steady supply of freshwater, combined with hydraulic head pressure from the surrounding high ground, can create low salinity pore water within the enclosure. These saturated brackish growing conditions can allow emergent mesophyte plant communities to maintain as the dominant cover type within the enclosure.

When tidal inundation frequencies increase through embankment breaching or sea level rise, the pore water salinity will increase. These increases in tidal exchange can then cause the salinity levels within the enclosure to exceed the tolerances of the brackish plant community. During early stages of this transition process, pore water salinities combined with the higher zone of saturation position within the soil column can maintain salinities that exceed the tolerances of brackish species and create saturated conditions that inhibit the establishment of emergent halophytes. These conditions prevent salt marsh species from spreading into the enclosure as the brackish marsh species are reduced, increasing the percent cover of bare soils and standing water.

The recommended restoration action to stabilize the growing conditions within the enclosure is to control the zone of saturation position in the soil column with the introduction of small channel hydrology. In order to position the zone of saturation at a depth below the marsh surface that is sufficient to prevent invasive species from accessing the lower salinity groundwater under the soil surface, the channel depth entering the enclosure will be at a depth of thirty-inches before tapering to meet the micro-runnel profile of the single channel hydrology network upgradient of the clay-cored embankment.

Discharge from subterranean ditch voids indicates clay-cored embankment use at Smelt Brook Preserve

Photos by G.Wilson

Micro-runnel Examples

Nelson's Island, Parker River National Wildlife Refuge - Rowley MA: Hand-dug Micro-runnel A

A 60-foot micro-runnel was used to restore lateral hydrological connectivity from a linear subsidence basin to the adjacent primary channel. Note the beneficial reuse of the cut materials as structured micro-topography to increase Saltmarsh Sparrow nest site availability.

Crane's Beach Marsh, Crane's Wildlife Refuge - Ipswich MA: Mechanically-dug Runnel B

A long 125-foot micro-runnel was used to establish lateral connectivity between two primary channel segments. The use of the micro-runnel in conjunction with ditch remediation stopped an accelerated oxidative subsidence rate of a 435-foot ditch void adjacent to the creek bank, as well as addressing a two-acre early Decline location.

Recommended Equipment for Small Channel Hydrology (hand tools and a small excavator are used to create micro-runnels)

Hand Spade

Potato Digger

5,000 - 10,000# Class Excavator

Weight Dispersal Matting

Structured Micro-Topography

The Structured Micro-Topography technique (also known as Marsh Habitat Islands) is a nature-based restoration solution that utilizes sediments generated while restoring tidal channels along the excavation pathway.

This beneficial re-use technique can be used to increase nest site availability and reliability for tidal marsh dependent avian species by constructing nesting islands. The final profile and structured design of these nesting islands are based on salt marsh agricultural techniques developed in the 1700-1800s.

The nesting island is constructed by increasing marsh elevation and creating a mound using peat soils, with a specific form that achieves increased plant productivity. Location of the island on the landscape is based on the distance from an excavation pathway, usually established within two to ten feet from a runnel on either side. Final placement is determined during implementation based on site specific conditions, in order to blend into the location so as not to become a predator sink.

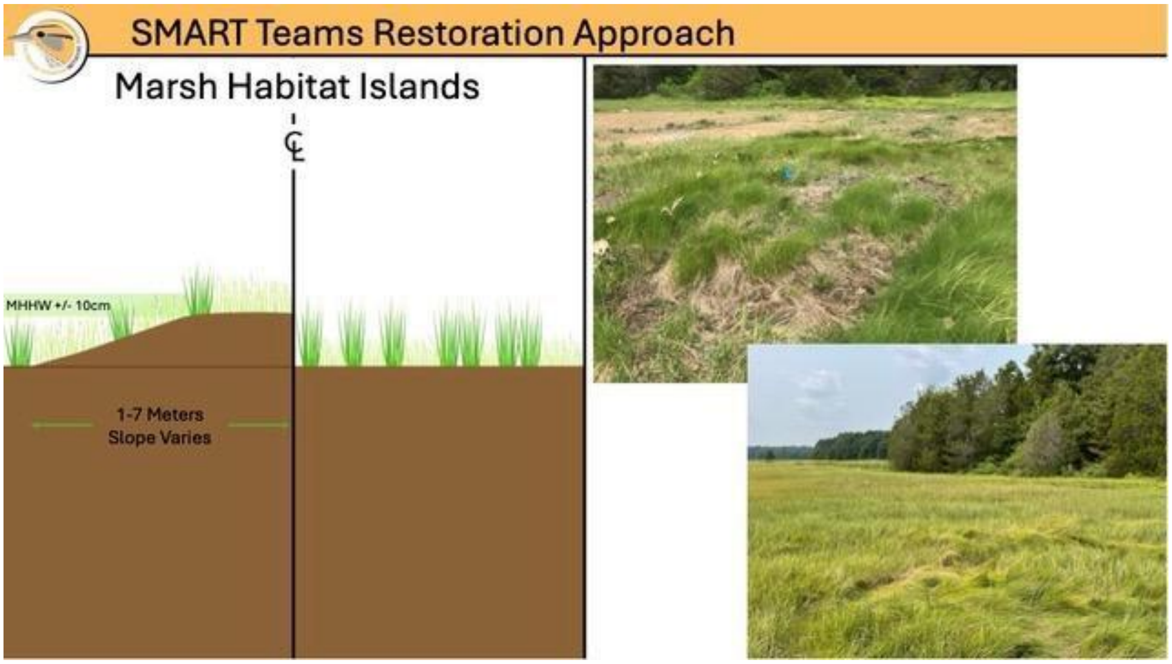
Typical applications of this technique are a beneficial re-use for peat soils generated during the Tier 1 platform hydrology stabilization and the Tier 2 surface hydrology enhancement activities of the Salt Marsh Adaptation and Resiliency Teams' 4-Tiered Restoration Model (SMARTeams/4TRM). Size and finished grade elevations vary based on material availability, plant species requirements, and tidal marsh target species requirements.

Site specific parameters regarding structured micro-topography will be determined on-site during implementation.

Structured Micro-Topography
Parker River National Wildlife Refuge
May 23, 2019

Structured Micro-Topography
Parker River National Wildlife Refuge
August 17, 2020

Delineation of Structured Micro-Topography
by S. Adamowicz, PhD of the Rachel Carson
National Wildlife Refuge



Saltmarsh Sparrow Recovery Strategy

The foundation of the Salt Marsh Adaptation and Resiliency Teams' Saltmarsh Sparrow Recovery Strategy (SMARTeams/SSRS) is the SMARTeams' 4-Tiered Restoration Model described above. Stabilizing and restoring a parallel salt marsh successional trajectory relative to sea level, by using the existing historical salt marsh agricultural infrastructure, will reduce the continued loss of elevation. After the salt marsh elevation has been stabilized, and recovering the elevations lost by legacy impairments, additional wildlife management considerations can then be included in the design process.

The Saltmarsh Sparrow is the only species of bird that is endemic to the east coast of the United States. Saltmarsh Sparrow populations have been declining by nine percent annually since the early 1990's, resulting in the species being listed as Endangered in the State of Maine, as well as Special Concern in the States of New Hampshire and Massachusetts. The decline in this species is thought to be due to a combination of salt marsh subsidence and the increased frequency of storm tides that result in nest failure. To address these concerns, the primary short-term strategy is to increase nest site availability at higher marsh elevations for a 20-to-30-year management period, which will allow the species to persist in the landscape while the natural accretion process restores marsh elevations relative to local sea levels. The proposed nesting islands cannot be built to an elevation where they lose habitat viability resulting from predation, however, and this will limit their longevity due to sea level rise. Managing for longer term accelerated accretion to increase productivity rates would expand high quality habitats in the high marsh within 15 to 20 years, in advance of sea level rise reaching the elevations of the nesting islands.

SMARTeams/SSRS New England Initiative Standards

1. Saltmarsh Sparrow (*Ammospiza caudacuta*) is an avian salt marsh specialist species that successfully forages in a diversity of habitats found in salt marshes throughout its range.
2. Subsidence created by historical salt marsh impairments, compounded by climate change, have reduced the stability of salt marshes as a breeding habitat for this species.
3. Lack of reproductive success is largely responsible for the sudden decline in the species population throughout its range. Two commonly identified sources for nest failure appear to be habitat driven causes created by legacy land use impairments.

a. Nest Inundation: Portions of salt marshes throughout the Saltmarsh Sparrow's breeding range have subsided due to prior land-use practices, causing flooding of nesting areas and making these locations less reliable for nesting success.
b. Nest Depredation: Legacy impairments reduce marsh productivity in much of the high marsh portions of salt marshes. This loss of aboveground biomass production is directly proportional to stem density and stem length of the existing salt marsh vegetation. In locations where vegetation is sparse, the available nesting habitat for Saltmarsh Sparrows is reduced in both vertical structural support and concealment cover.

4. Currently, range-wide extirpation for the Saltmarsh Sparrow is estimated to occur in 20-30 years. To improve the ability of the species to survive in the wild, there is a need to maintain the population in multiple locations throughout the species' range.
5. Research indicates that this species has high nest site fidelity and tends to identify nesting sites that are higher in elevation than the surrounding marsh elevations, including on man-made agricultural embankments.
6. One possible solution to extend the species extirpation horizon in specific areas is to identify their existing probable and potential breeding locations, and increase the availability of high-quality, high marsh habitat in those areas with the use of structured micro-topography. Successfully enhancing and increasing the species' available nesting sites, in consideration of Saltmarsh Sparrow's strong natal fidelity, will develop, enhance, or extend source populations to maintain species distribution within the landscape. Planning for and providing higher-in-elevation nesting sites that maintain high aboveground biomass productivity will increase successful first year recruitment rates, stabilizing and increasing the population for a specific location.
7. An expanded application of this effort can include using structured micro-topography in portions of marshes favorable for the species that currently have only minor breeding populations. By increasing high quality nest site availability, first year recruitment in these minor population locations will increase to establish additional stabilized source population locations.

Saltmarsh sparrow Photo by G.Wilson

Saltmarsh Sparrow Recovery in the York River - Smelt Brook Salt Marsh

The Saltmarsh Sparrow Recovery Strategy for York River – Smelt Brook Salt Marsh Restoration Project is outlined below:

- There are breeding populations of Saltmarsh Sparrow and Nelson's Sparrow in the York River and Smelt Brook marshes with some locations that are known and, potentially, others that are unknown.
- Traditionally, the reclamation embankment systems used by salt hay farmers in the 1800-1900s were in the high meadow portions of salt marshes. Spatially, high meadow locations contain the high-quality high marsh habitat documented as preferred areas for Saltmarsh Sparrows' breeding.
- Focusing in on the highest probability locations, which are in the early and late Decline stages, should mean that the marsh elevations within that subset of reclamation embankment enclosures have potentially maintained their elevation as the highest and driest portions of the salt marsh. Out of all the identified locations in the highest probability areas, the early and late Decline stage locations have the greatest probability to currently support a population of Saltmarsh Sparrows.
- Stabilizing single channel hydrology in reclamation embankment enclosures that are in the early and late Decline stages will maintain current elevations. Addressing the legacy impairments will start to increase marsh elevations within reclamation embankment enclosures through the natural accretion process.
- Adding structured micro-topography islands to reclamation enclosures within the early and late Decline stages will offer the greatest potential for increasing Saltmarsh Sparrow high quality nesting habitat within the York River and Smelt Brook focus areas. By increasing first year recruitment and nesting success, these portions of the York River - Smelt Brook Salt Marsh can become, or will continue to serve as, source populations for Saltmarsh Sparrows.
- These proposed nesting islands must be limited in elevation height so as to maintain habitat viability and not be exposed to increased predation risk.
- This approach is modeled after the Furbish Salt Marsh Restoration Project at Rachel Carson National Wildlife Refuge in Wells, Maine.

Female Nelson's sparrow Photo by G.Wilson

Vegetation Management

Vegetation data was collected during field investigations conducted in the 2024-2025 growing seasons. Data included were the inventoried agricultural infrastructure and impairments.

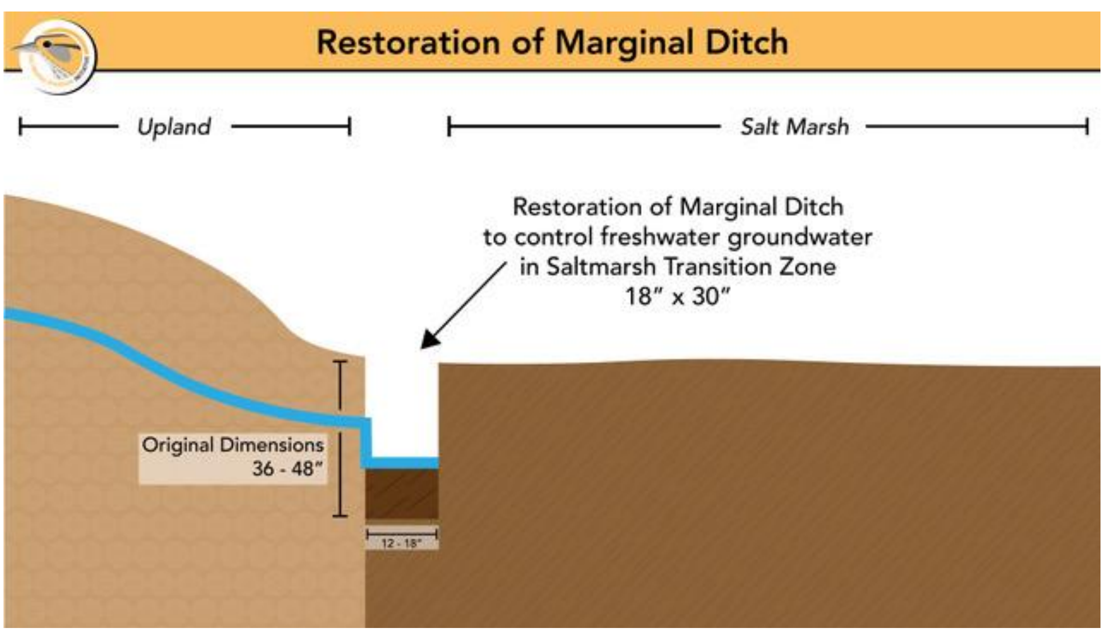
Mega-pool Subsidence Basins

Mega-pool subsidence basins are portions of the marsh that are displaying growing conditions associated with Decline stages of the waterlogged subsidence trajectory. Intersecting the waterlogged subsidence trajectory prior to the formation of, or expansion of, a mega-pool subsidence basin can avoid the marsh collapse process from causing further losses in surface elevations. Mega-pool subsidence basins have been identified within the Smelt Brook Preserve Project Area 2; these are notably larger and more persistent as a result of being held in succession due to the presence of clay-cored embankments.

Phragmites Management Strategies

Phragmites (*P. australis*) is a vegetation species that requires special consideration, as it is an invasive plant species that needs to be controlled. As part of Tier 4 of SMARTeams/4TRM, long-term management strategies will address the presence of Phragmites, reduce future encroachments into the salt marsh (where applicable), and plan for marsh migration. Both tidal water salinity and soil porewater salinity can be controlling factors for Phragmites persistence and expansion in a salt marsh. The presence of freshwater may cause lower groundwater salinity within the voids between soil particles (porewater), which can allow Phragmites to persist in the salt marsh even when flooded by higher salinity tidewater. This is due to marsh soils remaining lower in salinity within the Phragmites active rhizosphere, as a result of the freshwater influence from the groundwater. To prevent this, restoration approaches involve reestablishing marginal ditching to drain groundwater (freshwater) from Phragmites areas.

In locations where salt marsh reclamation embankment practices have terraced the landscape, it is recommended to restore tidal channel connectivity within the upper embankment enclosure in order to increase soil salinity and reduce Phragmites vigor in the adjacent marsh terraces. Restoring the marginal ditch, in combination with restoring single channel hydrology in the salt marsh, will increase marsh salinity by directing groundwater to exit the salt marsh along the margins, allowing tidal waters to have a greater influence in the marsh interior. Increasing the salt marsh porewater salinity will cause Phragmites to reduce in vigor and retract towards higher elevation areas. Marginal ditch restoration is accomplished in accordance with the diagram below.



In tidal waters with predominate salinity ranges of 15 to 22 ppt (parts per thousand), Phragmites can establish in portions of the marsh under certain conditions without freshwater groundwater influence. These conditions require the zone of saturation to be more than 20 cm below the surface of the marsh with the location having direct access to a brackish tidal water source, such as along a creek bank or a pool edge, with a flooding frequency that abates hyper-salination. Under these conditions, the low salinity tidal waters reduce the ability for evapotranspiration to increase soil salinity and soil sulfides beyond the tolerance of Phragmites. In certain brackish marsh areas, narrow-leaved cattail (*Typha angustifolia*) and a variety of sedges (*Carex* spp.) that thrive in saturated growing conditions can outcompete Phragmites in saturated brackish conditions. These saturated locations tend to have porewater salinity ranges of 8 to 15 ppt and the saturated condition needs to be no more than 5 to 10 cm below the marsh surface.

For the treatment of Phragmites within brackish marsh areas, a Tier 4 adaptive management approach is recommended. While brackish groundwater is sufficient to support brackish vegetation, under saturated brackish conditions native vegetation species will outcompete Phragmites. Soil saturation within the root zone shall be maintained by not expanding existing tidal channel networks. Under these conditions, ditch remediation may be necessary in certain locations to maintain and increase soil saturation in the brackish marsh areas. As sea level rise influences the brackish marsh areas, porewater salinities will transition to greater than 15 to 20 ppt and brackish vegetation will decline. In the later adaptive management phase, as brackish conditions decline, salt marsh conditions will be advanced by restoring small channel hydrology from adjacent areas of the marsh with higher tidal water salinity content by adding brackish ditch extensions. Small channel hydrology will be established by advancing single channel hydrology within the former brackish marsh saturated areas, which will lower the zone of saturation to a maximum depth of 20 cm below the surface of the marsh and facilitate halophyte colonization.

Recently killed trees are indication of sea level rise - Edkins Parcel

Existing phragmites causes potential risk in breaching clay-cored embankment enclosures - Smelt Brook Preserve

Photos by G.Wilson

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Edkins Parcel Photo by G.Wilson

Appendix A

Project-Specific Documentation

Plan Sheets Directory

York River - Smelt Brook Salt Marsh Restoration Project
Site Assessment and Preliminary Design Report

Overview Series

Sheet Overview-A	Project Areas and Ownership
Sheet Overview-B	Watershed Map
Sheet Notes	Data Sources & Sheet Notes

Project Sheet Series

Each project area is coded with a sheet series number and each project area sheet series has four plan sheets.

USFWS – Edkins Parcel (±28 acres)

Project Area 1 (partial)

Sheet 1-1	Lot Identification and Topography
Sheet 1-2	Existing Conditions Plan
Sheet 1-3	Proposed Actions Plan
Sheet 1-4	Proposed Conditions Plan (Single Channel Hydrology)

York Land Trust – multiple preserves and parcels (±104 acres)

Project Area 1 (partial) – First Parish parcels

Sheet 1-1	Lot Identification and Topography
Sheet 1-2	Existing Conditions Plan
Sheet 1-3	Proposed Actions Plan
Sheet 1-4	Proposed Conditions Plan (Single Channel Hydrology)

Project Area 2 – Smelt Brook Preserve

Sheet 2-1	Lot Identification and Topography
Sheet 2-2	Existing Conditions Plan
Sheet 2-3	Proposed Actions Plan
Sheet 2-4	Proposed Conditions Plan (Single Channel Hydrology)

Project Area 3 – Smelt Brook Preserve

Sheet 3-1	Lot Identification and Topography
Sheet 3-2	Existing Conditions Plan
Sheet 3-3	Proposed Actions Plan
Sheet 3-4	Proposed Conditions Plan (Single Channel Hydrology)

Project Area 4 – Smelt Brook Preserve and Near Point Preserve

Sheet 4-1	Lot Identification and Topography
Sheet 4-2	Existing Conditions Plan
Sheet 4-3	Proposed Actions Plan
Sheet 4-4	Proposed Conditions Plan (Single Channel Hydrology)

Coding System

Data Set Compilations

Data sets for each series location are provided in a separate electronic data file, including agricultural infrastructure (early and late period embankments), tidal channel networks, tidal channel restoration (early and late successional, brackish, and phragmites), and ditch remediation (linear and point treatment).

AI = Agricultural Infrastructure

EPE = Early Period Embankment

LPE = Late Period Embankment

TCN = Tidal Channel Network (Single Channel Hydrology)

TCR = Tidal Channel Restoration

ES = Early Successional

LS = Late Successional

Brackish = Brackish

Phrag = Phragmites

DR_LT = Ditch Remediation Linear Treatment

DR_PT = Ditch Remediation Point Treatment

Site Descriptions

Edkins Parcel/USFWS (±28 acres) – Project Area 1

Agricultural infrastructure (including early period and late period embankments) is shown on Sheet 1-2.

Late successional and early successional tidal channel restoration locations are shown on Sheet 1-3:

- Late successional tidal channel restoration lengths: there are 30 tidal channels with a total treatment length of 1,552 feet.
- Early successional tidal channel restoration lengths: there are 21 tidal channels with a total treatment length of 1,619 feet.
- Combined tidal channel restoration treatment length of 3,171 feet provides:
  - beneficial re-use volume (estimated soil material) = 117 cubic yards
  - structured micro-topography (estimated # islands) = 78 islands

Ditch remediation linear treatment and point treatment ditches are shown on Sheet 1-3:

- Linear treatment ditch lengths: there are 18 ditches with a total treatment length of 1,065 feet.
- Point treatment ditch lengths: there are 24 ditches with a total treatment length of 1,184 feet.

Invasive phragmites vegetation communities are shown on Sheets 1-3 and 1-4. There are two treatment ditches proposed within an existing phragmites stand for a total of 155 linear feet.

Restored tidal channel networks are shown on Sheet 1-4 (total length of 23,282 feet).

Smelt Brook Preserve, Near Point Preserve, First Parish/York Land Trust (±104 acres) – Project Areas 1, 2, 3, and 4

Agricultural infrastructure (including early period, late period and clay-cored embankments) is shown on Sheet 2 for each project area.

Late successional and early successional tidal channel restoration locations are shown on Sheet 3 for each project area:

- Late successional tidal channel restoration lengths: there are 96 tidal channels with a total treatment length of 17,511 feet.
- Early successional tidal channel restoration lengths: there are 49 tidal channels with a total treatment length of 4,244 feet.
- Combined tidal channel restoration treatment length of 21,755 feet provides:
  - beneficial re-use volume (estimated soil material) = 806 cubic yards
  - structured micro-topography (estimated # islands) = 537 islands

Ditch remediation linear treatment and point treatment ditches are shown on Sheet 3 for each project area:

- Linear treatment ditch lengths: there are 55 ditches with a total treatment length of 1,782 feet.
- Point treatment ditch lengths: there are 34 ditches with a total treatment length of 840 feet.

Invasive phragmites vegetation communities are shown on Sheets 3 and 4 for each project area. There are eight treatment ditches proposed within existing phragmites stands for a total of 1,820 linear feet. An additional 4,985 linear feet of future treatment ditches are proposed within brackish areas.

Restored tidal channel networks are shown on Sheet 4 for each project area (total length of 67,389 feet).

Area of subsidence - Edkins Parcel Photo by G.Wilson

York River-Smelt Brook
Salt Marsh Restoration Project

Northeast Wetland Restoration
17 Keay Road, Berwick, ME, 03901
207-252-4841

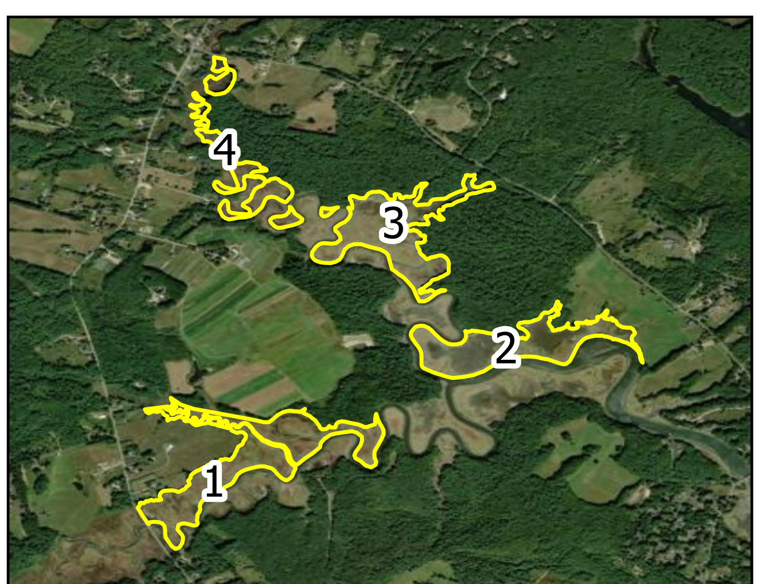
York, ME
August 27th, 2025

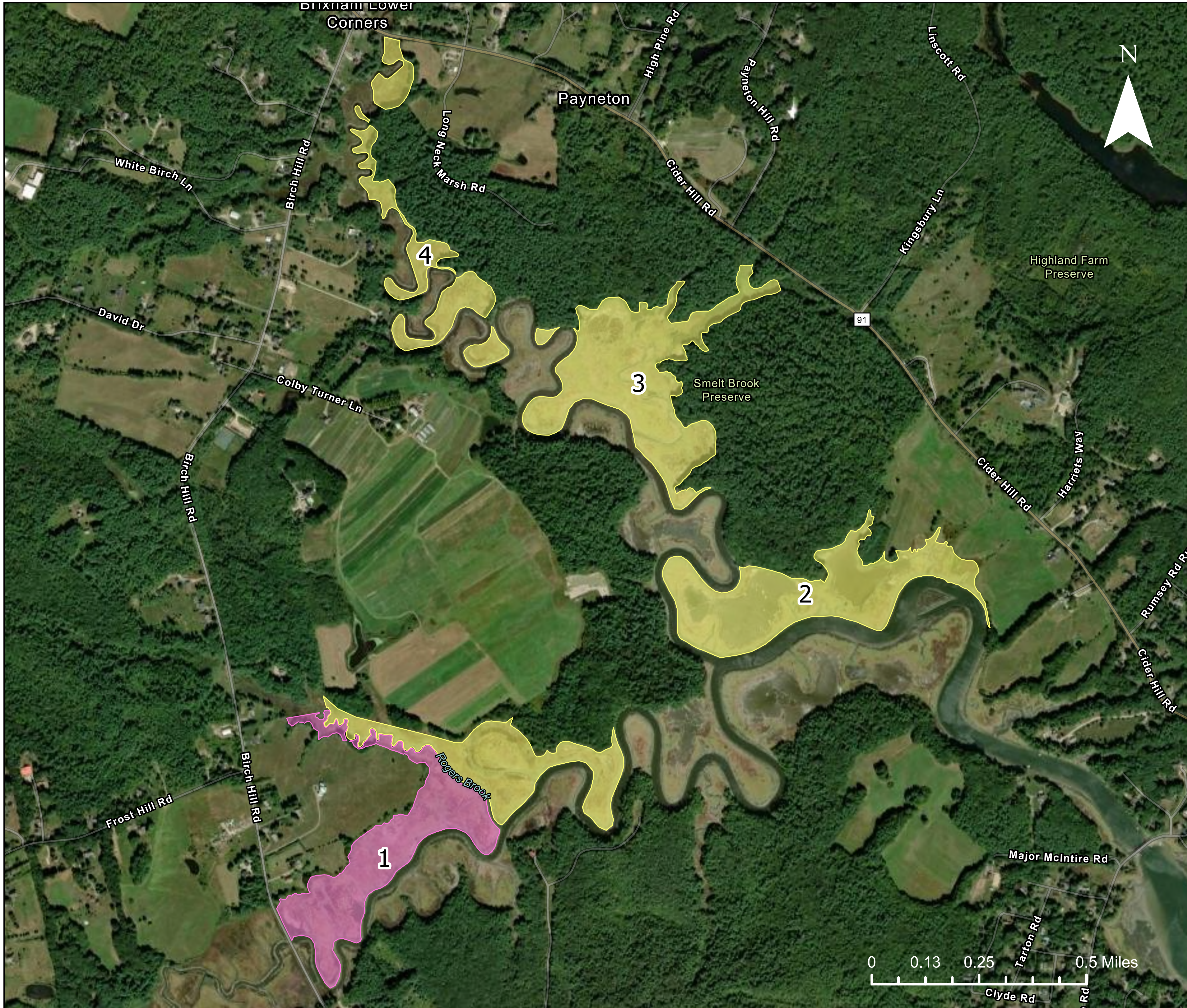
Overview
Project Areas and Ownership
Sheet Overview-A

Legend

Project Area and Ownership

- Edkins (USFWS), 28 ac
- Smelt Brook Preserve First Parish and Near Point Preserve (York Land Trust), 104 ac





York River-Smelt Brook Salt Marsh Restoration Project

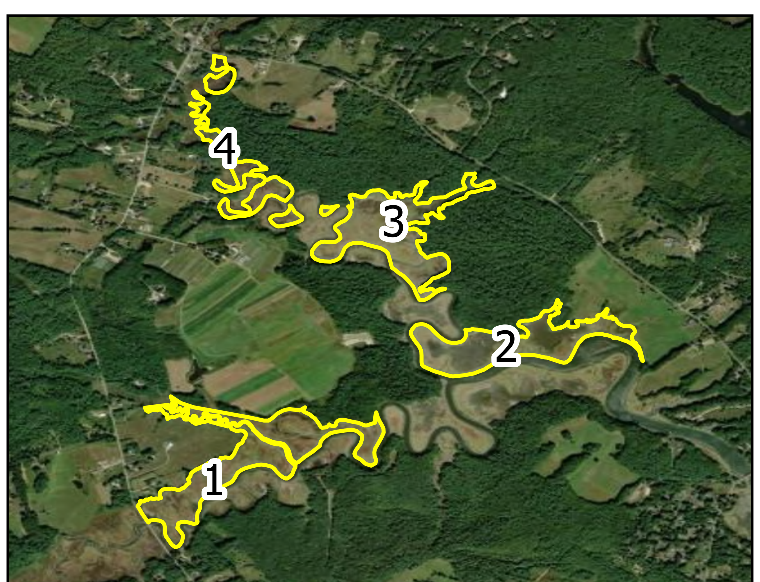
Northeast Wetland Restoration
17 Keay Road, Berwick, ME, 03901
207-252-4841

York, ME
August 27th, 2025

Overview
Watershed Map
Sheet Overview-B

Legend

Project_Areas
Watershed Boundary (HUC12)



York River-Smelt Brook
Salt Marsh Restoration Project

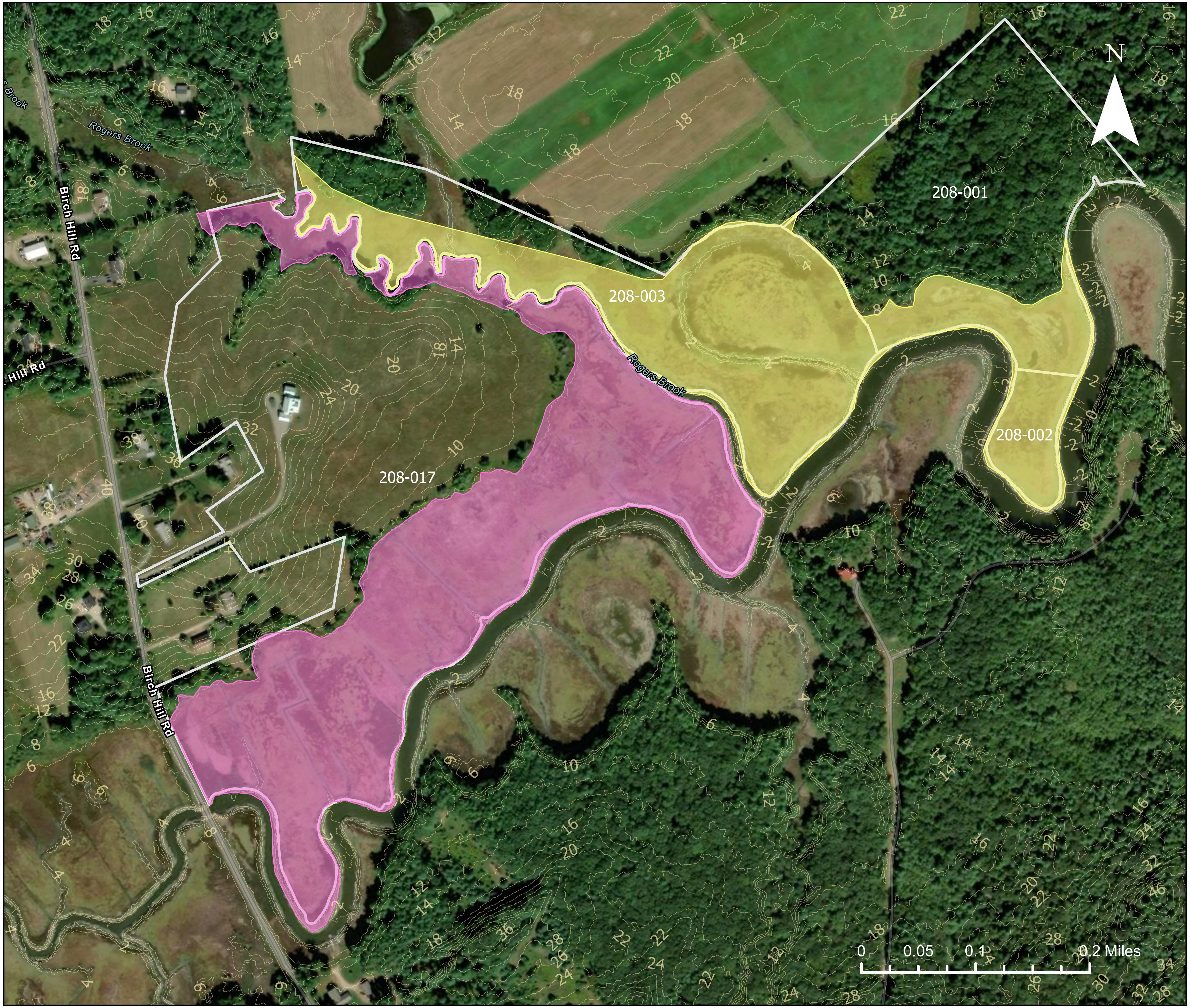
Northeast Wetland Restoration
17 Keay Road, Berwick, ME, 03901
207-252-4841

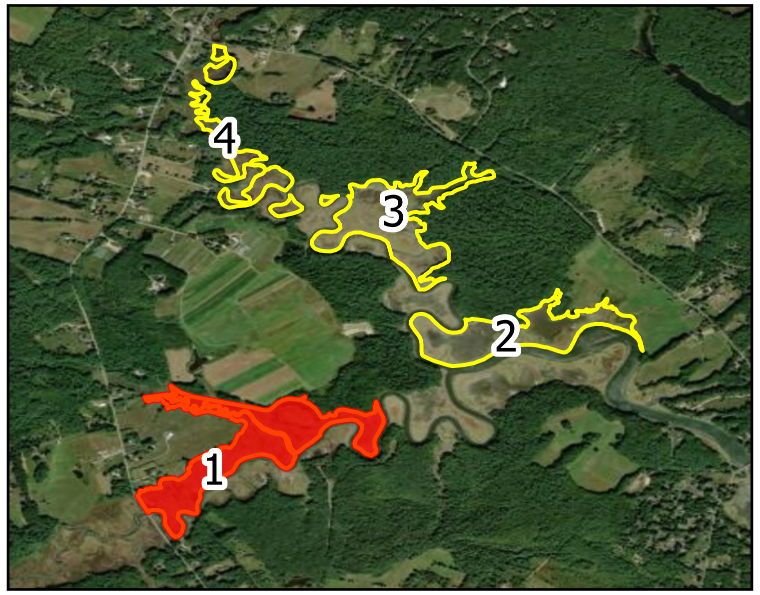
York, ME
August 27th, 2025

Project Area 1
Lot Identification and Topography
Sheet 1-1

Legend

Contours (2 ft)
Tax parcels
Project Area and Ownership
Edkins (USFWS)
First Parish (York Land Trust)





York River-Smelt Brook
Salt Marsh Restoration Project

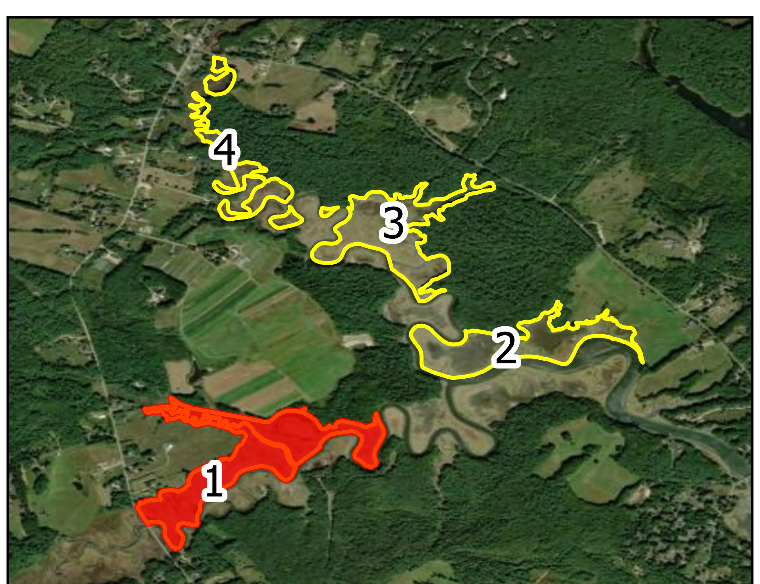
Northeast Wetland Restoration
17 Keay Road, Berwick, ME, 03901
207-252-4841

York, ME
August 27th, 2025

Project Area 1
Existing Conditions Plan
Sheet 1-2

Legend

Agricultural Infrastructure
- Early Period Embankments
- Late Period Embankments
- Clay Cored Embankments



York River-Smelt Brook Salt Marsh Restoration Project

Northeast Wetland Restoration
17 Keay Road, Berwick, ME, 03901
207-252-4841

York, ME
August 27th, 2025

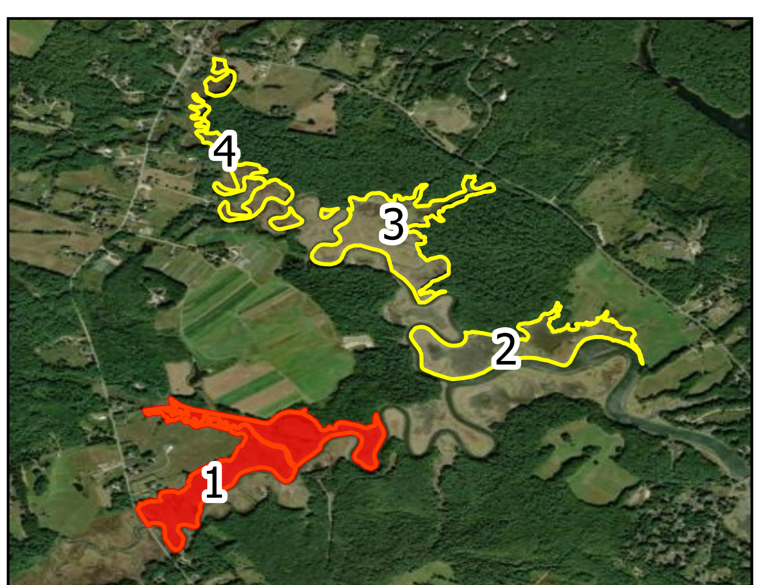
Project Area 1
Proposed Actions Plan
Sheet 1-3

Legend

Proposed Ditch Remediation
- Linear Treatment
- Point Treatment

Proposed Phragmites Control
- Brackish Ditch
- Marginal Ditch
- Phragmites Control Areas

Proposed Tidal Channel Restoration
- Late Successional
- Early Successional



York River-Smelt Brook Salt Marsh Restoration Project

Northeast Wetland Restoration
17 Keay Road, Berwick, ME, 03901
207-252-4841

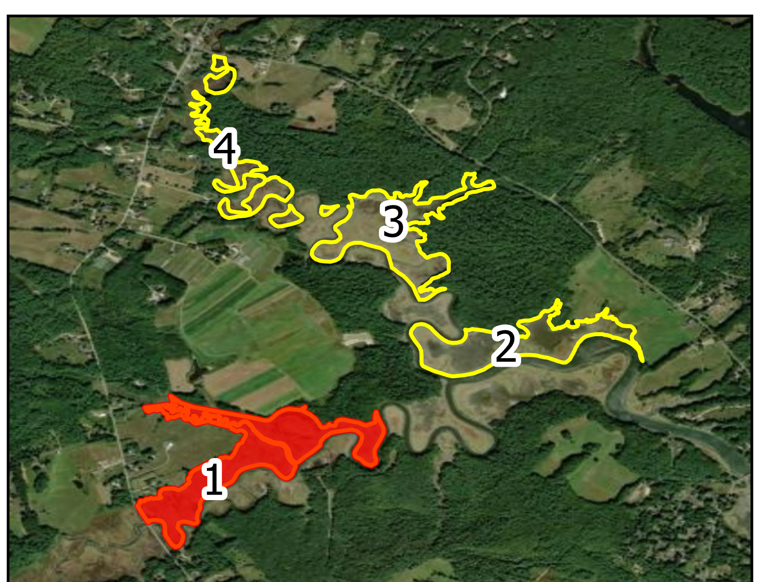
York, ME
August 27th, 2025

Project Area 1
Proposed Conditions Plan (Single Channel Hydrology)
Sheet 1-4

Legend

Tidal Channel Network
- Tidal Channel Network

Proposed Phragmites Control
- Brackish Ditch
- Marginal Ditch
- Phragmites Control Areas



York River-Smelt Brook Salt Marsh Restoration Project

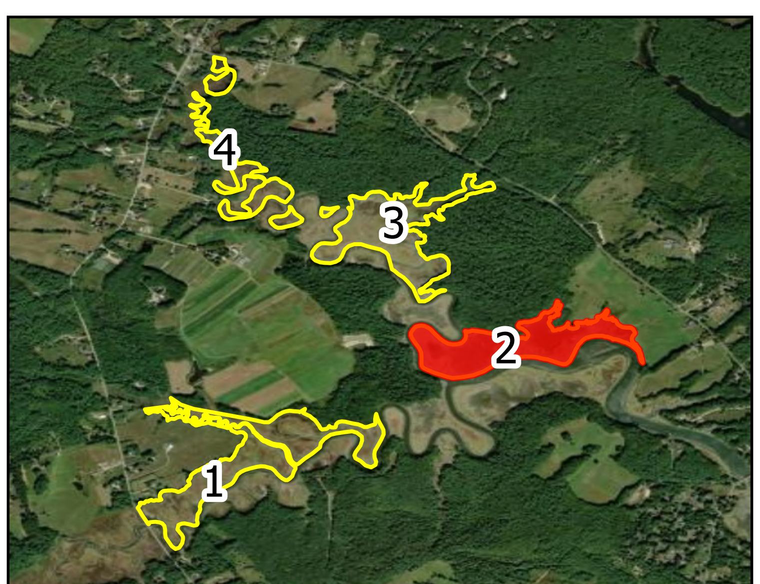
Northeast Wetland Restoration
17 Keay Road, Berwick, ME, 03901
207-252-4841

York, ME
August 27th, 2025

Project Area 2
Lot Identification and Topography
Sheet 2-1

Legend

Contours (2 ft)
Tax parcels
Project Area and Ownership
Edkins (USFWS)
Smelt Brook Preserve (York Land Trust)



York River-Smelt Brook Salt Marsh Restoration Project

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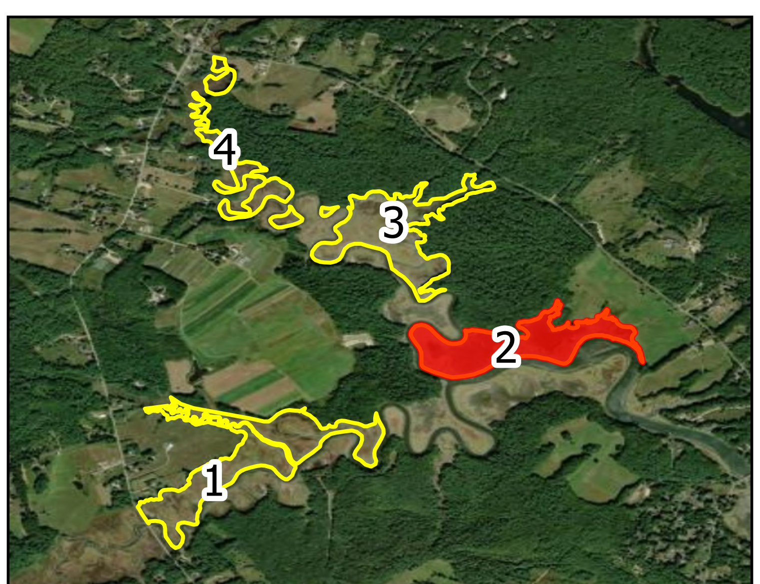
17 Keay Road, Berwick, ME, 03901
207-252-4841

York, ME
August 27th, 2025

Project Area 2
Existing Conditions Plan
Sheet 2-2

Legend

Agricultural Infrastructure
- Early Period Embankments
- Late Period Embankments
- Clay Cored Embankments



York River-Smelt Brook
Salt Marsh Restoration Project

Northeast Wetland Restoration
17 Keay Road, Berwick, ME, 03901
207-252-4841

York, ME
August 27th, 2025

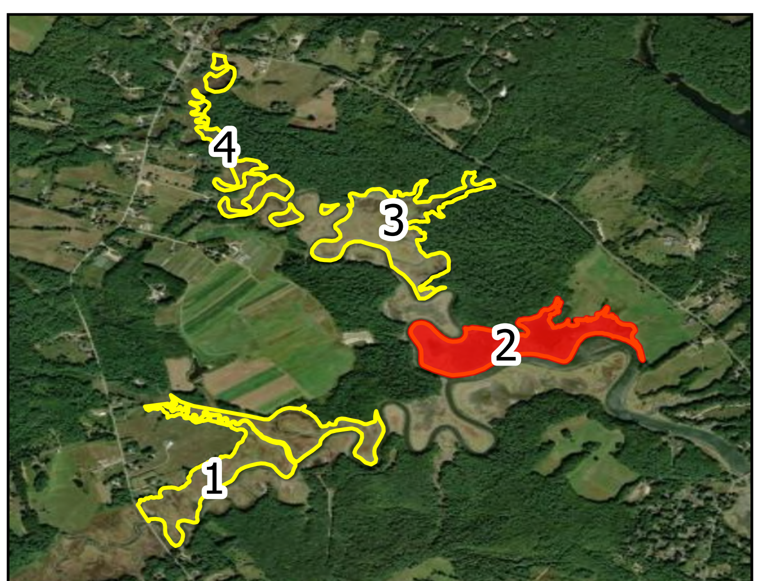
Project Area 2
Proposed Actions Plan
Sheet 2-3

Legend

Proposed Ditch Remediation
- Linear Treatment
- Point Treatment

Proposed Phragmites Control
- Brackish Ditch
- Marginal Ditch
- Phragmites Control Areas

Proposed Tidal Channel Restoration
- Late Successional
- Early Successional



York River-Smelt Brook Salt Marsh Restoration Project

Northeast Wetland Restoration
17 Keay Road, Berwick, ME, 03901
207-252-4841

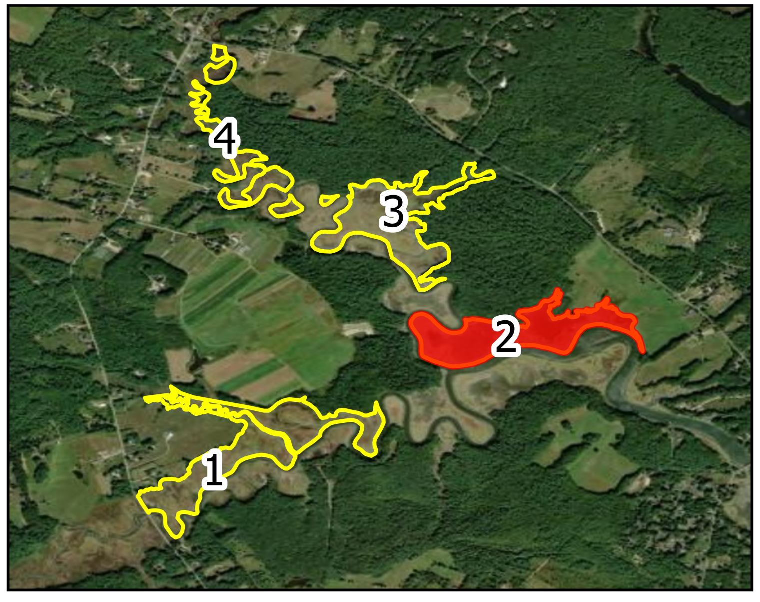
York, ME
August 27th, 2025

Project Area 2
Proposed Conditions Plan (Single Channel Hydrology)
Sheet 2-4

Legend

Tidal Channel Network
- Tidal Channel Network

Proposed Phragmites Control
- Brackish Ditch
- Marginal Ditch
- Phragmites Control Areas



York River-Smelt Brook Salt Marsh Restoration Project

Northeast Wetland Restoration
17 Keay Road, Berwick, ME, 03901
207-252-4841

York, ME
August 27th, 2025

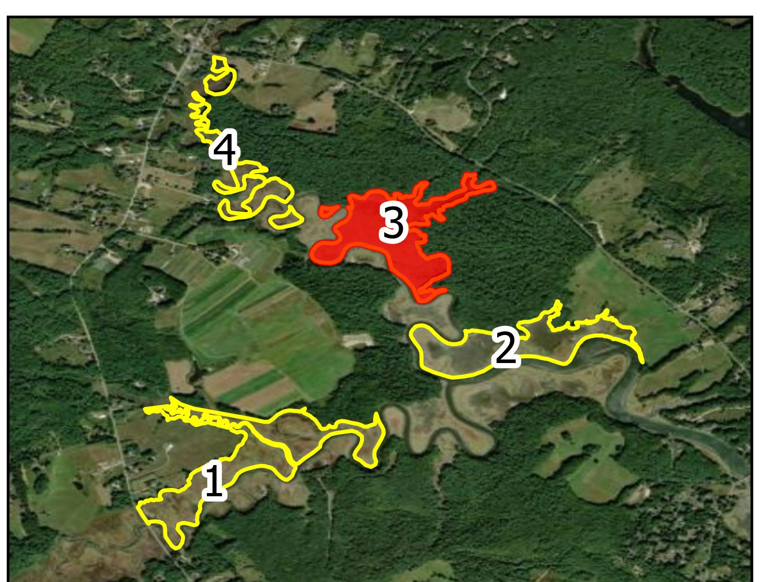
Project Area 3
Lot Identification and Topography
Sheet 3-1

Legend

- Contours (2 ft)
- Tax parcels

Project Area and Ownership

- Edkins (USFWS)
- Smelt Brook Preserve (York Land Trust)



York River-Smelt Brook Salt Marsh Restoration Project

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17 Keay Road, Berwick, ME, 03901
207-252-4841

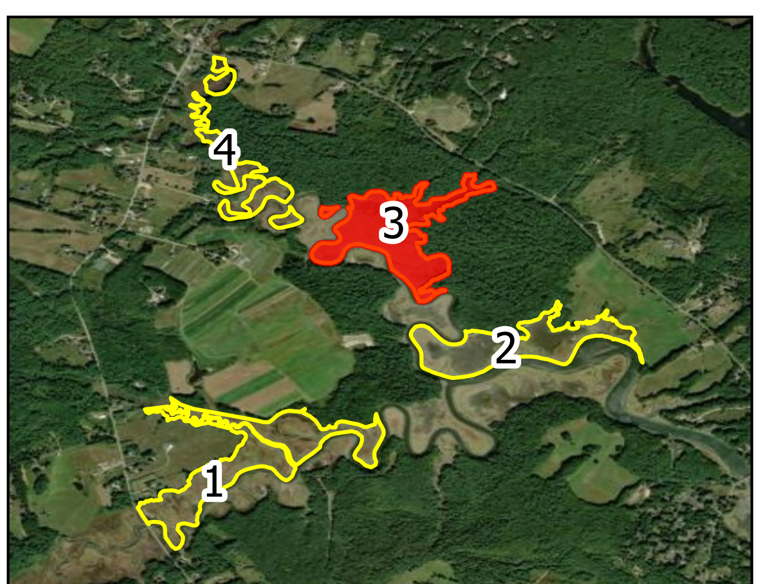
York, ME
August 27th, 2025

Project Area 3
Existing Conditions Plan
Sheet 3-2

Legend

Agricultural Infrastructure

- Early Period Embankments
- Late Period Embankments
- Clay Cored Embankments



York River-Smelt Brook Salt Marsh Restoration Project

Northeast Wetland Restoration
17 Keay Road, Berwick, ME, 03901
207-252-4841

York, ME
August 27th, 2025

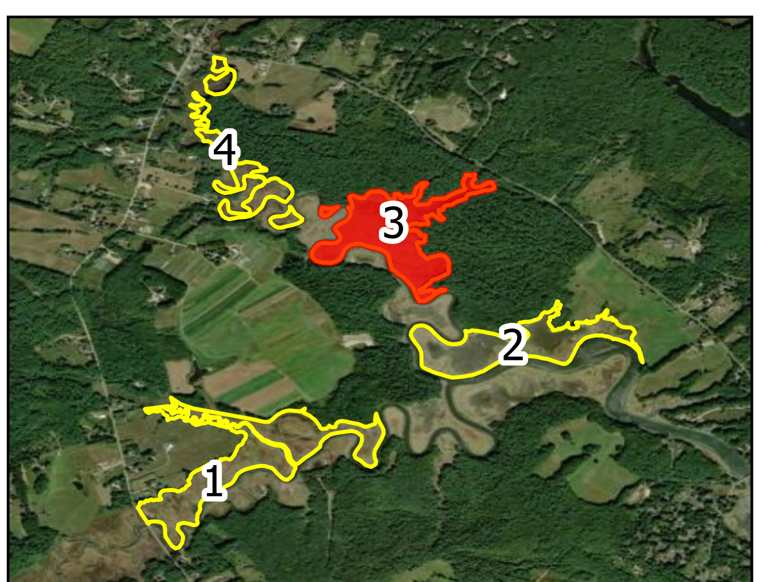
Project Area 3
Proposed Actions Plan
Sheet 3-3

Legend

Proposed Ditch Remediation
- Linear Treatment
- Point Treatment

Proposed Phragmites Control
- Brackish Ditch
- Marginal Ditch
- Phragmites Control Areas

Proposed Tidal Channel Restoration
- Late Successional
- Early Successional



York River-Smelt Brook Salt Marsh Restoration Project

Northeast Wetland Restoration
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207-252-4841

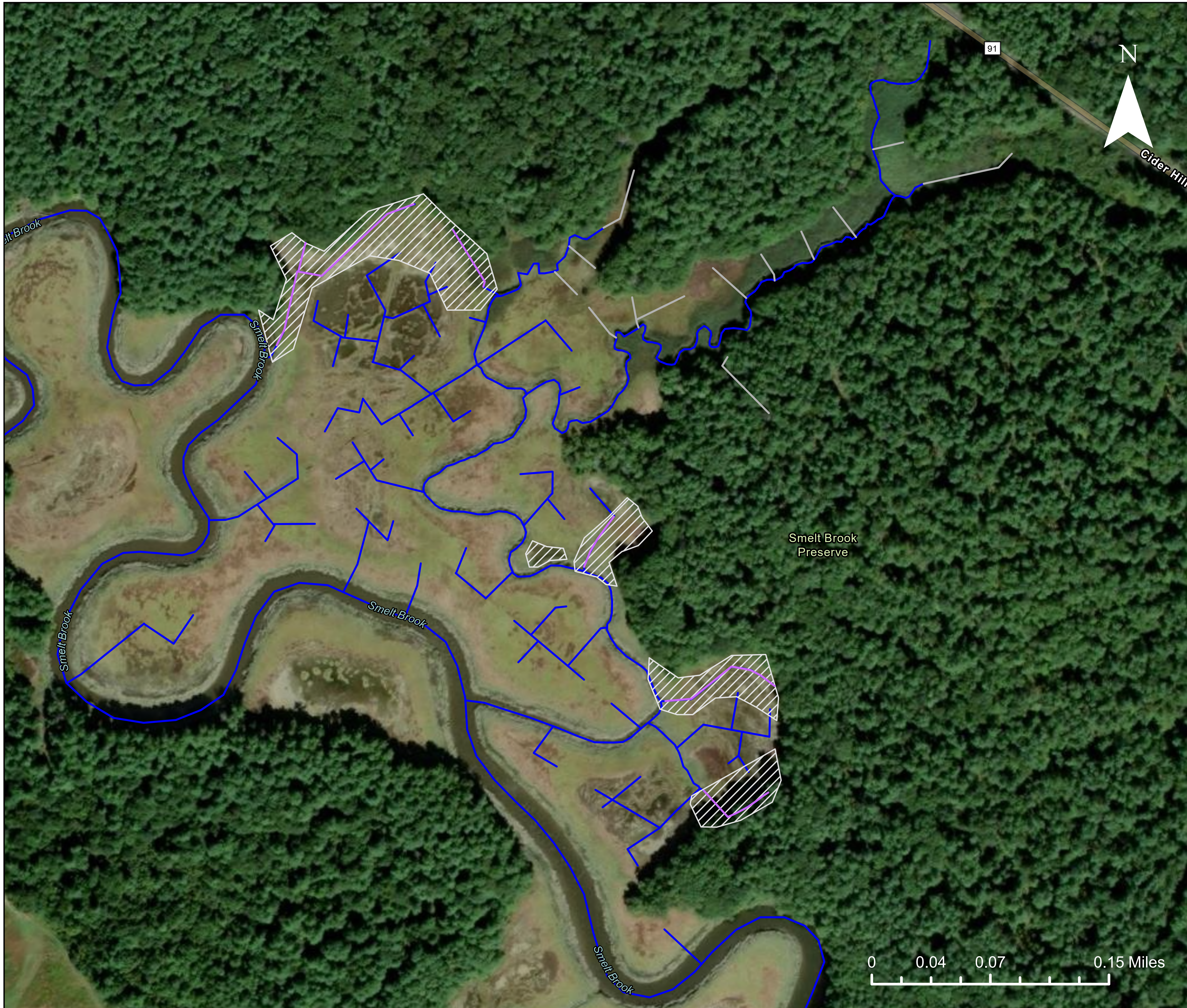
York, ME
August 27th, 2025

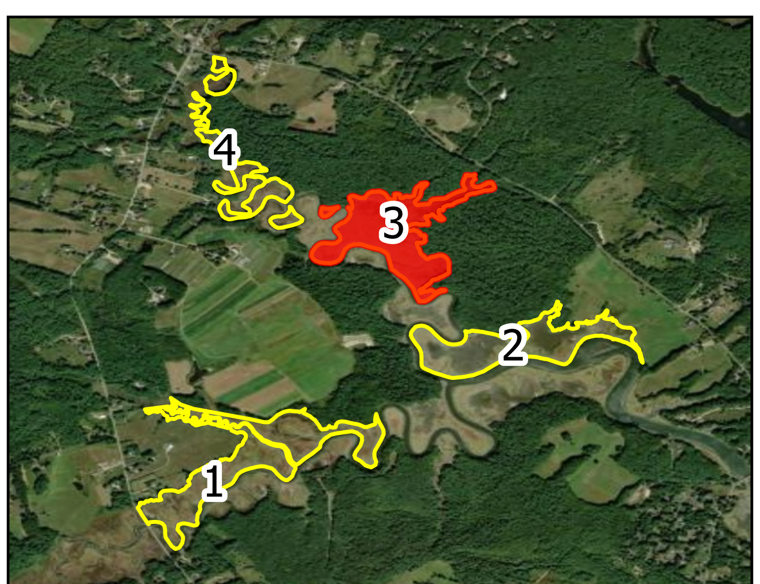
Project Area 3
Proposed Conditions Plan (Single Channel Hydrology)
Sheet 3-4

Legend

Tidal Channel Network
- Tidal Channel Network

Proposed Phragmites Control
- Brackish Ditch
- Marginal Ditch
- Phragmites Control Areas





York River-Smelt Brook Salt Marsh Restoration Project

Northeast Wetland Restoration
17 Keay Road, Berwick, ME, 03901
207-252-4841

York, ME
August 27th, 2025

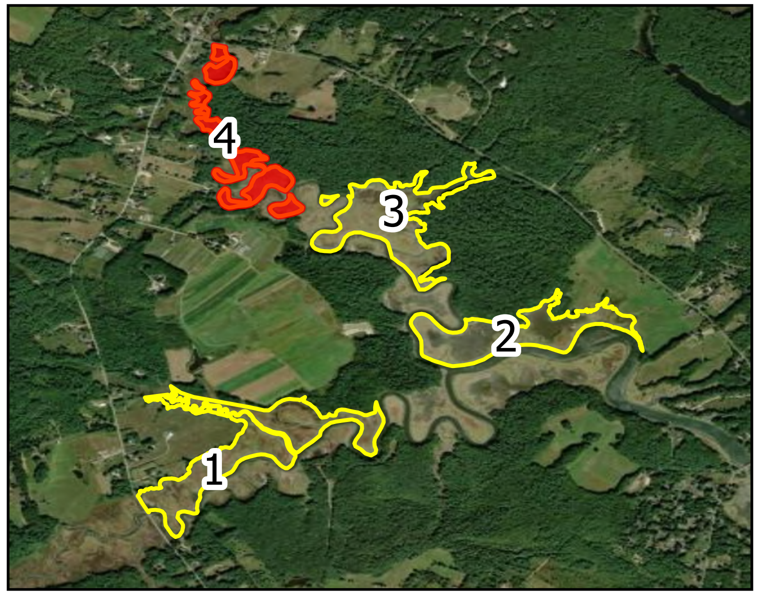
Project Area 4
Lot Identification and Topography
Sheet 4-1

Legend

- Contours (2 ft)
- Tax parcels

Project Area and Ownership

- Edkins (USFWS)
- Near Point Preserve and Smelt Brook Preserve (York Land Trust)



York River-Smelt Brook Salt Marsh Restoration Project

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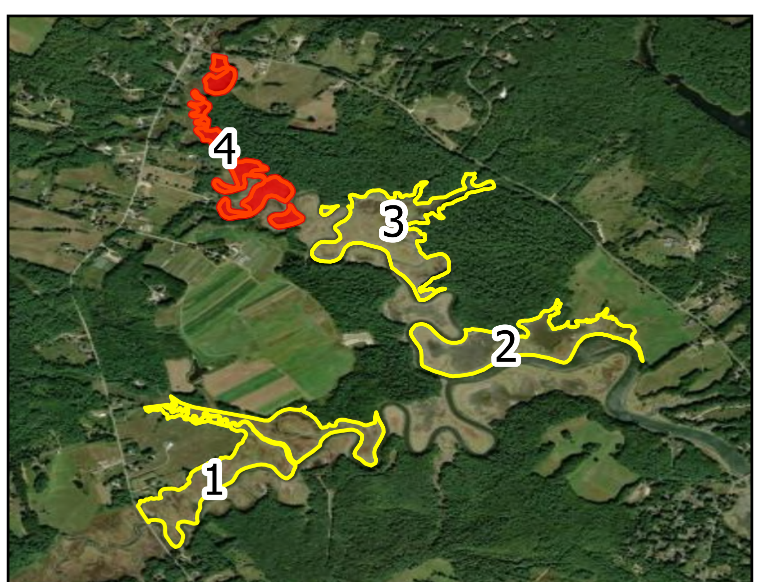
207-252-4841

York, ME
August 27th, 2025

Project Area 4
Existing Conditions Plan
Sheet 4-2

Legend

Agricultural Infrastructure
- Early Period Embankments
- Late Period Embankments
- Clay Cored Embankments



York River-Smelt Brook Salt Marsh Restoration Project

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York, ME
August 27th, 2025

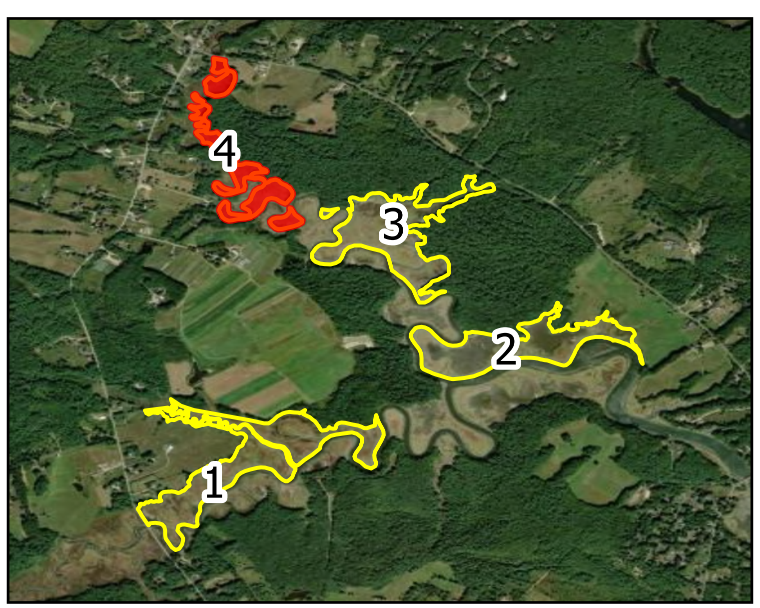
Project Area 4
Proposed Actions Plan
Sheet 4-3

Legend

Proposed Ditch Remediation
- Linear Treatment
- Point Treatment

Proposed Phragmites Control
- Brackish Ditch
- Marginal Ditch
- Phragmites Control Areas

Proposed Tidal Channel Restoration
- Late Successional
- Early Successional



York River-Smelt Brook Salt Marsh Restoration Project

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York, ME
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Project Area 4
Proposed Conditions Plan (Single Channel Hydrology)
Sheet 4-4

Legend

Tidal Channel Network
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Proposed Phragmites Control
- Brackish Ditch
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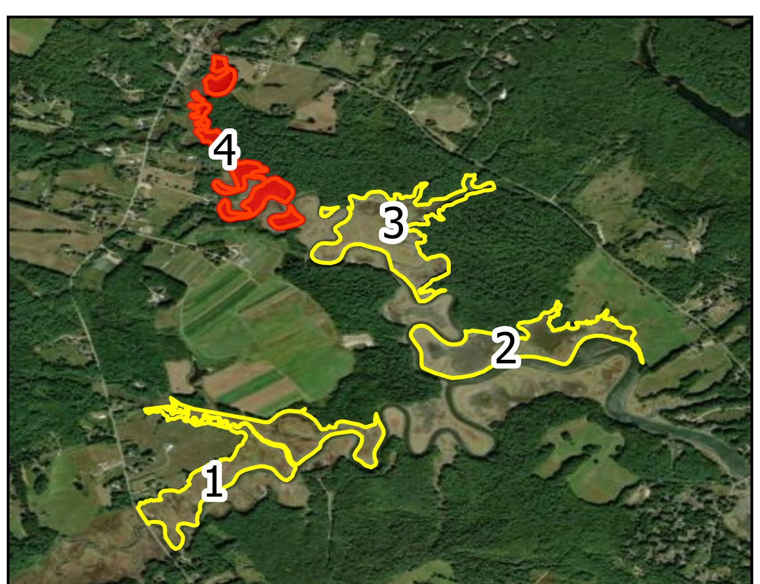
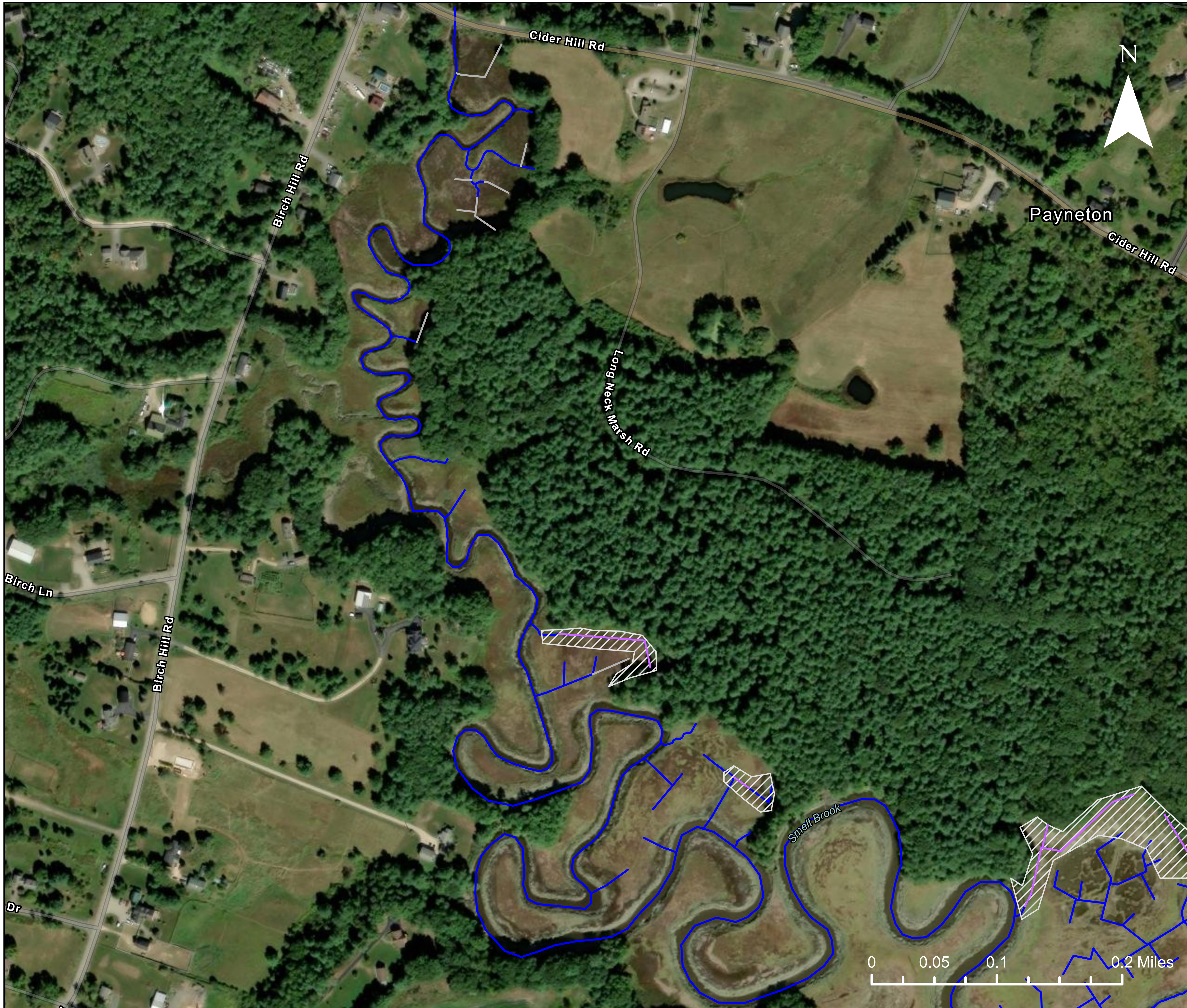
- Phragmites Control Areas





Notes

Data Sources

1. Aerial Imagery Source: ArcPro World Imagery. Credits: ESRI, Maxar, Earthstar Geographics, and the GIS User Community. Resolution: 0.15 meters. Imagery Date: 3/20/2023. https://services.arcgisonline.com/ArcGIS/rest/services/World_Imagery/MapServer
2. Contours Source: Maine Gov. 2 foot contours. Projection: NAD_1983_UTMZone_19N. https://gis.maine.gov/mapservices/rest/services/Elevation/Maine_Elevation_Contours_2_Feet_19T/MapServer
3. Tax Parcel Source: Maine Parcels Organized Towns. Maine Geolibrary. Updated October 9th, 2024. Projection: NAD_1983_UTMZone_19N. https://services1.arcgis.com/RbMX0mRVOFNTdLzd/arcgis/rest/services/Maine_Parcels_Organized_Towns/FeatureServer
4. HUC12 Source: National Watershed Boundary Dataset (WBD). CONUS 1:24,000 scale. Funded by USDA-NRCS, USGA and EPA along with other federal, state, and local agencies. Projection: WGS 1984 Web Mercator (auxiliary sphere). https://services.arcgis.com/P3ePLMYs2RVChkJx/arcgis/rest/services/Watershed_Boundary_Dataset_HUC_12s/FeatureServer

Sheet Notes

Sheet 3 (Proposed Actions Plan): Proposed Micro-runnels and Habitat Islands will be constructed based on field conditions. The project narrative specifies general field conditions or targets that will be used by restoration ecologist to determine runnel or habitat island placement.

Sheet 4 (Proposed Conditions Plan): Phragmites control areas will require periodic maintenance

Appendix B

Monitoring Table

Goal and Technique	Objective	Timeline	Monitoring Measurement	Monitoring Frequency not including baseline	Milestones			Explanation of metrics	Trigger to ID problem	Adaptation Actions
Halt subsidence trajectory due to excess ditching	Reduce number of hydrologic paths & reduce drainage				Year 1	Year 3	Year 5			
Ditch remediation by treating selected historic ditches with salt marsh hay	Ditch bottom within 20 cm of marsh surface	5 years	Transect survey	Pre-restoration + Years 1, 3 & 5	ditch bottom builds ≥10 cm*	ditch bottom builds ≥20 cm	Ditch bottom <20cm from marsh surface	Elevation change in remediated ditch centers from average elevations between observation year and baseline year	50% less of milestones	Add cut marsh hay to ditch for one or more years
	Vegetated with *S. alterniflora*	5 years	Transect survey	Pre-restoration + Years 1, 3 & 5	0-5% cover	0-5% cover	25% cover	Percent cover averaged from *S. alterniflora* rooted in ditch centers	50% less of milestones	Add seed heads or plant with S. alterniflora culms
	Groundwater elev. rises between treated ditches	5 years	GW WLR	Pre-restoration + Years 1, 3 & 5 (for 29 days)	0 cm	2 cm	5 cm	Taken from average water levels monitored between years	50% less of milestones	Add additional hay treatment to closest ditch
	Platform accretes greater than SLR	5 years	Marker Horizons	Years 1, 3 & 5	3 mm/yr**	3 mm/yr**	5 mm/yr	Averaged from accretion at marker horizons set in marsh platforms between ditches	50% less of milestones	Explore other methods for platform accretion to be permitted or do nothing.

Goal and Technique	Objective	Timeline	Monitoring Measurement	Monitoring Frequency not including baseline	Milestones			Explanation of metrics	Trigger to ID problem	Adaptation Actions
Halt subsidence trajectory from over-saturation					Year 1	Year 3	Year 5			
Create or Revive drainage paths from pannes and pools to provide regular tidal flood/drain cycles	Water drains off marsh; surface water of pools and ground water (GW) falls	2-3 years	WLR in pool/panne	Pre-restoration + Years 1, 3 & 5 (for 29 days)	WL drops 5 cm	WL drops 10 cm	WL maintained	Average water levels monitored over a month between years	WL decline < 50% of targets	Remove blockages where needed
	Target area revegetates	5 years	Transect survey	Pre-restoration + Years 1, 3 & 5	stable cover	10% incr. cover	20% incr. cover	Change in percent cover averaged across transects from baseline	50% less of milestones	Add seed heads or plant with S. alterniflora culms
	Revegetation where pool drainage exposes mud	5 years	Drone survey	Pre-restoration + Years 1, 3 & 5	calculate area of revegetation	revegetation of 50% of est. area	revegetation of 80% of est. area	Shallow pool 'edges' will drain and increase vegetation	50% less of milestones	Add seed heads or plant with S. alterniflora culms

* Each application should raise the ditch bottom 10 cm. By year 3 there will be 3 applications, but when settling is taken into account, total material height is 25 cm. By year 5 the ditch bottom is within 20 cm of surface and receiving sunlight.

** Based on current marsh accretion rates in control areas (Payne et al. 2019) in Great Bay NH as well as preliminary data from two control SETs at Old Town Hill pilot project, Newbury, MA

Appendix C

Agricultural Infrastructure Examples

<u>Kent's Island Marsh - Newbury, MA</u>

Remnants of a large water control structure. Due to the central location in the marsh and the width of the embankment over the water control structure, it is believed that this was a haul road location.

Kent’s Island Bridge Marshes - Newbury, MA

Subtle reclamation embankment that forms perfect offset from the upland transition zone.

Kent’s Island Bridge Marshes - Newbury, MA

Freshwater pooling behind a reclamation embankment.

Great Marsh North - Newbury, MA

Three early period embankments intersected by a late period borrow ditch. Note the bright yellow obstruction point formed just above the soil probe handle. This is a prime example of natural ditch remediation Form II where the *S. alterniflora* grows across the unconsolidated ditch slurry.

<u>Parker River North Marshes - Newbury, MA</u>

A well-used game trail along a large reclamation embankment. Note the obvious elevation difference between the left enclosure and the right enclosure.

Parker River North Marshes – Newbury, MA

Salt marsh subsidence associated with the early Decline stage of salt marsh secondary succession exposing the inner and outer borrow ditches of a reclamation embankment. Note the obvious elevation difference between the right enclosure and the left enclosure.

Rough Meadows Wildlife Sanctuary, Rowley, MA

Prominent linear subsidence basins resulting from closely spaced borrow ditches. This technique was frequently used to extend higher embankment elevations far out into a sloping marsh.

Rough Meadows Wildlife Sanctuary, Rowley, MA

Obstruction point formation resulting from the reduced velocity associated with closely spaced ditches. Note the standing water in the ditch void up-gradient of the obstruction point. This condition leads to the isolation of portions of the sub-tideshed.

Appendix D

New England Farmer Articles

NEW ENGLAND FARMER.

Published every Saturday, by THOMAS W. SHEPARD, Rogers' Building, Congress Street, Boston; at $2,50 per ann. in advance, or $3,00 at the close of the year.

Vol. I. BOSTON, SATURDAY, MARCH 1, 1823. No. 31.

ON EMBANKMENTS, DIKES, DRAINS, &c. FOR THE PURPOSE OF RECLAIMING LANDS FROM THE SEA, RIVERS, &c.

BY THE EDITOR.

Having been requested by some respectable correspondents to furnish such information as might be at our command, on the abovementioned subjects, we proceed to lay before our readers the result of our researches. We would premise, however, that we have no knowledge on this topic, derived from experience, and that books are the sources from which we have deduced nearly all which we shall venture to suggest.

The first object to be considered, before attempting to reclaim land, that at low water is left uncovered by the sea, is, whether or not the quality of the surface to be gained, is such as to be capable of profitable cultivation. In many cases, what is exposed at low water, and might easily be banked out, is an accumulation, to a great depth, of barren sand or gravel. But there are other places, where the sea, at low water, recedes so far, as to leave dry, large portions of surface, which is composed of a deposition of fine earth washed down from higher land.

Embanking, so as to exclude the sea, is more or less expensive, according to the nature of the materials of which the beach is composed. If the soil is of a sandy nature, it is generally necessary to face it with stone on the side next to the sea; otherwise the waves would soon make breaches in it. It is also necessary to give it a very considerable slope, and, at the foundation, to have the stones bedded, and laid in such a way that they may bind well together. The height of the embankment, should, in all cases, be at least two feet more than that of the highest tide.

When the materials of which the bank is formed are of a clayey or adhesive nature, strong turf may answer the purpose of facing the bank, and these should be well beaten and pinned down as soon as laid. The inside or land side slope should also be faced with turf.

If turf is to be used in covering the outside slope it must all be laid with the grass uppermost, and well beaten down with a flat sod-beetle, made for that purpose; and for their better security, it may be proper to drive a small stake of about 18 inches long, or more, through every sod. The sods for this purpose, should at first be carefully taken up, and traced by a line, all of the same breadth, and their edges cut as even as possible, that they may make the closer joints.

An American writer on this subject, (whose observations may be seen at length in the American Farmer, vol. ii, p. 131,) in treating of the difficulties which occur in reclaiming marsh lands, says that they arise "chiefly because of their exposure on the sea coast to severe gales of wind, and high spring tides. In a great measure to the spongy, light nature of the marsh land, it being in a degree composed of the roots of rushes and marsh grass. Likewise from want of attention in yearly repairing and raising the banks, which settle and contract very much as the roots decay; the mud also, by drying, moulders into a fine dust and is blown away by every high wind. They who succeed best, have a sufficient space between the edge of the river or the creek and the bank, to save it as much as possible from being washed by the spring tides, or undermined by the encroachments of the river or creek. They form the bank by earth taken altogether from within it, and leave no ditch between the bank and the creek or river. They likewise leave a considerable margin between the bank and the ditch formed by digging out the earth, and cover the top of the bank with highland earth to mingle with the mud as it cracks by drying, and to prevent it from being washed and blown away." Probably the practice of covering the bank with turf, as above recommended, would secure it from being washed, or blown away, as effectually as any method which could be adopted.

When the sea encroaches on a low shore, it will be proper before attempting to execute any regular embankment, to make a careful survey of the coast, which is injured, in order to ascertain if there be any local circumstances, that can help to raise a natural barrier against the encroachment. In many places the sea is continually stiring up, and driving against the coast, quantities of sand and other materials, which either remain and serve to form hills or flats, or are carried back by the ebbing of the tide which brought them. In general, where the materials are of a solid nature, as shells, plants, or slime, they rest and accumulate, and raise the land above the danger of any encroachment from the sea. But where the shore consists entirely of sand, whatever quantities may be pushed forward at each tide, are immediately dispersed by the winds, and the shore remains open and exposed to every high swell of the sea. In such case, however, means may be adopted, for collecting and fixing the flying particles of sand; and it is certainly proper to prefer so economical an expedient to an expensive regular embankment.

Johnstone's chapter on Embankments, in the General Report of Agriculture in Scotland, vol. ii, p. 629, contains an account of a work of this kind, of which what follows is the substance.

The sea had for many years made encroachments on the estate of the Earl of Ashburnham, at Bembrey, in Scotland. It was the general opinion that a regular embankment must be formed, which would cost some thousand pounds, the Earl having several miles of coast. Mr. Tatlow, who first proposed the mode of embanking about to be related, observes, "the view that I first took, was upon a very windy day, and the shore, an entire sand, which extended at low water many miles. In riding along I perceived that any piece of wood, or accidental impediment to the course of the sand, raised a hill. It immediately occurred to me, that by making a hedge at the weak and low places, with wings to catch the sand as the wind blew it in different directions, I should obtain the desired effect. I therefore directed stakes nine feet long to be cut and driven one foot and a half into the sand, at two feet and a half distance from each other; betwixt which I had furze interwoven, so as to form a regular furze hedge, seven feet and a half high." This mode of embankment, it appears, proved successful. "Its present appearance," says the inventor after a trial of some months, "plainly evinces, that, at a trifling expense, I can secure Lord Ashburnham's estate from being inundated; for whenever the first hedge is not high enough to prevent the sea overflowing, another may be built upon the land formed by that hedge, and so on in succession till it is perfectly safe."

When the land is only overflowed during spring tides, there is time in the intervals, either to complete the embankment required, or to finish it in such a manner, that the flowing of the tide can do it no injury. But if the sea ebbs and flows every tide upon the land which is to be reclaimed, only small pieces of the work can be executed at a time, and the force of the water, at the flowing of each tide, is apt to destroy all that has been previously performed.

When only a part of the embankment can be executed before the return of flood tide, it is proper that what is done should be done in a complete manner. Thus, supposing a length of thirty or forty feet can be finished in one tide, it is better to raise it to its intended height, and to face the slope well with turf, than to commence a greater extent of bank and leave it in an unfinished state, exposed to the violence of the waves. It may be further remarked that, in low flooded lands, there are always several hollows, or water-runs, formed by the regress of the tide; and where the embankment has to be executed in different portions, it may be proper to build in the first place, across or over the spaces between these water-runs, so that the sea, having its usual channels of evacuation left open, will have the less tendency to injure the work. The spaces thus left may be filled up during the intervals between the spring tides.

A writer in the American Farmer, vol. ii, p. 131, gives a method of securing an unfinished embankment against being demolished by a current or tide which appears to us to be cheap, practicable, and is as follows. "A sufficiency of earth is collected, either by digging in the vicinity or by transporting it from the nearest high ground. A number of poles or stakes are then cut and brought to the bank, and at low water driven into the mud so as to form an angular pen in advance from each side of the gap. The poles are left thus driven in until the next low water, that they may adhere to the mud more firmly by suction: the earth is then thrown into the pen, and is protected by them from the friction of the tide until the next low water.—Other poles are then driven in advance of these on the same plan, and filled with earth, until the gap is gradually, but certainly closed."

The elevation and slope of the embankment should depend on the degree of exposure to the winds and tides, and the height to which the greatest tides are accustomed to rise. In every case, the bank should be at least two feet higher than the water during the greatest spring tides. In determining the slope, great care

(Fessenden & Sheppard, 1823)

must be taken in proportion it to the force of the sea, as nothing can be more ruinous, than to make the bank too bold or upright. A wave which falls on a flat surface dies without a struggle, while one that is stemmed by an abrupt rock strikes with tenfold force.

Along the back of all sea-banks, trenches should be made, and sluices erected at different parts to shut of themselves against any external water, and to open when the tide ebbs to let out any water from within.

These sluices should be so constructed as to let the water out of the marsh without admitting water from the sea. A method by which this may be accomplished is described by a writer in the American Farmer, vol. ii, p. 244, and is, in substance, as follows. It has been found that the common gates, heretofore used to exclude the tides from marshes, will not always answer. The tide creeps in so slowly, that it will not shut such a gate in time, nor press it too with sufficient firmness to exclude the flood tide; for chips, weeds, &c. were gently wafted into the gate way and lodged there, so as to prevent the gate from shutting quite close.—These tide gates were hung on hinges, either perpendicularly or horizontally, and it was found difficult to have them kept in such exact order as to exclude a slow tide. These, and other evils attending the old tide gates, are completely removed by the new invented *Tide Trunk*, which is perfectly firm, and closed merely by the act of the water's rising to a given point, without the least current whatever.

A Tide Trunk is a wooden oblong vessel, or square pipe, like a chest, open at the end next to the sea, river, or other water, which it is wished to shut out of the marsh, but closed at the end next to the marsh. At the closed end is a hole in the top. Beneath this hole, inside of the trunk, or chest, is placed a valve, consisting of light wood, which lies on the bottom, unless it is caused to float by the water flowing into the open end of the trunk, when it rises and shuts the hole at the top of the trunk. To the top of this valve is fixed a small iron rod, which rising perpendicularly, passes through a frame consisting of two upright pieces attached to the opposite sides of the trunk, and two cross pieces framed into the upright pieces in such a manner that holes may be bored in them thro' which the iron rod may slide up and down freely, and be kept in a perpendicular position, and thus keep the valve in its proper position, under the aperture of the trunk. The iron rod must be allowed to play with perfect ease thro' the frame, and be so light as not to prevent the valve from floating; and if there be any apprehension of its sinking the valve, the under surface of the valve may be coated with cork, to make it sufficiently buoyant to rise with the rod. There are other methods, which some prefer to keep the valve in its proper position, such as having perpendicular rods to pass thro' the top of the trunk in such a manner as to confine the valve to its place; or having slips of boards nailed perpendicularly on the inside of the trunk, in such manner as to give the motions of the valve the requisite direction. The upper surface of the valve must be smooth, and made to fit closely the under surface of the top of the trunk round the aperture or hole through which the water is admitted, as it drains from the marsh. The valve should be allowed to move freely in the trunk, and yet be so large as entirely to close the aperture, in whatever way it may float up to it. Mr. Johnstone appears to entertain an opinion that a less complicated apparatus might answer the purpose of excluding the water of the tide from the trunk, and merely directs that the trunk have a proper flood-gate, or valve, fixed to the mouth of it, by hinges on the upper side.

As the water proposed to be drained off must flow over the top of the trunk, and descend into the aperture; and as it is important that the marsh should be drained as nearly down to low water mark as possible, the trunk, whatever may be its depth or width, should not be placed, with the interior surface of its top more than six inches above the ordinary low water mark; because there should be room for the water, pouring into the aperture from the marsh to clear itself over the valve. The height from low water mark to the top of the trunk, being so much deducted from the depth to which the marsh can be drained by the trunk; it should therefore, to pass the greatest quantity of water, be made broad in proportion to its depth, so as to allow of a large aperture, and to be placed as low as is compatible with its object and utility.

If one trunk should not be adequate to the necessary draining, two or more may be inserted —and as the tides are very irregular, it might be well to place one trunk lower down, on a level with uncommonly low tides, so as to take advantage of the greatest degree of draining, which such tides would afford. At the mouth of each trunk, it may be well to drive down stakes in such a manner as to prevent the entrance of leaves, chips, and other substances, which might impede the operation of the valve.

Mr. Johnstone in his tract upon embankments directs "to ascertain the exact height of the highest flood-tides, so that the embankment be raised at least two feet above what these may ever approach to. When this is done, the level must be taken, and stakes fixed to the proper height along the whole line to be embanked. Two frames of wood, of the exact form of the bank, should be made, and set up at the distance of twenty or thirty feet from each other, *exactly on the same level*, to guide and direct the height and dimensions of its construction, and the same level must be kept throughout the whole line. This is more requisite than in the case of rivers that have a descent in their current, and where the height of the water is regulated by the fall of the stream; for the surface of the sea water, being all on a level, the top of the embankment requires to be exactly parallel with the horizon, without a rise or declension in any part."

As the pressure of the water upon an embankment against the tide, is different from that against the current of a river, it is not necessary to have it so straight, or of that uniform smoothness which is requisite where a running stream is to glide along the side of it. Where the embankment crosses any creeks or hollows, it will be necessary to increase the width of the base in proportion to the depth.

In forming the bank, the breadth, height, and strength must be made in proportion to the depth and weight of the water it may have to resist; taking into consideration the exposure to winds and the rapidity of the motion of the tide. As has been before observed, in substance, the more the slope towards the water approaches to a degree of flatness, the greater will be the firmness and durability of the structure. In difficult cases, it is advisable, that the surface next the water should form an angle to a perpendicular line, of from forty to sixty degrees, according to the force to be opposed, and the nature of the materials of which the mound or bank is to be constructed. Where the foundation is firm and solid, the natural earth of the ground, where it is erected, may be employed, and will answer for the body of the bank, and for the inner surface, and where the pressure or force of the water is not very violent, the slope next to it may be formed of the same materials. But in cases where the force of the waves, by exposure to strong winds, operates more violently against the bank, the outer slope should be formed to the depth of two feet, with clay, or the strongest earth that can be conveniently got; and that, as well as the top, covered with well swarded turf. The inner slope, or that next the field or marsh to be reclaimed, should be sown with grass seeds.

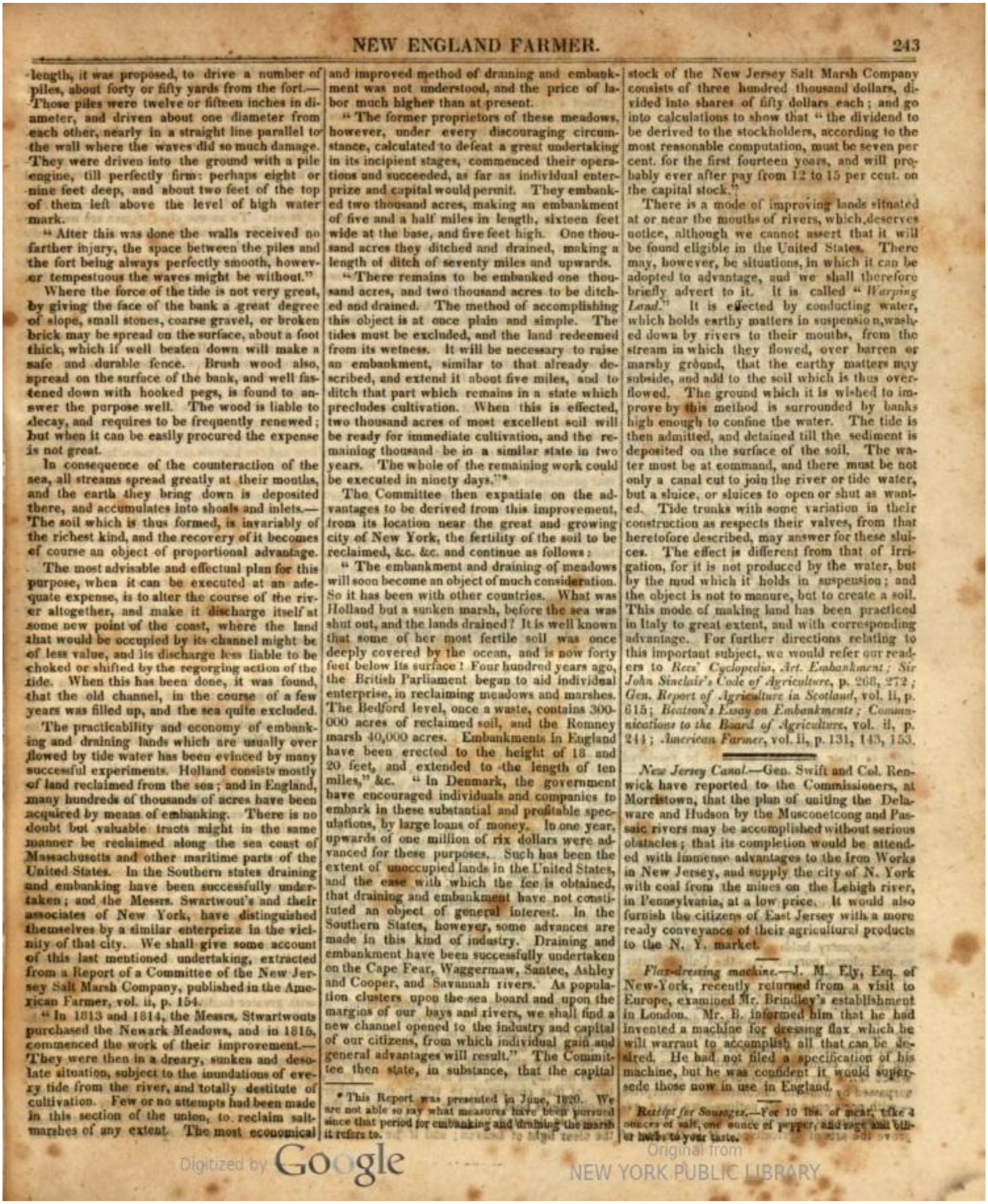
Mr. Johnstone says that "The stuff for forming the bank, should be mostly taken from the side next the water, that as little of the surface within may be broken as possible; only by what is taken from the back cut or drain, that is necessary, along the embankment on that side."—An American writer, however, advises in banking against a river or creek, to leave "a sufficient space between the edge of the river or creek, and bank," and to "form the bank by earth taken altogether from within it."* Mr. Johnstone, however, in advising to take the stuff to form the bank from the side next to the water is giving directions for embanking against the sea, and the American writer has reference to preventing the encroachment of water from a river or creek. We shall leave this question to be decided by professional engineers, observing, that all writers on this subject agree that the earth of which the embankment is composed, should not be dug out very near to it, but a considerable margin should be left between the excavation formed by digging out the earth, and the mound or embankment which is formed by such earth.

No stones should be left near the foot of the embankment; for the tide forming eddies round them, would soon make holes and break through the bank.

Embankments of the kind under consideration are liable to be destroyed by the waves, ascending the inclined plane next to the sea, and, when the tide ebbs, returning with force, and washing away materials with which the bank is composed. Covering the bank with turf, as before recommended may in many cases answer the purpose. As a further security, in situations of great exposure, the most effectual protection is to drive piles in front of the bank, to break the force of the waves. An English engineer, Mr. Beatson, says, "some years ago, when I was on duty as an engineer at a fort near Portsmouth, built on a point of land much exposed to the sea, the waves made such havoc, that the walls on that side were constantly giving away, although built in a most substantial manner, and having bulwarks of large heavy stones besides, to protect the foundation: however all would not do, these bulwarks were soon knocked to pieces, and several times the wall itself. At

* American Farmer, vol. ii, p. 131.

(Fessenden & Sheppard, 1823)



length, it was proposed, to drive a number of piles, about forty or fifty yards from the fort.—Those piles were twelve or fifteen inches in diameter, and driven about one diameter from each other, nearly in a straight line parallel to the wall where the waves did so much damage. They were driven into the ground with a pile engine, till perfectly firm: perhaps eight or nine feet deep, and about two feet of the top of them left above the level of high water mark.

"After this was done the walls received no farther injury, the space between the piles and the fort being always perfectly smooth, however tempestuous the waves might be without."

Where the force of the tide is not very great, by giving the face of the bank a great degree of slope, small stones, coarse gravel, or broken brick may be spread on the surface, about a foot thick, which if well beaten down will make a safe and durable fence. Brush wood also, spread on the surface of the bank, and well fastened down with hooked pegs, is found to answer the purpose well. The wood is liable to decay, and requires to be frequently renewed; but when it can be easily procured the expense is not great.

In consequence of the counteraction of the sea, all streams spread greatly at their mouths, and the earth they bring down is deposited there, and accumulates into shoals and inlets.—The soil which is thus formed, is invariably of the richest kind, and the recovery of it becomes of course an object of proportional advantage.

The most advisable and effectual plan for this purpose, when it can be executed at an adequate expense, is to alter the course of the river altogether, and make it discharge itself at some new point of the coast, where the land that would be occupied by its channel might be of less value, and its discharge less liable to be choked or shifted by the regorging action of the tide. When this has been done, it was found, that the old channel, in the course of a few years was filled up, and the sea quite excluded.

The practicability and economy of embanking and draining lands which are usually over flowed by tide water has been evinced by many successful experiments. Holland consists mostly of land reclaimed from the sea; and in England, many hundreds of thousands of acres have been acquired by means of embanking. There is no doubt but valuable tracts might in the same manner be reclaimed along the sea coast of Massachusetts and other maritime parts of the United States. In the Southern states draining and embanking have been successfully undertaken; and the Messrs. Swartwout's and their associates of New York, have distinguished themselves by a similar enterprize in the vicinity of that city. We shall give some account of this last mentioned undertaking, extracted from a Report of a Committee of the New Jersey Salt Marsh Company, published in the American Farmer, vol. ii, p. 154.

"In 1813 and 1814, the Messrs. Stwartwouts purchased the Newark Meadows, and in 1816, commenced the work of their improvement.—They were then in a dreary, sunken and desolate situation, subject to the inundations of every tide from the river, and totally destitute of cultivation. Few or no attempts had been made in this section of the union, to reclaim salt-marshes of any extent. The most economical and improved method of draining and embankment was not understood, and the price of labor much higher than at present.

"The former proprietors of these meadows, however, under every discouraging circumstance, calculated to defeat a great undertaking in its incipient stages, commenced their operations and succeeded, as far as individual enterprize and capital would permit. They embanked two thousand acres, making an embankment of five and a half miles in length, sixteen feet wide at the base, and five feet high. One thousand acres they ditched and drained, making a length of ditch of seventy miles and upwards.

"There remains to be embanked one thousand acres, and two thousand acres to be ditched and drained. The method of accomplishing this object is at once plain and simple. The tides must be excluded, and the land redeemed from its wetness. It will be necessary to raise an embankment, similar to that already described, and extend it about five miles, and to ditch that part which remains in a state which precludes cultivation. When this is effected, two thousand acres of most excellent soil will be ready for immediate cultivation, and the remaining thousand be in a similar state in two years. The whole of the remaining work could be executed in ninety days."*

The Committee then expatiate on the advantages to be derived from this improvement, from its location near the great and growing city of New York, the fertility of the soil to be reclaimed, &c. &c. and continue as follows:

"The embankment and draining of meadows will soon become an object of much consideration. So it has been with other countries. What was Holland but a sunken marsh, before the sea was shut out, and the lands drained? It is well known that some of her most fertile soil was once deeply covered by the ocean, and is now forty feet below its surface! Four hundred years ago, the British Parliament began to aid individual enterprise, in reclaiming meadows and marshes. The Bedford level, once a waste, contains 300-000 acres of reclaimed soil, and the Romney marsh 40,000 acres. Embankments in England have been erected to the height of 18 and 20 feet, and extended to the length of ten miles," &c. "In Denmark, the government have encouraged individuals and companies to embark in these substantial and profitable speculations, by large loans of money. In one year, upwards of one million of rix dollars were advanced for these purposes. Such has been the extent of unoccupied lands in the United States, and the ease with which the fee is obtained, that draining and embankment have not constituted an object of general interest. In the Southern States, however, some advances are made in this kind of industry. Draining and embankment have been successfully undertaken on the Cape Fear, Waggermaw, Santee, Ashley and Cooper, and Savannah rivers. As population clusters upon the sea board and upon the margins of our bays and rivers, we shall find a new channel opened to the industry and capital of our citizens, from which individual gain and general advantages will result." The Committee then state, in substance, that the capital stock of the New Jersey Salt Marsh Company consists of three hundred thousand dollars, divided into shares of fifty dollars each; and go into calculations to show that "the dividend to be derived to the stockholders, according to the most reasonable computation, must be seven per cent. for the first fourteen years, and will probably ever after pay from 12 to 15 per cent. on the capital stock."

There is a mode of improving lands situated at or near the mouths of rivers, which deserves notice, although we cannot assert that it will be found eligible in the United States. There may, however, be situations, in which it can be adopted to advantage, and we shall therefore briefly advert to it. It is called "*Warping Land*." It is effected by conducting water, which holds earthy matters in suspension, washed down by rivers to their mouths, from the stream in which they flowed, over barren or marshy ground, that the earthy matters may subside, and add to the soil which is thus overflowed. The ground which it is wished to improve by this method is surrounded by banks high enough to confine the water. The tide is then admitted, and detained till the sediment is deposited on the surface of the soil. The water must be at command, and there must be not only a canal cut to join the river or tide water, but a sluice, or sluices to open or shut as wanted. Tide trunks with some variation in their construction as respects their valves, from that heretofore described, may answer for these sluices. The effect is different from that of irrigation, for it is not produced by the water, but by the mud which it holds in suspension; and the object is not to manure, but to create a soil. This mode of making land has been practiced in Italy to great extent, and with corresponding advantage. For further directions relating to this important subject, we would refer our readers to *Rees' Cyclopedia, Art. Embankment; Sir John Sinclair's Code of Agriculture*, p. 268, 272; *Gen. Report of Agriculture in Scotland*, vol. ii, p. 615; *Beatson's Essay on Embankments; Communications to the Board of Agriculture*, vol. ii, p. 244; *American Farmer*, vol. ii, p. 131, 143, 153.

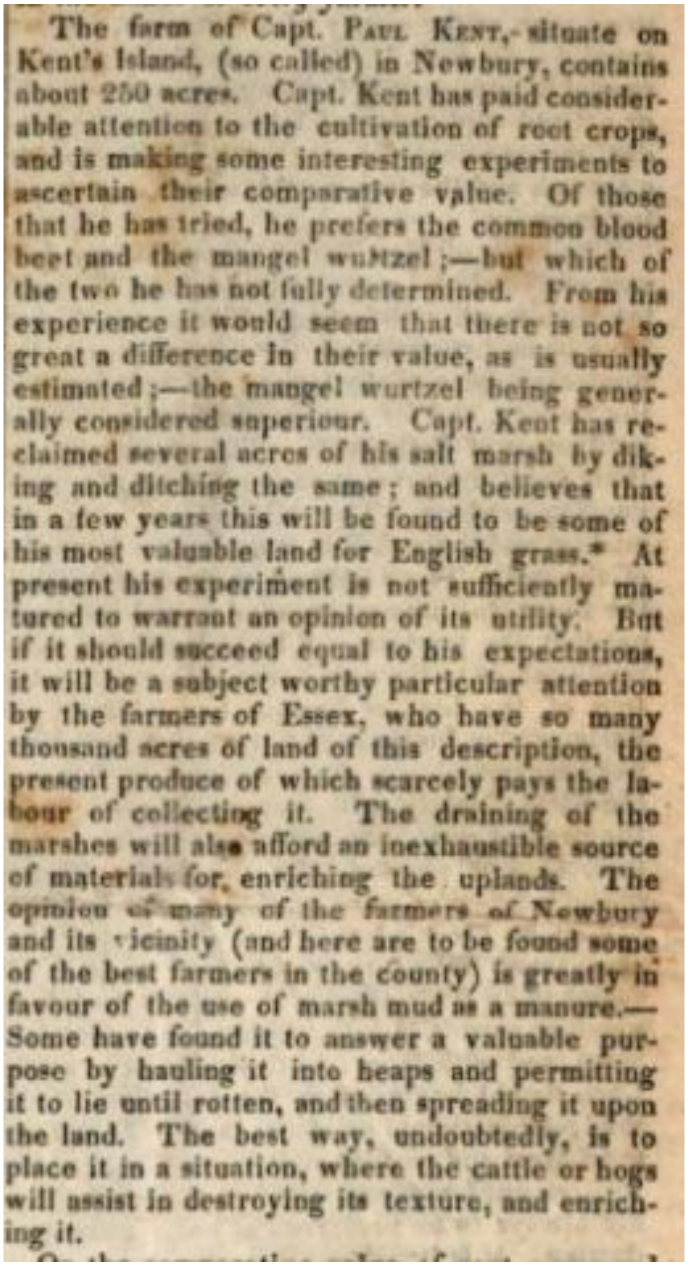
New Jersey Canal.—Gen. Swift and Col. Renwick have reported to the Commissioners, at Morristown, that the plan of uniting the Delaware and Hudson by the Musconetcong and Passaic rivers may be accomplished without serious obstacles; that its completion would be attended with immense advantages to the Iron Works in New Jersey, and supply the city of N. York with coal from the mines on the Lehigh river, in Pennsylvania, at a low price. It would also furnish the citizens of East Jersey with a more ready conveyance of their agricultural products to the N. Y. market.

Flax-dressing machine.—J. M. Ely, Esq. of New-York, recently returned from a visit to Europe, examined Mr. Brindley's establishment in London. Mr. B. informed him that he had invented a machine for dressing flax which he will warrant to accomplish all that can be desired. He had not filed a specification of his machine, but he was confident it would supersede those now in use in England.

Receipt for Sausages.—For 10 lbs. of meat, take 4 ounces of salt, one ounce of pepper, and sage and other herbs to your taste.

* This Report was presented in June, 1820. We are not able to say what measures have been pursued since that period for embanking and draining the marsh it refers to.

(Fessenden & Sheppard, 1823)



The farm of Capt. Paul Kent, situate on Kent's Island, (so called) in Newbury, contains about 250 acres. Capt. Kent has paid considerable attention to the cultivation of root crops, and is making some interesting experiments to ascertain their comparative value. Of those that he has tried, he prefers the common blood beet and the mangel wurtzel;—but which of the two he has not fully determined. From his experience it would seem that there is not so great a difference in their value, as is usually estimated;—the mangel wurtzel being generally considered superiour. Capt. Kent has reclaimed several acres of his salt marsh by diking and ditching the same; and believes that in a few years this will be found to be some of his most valuable land for English grass.* At present his experiment is not sufficiently matured to warrant an opinion of its utility. But if it should succeed equal to his expectations, it will be a subject worthy particular attention by the farmers of Essex, who have so many thousand acres of land of this description, the present produce of which scarcely pays the labour of collecting it. The draining of the marshes will also afford an inexhaustible source of materials for enriching the uplands. The opinion of many of the farmers of Newbury and its vicinity (and here are to be found some of the best farmers in the county) is greatly in favour of the use of marsh mud as a manure.—Some have found it to answer a valuable purpose by hauling it into heaps and permitting it to lie until rotten, and then spreading it upon the land. The best way, undoubtedly, is to place it in a situation, where the cattle or hogs will assist in destroying its texture, and enriching it.

Report on Farms in Essex (1824). Farm of Capt. Paul Kent, Kent's Island, Newbury, MA.

The farm of Mr Jacob Perley, in Newbury, under the direction of his son, Mr Putnam Perley, contains about 180 acres, and is well cultivated. The mode adopted by him of draining his salt marshes, and the peculiar manner of constructing the ditches, is worthy of particular attention. The ditch is made wider at the bottom than at the top—say about fourteen inches at the bottom and seven inches at the top.—Ditches of this kind may be made with a ditching knife properly constructed for the purpose, (something in the form of the knife used for cutting turf in peat meadows) we were assured, much more expeditiously, than ditches of the usual form, with upright sides. They do not disfigure the marsh so much, nor leave such obstructions in the way of mowing and raking as wider ditches. They answer even a better purpose in draining, for the top being narrow, it is less liable to be filled up by loose substances, floating upon the marshes. In a very short time the sides approach so near each other, as to afford no obstruction whatever to the ordinary labour upon the land; and the ditches may be crossed by teams with perfect safety. By a little additional labour the top sod may be taken out in such form, as to be placed back, like the key stone to an arch; and this completely protects the ditch from being filled up, and leaves the surface of the marsh entire. In this way natural bridges may be constructed in every part, where it is necessary to pass; or the whole ditch may be covered with but little extra labour; and the improved appearance of the marsh would well pay for this labour. The value of these ditches is known to every farmer who has any experience on the subject. It is said the produce of the land is often doubled and trebled, in the course of a few years.—The very fine appear-

Report on Farms in Essex (1824). Farm of Jacob Perley, Newbury, MA.

From the Repertory of Patent Inventions.

On the Recovery of Land from the Sea. By Mr James Blackburn, Land Surveyor, Lothbury.

The art of embanking and draining is, perhaps, one of the most ancient, for we find that those nations which have been most famous for their works of art, have practised it to a great extent. The Egyptians appear to have been the first nation on record that recovered lands from the water; Sesostris first embanked the cities on the banks of the Nile; and Sebecon, the Ethiopian, employed all persons condemned to death in the same undertaking. The Babylonians were next in this art, for Sir W. Raleigh, in his history of the world (giving a reason why so little is written of Belus, who succeeded Nimrod, the first Assyrian monarch,) says, he spent much of his time in disburthening the low lands of Babylon, and drying and making firm ground of all those great fens and overflown marshes which adjoined to it. Herodotus, speaking of Semiramis, Queen of Babylon, says, "she raised banks throughout the whole level worthy of observation; whereas, before she did so, it was wont to be drowned by water;" and again, that Nitrocis, another queen of the same empire, raised banks on the verge of the river, for bigness and height wonderful to behold.

In Thessaly, a lake near the hills Pelion, Ossa, Olympus, and Pindus, and which, with the rivers in the neighbourhood, made all Thessaly a sea, was recovered by cutting a passage, by which it flowed into the ocean, and is now a place of great fertility. "Of Acarnania this is observable, that where Achilois, a river of that country, runs into the sea, it hath already made continent one half of the islands called Echinades; and that the fable goes, that Hercules here encountering Achilois, who is said to have transformed himself into a bull, because of the roaring noise of the river, broke off one of his horns, and gave it to Oeneus, in pledge of his marriage with Deianira his daughter. They who collect truth out of fables, say, that Hercules, who was generally beneficial, for the sake of Oeneus, his father-in-law, restrained the exorbitant overflowing of the river with banks and trenches, and drained a great part of the adjacent country; and this was the cornucopia which the poets made the emblem of plenty."

Not only, however, did the Grecians practise this art, for we find several instances in which it was done among the Romans. In the year 593, when L. Anicius Gallus and Cornelius Cethegus were consuls, the senate directed their attention to the improvement of a great level of waste, lying under water in Latium, about 40 miles from Rome, and engaged a part of the army, then unemployed, in the undertaking; decreeing that one consul should attend the enemy in Gallia, and the other undertake the recovery of the Pompeian marshes. This immense undertaking was accomplished, and twenty-three towns were erected on the lands which the sea had covered. But in after times, when civil discords distracted the empire, the embankments were neglected, and the land again inundated; although they were ultimately twice drained by the emperor Trajan and Theodoricus, king of Italy. The fens about Placentia were drained by Scaurus: and the territory of Ferrara is yet secured by banks and works which hinder their inundation, particularly by the help of the Rotto di Ficarollo and Ramo di Polistella.

The country of Gallia Cisalpina abounds with rivers, especially that territory belonging to the Venetians, which, lying flat and towards the sea, became, by the flowing of the tides, a fenny marsh; but by the help of trenches and banks in such a manner as were long before experimented in Lower Egypt, some part thereof has been drained and made useful for tillage. The drainage and embankments of the Fucine lake was a work of great magnitude, accomplished by the Romans. The emperor Claudius employed 30,000 men, for the space of seven years, upon this work; and although it was not accomplished by him, yet Adrian, the successor of Trajan, completed the recovery.

In the Belgic provinces, or Flanders, recoveries of most extensive tracts of fen and marsh land have been effected; for we find that Cæsar's conquests were opposed by them; and a learned writer, Uridius, affirms, that where now is situated the territory of Furnes were mighty fens extending to the main ocean. Dungdale says, "Much could I say, from the authority of authentic historians, to manifest how full of marshes, lakes and fens, this country anciently was, though now there is little appearance of it; for, by the industry of the inhabitants, they are so banked and drained, that the fertility of it hath made it one of the richest and most populous countries in the world."

"Holland," says Bertius, "is the gift of the ocean and of the river Rhine." And Nannius informs us, that Holland is the gift of the North wind and of the river Rhine, and was in the beginning no more a higher place than ordinary, over which the tides did usually flow; but that, by some extraordinary agitation of the sea, sand heaps were raised, around which the inhabitants of the adjacent shores made banks, to keep them from their original state: the Batavians, a nation of Germany, were the first to make any efficient embankment of that country. The Danes and the Normans, on their invasion, preserved them in the state the Batavians had left them, and the Saxons contributed to the same work.

Great quantities of land have been reclaimed on the banks of the Loire, in France; and it is well known that Friesland, Zeeland, and Holstein, in part owe their existence to the embankments of their shores. Did we need seek for farther proofs of these undertakings having been accomplished in other countries, we know that "the Celestial Empire" gave to China two of her fairest provinces by the same spirit of honourable enterprise.

The governments of the nations that have practised this art, have always considered the acquisition of additional territory to be of great national importance; but it cannot for a moment be doubted but that to us, whose insular situation deprives us of neighbouring unoccupied provinces, to which our teeming population may emigrate, the acquisition of portions of land adjoining our shores, is of far greater moment; yet, obviously true as is this assertion, it is alike extraordinary and unaccountable, that fine tracts of land, presented twice every day to the observation of the public, should be lost to all those purposes for which they are so admirably adapted. Commons have been enclosed at such an expense that the land, in many cases, is not worth the cost, and the industrious cottagers have thereby often been deprived of one mean of comfort and support; but here is land rich in its quality, capable of producing the finest crops, lost to the country for the want of that exertion which has been so liberally extended to other undertakings, which, in comparison to this, are insignificant indeed.

It is stated by Mr Beatson, in the second volume of "Communications to the Board of Agriculture," and by Mr Loudon, in his work on Gardening, that there are yet about three millions of acres (or one fifteenth part of the whole country) on the English and Scottish coasts which might be recovered and added to the kingdom, and which would prove as valuable land as any part already in cultivation. No computation has been made of the quantity that may be reclaimed in Ireland, but it cannot be less than one million of acres, which, if recovered, would give to that country, advantages most apparent. This calculation, however, must of course be in some degree speculative, as no survey has ever taken place; but that the reader may judge how large is the quantity that may be recovered, it should be stated, that every particle of land, whether fen, marsh, or waste, from which the very lowest ebb tides recede, may be embanked, drained, and put into cultivation. It has been objected by some, that a considerable portion of the land so presented, would not be worth recovering; this, however, is a mistake; Mr Loudon (than whom no man is more capable of giving an opinion on this subject) says, that "no kind of land whatever can be gained from the sea which is not valuable, because it can be flooded at all times by the sea, and frequently by fresh water. By flooding, the most barren land, with only an inch or two of soil, will bear excellent pasture, and much land, that is often reckoned barren and useless, is partly composed of broken shells, which contain considerable portions of calcareous earth, admirably adapted for productiveness." Indeed the value of land recoverable from the sea, is not sufficiently understood. The staple soil is well known to be variable in its quality and produce, but the recovered land most frequently consists of soil from three to four feet in depth, containing fine vegetable matter, the remains of sea-weed, marine animals, and other substances deposited by the tide, saturated with salt, and so extremely fertile, that in many instances it has been cropped for twenty years incessantly, without manuring.

RYE BREAD.

"Even those (says Mr Jacob, in his recent report on the state of agriculture on the continent) who can afford wheaten bread, eat commonly that of rye from choice. At the tables of the first families, both in Germany and Poland, though wheaten bread was always to be seen, I remarked that the natives scarcely ever tasted it; and I have met many Englishmen, who after a long residence in those countries, have given the preference to bread of rye. From the time I left the Netherlands, through Saxony, Prussia, Poland, Austria, Bavaria, and Wurtemburg, till I entered France, I never saw, either in the baker's shops, in the hotels, or private houses, a loaf of wheaten bread. In every large town, small rolls made of wheaten flour could be purchased, and they were to be seen at the tables at which the foreigners were seated.—Wheat is only used by the natives in making what our English bakers would call fancy bread, or in pastry and confectionary. If there be no foreign demand for wheat, the difficulty of selling is very great."

Important Decision.—The Circuit Court of the United States, now sitting in Philadelphia, Judge Washington presiding, has decided, that the Bank of the U. S. is holden to pay the half notes of its Bank, where the other has not been paid.