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Mitigating Environmental Impacts of the Abandoned Interstate 95 Embankment across Rumney Marsh

TITLE

Mitigating Environmental Impacts of the Abandoned Interstate 95 Embankment across Rumney Marsh

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Author

Edward Reiner, Senior Wetland Scientist,
US EPA New England,
Boston, Massachusetts.

Edited by

Valerie Bataille, Environmental Specialist
US EPA New England,
Boston, Massachusetts

Cover photo: *August 8, 2015, photo depicting the relocated Pines River crossing at the abandoned I-95 embankment in Rumney Marsh. Photo Credit Bill James.*

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This report was prepared by Edward Reiner, Senior Wetland Scientist, US EPA New England, Boston, Massachusetts. Mr. Reiner graduated from Northeastern University with a Bachelor of Science and a Master of Science degree in Biology. Mr. Reiner started as a co-op student with EPA in 1976 and joined the Region 1's Wetland Program in 1979. He has been working on Rumney Marsh wetland protection and restoration throughout his career with EPA. For this study, he applied the knowledge gathered over four decades of working on Rumney Marsh salt marsh protection and restoration projects and collaborations.

This work would not have been possible without the help and support of the United States Environmental Protection Agency (EPA) New England Regional Laboratory and staff that provided the depth gauge, GPS instruments, and pressure transducers used during the study. Francis Choi, formerly with Northeastern University Marine Science Center (NUMSC), also provided pressure transducers, performed the elevation survey, and installed the transducers. Former EPA intern, Tamer Sullivan, assisted with bathymetry and water level data collection in 2018. Retired EPA employee, Jennie Bridge, helped edit the document. Daniel Morse, GIS Analyst at LinTech Global Inc. (working under EPA IT services support contract no. GS-35F-0343W/68HE0319F0020), developed the Rumney Marsh GIS maps and the analysis and graphics for the bathymetry data, the increased dimensions of the bridges, and the salt marsh vegetation and elevation analysis. Ed Kim assisted with data analysis and graphics. Rachel Croy assisted with the evaluation and presentation of data and report preparation.

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DISCLAIMER

This report was developed by the U.S. Environmental Protection Agency (hereafter EPA or the Agency) to inform restoration planning in Rumney Marsh. An external peer review was conducted in accordance with EPA's peer review process. This project was conducted under an approved Quality Assurance Project Plan. Any mention of trade names, manufacturers, or products does not imply an endorsement by the United States Government or the EPA. EPA and its employees do not endorse any commercial products, services, or enterprises. Links to websites outside of the EPA website are provided for the convenience of the user. Inclusion of information about a website, an organization, a product, or a service does not represent endorsement or approval by EPA, nor does it represent EPA opinion, policy, or guidance unless specifically indicated. EPA does not exercise any editorial control over the information that may be found at non-EPA websites. This is a work of the U.S. Government and is not subject to copyright protection in the United States. All charts not sourced are credited to EPA.

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EXECUTIVE SUMMARY

This study focuses on the coastal wetland restoration opportunity associated with removal of the abandoned Interstate 95 (I-95) highway embankment. Between 1967 and 1969, approximately 120 acres (49 hectares) of Rumney marsh were filled with six million cubic yards (4.6 million cubic meters) of sand and gravel, creating an embankment 2.4 miles (3.9 kilometers) long for the I-95 project that was never completed (Figures 1 and 2). The highway project was abandoned in 1972, however, the embankment was left in place. Details from the 1966 U.S. Army Corps of Engineers (USACE) permit under Section 10 of the Rivers and Harbors Act of 1899, are provided in figures 4-6. Only a narrow rock armored channel was left for drainage and tidal flow to 444 acres (180 hectares) of wetlands located west of the embankment (Figure 6).

With the potential to restore up to 50 additional acres (20.2 hectares) of salt marsh and intertidal area, removing the abandoned I-95 embankment from Rumney Marsh is the single largest opportunity to restore previously filled coastal wetlands in Massachusetts. Restoring the former drainage patterns would also improve tidal flow and drainage to an additional 444 acres (180 hectares) of coastal wetlands on the upstream side of the embankment. Restoring drainage patterns within the high salt marsh is essential for improving the resilience of the marsh to rising sea levels, as well as protecting the breeding habitat of the saltmarsh sparrow.

The purpose of this study was to evaluate if removal of the abandoned I-95 embankment at Rumney Marsh in Revere and Saugus, Massachusetts, to restore the salt marsh, tidal creeks, and previous drainage patterns, would increase tidal flooding over present conditions. Findings are provided from several water level monitoring studies which quantify an increase in tidal hydrology along the Pines River, attributable to the 2009-2012 reconstruction of three bridges on State Route 107. The bridges' reconstruction, using longer and higher spans over the waterways, restored a more normal tidal hydrology throughout the Pines River estuary. This finding reveals that Route 107 was responsible for the lower tidal water levels previously documented by USACE in the East Saugus Marsh.

The goals of this study were to determine the depth of the Pines River to illustrate the bathymetry in the marsh. Bathymetry is the study of underwater depth. This project collected bathymetric data of the Pines River as it flows through three tidal restrictions (the railroad crossing, the Route 107 crossing, and the Pines River/I-95 embankment armored channel). We also collected bathymetry data of the constructed drainage channel on the upstream side of the abandoned I-95 embankment. This drainage channel has been widening due to erosion of the salt marsh peat banks. Erosion of the embankment itself, as well as the peat erosion, contribute to channel sedimentation. Lastly, we collected bathymetry data of the channel from the East Branch of the Pines River. The East Branch of the Pines River bridge was specifically lengthened and raised to provide increased tidal flow and drainage for the Ballard Street Salt Marsh Restoration Project in Saugus.

The bathymetry data revealed significant scour holes on both sides of the railroad bridge, Route 107 bridge, and the I-95 embankment opening of the Pines River. All three crossings in Rumney Marsh (embankment, road, and rail), caused a loss of sheet flow across the high marsh surface. Flows are now concentrated at the waterway openings, increasing water velocity. Scour holes typically develop at bridges or culverts due to the increased flows through undersized structures. The finding of deep scour holes by itself is indicative of the presence of tidal restrictions and may be useful for future modeling of the estuary. Details concerning the bathymetric investigation methods and results are provided in Appendix A.

Another goal was to conduct a water level study to evaluate tidal flooding in Rumney Marsh. The water level data obtained in collaboration with Francis Choi at Northeastern University Marine Science Center (NUMSC) provides a means for evaluating drainage/flooding issues in East Saugus and any potential ecological restoration projects associated with the removal of the abandoned I-95 embankment. The data collected from the water level study allowed for the quantification of the tidal restrictions in the marsh and established that the removal of the abandoned I-95 embankment would not increase flooding to the East Saugus community.

The water level investigation was conducted over a 142-day period in 2019, using Onset HOBO U-Series water level pressure transducers installed at seven strategically selected stations throughout the marsh (Figure 14).[1] We used the same standard operating procedures (SOPs) as previous tidal water level studies; however, our study maintained the equipment for a longer period. We calculated Mean High Water (MHW), Mean Higher High Water (MHHW), and reported the maximum tide observed during two time periods. For our first 52-day study results, we found relatively similar tidal datum metrics throughout the Pines River estuary, with only a slight reduction of tides caused by the railroad bridge for the maximum tide (0.06 feet or 1.8 cm). A slightly larger reduction of 0.14 feet (4.3 cm) was observed for the maximum observed tide above the Route 107 bridges. Maximum tidal water levels on the upstream side of the abandoned I-95 embankment was equal to the immediate downstream side, which was approximately 0.25 feet (7.6 cm) lower than the lower Pines River due to the combined effects of the two downstream bridges.

Our subsequent 90-day study results showed a similar reduction of the maximum tide by 0.05 feet (1.5 cm) caused by the railroad bridge, and an additional 0.1 feet (3.05 cm) reduction to the maximum tide from Route 107. For the 90-day study, the maximum tide on the upstream side of the abandoned I-95 embankment was 0.25 feet (7.6 cm) lower than the lower Pines River. The study results reveal that the Route 107 Bridges' Reconstruction Project successfully restored a more normal tidal hydrology throughout the Pines River estuary, as evidenced by the similar tidal datums of MHW and MHHW. The data revealed there is a slight tidal restriction caused by the Route 107 bridges during the highest tides, which was intentionally designed to avoid increasing tidal flooding.

The most significant threat of flooding for the project area is from tidal surges that may occur during spring high tide periods. Storm or tidal surges occur due to low pressure weather systems such as cyclones. Tidal surge is measured by the difference between the actual and predicted tide. During our study, the area was not subjected to a significant storm surge coinciding with spring high tides. Therefore, we include an evaluation of information about storm surges that have been photographically documented. Photographic evidence of numerous tidal flooding events at one property along the East Saugus Marsh shoreline is included in Appendix C. For each of the storm events, we subtracted the Boston Harbor tide gauge predicted highest tide from the verified highest tide to determine the storm surge amounts. In addition, we calculated the difference between the peak Boston and East Saugus Tides.[2]

The reported storm surges produced 0.3-to-3.4-foot higher tides than predicted, causing street flooding at Beachview and Belair Streets in East Saugus. Based on the photographic evidence combined with ground elevation and fence measurements, EPA estimates these tidal flood events resulted in water levels reaching elevation 6.4 to 7.5 feet NAVD88. The frequent tidal flooding at elevations approaching or exceeding the predicted annual highest tide, is evidence in clear support of our conclusion that the I-95 embankment does

[1] https://www.onsetcomp.com/products/data-loggers/u20-001-01
[2] https://tidesandcurrents.noaa.gov/waterlevels.html?id=8443970

not provide a reduction of tidal flooding in East Saugus. Based on the data collected and analysis of the tidal fluctuations, we conclude that removal of the abandoned I-95 embankment from the marsh would not increase flooding over existing conditions.

The removal of the abandoned I-95 embankment and restoration of the marsh is both an allowable activity with respect to permitting and environmental review considerations, and a goal in the Rumney Marshes Area of Critical Environmental Concern designation. Appropriately designed excavation, dredging, and associated placement of fill activities required to restore the marsh would be eligible for permitting as an Ecological Restoration Project under the Massachusetts Wetland Protection Act, and the USACE General Permit for Aquatic Habitat Restoration, Enhancement and Establishment Activities under the Massachusetts General Permit.[3] Demonstrating that the embankment does not provide flood protection, and adversely impacts drainage for the community and the condition of the marsh, is critical to mitigating the environmental impacts.

Most importantly, breaching the embankment to restore the former flow path of the East Branch of the Pines River would improve drainage for the marsh and community residents. Improving drainage is critical as "waterlogged" areas in a salt marsh typically result in plant die-off, marsh decay, and subsidence of the marsh (Day et al. 2011, Burdick et al. 2020). Improving drainage will contribute to increased marsh resiliency to sea level rise by helping to maintain high salt marsh areas.

High salt marsh areas are vital for breeding of saltmarsh sparrow (*Ammodramus caudacutus)* which nests in the high marsh.[4] Saltmarsh sparrow populations are declining due to nest flooding and predation. The saltmarsh sparrow was listed as Special Concern under the Massachusetts Endangered Species Act (MESA) in 2020 and is expected to be listed under the United States Endangered Species Act. To understand the breeding of saltmarsh sparrows and how rising tides affect them, view the video at https://www.pbs.org/video/nature- saltmarsh-sparrow-chick-escapes-death.

With the expected sea level rise projections, alternative retreat, flood proofing, raising building elevations, or flood control berms or walls will be needed. Berms or walls, however, do not solve all problems as groundwater also rises with sea level, and interior drainage would need to be accommodated by providing ponding areas or pump stations.

Present and future concerns for tidal flooding in the larger estuary area have resulted in efforts to resurrect the formerly proposed Saugus River and Tributaries Flood Damage Reduction Project, which would construct a series of closable floodgates at the mouth of the Saugus River.[5] Regardless of any larger flood control project that may be needed in the future to address sea level rise, continued removal of embankment fill would promote ecological restoration of the marsh. Fill removal also creates additional flood storage in the marsh. Protecting an estuary storage area is a critical component of the USACE Saugus River and Tributaries Flood Reduction Project. The abandoned I-95 embankment provides no flood protection benefit for East Saugus and can be removed without increasing present tidal flooding conditions. Thus, removal of the I-95 embankment is compatible with and supportive of the Saugus River and Tributaries Flood Damage Reduction Project, should it be implemented.

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[3] https://www.nae.usace.army.mil/Missions/Regulatory/State-General-Permits/Massachusetts-General-Permit/

[4] https://www.fws.gov/species/saltmarsh-sparrow-ammodramus-caudacutus

[5] https://apps.dtic.mil/dtic/tr/fulltext/u2/a217016.pdf

This EPA report consolidates multiple lines of evidence supporting the position that the tides in the upper Pines River are partially restricted by the downstream bridges, not the abandoned I-95 embankment. This study concluded that removal of the embankment to restore former drainage patterns and sheet flow across the marsh would result in positive environmental impacts without increasing the existing or future flooding problems. This report, associated data, and other information about Rumney Marsh can be found at EPA R1-Rumney-Marsh-Wetland. In addition we will also be publishing this EPA Report on EPA's Science Inventory.

INTRODUCTION

This EPA report analyzes multiple lines of evidence to determine if the tides in the Pines River are restricted by the downstream bridges and the abandoned I-95 embankment.

Study Goals and Objectives

The goal of this study was to document depth of the Pines River in Rumney Marsh through a bathymetric study. Bathymetric data was collected along the Pines River as it flows through three tidal restrictions (the railroad crossing, the Route 107 crossing, and the Pines River abandoned I-95 embankment armored channel). The objective of this study was to document channel depth along the Pines River, the constructed drainage channel on the upstream side of the embankment, and the channel leading from the East Branch of the Pines River along the east side of the abandoned I-95 embankment in Saugus. This data will be useful if hydraulic modeling studies are needed to evaluate potential flooding impacts from embankment fill removal options.

An additional goal of the study was to document if water levels vary on the different sides of the tidal restrictions. The objective was to collect sufficient water level data in order to quantify the tidal restrictions in the marsh. This would determine whether the removal of the abandoned I-95 embankment would increase flooding to the East Saugus community. The water level data provides a means for evaluating drainage/flooding issues in East Saugus and any potential ecological restoration projects associated with the removal of the abandoned I-95 embankment.

Research Study Setting

Situated at the lower end of the 47 square mile (122 square kilometer) watersheds of the Saugus and Pines Rivers, the 1657-acre (671-hectares) Rumney Marsh is the largest remaining estuarine ecosystem in the metropolitan Boston area (Figure 1). Rumney Marsh supports an abundance of natural resources, including 38 species of resident and migratory fish, shellfish, shorebirds, wading birds, and waterfowl. In recognition of the importance of protecting these resources, the Commonwealth of Massachusetts, in 1988, designated most of the marsh as an Area of Critical Environmental Concern (ACEC).[6]

On its east side, the marsh is bounded by Revere Beach, a developed barrier beach within the Pines River portion of the marsh. On its west side, commercial and residential property borders the marsh. To the northwest, the marsh is bounded by uplands of the East Saugus and Cliftondale neighborhoods. To the north, the Saugus River is flanked with industrial and commercial property in Lynn, including the General Electric Corporation facilities.

[6] https://www.mass.gov/files/documents/2016/08/pf/rm-des.pdf

The population that is most impacted from flooding adjacent to the area assessed for this study is approximately 3,316 people. According to EPA's EJ screening tool, that is only for pre-decisional use, the impacted area which is upstream of route 107 is comprised of 32% percent people of color, representing 52%ille in the USA and in the 80%ille in the USA for limited English-speaking households, i.e., Indo-European language and other languages. EJ Screen denotes a number of selected Air pollution indices that are particularly high in this impacted area, Diesel Particulate Matter, Air Toxics Risks, Air Toxics Respiratory HI are in the 80-90th %Ille in the USA and the proximity of an RPM facility and hazardous waste are also in the 80thille in the USA. For additional information, see [EPA Environmental Justice].

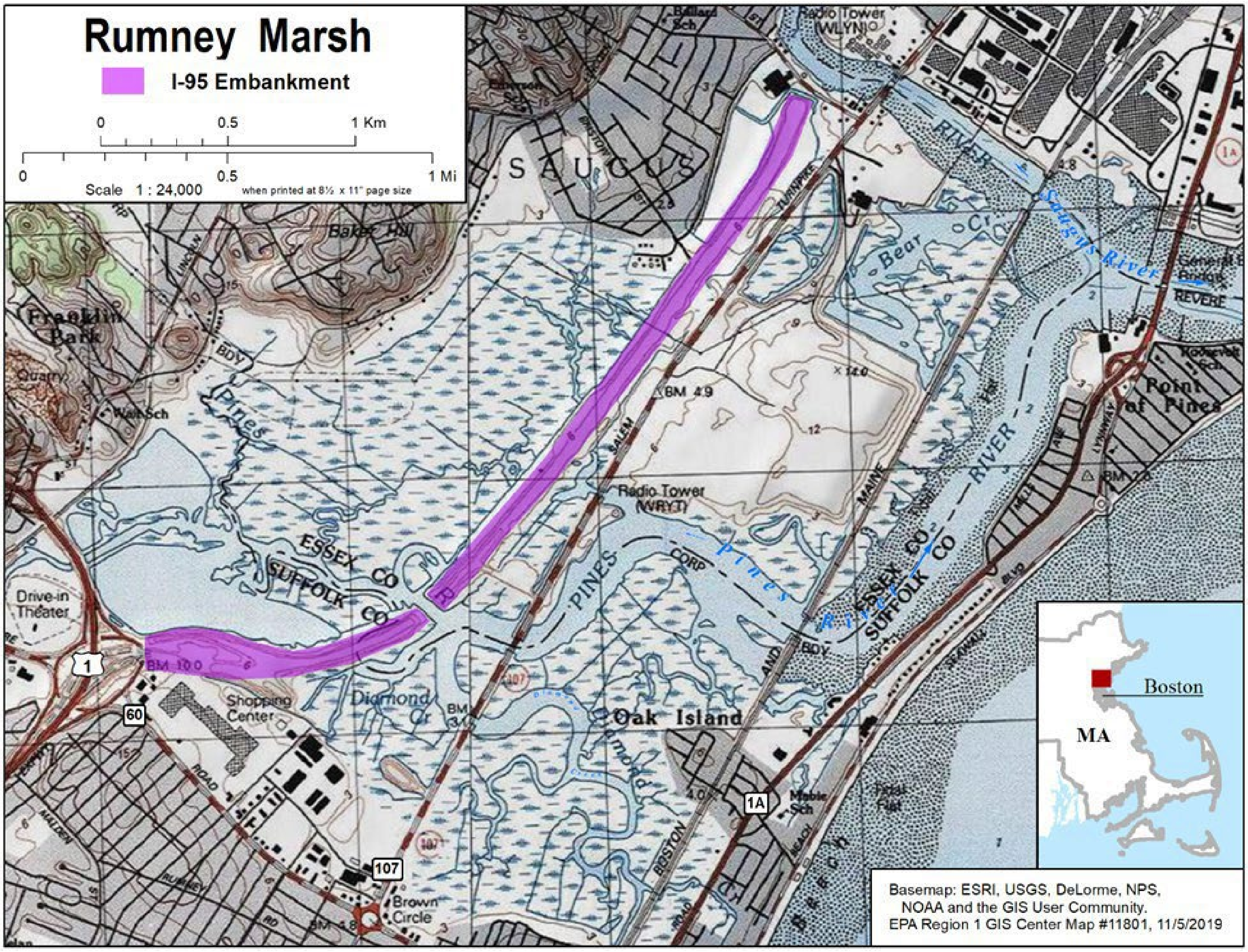

Figure 1. *United States Geological Survey (USGS) topographic map highlights the abandoned I-95 highway embankment across the full width of the marsh with only one opening at the relocated Pines River crossing. Route 107 (Salem Turnpike) and the Boston and Maine (now MBTA) Railroad are also depicted as crossing the length of the marsh.*

The Saugus Iron Works National Historic Site is located at the upper limit of the estuary, approximately 4.5 miles (7.2 kilometers) from the mouth of the Saugus River. The Saugus Iron Works, America's first successful ironworks, operated from 1646 to 1668. With more than 350 years of development history since the arrival of

English colonists in the seventeenth century, the marsh has been impacted in many ways. EPA has estimated that 1,258 acres (509 hectares) or approximately 43% of the marsh was filled from 1803-2007 and an additional 87 acres (35.2 hectares) was dredged and converted to mudflat or open water (Figure 2).

Based on studies conducted in 1987, the USACE characterized the estuary as containing 236 acres (95.5 hectares) of tidal river, 330 acres (133.5 hectares) of mud flats, and 115 acres (46.5 hectares) of regularly flooded low salt marsh (*Spartina alterniflora*).[7] Approximately 955 acres (386.5 hectares) were irregularly flooded habitats including 510 acres (206.4 hectares) of high marsh (*Spartina patens* and *Distichlis spicata*), 181 acres (73.2 hectares) of undifferentiated high marsh, and 141 acres (57.1 hectares) of *Phragmites australis* marsh. The USACE also distinguished specific acreage for several other cover types, including short form *Spartina alterniflora*, *Iva frutescens*, *Distichlis spicata*, *Juncus gerardii*, *Typha spp*., panne, non-vegetated areas, tidal creek, and pond. Estuary resources also included 5.5 acres (2.2 hectares) of shrub swamp, 3.2 acres (1.3 hectares) of wooded swamp, and 6.6 acres (2.7 hectares) of upland. The USACE also documented the acreage and type of wetlands upstream of the abandoned I-95 embankment in both Revere and Saugus in May 1987 as containing a total of 475 acres (192 hectares) of wetlands (Table 1). This acreage included 38 acres of *Phragmites* (15.4 hectares) in ponding areas. Excluding the Ballard Street salt marsh, the upper Pines River contains approximately 444 acres (179.7 hectares) of wetlands (IEP 1988, USACE 1989).

Table 1*. Wetland acreage from a May 1987 survey in the upper Pines River from USACE 1991b*

Wetland Acres - Upper Pines River, May 1987

	Saugus	Revere	Total Acres
Sub - Tidal Rivers	0	28	28
Mudflats	0	58	58
Low Salt Marsh Grasses	21	20	41
High Salt Marsh Grasses	245	28	273
Pannes	4	0	4
Phragmites Reeds			
in High Marsh	7(10-20)*	3	10 (13-23)*
in Ponding Areas	38	0	38
Marsh Elder Bush	14	0	14
Shrub/Wooded Swamps & Cattails	9	0	9
TOTAL	338	137	475

* Includes areas of phragmites not shown on the cover maps.

Rumney Marsh Background

Construction of roads and railroads in the nineteenth century, as well as more recent road projects, segmented the marsh and affected tidal hydrology. Salem Turnpike (Route 107) was constructed across the marsh in 1803 providing stagecoach service, later, a horse railway, and in 1860 an electric trolley car between Salem and Boston, and finally, the current automobile roadway. This road bisected the marsh in a roughly north-south direction. The 2.3-mile (3.7-kilometer) roadway crossing of the marsh prevented sheet water flow

[7] *Spartina alterniflora* has been reclassified as *Sporobolus alterniflorus* after a taxonomic revision in 2014. *Spartina patens* has been reclassified as *Sporobolus pumilus.*

across the high marsh surface, restricting tidal flow to four relatively small bridges at the major rivers and creeks in the marsh (Figure 2).

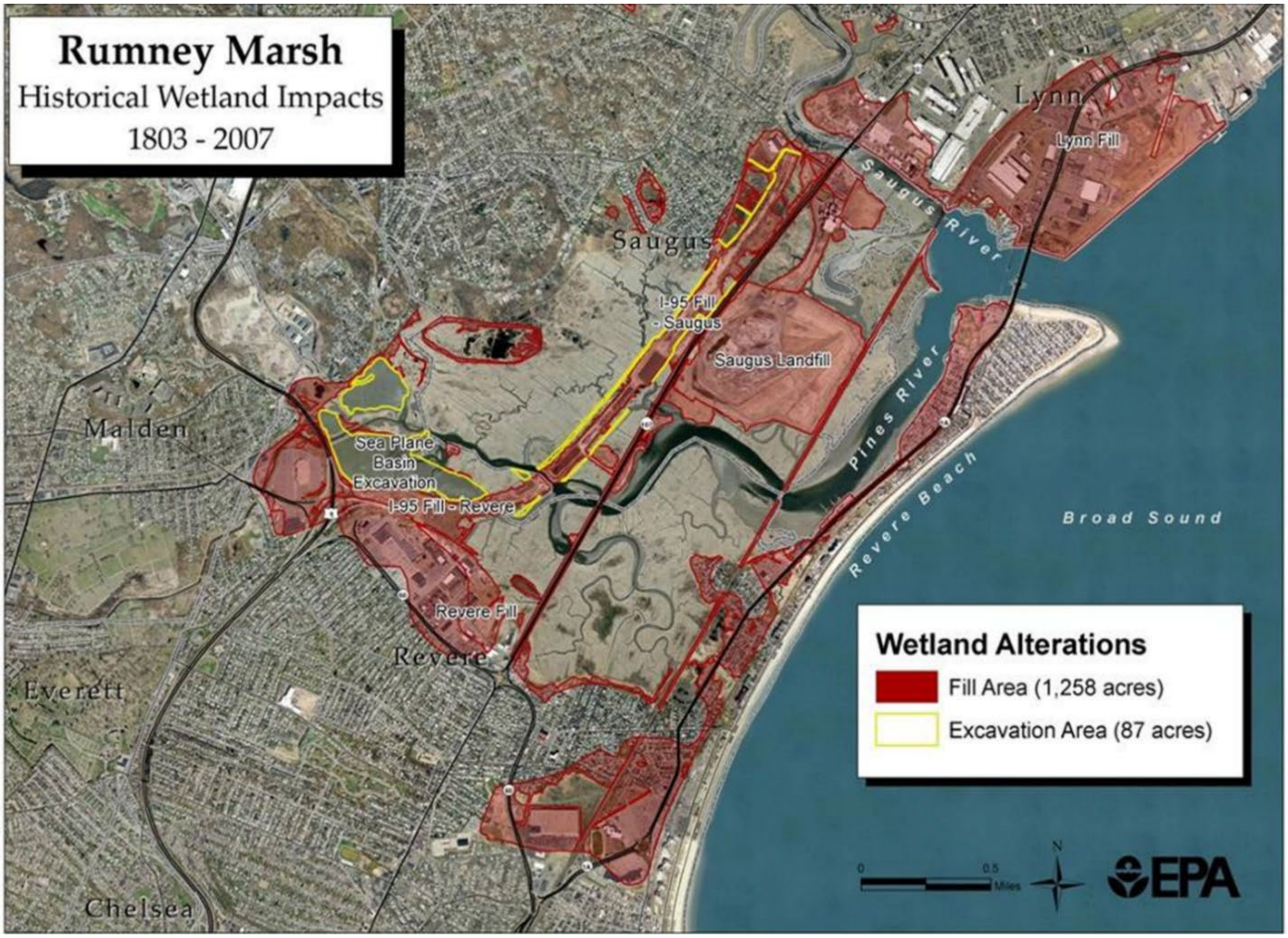

Figure 2. *Rumney Marsh historical wetland impacts 1803–2007. Approximately 1,258 acres, 43% of the marsh, has been filled, as shown in red. The yellow shaded area depicts 87 acres where salt marsh had been dredged or excavated. The upper estuary area is not depicted.*

A public works project in 1928 filled more than 300 acres (120 hectares) at the mouth of the estuary in Lynn for the Lynn Harbor Improvement and Nuisance Abatement project. Landfills in Saugus filled approximately 200 acres (80 hectares) of marsh. The Saugus landfill eliminated tidal flow across the width of the marsh preventing the normal spring tide sheet flows across the high salt marsh between the Saugus River and Pines River on the downstream side of Route 107 (Figures 1 and 2). The 1930s brought about marsh reclamation work in salt marshes, which constructed grid ditches for drainage and mosquito control. In the late 1940s or early 1950's in Revere, two large excavations were made in the marsh, one of which was used for a short time as a seaplane basin. The underlying sands and clay soils from the marsh were used for the construction of Logan International Airport. In the 1950s, the Pines River was channelized by the Metropolitan District Commission for a flood control project at Town Line Brook.

According to studies by the USACE, the ongoing development of Lynn, Saugus, and Revere between 1951 and 1971 resulted in a total of 613 acres (248 hectares) of salt marsh loss (about 33% of salt marsh resources) over that 20-year period (USACE 1989a). EPA's analysis of historical wetland impacts from 1803-2007 revealed approximately 43% of the original marsh had been filled for commercial, industrial, and residential development, largely in the twentieth century. Fill areas encompass approximately 1,258 acres (509 hectares) of salt marsh, intertidal, and subtidal area of the total estimated 2,908-acre (1,177 hectares) estuary. An additional 86 acres (35 hectares) of salt marsh were altered by excavation for gravel, construction of the Seaplane Basin adjacent to the Revere Airport (now part of Northgate Shopping Center), relocation of the Pines River, and construction of drainage channels associated with the abandoned I-95 project (Figure 2).

Between 1967 and 1969, approximately 120 acres (49 hectares) of Rumney Marsh were filled with six million cubic yards (4.6 million cubic meters) of sand and gravel, creating an embankment 2.4 miles (3.9 kilometers) long for the I-95 project that was never completed (Figure 1). Extending from Route 1 in Revere, adjacent to the Pines River across the full width of Rumney Marsh to East Saugus, the embankment filled in the original meandering Pines River channels and the East Branch of the Pines River, adversely affecting tidal flooding and drainage patterns. Figure 3 depicts the outline of the embankment fill on a 1960 aerial photo. Tidal creeks in East Saugus, which were severed by the embankment, were relocated to a "temporary" drainage channel which directed flow to a single rock-armored Pines River channel. The I-95 project was later abandoned in 1972, leaving the embankment in place. Details from the 1966 USACE permit under Section 10 of the Rivers and Harbors Act of 1899, are provided in figures 4-6. Only a narrow rock armored channel was left for drainage and tidal flow to 444 acres (180 hectares) of wetlands located west of the embankment (Figure 6).

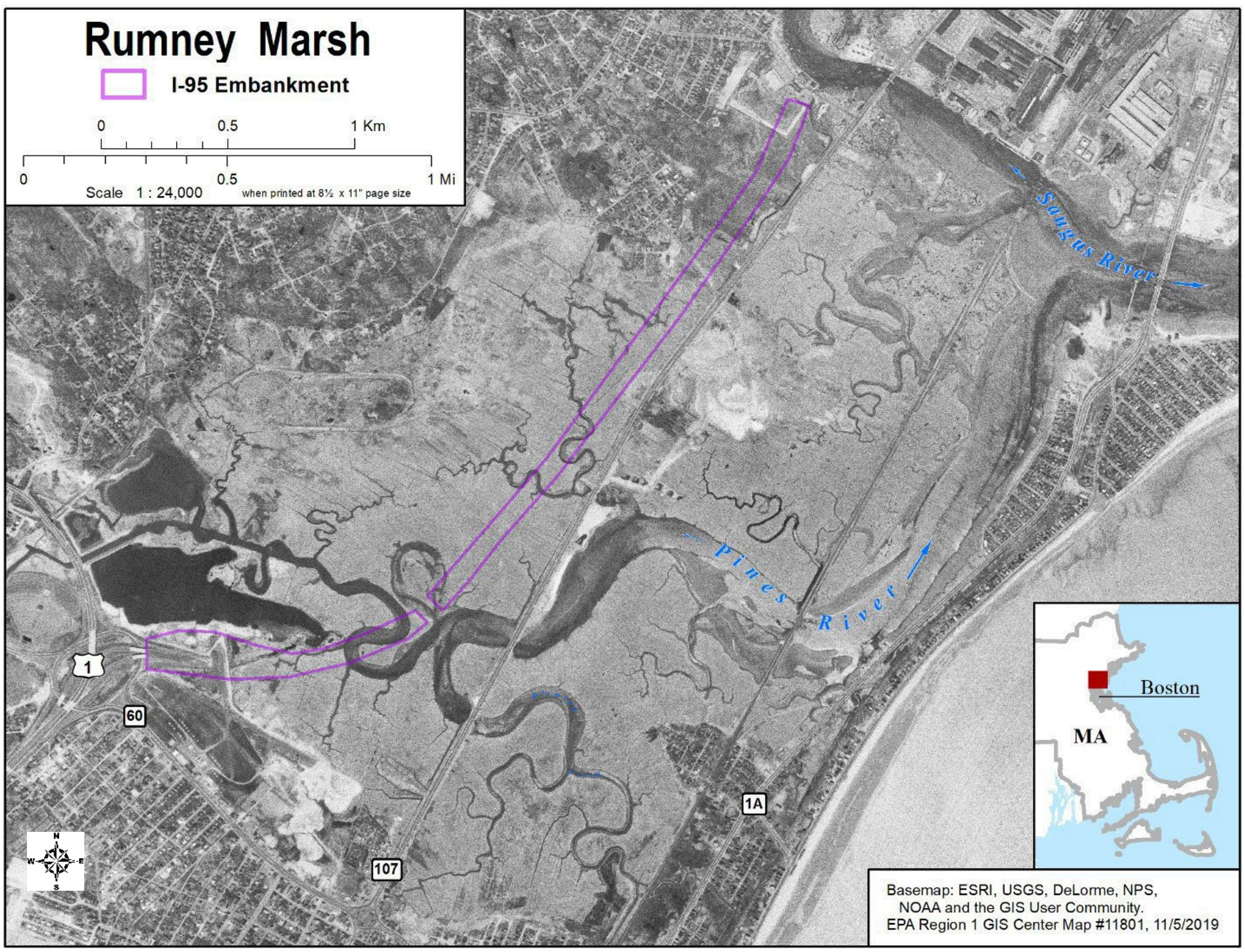

Figure 3. *Air photo (courtesy USGS) from May 1, 1960, showing the Pines River and its branches as well as the future I-95 highway embankment outlined in purple.*

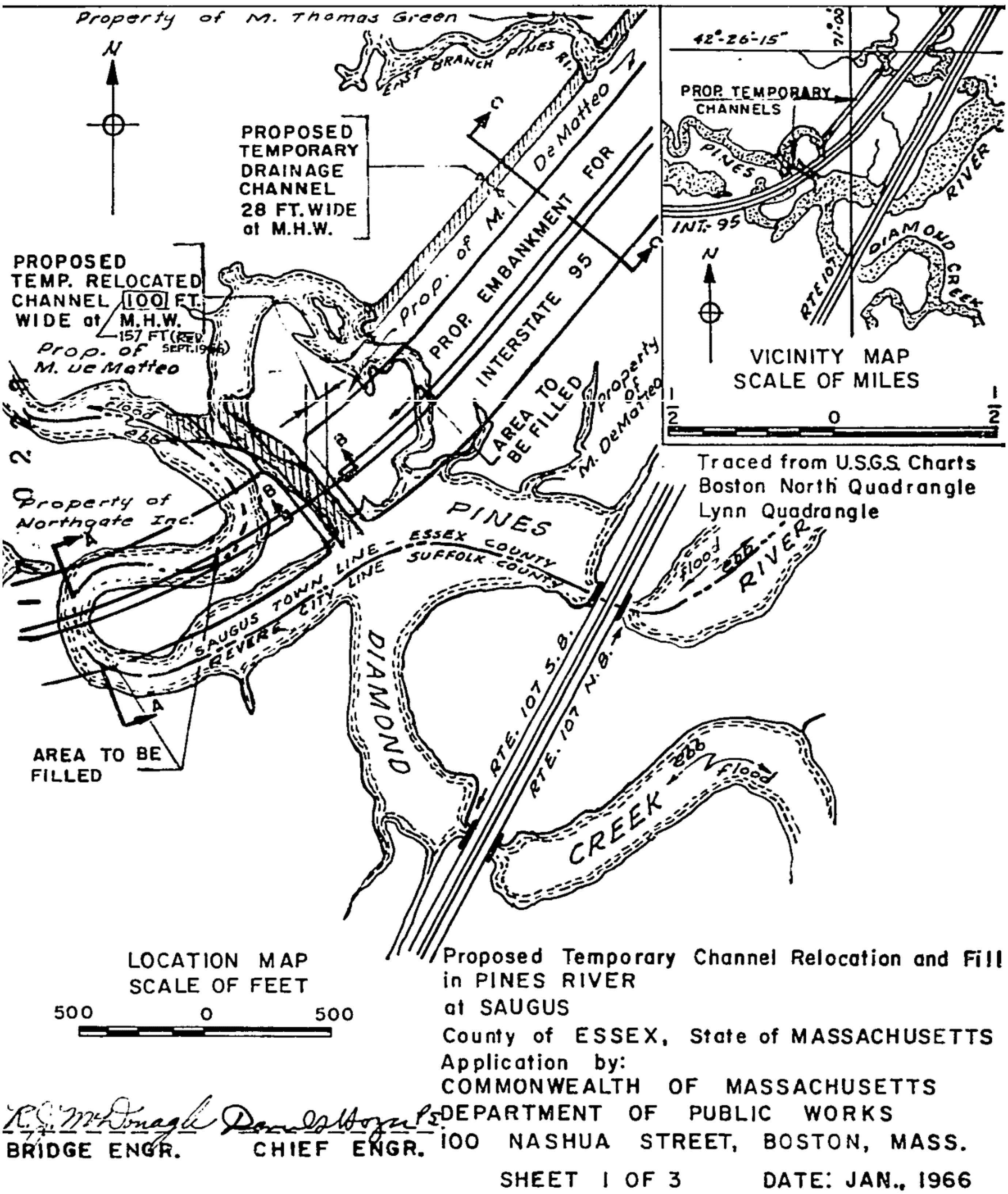

Figure 4. *Sheet 1 of 3 from USACE permit file 1966-00038 to relocate a portion of the Pines River, excavate a temporary channel and place fill for an embankment for the Interstate 95 Highway Project in the Pines River at Saugus Massachusetts.*

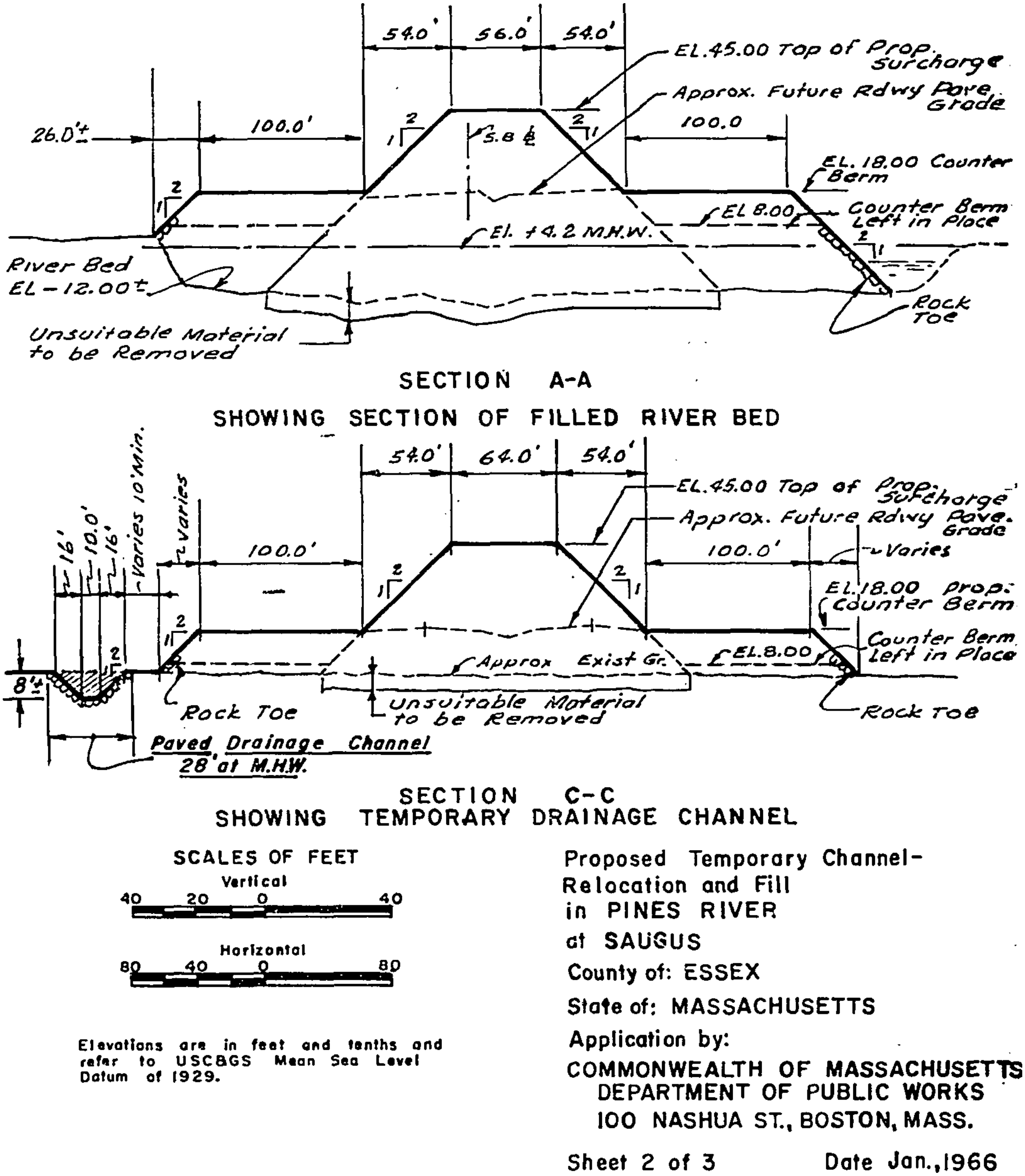

Figure 5. *Sheet 2 of 3 from USACE permit file 1966-00038 plan shows details for the embankment construction and the drainage channel which was constructed along the embankment in Saugus.*

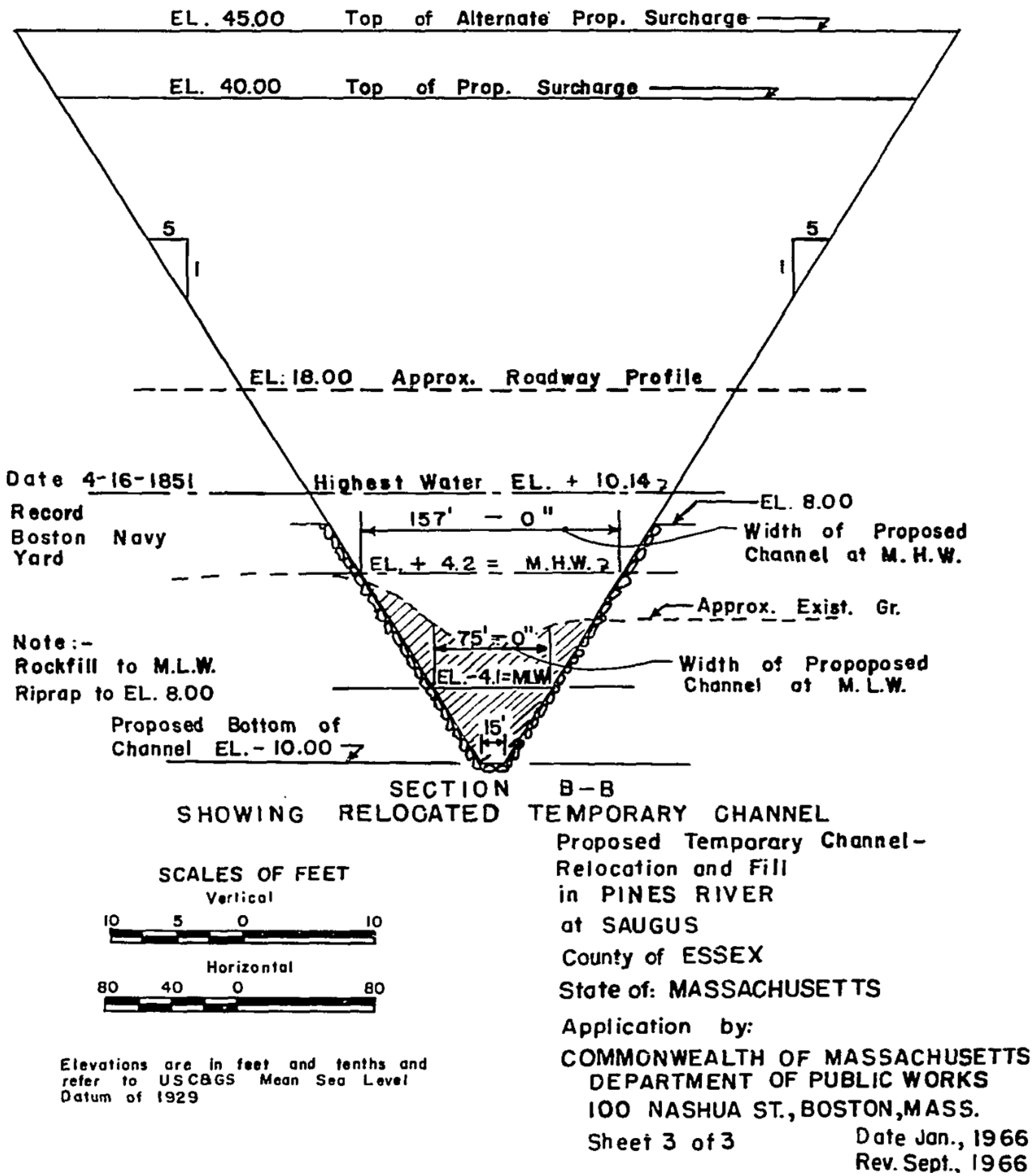

Figure 6. *Sheet 3 of 3 from USACE permit file 1966-00038 for the relocated Pines River Crossings shows the armored crossing dimensions and depth.*

In 1972, during consideration of the environmental impacts for the construction of I-95 through Boston, Massachusetts, Governor Francis Sargent stopped the highway project for social and environmental reasons. While the damage to Rumney Marsh was already done, the highway would have also bisected Lynn Woods Reservation, a 2,200-acre (890-hectare) municipal forest park in Lynn.

Extensive flooding across southern New England occurred during a February 6-7, 1978, blizzard which was considered a 100-year tidal flood event. The tidal flooding affected low lying areas surrounding both the Pines and Saugus River estuary with flood levels reported to elevation 11.0 feet NGVD29. The elevation of the marsh in East Saugus was 5-6 feet NGVD29, whereas high water was surveyed there at 10.5 feet NGVD29. This is due to an astronomically high tide of 6.9 feet combined with a storm surge of 3.4 feet (USACE 1989e).

In 1988, when the highway layout land was no longer needed for highway purposes, the original landowners attempted to regain title for commercial development. The land, however, was kept in public ownership for flood control and recreational purposes and transferred to the Metropolitan District Commission (MDC). The land is now managed by the Massachusetts Department of Conservation and Recreation (DCR).[8]

Removal of the abandoned highway embankment and restoration of the marsh are specifically included as goals in the August 22, 1988, designation of the marsh as an Area of Critical Environmental Concern (ACEC).[9] Approximately 37 acres (15 hectares) of salt marsh and intertidal areas have already been restored to date by embankment fill removal projects, as mitigation for aquatic impacts elsewhere. This represents about 31% of the original embankment fill footprint impacts to wetlands. These projects were required to maintain a continuous flood control berm across the marsh based on the belief that the narrow opening of the embankment was restricting the tides to the upper marsh and, thereby, providing flood protection to properties abutting the marsh.

On July 11, 1989, a "Care and Control Agreement Between the Town of Saugus and the Metropolitan District Commission" (now DCR) was signed that requires, in part, the maintenance of a minimum height flood control berm. The specific provision states:

> "*3. No further sand removal, beyond that necessary and approved for The Revere Beach Erosion Control Project will occur except in conjunction with reservation construction, landscaping, or any program of marsh restoration. The flood protection barrier will be maintained at a minimum height of 13.5 N.G.V.D."*

In 1990 the USACE responded to comments submitted regarding the Saugus River and Tributaries Flood Reduction Project. EPA, National Marine Fisheries Service, US Fish and Wildlife Service, and Massachusetts Coastal Zone Management requested the USACE evaluate breaching the I-95 embankment, concurrent with the project for environmental restoration of the marsh. Additionally, this would serve as mitigation of project impacts to the aquatic environment. In a reply to comments from the National Marine Fisheries Service letter dated April 17, 1990, the USACE stated:

> *"The complete removal of the I-95 fill is not part of this project's required mitigation. The MDC currently intends to use the embankment as a linear park but would entertain partial use for ecological*

[8] EOEA Number 8369 MEPA Certificate for the Saugus 143-Acre transfer dated October 11, 1990

[9] https://www.mass.gov/files/documents/2016/08/pf/rm-des.pdf

enhancement. It is unknown whether breaching the fill will provide significant additional flushing or by how much. Route 107 may be the significant constriction."[10]

Pursuant to their mission of Environmental Protection established by Section 306 of the Water Resources Development Act of 1990, the USACE investigated breaching the abandoned I-95 embankment to restore the functioning of the salt marsh. Between 1990 and 1993, the USACE Hydraulics Laboratory, Waterways Experiment Station in Vicksburg, Mississippi (now called Engineering Research and Development Center - ERDC), undertook a numerical model investigation of the estuary hydraulics.[11] The USACE Hydraulics Laboratory specifically evaluated an intentional breaching of the abandoned I-95 embankment to improve tidal inundation to the upper Pines River wetlands. The USACE estimated that intentional breaching where the East Branch of the Pines River was cut off by the embankment, and widening of the existing Pines River channel, would increase the peak tides by about 0.5 feet (15 cm) during spring tides. The USACE also estimated that the breaching would decrease the time to peak water level delay from two hours to one hour.

Between 1991-1993, the USACE developed plans to restore degraded wetlands and increase tide levels to nearly 500 acres of wetlands hydrologically impacted by the abandoned highway embankment. This plan to breach the embankment and widen the Pines River channel was intended to follow the construction of the regional floodgate. This is because without the regional floodgate, the expected increased tidal flooding to the marsh would impact about 30 homes and several commercial properties that border the shoreline in East Saugus and as many as 140 homes in the adjacent neighborhood. While the land bordering the salt marsh edge already has a berm which is approximately 1-2 feet high, the USACE plans included walls or berms to protect the area from increased tidal flooding.[12]

In 1993, the Saugus River Floodgate Project was deauthorized after the Secretary of Environmental Affairs opposed the construction. Currently, renewed interest in the project by the communities, along with the Governor's interest to help communities facing flooding from sea level rise, may help to restart the project.

In 1996, local, state, and federal stakeholders began to develop a salt marsh restoration plan for Rumney Marsh and Belle Isle Marsh, which is also included in the Rumney Marshes ACEC. In May 2002, following nearly six years of work, the Wetland Restoration Program at the Department of Environmental Management (part of the Commonwealth of Massachusetts Executive Office of Environmental Affairs), published the Rumney Marshes Area of Critical Environmental Concern Salt Marsh Restoration Plan.[13] This plan identifies projects that had already been constructed, as well as potential future salt marsh restoration projects in Boston, Revere, and Saugus. To update and maintain a resource for wetland restoration planning in Rumney Marsh, EPA created the Rumney Marsh Restoration Areas map (Figure 7).[14]

Between 2009 and 2012, three bridges on State Route 107 which crosses Rumney Marsh, just downstream of the abandoned I-95 highway embankment, were reconstructed by the Massachusetts Highway Department (Mass Highway). The bridges were purposely reconstructed with longer spans to improve tidal flow and flushing and decrease erosive conditions. In addition, the low chord of the bridges was raised in height to provide safer recreational navigation in the marsh.

[10] https://apps.dtic.mil/sti/pdfs/ADA235142.pdf
[11] https://apps.dtic.mil/dtic/tr/fulltext/u2/a266336.pdf
[12] https://saugusriverfloodgate.com/the-project/restoration-plan-features
[13] https://www.mass.gov/doc/rumney-marshes-acec-salt-marsh-restoration-plan/download
[14] https://www.epa.gov/sites/production/files/2018-07/documents/rumney-marsh-restoration-areas.pdf

Wetland Protection and Restoration Efforts

Massachusetts enacted the first wetland protection legislation in the nation in 1963. The Federal Clean Water Act, enacted in 1972, created a federal wetland permit program to regulate alteration of wetlands. Coastal wetland filling, however, was commonly permitted until the Massachusetts Wetland Protection Act was amended in 1978 with regulations for the protection of coastal wetlands. These state regulations and subsequent changes have nearly halted legally permitted losses of salt marsh.[15]

Pursuant to requirements under the Federal Clean Water Act and the Massachusetts Wetland Protection Act, permits are required for certain activities in coastal wetlands. Local Conservation Commissions must issue Orders of Conditions for work in coastal resource areas subject to state guidance and regulations.[16] Massachusetts has one of the strongest regulations in the country regarding the protection of salt marsh. Salt marsh is rarely allowed to be permanently impacted, except for certain projects that clearly have no alternatives and are in the public interest. Under Section 404 of the Clean Water Act, and pursuant to the Massachusetts Wetland Protection Act, unavoidable impacts to wetlands will generally require mitigation such as wetland restoration or creation.

Efforts to remove the abandoned I-95 embankment have been complicated to date, based on the belief that fill removal which breaches the embankment, would increase tidal flooding to developed property on the upstream side. Removal was first considered in 1985, when 800,000 cubic yards (611,643 cubic meters) of embankment sands and gravel fill were excavated and placed on Revere Beach by the USACE. The project lowered the height of the embankment fill in Saugus to within four to five feet (1-1.5 meter) of the original marsh surface, while maintaining a continuous higher flood protection berm across the marsh. As part of the agreements for that project, 15 cents per cubic yard was to be provided for marsh restoration by others. The money, however, was never allocated toward restoration projects.

The August 22, 1988, designation of the Rumney Marsh Area of Critical Environmental Concern brought new attention to the marsh and included a goal to remove the abandoned highway embankment and restore the marsh.[17] Restoration efforts to date have beneficially reused several million cubic yards of the original embankment fill for various public highway projects, starting in the 1980s with the Peabody Connector project at I-95 and Route 128.

Numerous large public works projects starting in the 1990s removed portions of the I-95 fill embankment to mitigate aquatic resource impacts that occurred elsewhere. The Central Artery/Third Harbor Tunnel Project, the USACE Roughans Point Shore Protection Project, and the USACE Saugus River Navigation project each restored intertidal habitat by excavation and grading activities to mitigate loss of intertidal habitat elsewhere. In 2016, a runway safety project at Logan International Airport by the Massachusetts Port Authority (MassPort) and the Nahant Causeway improvement by the DCR contributed to additional removal of fill and restoration of intertidal areas and salt marsh. The acreage of habitat that was restored for each of these projects is provided in Appendix B.

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[15] https://www.mass.gov/doc/310-cmr-1000-the-wetlands-protection-act/download

[16] https://www.mass.gov/doc/applying-the-massachusetts-coastal-wetlands-regulations-a-practical-manual-for- conservation/download

[17] https://www.mass.gov/files/documents/2016/08/pf/rm-des.pdf

Excavation for the DCR's Winthrop Shores Beach Nourishment Project removed an additional 280,000 cubic yards (214,000 cubic meters) of fill material in Saugus in 2015. This excavation reduced the width of the abandoned embankment at the northern end near Ballard Street, in conjunction with an intended salt marsh and flood improvement project. About 6.1 acres (2.4 hectares) adjacent to this portion of the embankment are now at elevations low enough that wetlands have developed in the excavated area. However, a berm was left in place, separating it from the adjacent Ballard Street Salt Marsh. If project funding can be found, and permit plans agreed upon, restoration of improved tidal flows to the Ballard Street Salt Marsh would allow for another 34.5 acres (14 hectares) of wetland restoration.

The restoration projects at the abandoned I-95 embankment completed to date have cumulatively restored 37 acres (15 hectares) of salt marsh and intertidal areas. This represents about 31% of the original embankment fill footprint impacts to wetlands. EPA estimates that an additional 50 acres (20.3 hectares) of embankment can be removed. Additional areas of salt marsh can be restored along the eroding "temporary" drainage channel, following the restoration of the East Branch of the Pines River crossing.

While the height and width of the embankment have been reduced by these fill removal projects, all were required to retain a portion of the embankment for flood protection. EPA's 2019 tidal water level study revealed that the embankment does not reduce tidal flooding. This finding will allow continued removal of the embankment, restoration of the former tidal creeks, and sheet flow across the restored marsh surface, which will, in turn, improve marsh resilience to rising sea level.

Figure 7 depicts the locations of the tidal restrictions (bridges) that were reconstructed, as well as the status of various fill removals and tide gates (details for each area can be found in Appendix B). The locations of the former tidal channels that were altered by embankment construction are depicted in the blue dotted lines.[18]

Figure 8 is a 2021 aerial photo showing the retained flood protection berms (outlined in red) surrounding three completed wetland restoration projects in Saugus. The former waterways are depicted in blue and white dashes. The map depicts a suggested fill removal focus area that would be a high priority for restoring marsh habitat and drainage across the marsh. Removal of the area outlined in red would allow for the restoration of sheet flow across 3,200 linear feet of the East Saugus Marsh, while also restoring drainage and tidal flow at the East Branch of the Pines River. Restoring the severed former waterway crossings would decrease erosive conditions by lowering the velocity of tidal water flow.

[18] https://www.epa.gov/system/files/documents/2022-01/rumney-marsh-restoration-areas-2022.pdf

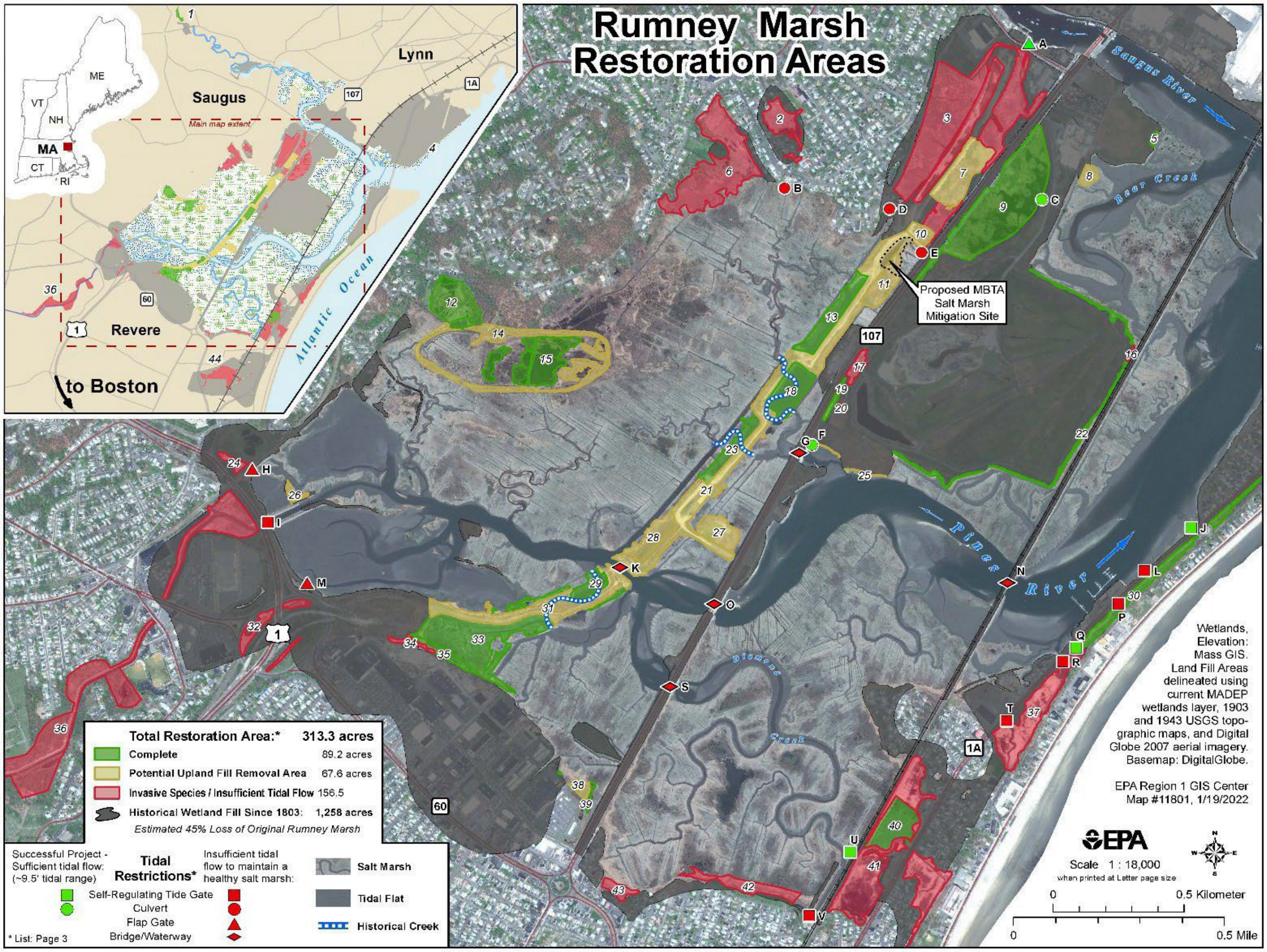

Figure 7. *EPA Rumney Marsh Restoration Areas map depicts locations and status of various fill removals, restoration projects, and tidal restrictions (details for each area can be found in Appendix B). The locations of the former tidal channels that were altered by embankment construction are depicted in the blue dotted lines.*

To restore this area, approximately 113,000 cubic yards (cy) would need to be excavated. The excavated material could be used to restore additional salt marsh by filling portions of the constructed "temporary" drainage channel. Additional areas of embankment removal, including the widening of the Pines River crossing, would require a total of approximately 208,000 cubic yards of excavation.[19] Some of this excavated material can be used to restore salt marsh within the "temporary" channel that would no longer be needed.

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[19] The following were volumes computed for a 60-foot-wide berm at elevation 13.5 feet NGVD29 and a base at elevation 5.0, 130 feet in width: site #13 @ 53,000 cy; #18 @ 30,000 cy; #23 @ 30,000 cy; #29 @ 27,000 cy; and widen Pines River opening @69,000 cy for a total of 208,000 cy. These volumes were calculated based on removal of retained embankments adjacent to completed restoration sites 13, 18, 23, and 29 shown in Figure 7.

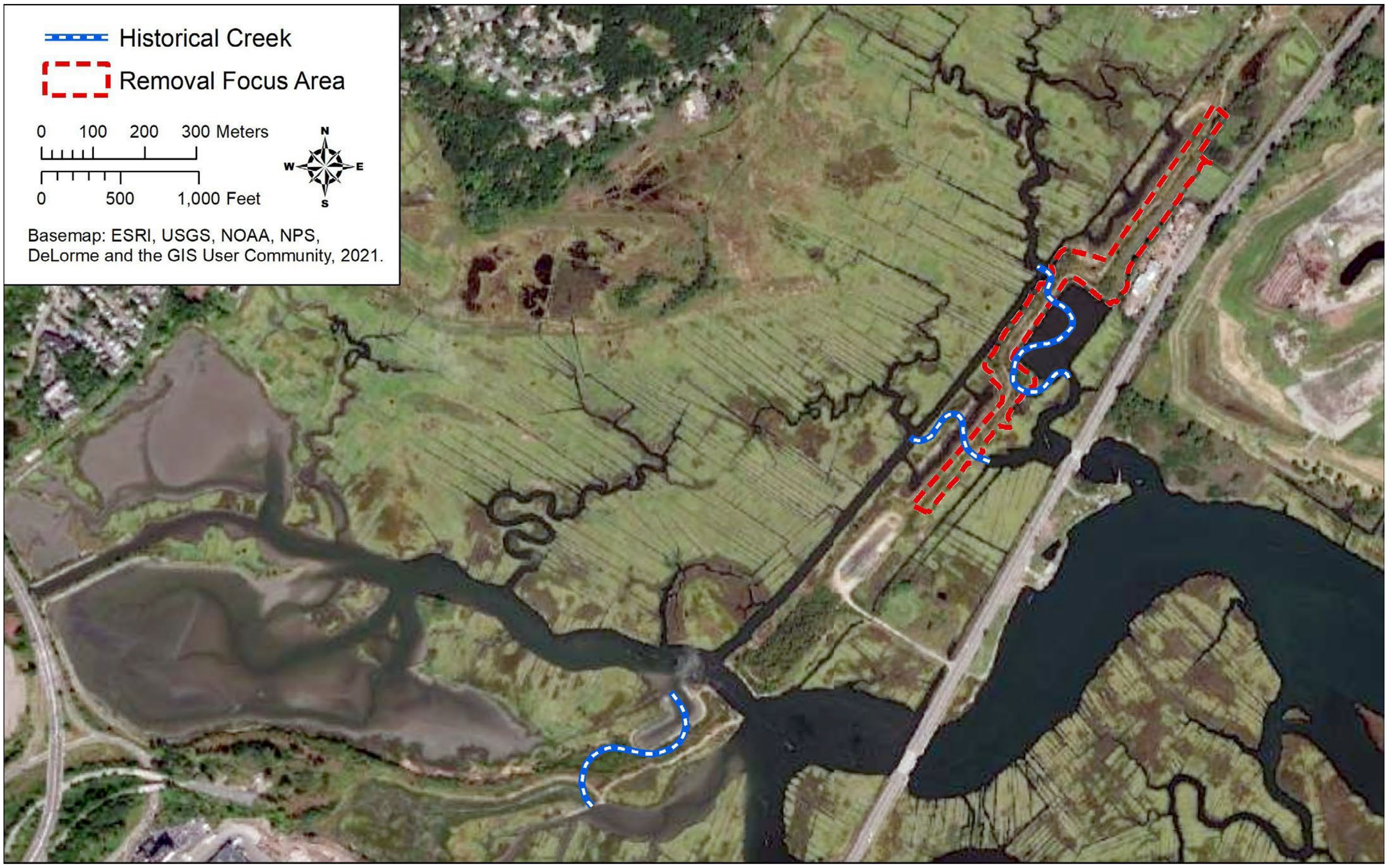

Figure 8. *Satellite photo from 2021 of Rumney Marsh abandoned I-95 embankment showing the retained flood protection berm that would be a high priority for removal to restore marsh habitat and drainage across the marsh.*

Previous Hydrology Studies

Between 1986-1993, the USACE performed numerous hydrology studies for the proposed regional floodgate. USACE studies reported that the restriction to tidal water flow from the embankment lowered the highest tides of the year by 0.5 feet (15 cm) at Town Line Brook in Revere, and as much as 1.7 feet (50 cm) in East Saugus (USACE 1989). Similarly, the USACE model, which included intentional widening of the Pines River Channel, and creation of a new channel at the East Branch of the Pines River, predicted that Spring High Tides would increase by 0.5 feet (15 cm).[20]

Tidal observations were made by the New England Division of the USACE and USGS during a storm event on January 2, 1987. The results showed that that the peak water level reached elevation 9.5 feet NGVD29 in the Pines River at the Town Line Brook, which was nearly the same as at the Fox Hill Drawbridge on the Saugus River, where the peak water level reached elevation 9.57 feet NGVD29. The USACE wrote:

> *"It can be seen that in general, for significant storm tides, water levels are less impacted by restrictions (i.e., bridge openings, I-95 embankment, etc.) than they are at normal spring tides. This can be seen by comparing the water levels of Fox Hill drawbridge and estimated water levels for Town Line Brook*[20]

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[20] https://apps.dtic.mil/dtic/tr/fulltext/u2/a266336.pdf

which show almost no difference. In comparison the corresponding spring tide differences were approximately 0.5 foot lower" (USACE 1989c).

From the same storm event of January 2, 1987, the high-water mark was estimated for the Pines River Marsh at East Saugus as 8.5 feet NGVD29, which is 1.0 feet lower than at the Town Line Brook Tide gate structure. The lower estimated tidal water level at East Saugus was likely caused by frictional dampening of the tide by the marsh vegetation.

USACE also observed that the embankment restricts drainage by acting as a dam at extreme low tides, not allowing the upstream area to drain completely. The USACE stated:

"The upper Pines River is impacted by the flow constriction in the abandoned I-95 embankment which does not allow the ponded area upstream from the embankment to drain freely. This was first noted during tide measurement on May 18, 1987. A value of -5.1 feet NGVD was measured at the Fox Hill drawbridge at dead low tide. Visual inspection of the I-95 constriction shortly thereafter during another low tide condition revealed that the constriction acts as a dam at extreme low tide (tides below elevation -3.0 NGVD), not allowing the upstream area to drain completely" (USACE, 1989c).

Route 107 Bridges Reconstruction

Three bridges along the Pines River in Saugus and Revere on State Route 107 were reconstructed by the Massachusetts Highway Department (Mass Highway) between 2009-2012. The bridges reconstruction, using longer and higher spans over the waterways, restored a more normal tidal hydrology throughout the Pines River estuary. EPA's involvement with the bridge project started many years earlier in 1995, when the project was first introduced to the Corps of Engineers and other federal and state agencies. At that time, three issues were raised with respect to the project:

1. Elevation of the low chord of the bridge with respect to recreational boat passage beneath the structures.
2. The possibility of increasing tidal flux to up-estuary areas by means of increasing the hydraulic opening of the bridges; and
3. Public safety issues arising from the fact that Route 107 is closed during some storm events owing to overtopping of the causeway.

Due to the low elevation of the former steel bridge support beams, they were subject to inundation at the highest tides. Consequently, the former bridges restricted river flow, causing increased water velocity. This, in turn, caused bank erosion, increased turbidity, and sedimentation. These concerns were resolved by raising the low chord of the bridges by about 1.5 feet (0.5 meters) to provide 3.5 feet (1.1 meters) minimum clearance for recreational boat passage, as measured from Mean High Water. MHW was shown as elevation 5.0 NGVD29 in the 2006 Water Quality Certification, which would require a low chord minimum of 8.5 feet NGVD29.

The conversion of tidal datums can be calculated using the National Geodetic Survey Coordinate Conversion and Transformation Tool (NCAT). [21] For Rumney Marsh, the correction factor for orthometric height varies

[21] https://geodesy.noaa.gov/NCAT/

from -0.89 to -0.93, depending on location. We chose to use an average of -0.91 as an approximate correction factor. Therefore, the low chord would be about 7.6 feet NAVD88. The tidal flushing issue was resolved by lengthening the bridges as well as increasing their height. These changes have restored a more normal tidal hydrology throughout the Pines River estuary.

Bridge R-05-009 over Diamond Creek (Figure 7, site S) was replaced with a single span structure 60-feet in length (18.3 meters), tripling the existing opening to enhance tidal flushing. The horizontal clearance, as measured from Mean Low Water (MLW), did not change. However, as measured from MHW, the horizontal clearance increased from 26.5 feet (8 meters) to 57.5 feet (17.5 meters).[22] The tripled length of the opening in conjunction with the sloped riprap was expected to expand the hydraulic opening by over 40% according to an August 7, 1996, memo from the design consultant. Evaluating the cross section of the bridge, however, we estimate the hydraulic improvements provide a 60% increase in channel capacity measured from MLW to MHW water levels and a 96% increase for the full height of the bridge opening (Figure 10).

Bridge R-05-007=S-05-002 over the Pines River (Figure 7, site O) was replaced with a three-span structure that provided a 28% increase in the opening to enhance tidal flushing according to the application information. Horizontal clearance as measured from MLW did not change. However, as measured from MHW, horizontal clearance increased from 116 feet (35.4 meters) to 147 feet (44.7 meters).[23] EPA estimates this provided a 13% increase in flow capacity at MHW levels and a 29% increase at the full height opening (Figure 10).

Bridge S-05-003 over the East Branch of the Pines River (Figure 7, site G) in Saugus was also replaced with a single span structure, 60 feet in length (18.2 meters), tripling the existing opening to enhance tidal flushing. Horizontal clearance, as measured from MLW, did not change. However, as measured from MHW, horizontal clearance increased from 20.5 feet (6.2 meters) to 57.5 feet (17.5 meters).[24] The photographs in figure 9 depict this bridge during and after completion. The increased length of the bridge in conjunction with the sloped riprap expanded the hydraulic opening at MHW by 93% and by 139% for the full opening (Figure 10).

Figure 9. *During and after construction photographs of the East Branch Pines River bridge S-5-3 crossing show how the vertical walls of the former bridge were changed to a riprap slope, which increased channel conveyance. Photo credit Ed Reiner.*

[22] Massachusetts Water Quality Certification transmittal W071542
[23] Massachusetts Water Quality Certification transmittal W071543
[24] Massachusetts Water Quality Certification transmittal W071541

	Horizontal Clearance (feet)				Vertical Clearance (feet)				Cross-Sectional Area (square feet)			Cross-Sectional Area (square feet)		
	Existing		Proposed		Existing		Proposed		10-foot tidal range only			Full Height of Opening		
Bridge	MHW	MLW	MHW	MLW	MHW	MLW	MHW	MLW	Existing	Proposed	Increase	Existing	Proposed	Increase
R-5-9	26.5	26.5	57.5	26.5	1.91	11.91	3.5	13.5	265	425	60%	316	620	96%
R-5-7 = S-5-2	116.3	116.3	146.7	116.3	2.2	12.2	3.5	13.5	1163	1316	13%	1418	1836	29%
S-5-3	20.5	20.5	57.5	20.5	2.56	12.16	3.5	13.5	205	395	93%	249	596	139%

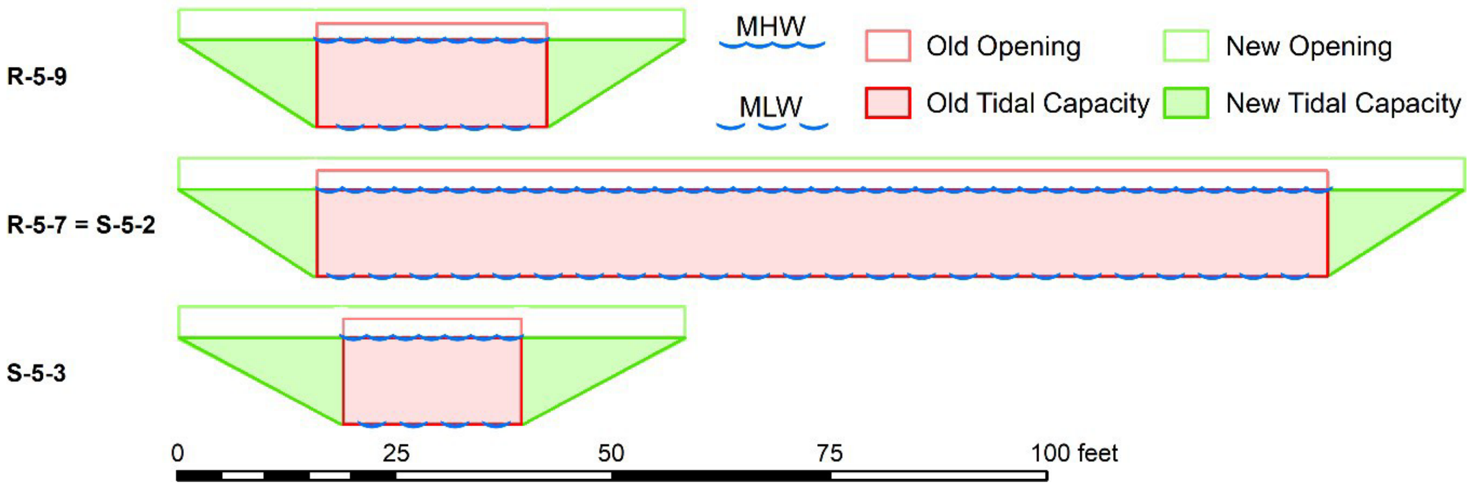

Figure 10. *Graphic depiction of the three Route 107 bridges dimensional clearances used to calculate the percent increase in cross sectional area at both the MHW level and the full height of the bridge opening.*

During the 1999 permit review for the bridge project, Mass Highway agreed to include two new 48-inch (1.22 m) culverts to improve tidal flow and flushing at two additional areas of the marsh. This work replaced a buried 12-inch (0.375 m) culvert under the DCR access road from Route 107 (adjacent to site 27 in Figure 7). This new culvert on the DCR access road increased the tidal flow and flushing between the Pines River and the East Branch of the Pines River, which contributes to additional improvements in the tidal flow and flushing in the marsh. The second new culvert replaced a failed culvert along Route 107 near the East Branch of the Pines River, restoring tidal flow to a salt marsh adjacent to the road (Figure 7, site 19).

RESULTS

2018 Bathymetry study

A bathymetry study was undertaken in 2018 to document the depth along the Pines River as it passes the railroad bridge, Route 107 Pines River Bridge, and the I-95 embankment (Figure 11). Depth along the East Branch of the Pines River as well as the Pines River Channel was also measured. Due to the low vertical clearance at the railroad bridge and Route 107 bridges, this study was done by kayak. Depth measurements were obtained using a depth gauge (H22PX – HawkEye® Handheld Sonar System) to log depth of the water paired with a GPS device to log location (at a meter accuracy level). The depth measurements were manually input to the GPS device to create a record with time, depth, and position.

These GPS records were post-processed with Trimble Pathfinder Office to a mean horizontal accuracy of less than one meter. While the soundings were collected as feet below the survey vessel, the local tidal range of almost ten feet required that we adjust these depths using NOAA tidal measurements, by correlating their time stamps. We converted the surveyed depths to NAVD88, the datum of most other local data.

The bathymetry study revealed significant scour holes at the railroad crossing, Route 107 bridge and the I-95 embankment opening along the Pines River. Scour holes typically form at bridges or culverts due to the

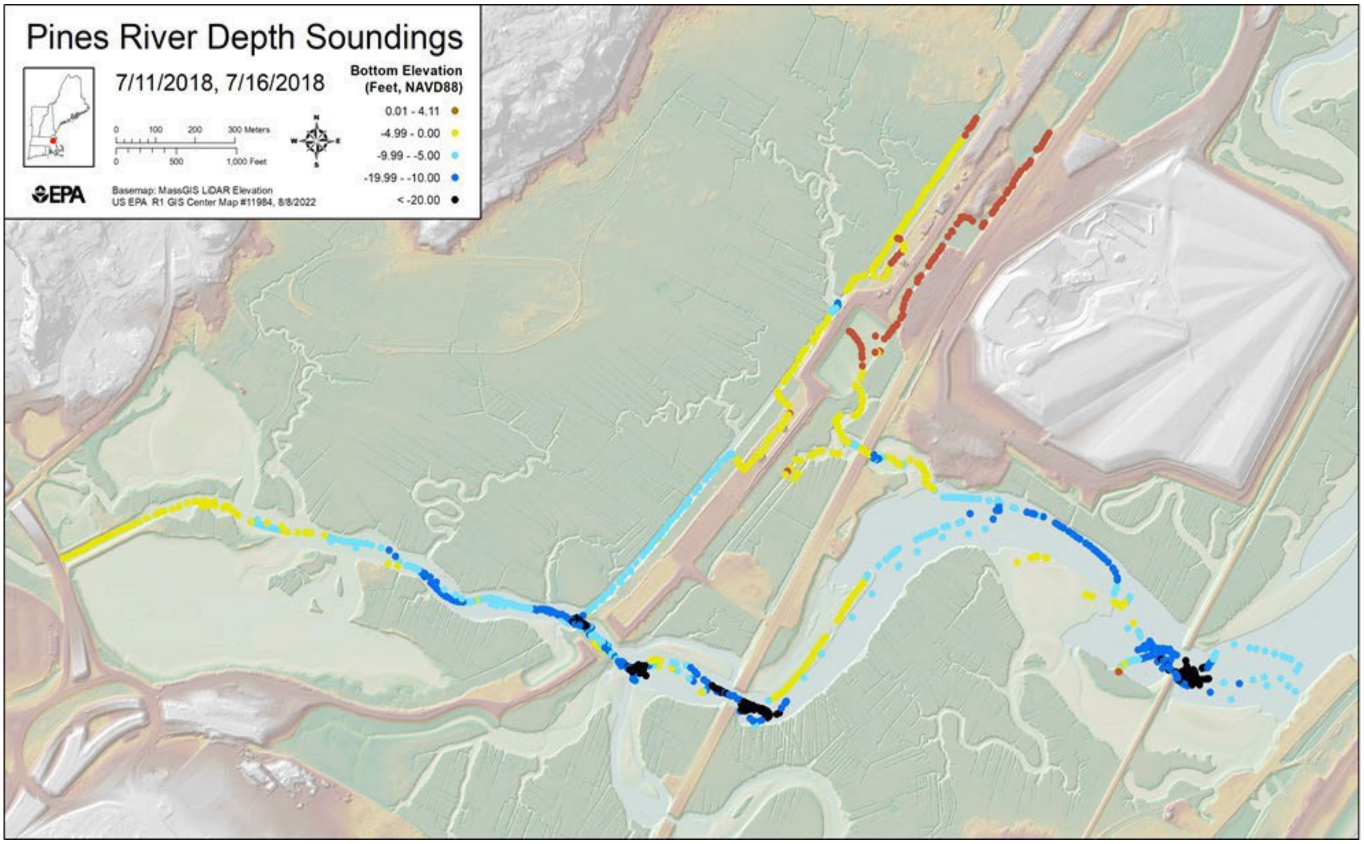

Figure 11. *July 2018 results from Bathymetry study Pines River, Pines River Channel and East Branch Pines River in Saugus and Revere Massachusetts.*

increased flows through undersized structures. Normally, water flows across the high marsh surface in a manner which decreases the velocity and drops sediment on the marsh surface. Rumney Marsh is unique in that tidal water must flow through three consecutive restrictions before it breaks the plane of Mean High Water to flood the high marsh platform. The restrictions to tidal flow, as previously discussed, include the Eastern Railroad, constructed in the 1830’s, Route 107 (Salem Turnpike), first constructed in 1803, and the 1967-1969 construction of the I-95 embankment.

Our study found the bottom channel elevation at the I-95 embankment crossing is generally at elevation -9 to -10 feet NAVD88. Scour holes outside of the rock armored crossing, however, reveal bottom elevations of -26 to -33 feet NAVD88. The scour holes at the railroad crossing have the deepest depths, with measured elevations at -22 to -47 feet NAVD88. The scour holes at the Route 107 bridge measured -24 to -38 feet NAVD88. The deeper scour hole on the downstream side of the crossings demonstrates an ebb dominant tidal regime with significant current velocities (Appendix Figure B3).

A study by the Corps of Engineers Waterways Experiment Station found the maximum velocity in the channel of the Pines River at the 1-95 embankment opening was 6.3 feet per second (FPS) at the surface. This was the highest velocity water flow found during the study. Ebb tides had a stronger current, which was consistent with the EPA study finding deeper scour holes on the downstream side. According to the USACE, freshwater inflow to the area did not contribute significantly to channel flow (USACE, 1991). The average rate of saltwater interchange to the estuary calculated as 9,400 cubic feet per second (CFS) is approximately 100 times the average freshwater inflow from the watershed at 80 CFS (USACE, 1989e).

Figure 12 is a graphic representation of the scour hole depths at each of the three tidal restrictions. The greater depth of the downstream scour holes is indicative of ebb dominant tidal flows.

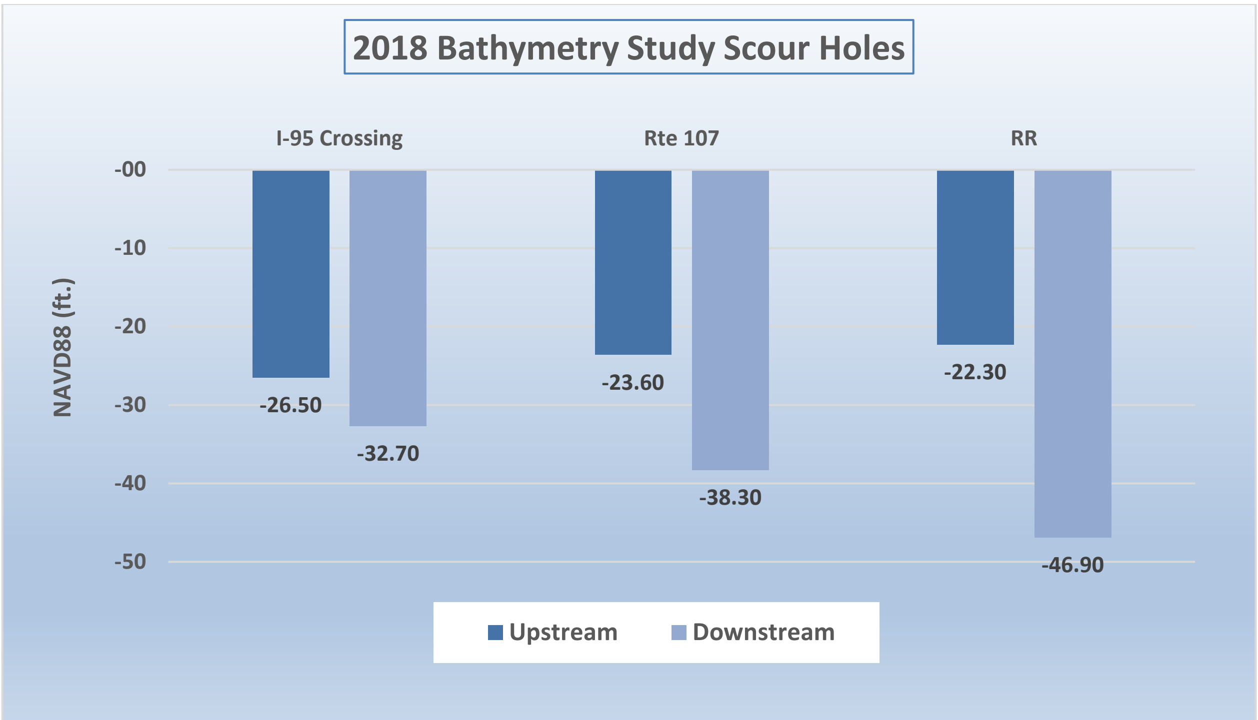

Figure 12. *Depth of scour holes at three tidal restrictions in Rumney Marsh.*

Our study also showed the depth along the constructed drainage channel on the west side of the abandoned I-95 embankment became shallower with the distance from the relocated Pines River channel. The channel becomes narrower and eventually was shallow enough to support *Spartina alterniflora*. During our investigation, we observed significant erosion of the salt marsh along the constructed drainage channel (Figure 13).

According to the USACE 1966 permit, (Figure 5, Section C-C) this “temporary” drainage channel was intended to have a 2:1 side slope, an overall bank to bank width of 42 feet, and a MHW width of 28 feet. The channel has widened considerably over time due to peat bank erosion. Bare peat is subject to erosion by currents and minor wave action. The resulting undermined salt marsh creekbank edges break off without support. Burrowing crabs may contribute to the erosion process by their cavernous excavations. This erosion process is expected to continue without intervention.

Figure 13. *Photograph of the constructed "temporary" drainage channel in East Saugus looking south toward Revere taken February 23, 2022. The channel in some places is more than twice the original constructed width due to erosion of the salt marsh peat banks. Photo credit Ed Reiner.*

2019 Tidal Water Level Study

The purpose of the water level study was to evaluate if removal of the abandoned I-95 embankment at Rumney Marsh in Revere and Saugus, to restore the salt marsh, tidal creeks, and previous drainage patterns, would increase tidal flooding over present conditions. The 2019 study included an investigation of tidal water levels on both sides of the three tidal restrictions in the Pines River to determine how each of the road or rail crossings in the marsh affect tidal flooding since the reconstruction of the Route 107 bridges.

In addition, we evaluated the tidal restriction at the Ballard Street Salt Marsh in Saugus to document tidal flows. The Town of Saugus performed repairs to the culvert in January 2022. Repairs included new inlet and outlet structures and installation of a top hinged manually adjustable vertical sluice gate (combination gate) on the outlet structure. The town is required to comply with a tide gate Operation and Maintenance Plan which includes monitoring and reporting requirements pursuant to conditions in the Department of the Army permit.[25] Water level data from the Ballard Street Culvert investigation was previously provided to the Town of Saugus for their use and is not included in this report.

[25] Department of the Army No. NAE-2004-04377

Tidal Level Study Methods

In order to evaluate if removal of the abandoned I-95 embankment at Rumney Marsh would increase tidal flooding over present conditions, we collected tidal water level measurements using Onset HOBO U-Series Water Level pressure transducers installed at seven strategically selected stations throughout the marsh (Figure 14).[26] The loggers were deployed just above the sediment during low tide. Installation methods at most sites used a steel fencepost pounded into the sediment to allow attachment of the transducer in a fixed vertical orientation except at one location, at site D (Figure 14), where we attached the transducer to a metal truck tire chuck to allow a more discreet installation at the public pier facility. We followed manufacturer's guidance for use of the HOBO pressure transducers and EPA New England Region 1 SOP.[27]

The stations were selected based on the need to collect data on both sides of the potential tidal restrictions in the Pines River estuary; the railroad, Route 107, and the abandoned I-95 embankment. In addition, a station was in the Saugus River upstream of Route 107, as well as within the Ballard Street Salt Marsh.[28]

Francis Choi, from Northeastern University Marine Science Institute, surveyed the elevations of the pressure transducers using a Trimble R8 Global Navigation Satellite System (GNSS) RTK (Real Time Kinematic) system which provides 8-mm horizontal and 15-mm maximum vertical precision (0.59 inches).[29] The R8 unit was calibrated to the NOAA benchmark in Lynn Harbor to NAVD88 (m). Typical error in R8 vertical measurements is +/- 5cm (2 inches). Unit F installed upstream of the I-95 embankment in East Saugus was fastened to a tide gauge on a fence post previously installed by MassPort, providing a potential data accuracy check and additional means to evaluate water levels.

Readings were collected at six-minute intervals starting on April 16, 2019, and continued for 142 days, until battery failure on September 5, 2019. We discovered that the transducer at the lower Pines River (site B) reached a maximum memory limit and shut down automatically on July 15, after 90 days.

[26] https://www.onsetcomp.com/products/data-loggers/u20-001-01

[27] HOBO Water Temp Pro v2, Conductivity, & Water Level Logger SOP Revision 1 12/27/11, EPA New England Regional Laboratory.

[28] The data collected from the Ballard Street Salt Marsh and Saugus River was collected for a separate study and is not included in this report.

[29] https://geospatial.trimble.com/eol?dcs=Collection-19571&pt=Trimble%20R8%20GNSS%20Receiver

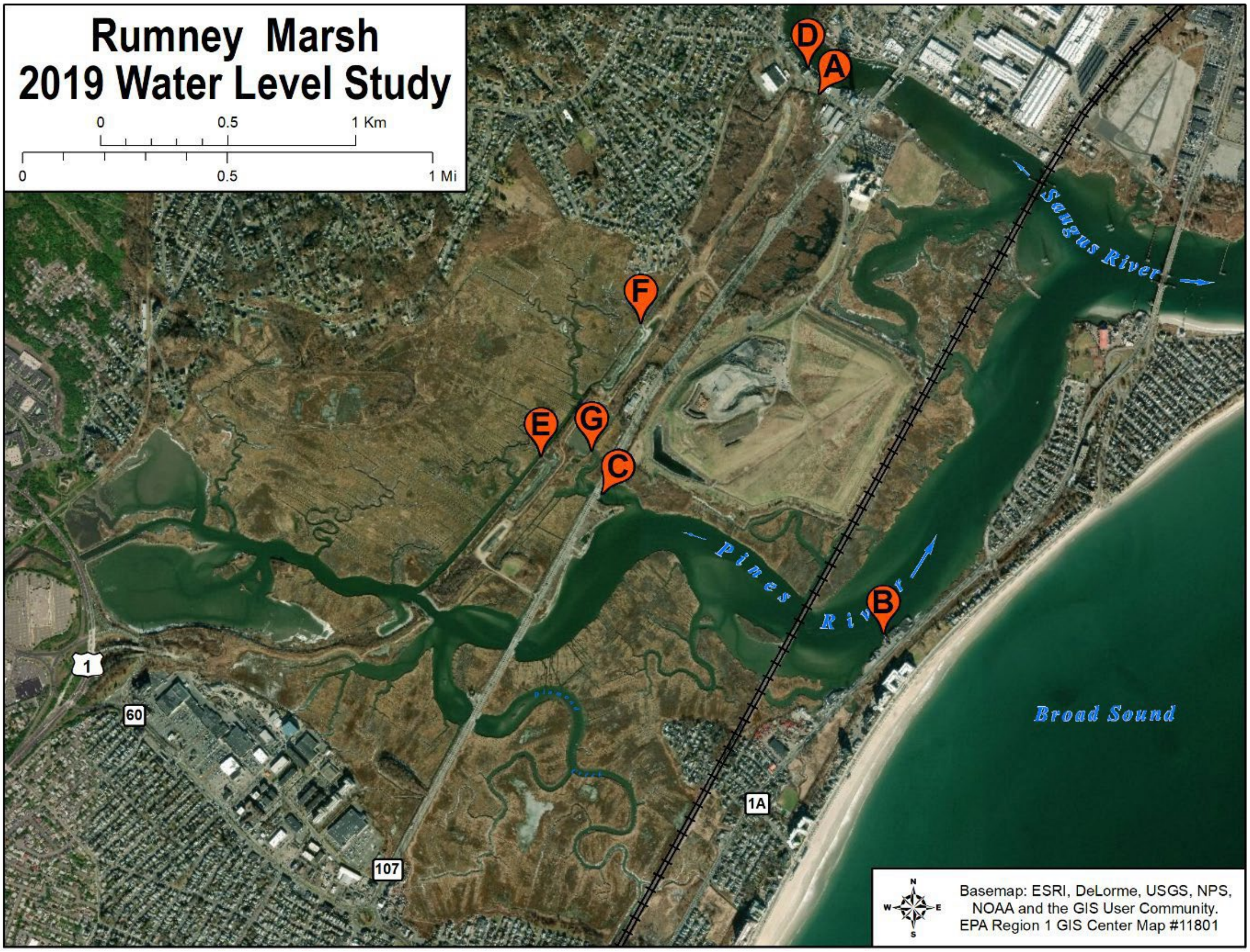

Figure 14. *Map of Rumney Marsh showing locations of pressure transducers deployed in 2019. A - Ballard Street salt marsh, B - Lower Pines River, C - Upstream Railroad, D - Saugus River, E - Upstream I-95, F - East Saugus, and G - Upstream Route 107.*

Unit A (Ballard St. salt marsh) was installed within the creek on the inside of the Ballard Street salt marsh adjacent to the four-foot round (1.3 m) culvert. This culvert, at the time of the study, was fitted with a temporary plate of steel chained to a deteriorating headwall to function as a makeshift tide gate for flood control purposes (Figure 15). The tides within the Ballard Street salt marsh are muted by the restrictive size culvert, as well as the makeshift tide gate, which was raised by six-inches (15-cm) at the invert to provide for fish passage and tidal flow to sustain the interior salt marsh. The Ballard Street salt marsh also receives flow from a culvert adjacent to Route 107 at a discontinued portion of Bristow Street (Figure 16). Tidal flow and drainage at this culvert flows to the reconstructed Route 107 bridge, which conveys the East Branch of the Pines River (Figure 9).

 

Figure 15. *(left) Former Ballard Street Culvert and makeshift tide gate.*
Figure 16. *(right) Bristow Street culvert provides tidal flow and drainage to the Ballard Street salt marsh from the East Branch Pines River bridge on Route 107. Photo credit Ed Reiner.*

Unit B (Lower Pines) was installed below the pier at North Shore Marine on the Pines River. Water levels at this location, according to studies by the USACE, are similar to those out of the estuary in Broad Sound and closely resemble the Boston Harbor tide gauge data [30] (USACE, 1990).

Unit C (Upstream Railroad) was installed on the downstream side of the Route 107 bridge at the East Branch of the Pines River, so water levels at this site reflect the tide restriction from the railroad crossing alone.

Unit D (Saugus River) was installed at the Lobsterman's pier and floats at the Harold L. Vitale Memorial Park on the Saugus River, upstream of the Belden Bly drawbridge on Route 107.

Unit E (Upstream I-95) was installed within the constructed Pines River channel at the northern outlet from the DCR salt marsh restoration area on the upstream side of the abandoned I-95 embankment.

Unit F (East Saugus) was installed on a physical tide gauge along the Pines River constructed channel at the northern outlet of the MassPort salt marsh restoration area.

Unit G (Upstream Route 107) was installed upstream of Route 107, but downstream of the I-95 embankment, to discern the relative effects of both the railroad crossing and Route 107. Photos of each of the stations A-F are depicted in Figure 17.

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[30] https://tidesandcurrents.noaa.gov/stationhome.html?id=8443970

Figure 17. *Photographs of the pressure transducer installations at sites A – Ballard Street, B – Lower Pines River, C – Upstream Railroad, D – Saugus River, E- Upstream I-95, F – East Saugus, and G – Upstream 107. Photo credit Ed Reiner.*

After retrieval of the units, the water pressure data from the transducers was downloaded and converted into water level with the use of Onset HOBOware software.[31] A constant barometric pressure of 101.010 (kPA) (measurement before deployment) was used as a baseline (an option under the barometric compensation assistant). The data was later adjusted using barometric pressure obtained from Northeastern University Marine Science Institute equipment installed nearby at the Oak Island tide gate in Revere. Sensor depth was

[31] https://www.onsetcomp.com/products/software/hoboware/

then normalized to the NAVD 88 measurement at each site to calculate water level at NAVD88 (m) from the initial elevation measurements of the pressure transducers by the Trimble R8 GNSS RTK.[32] We converted the data to feet and tenths to allow direct comparison with past studies at the marsh.

The water level data collected since deployment on April 16, 2019, was downloaded on June 7, 2019, after 52 days. The units were then reinstalled and obtained data for an additional 90 days. One unit (G, upstream Route 107), however, required movement of the fence post due to erosion of a salt marsh bank and sediment which accumulated at the transducer. The sensor was reinstalled 0.5 feet higher on the fence post, which required an adjustment to the elevation after June 7, at 11:00 am. When the data was retrieved, it was discovered that the adjustment to elevation was made by subtraction of 0.5 feet when it should have been by addition. To rectify this, we adjusted the downloaded elevations by adding 1.0 feet, which appears to correlate well with the water level measurements from the previous period. Because of the potential introduced error when we moved the sensor, we decided to evaluate the two sets of data separately.

The barometric pressure corrected water level data for each of the five units was input to NOAA's Tidal Datum Calculator to determine the tidal datums.[33] For this study, focusing on potential flooding impacts, we examined the tidal datum metrics of Mean High Water (MHW), Mean Higher High Water (MHHW), and reported the maximum tide to evaluate if there is a tidal restriction affecting flooding at higher tides. MHHW is the higher of the two daily tides, whereas MHW is an average of the two high tides each day. The maximum tide is the highest tide monitored during the study period.

While the study included a water level sensor unit A at the tidally restricted Ballard Street salt marsh in Saugus, and Unit D at the Saugus River upstream of Route 107, we decided to exclude those results from this study report for the following reasons. First, the water levels on the Saugus River have no bearing on the specific research question concerning the determination of tidal flooding along the Pines River and the effect of the I-95 abandoned embankment. Secondly, our study found higher water levels on the Saugus River, a result which we wanted to verify. This finding could be due to an error determining the elevation of the transducer. When the Town of Saugus installs a more easily read tide gauge at Ballard Street site A as well as at site D, our results will be further checked and allow for greater accuracy in future studies. Lastly, we felt it prudent to delay additional studies until completion of the Route 107 Saugus River Bridge reconstruction and the associated channel dredging to see if changes occurred because of the bridge project.

Peer Review

To ensure the reliability, credibility and integrity of this report, an informal and formal EPA Peer Review was conducted following EPA's Peer Review Handbook, 4th edition. "Peer review provides the greatest credibility for the EPA's scientific and technical work products when it involves qualified, external independent reviewers; is intensive in its examination; and operates through a formal and transparent process. Per the EPA's Peer Review Policy, external peer review is the approach of choice for all Influential Scientific Information (ISI) and is the expected procedure for a Highly Influential Scientific Assessments." Due to the significant influential nature of this study, EPA Region 1 categorized the nature of this work as Influential Scientific Information. OMB's Peer Review Bulletin defines ISI as scientific information that the Agency "reasonably can determine will have or does have a clear and substantial impact on important public policies

[32] https://geospatial.trimble.com/eol?dcs=Collection-19571&pt=Trimble%20R8%20GNSS%20Receiver

[33] https://access.co-ops.nos.noaa.gov/datumcalc/index.jsp

or private sector decisions." Accordingly, a formal Peer Review was conducted following EPA protocol. This study will be shared with the public via EPA's Science Inventory and provides public access as outlined in the Scientific Data Management Plan (SDMP) that addresses public access to publications and the underlying research data.

The informal and formal Peer Review ensured that the methodologies employed were accepted within the scientific community. During the informal Peer Review, comments were incorporated from Robert Hunt, retired Engineer, US Army Corps of Engineers. Mr. Hunt was the former Corps of Engineers Project Manager for the Saugus River Regional Flood Gate Project. Additionally, EPA New England Region employees Sandra Petrakis, Physical Scientist in the Drinking Water Quality and Protection Section, and Valerie Bataille, EPA New England Scientific Integrity Coordinator and Peer Review Coordinator, provided comments.

Formal peer review is generally considered to be the highest level of technical quality review. The study's formal peer review included a panel of experts knowledgeable in various aspects of the science associated with this research according to the US EPA's Peer Review protocols. A list of objectives was used for focusing the peer review charge questions to obtain input from qualified colleagues ("the relevant scientific community"). The research team worked with the Region 1 Peer Review Coordinator to assure that the study followed EPA's protocols. All comments received from the peer reviewers were evaluated and addressed. All significant recommendations were incorporated into the report. Once all recommendations from the peer reviewers were incorporated into this report, the report was cleared for publication via Agency protocols and published on EPA's Science Inventory.

The formal peer reviewers included the following: Steven C. Davis, President of Verrill Strategic Consulting, Inc. Mr. Davis was Director of the Massachusetts Environmental Policy Act office in the 1980's when many projects involving the marsh were reviewed by his office. Dennis Lowry, from AECOM Environment, who has specific knowledge of Rumney Marsh from his involvement with the USACE studies in the marsh dating back to 1986. Mr. Lowry has more than 40 years of experience as a professional wetland scientist including many coastal wetland restoration projects and tidal studies. David Hilgeman and Christina Wu, with the MassDEP Wetlands Program, Major Projects and Policy Unit, also provided peer review comments. David Robbins of the Federal Emergency Management Agency provided an additional peer review.

2019 Tidal Level Study Results

We used the NOAA Tidal Datum Calculator to calculate the tidal datums.[34] The results for the 52-day period from April 16-June 7, 2019 (Table 2) show the upstream side of Route 107 (site G) has a 0.14-foot (4.3 cm) lower MHW, MHHW and maximum tide, compared to the downstream side of Route 107 (site C), revealing a slight restriction to tidal flow at the East Branch Pines River bridge crossing. The MHW and MHHW datums from the two stations upstream of the abandoned I-95 embankment were very similar to the unrestricted Lower Pines station.

[34] https://access.co-ops.nos.noaa.gov/datumcalc/

__Table 2.__ Tidal datums for each of the five stations along the Pines River in Rumney Marsh, organized by restriction position in the estuary for the 52-day period from April 16-June 7, 2019, as calculated with the NOAA Tidal Datum Calculator. Water levels are in feet NAVD88.

Tide Datum	Lower Pines (B)	Railroad Bridge	Upstream Railroad (C)	Route 107	Upstream Rt. 107 (G)	I-95	Upstream I-95 (E)	East Saugus (F)
Maximum	6.31		6.25		6.11		6.12	6.09
MHHW	5.13		5.13		4.99		5.13	5.10
MHW	4.72		4.74		4.60		4.79	4.75

For the 90-day period from June 7-September 5, 2019 (Table 3), the upstream side of Route 107 (site G) showed a reduction of 0.10 feet at MHW, 0.11 feet at MHHW, and 0.10 feet for the maximum observed water level as compared to the downstream side (site C). The differences are consistent with the earlier 52-day study results.

__Table 3.__ Tidal datums for each of the five stations along the Pines River in Rumney Marsh, organized by restriction position in the estuary for the 90-day period from June 7-September 5, 2019, as calculated with the NOAA Tidal Datum Calculator. Water levels are in feet NAVD88.

Tide Datum	Lower Pines (B)	Railroad Bridge	Upstream Railroad (C)	Route 107	Upstream Rt. 107 (G)	I-95	Upstream I-95 (E)	East Saugus (F)
Maximum	6.44		6.39		6.29		6.19	6.19
MHHW	5.25		5.22		5.12		5.19	5.23
MHW	4.79		4.78		4.67		4.80	4.84

Figures 18 and 19 graphically depict the calculated tidal datums for each of the two study periods. Both results clearly show a slight dip in the tidal datums of MHW and MHHW due to the Route 107 bridges.

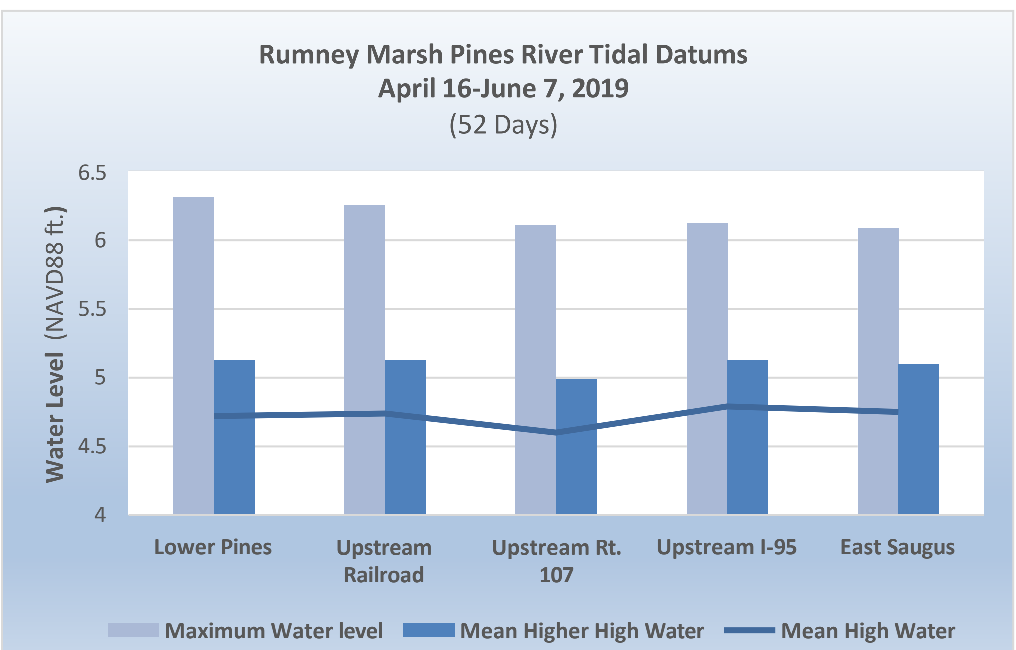

__Figure 18.__ Tidal Datums at five stations along the Pines River, organized by restriction position in the estuary for the 52-day period from April 16-June 7, 2019, calculated with the NOAA Tidal Datum Calculator. Water levels are in feet NAVD88.

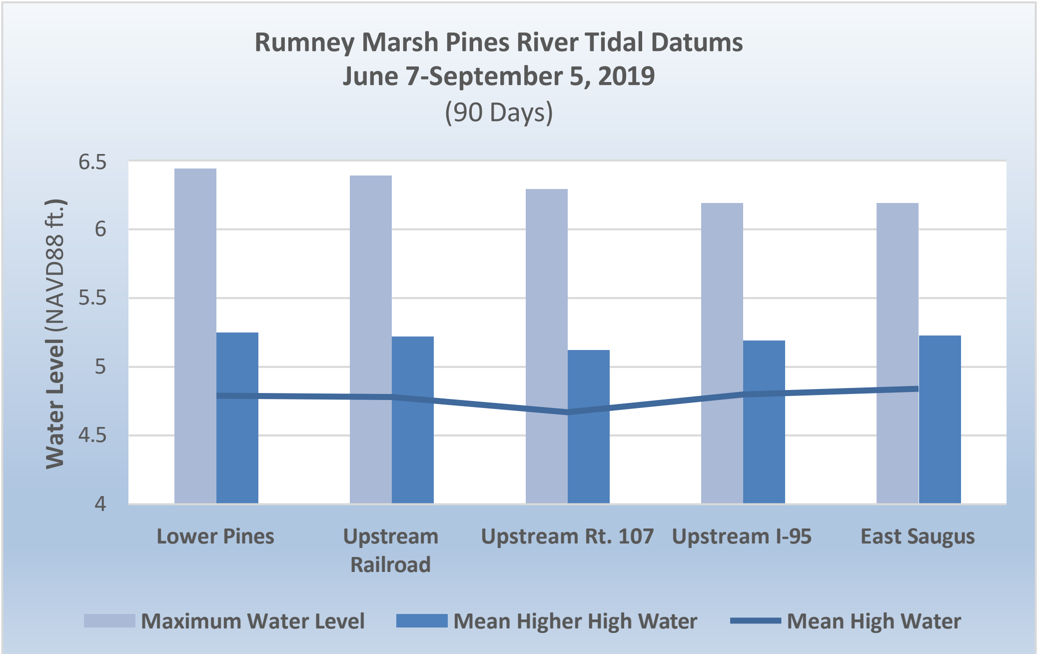

Figure 19. *Tidal datums for five stations along the Pines River, organized by restriction position in the estuary for the 90-day period from June 7-September 5, 2019, calculated with the NOAA Tidal Datum Calculator. Water levels are in feet NAVD88.*

Figure 20 depicts the peak daily tidal elevation (MHHW) observed for the first 52-days of the study. Figure 21 depicts the peak daily tidal elevation (MHHW) observed in the subsequent 90-day study period. The data results show very similar water levels amongst the stations with a slight tidal restriction caused by the railroad bridge and Route 107 bridges. Additional graphs and comparisons of stations are provided in Appendix E.

While our results reveal a slight tidal restriction caused by the East Branch of the Pines River bridge, we note that site G (Upstream 107) tidal datums may not reflect water levels in the Revere part of the Pines River estuary due to the potential tidal restriction at the DCR access road from Route 107 to the abandoned I-95 embankment. The DCR access road has two culverts along its length (Figure 7). Water levels at site G may also be affected by intertidal sediment bars that have accumulated both upstream and downstream of the East Branch Pines River bridge. To evaluate this further we compared water levels from the upstream side of the abandoned I-95 embankment to the upstream side of the railroad.

The upstream side of the abandoned I-95 embankment (site E) has 0.13-foot (4 cm) lower maximum water level as compared to upstream of the railroad (site C). We believe this is largely because of the Route 107 bridges which reduced the MHW, MHHW, and the maximum tide by 0.14 feet (4.3 cm) as described above. The minor difference of 0.01 feet means that there is essentially no difference in water levels between the Revere and Saugus portions of the estuary upstream of Route 107 and downstream of the abandoned I-95 embankment that otherwise would be due to the DCR access road to the embankment.

The maximum water level observed on the upstream side of the abandoned I-95 embankment in East Saugus (site F) during the additional 90-day study was only 0.25 feet lower than the Lower Pines River (site B). This amount of reduction in the maximum tidal water level is equal to the combined effect of the railroad bridge and Route 107 bridges.

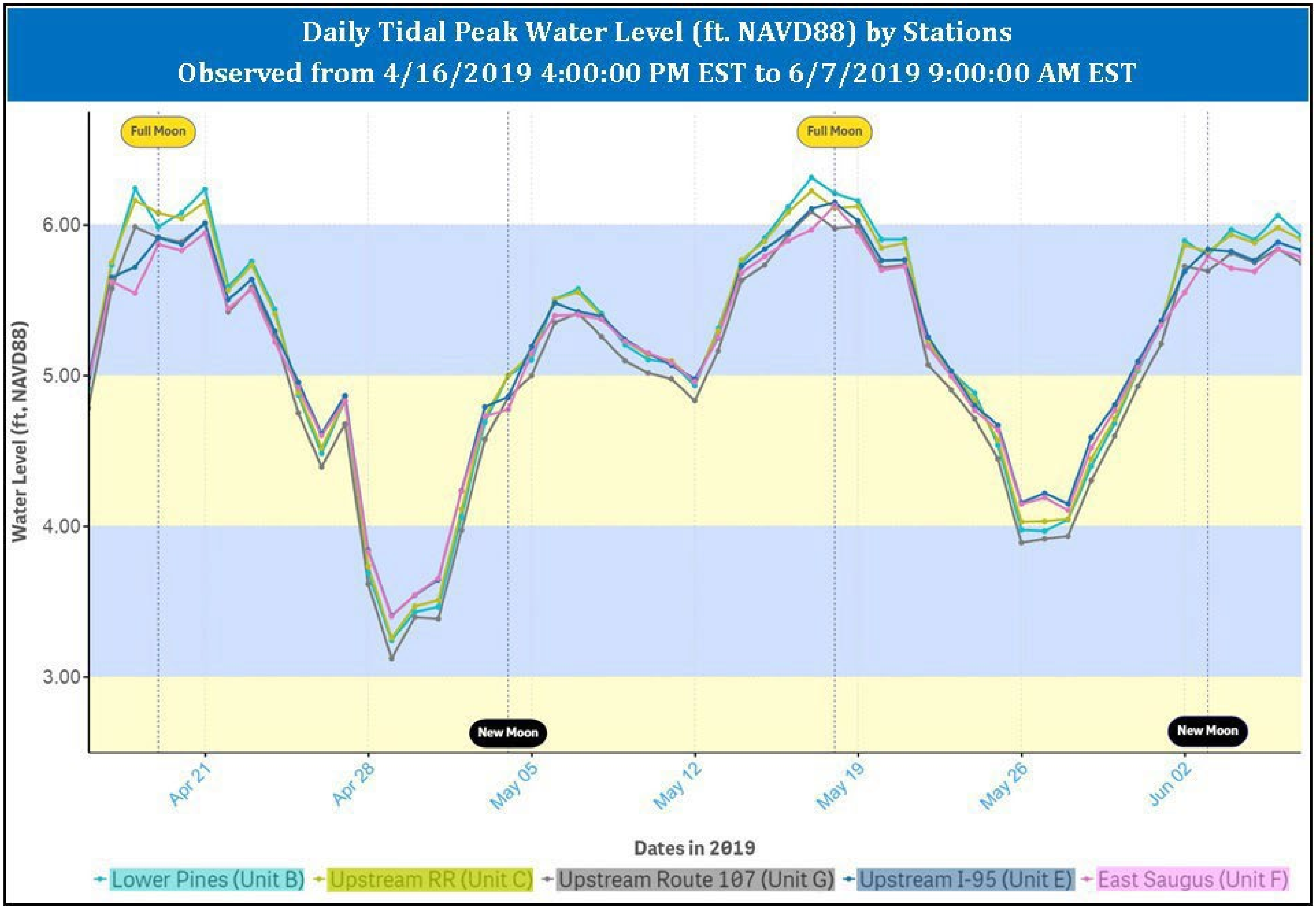

Figure 20. *Daily peak tidal water level (MHHW) from 5 stations along the Pines River in Saugus and Revere, Massachusetts for the 52-day period from 4/16/2019 - 6/7/2019.*

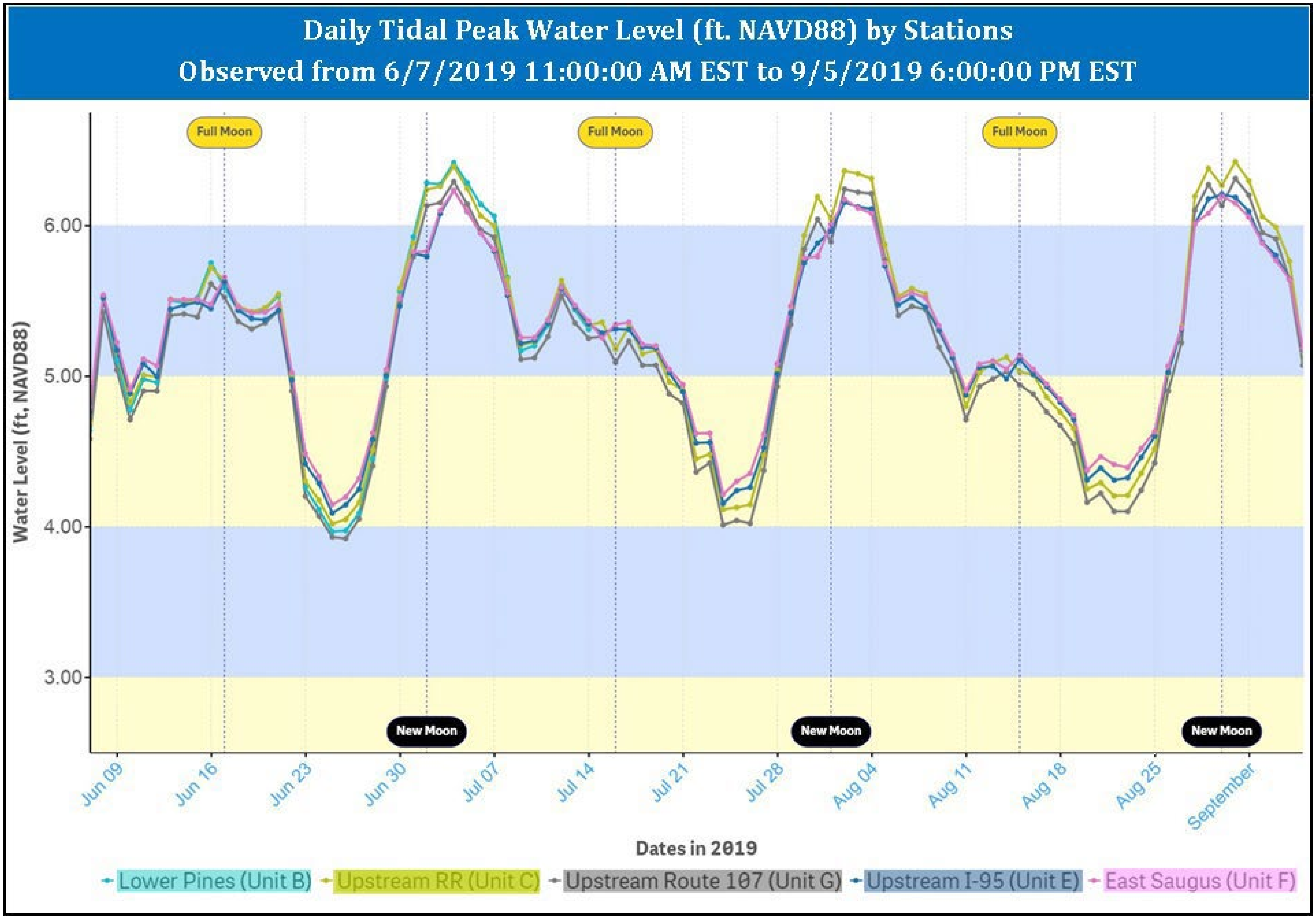

Figure 21. *Peak daily water level (MHHW) from 5 stations along the Pines River in Saugus and Revere for the 90-day period 6/7/2019 -9/5/2019.*

Tidal Data Analysis

Our study revealed significant changes due to the three bridges on Route 107 which had been reconstructed between 2009 and 2012. The longer spans, and increased height of the new bridges, increased the normal tides and bi-monthly spring tides throughout the Pines River estuary. A comparison of the 1989 USACE water level measurements to EPA's 2019 study reveals MHW has increased by 1.0 feet (30.5 cm), and the maximum water level increased by 1.3 feet (43 cm) in the area upstream of the abandoned I-95 embankment (Figure 22). The study data results revealed that the Route 107 bridges reconstruction increased tidal water levels upstream of the abandoned I-95 embankment.

The increased tidal datums of MHW and maximum spring tides, when factoring in sea level rise, is equal to the tidal restriction first observed by the USACE (USACE 1989). The increase is also consistent with the USACE model prediction and plans to restore the hydrology and functioning of the upper Pines River estuary by re-establishing the East Branch of the Pines River crossing and widening the relocated Pines River channel.[35]

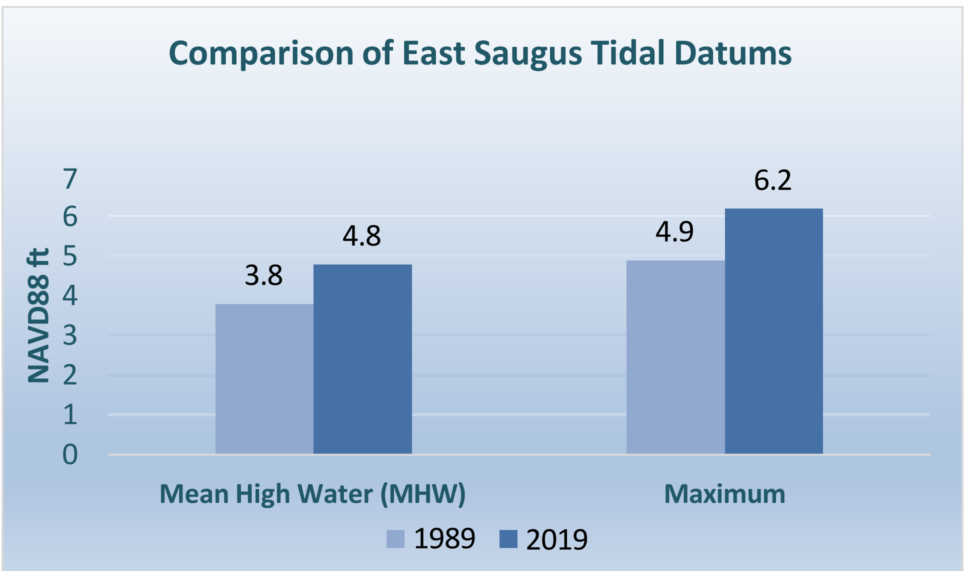

Figure 22. *Comparison of MHW and Maximum reported tidal datum metrics above the abandoned I-95 embankment in Saugus shows an increase of 1.0 feet for MHW and a Maximum observed increase of 1.3 feet between 1989 and 2019.*

To further explain how the bridges reconstruction improved tidal flow, we looked at the details in the permit plans. According to the state and federal permit application material, the three bridges combined increased the cross section available for flow from 163.25 feet (49 m) at MHW to 261.67 feet (80 m) at MHW, providing a 60.4% increase. In comparison, the relocated Pines River channel at the abandoned I-95 embankment measures 157 feet (48 m) across at MHW (Figure 6). The Route 107 combined three bridges provide 66.7% greater width at MHW for tidal flow and flushing in comparison to the relocated Pines River channel at the abandoned I-95 embankment.

[35] https://apps.dtic.mil/dtic/tr/fulltext/u2/a266336.pdf

This hydraulic capacity difference between the combined Route 107 bridges and the relocated Pines River channel explains the time lag to peak water level in the upper Pines River (Figure 23) and why the upper Pines River tide continues to rise after the lower estuary has started to ebb. It may also explain why during neap tidal cycles, these lowest tides of the month are slightly higher than the tides in less tidally restricted portions of the estuary (Figure 23).

The USACE calculated the existing peak flow area of the relocated Pines River channel at elevation 3.0 feet NGVD29 as 1,300 SF. The USACE also prepared plans to increase the existing opening to provide a new peak flow area of 5,500 SF at elevation 6.0 feet NGVD29. In addition, the USACE proposed to breach the I-95 embankment to restore the East Branch of the Pines River drainage with a new peak flow area of 1,150 SF at elevation 6.0 feet NGVD29 (USACE, 1991b). The combined peak flow capacity would be 6,650 square feet. These plans were intended to increase tidal flow to nearly 500 acres of wetlands as part of the intended environmental restoration of the marsh.[36]

For comparison, EPA calculated the cross-sectional area available for water flow at the three Route 107 bridges as 2,131 square feet up to MHW level, and 3,052 square feet for the maximum opening water height (Figure 10).

Figure 23 is a graph of the water level fluctuations during spring tides between April 19-20, 2019. Bi-monthly spring tides during the new and full moon periods, upstream of I-95 and at East Saugus, are only a few tenths of a foot lower in height due to the slight tidal restriction of the downstream bridges. The tidal phase delay is evident above the abandoned I-95 embankment, revealing the embankment still restricts the tides. However, this restriction affects the timing and duration of tides and does not affect the peak daily tidal height of the tide which is controlled by the downstream bridges.

[36] https://saugusriverfloodgate.com/the-project/restoration-plan-features

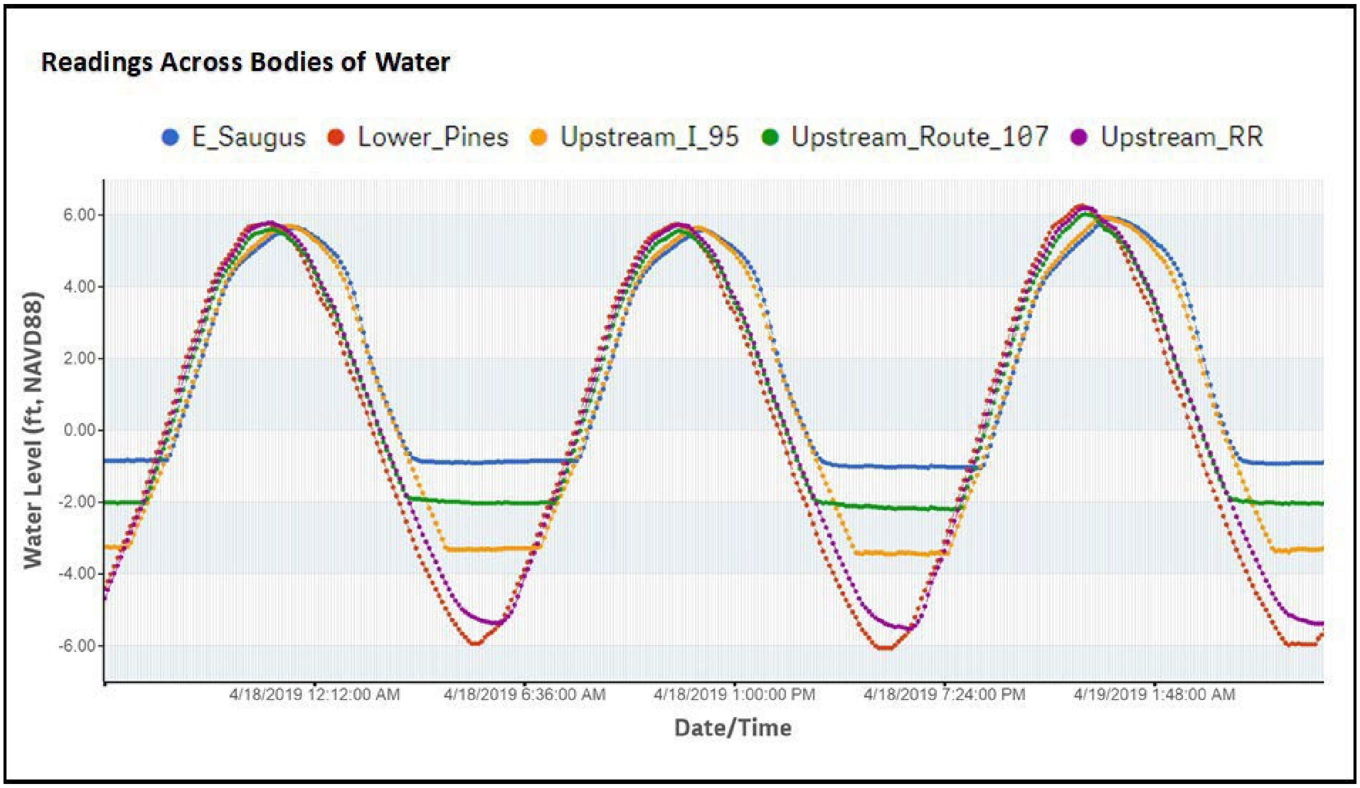

Figure 23. *Daily tidal water elevations during spring tide conditions April 18-19, 2019, depict the tidal phase delay and slightly lower peak tidal height above the abandoned I-95 embankment caused by the downstream bridges.*

Figure 24 is a graph of daily tidal water elevations during neap tide conditions on May 27, 2019. The Upstream I-95 and East Saugus sites during neap tides also show a phase delay to reach the peak tide. These peak tides were slightly higher than the downstream side of the abandoned I-95 embankment.

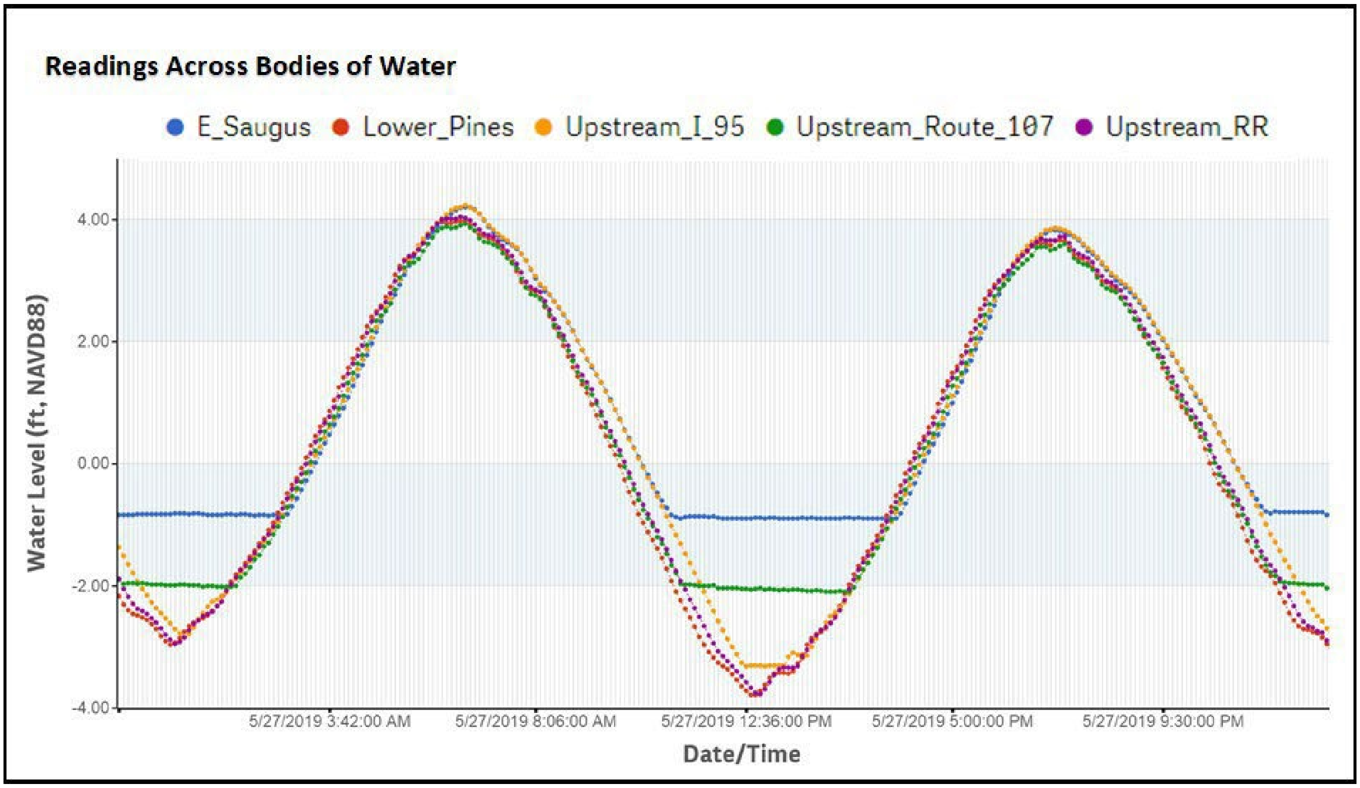

Figure 24. *Daily water level from five stations along the Pines River during neap tide cycle on May 27, 2019. The East Saugus and Upstream I-95 sites show a tidal phase delay and have the highest water level during neap tide cycles.*

The EPA 2019 water level study results are consistent with previous studies conducted after the completion of the Route 107 Bridges Reconstruction Project. As part of studies for the Ballard Street Salt Marsh Restoration Project, Massachusetts Division of Ecological Restoration (DER) in May 2014 collected tidal water level data on both sides of the abandoned I-95 embankment at three locations shown in Figure 25 (ACRE, 2015).

Figure 25. *Map of the tide gauge locations used for the May 15-29, 2014, deployment in the Pines River, from Applied Coastal Research and Engineering (ACRE 2015).*

Figure 26 graphically shows the tidal datums computed from a 15-day study in May 2014 for an intended salt marsh restoration project at Ballard Street in Saugus (ACRE, 2015). The study reported a maximum tide in the Pines River channel in East Saugus at elevation 6.3 feet NAVD88, very close to (0.1 feet higher) the EPA 2019 study results. The MHW and MHHW datums from the ACRE study, however, are higher than the EPA 2019 datums. Tides vary month to month and year to year according to the 19-year Metonic cycle.

While this difference may be due to the difference in time along the Metonic cycle, the shorter 15-day time frame of the ACRE study happened to pick up the higher end of the 29.5-day lunar tidal cycle which skews the results upward. The observed lower tidal datums at the Pines Creek culvert reveals the frictional damping of the tide by marsh channels and vegetation at this location and explains why water levels were higher on the upstream side of the abandoned I-95 embankment in this study.

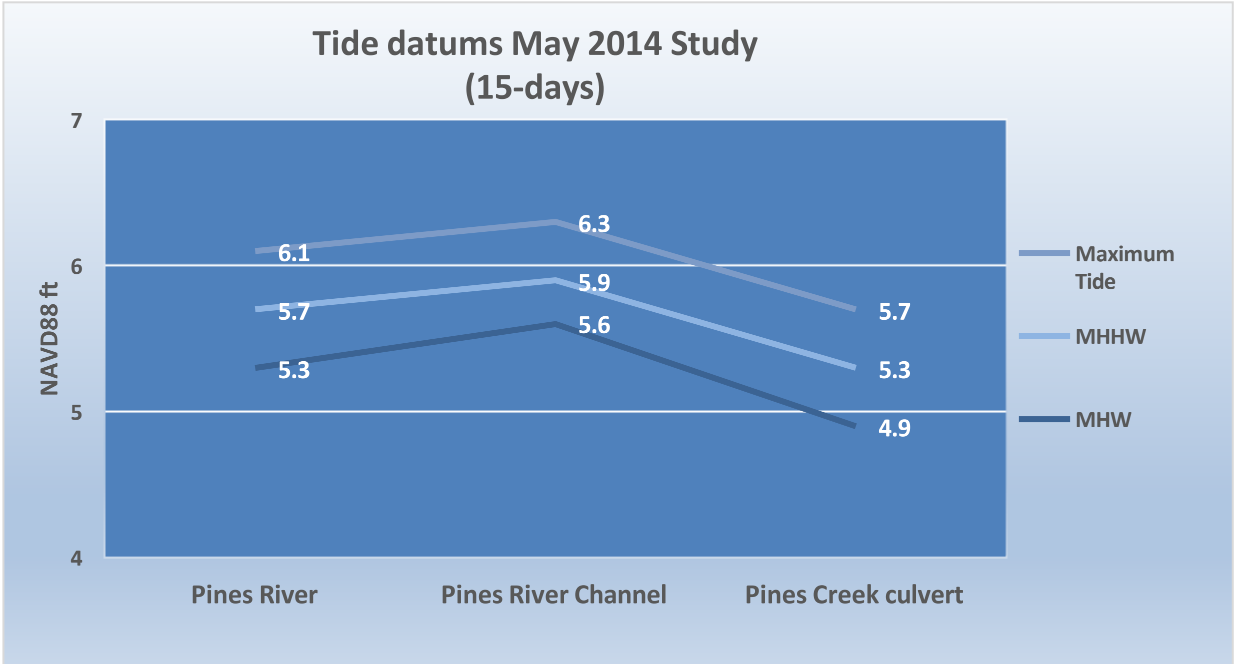

Figure 26. *Tidal datums computed from the 15-day records collected Pines River marsh system in May 2014. Datum elevations are in feet NAVD88. Data from ACRE 2015.*

Two other previous studies also provide results that are consistent with the EPA 2019 study. As part of the planning and design for Massachusetts Port Authority and the Department of Conservation and Recreation mitigation sites in East Saugus, Normandeau Associates Incorporated (NAI) studied the tides for the period of July 1 to August 1, 2014. In addition, the post construction tidal monitoring of the MassPort mitigation site by VHB Associates, pursuant to the USACE and MA DEP permit approvals, occurred from August 31, 2018, to September 28, 2018.

The raw data from these studies was evaluated using the NOAA Tidal Datum Calculator and included the Boston Harbor verified tidal data for the study dates as shown in Figure 27. Both sets of data reveal similar tidal datums and maximum tides to EPA's 2019 results. In comparison to Boston Harbor verified tides, East Saugus had consistently lower tidal datums of MHW, MHHW, and maximum tides. By providing the Boston Harbor tidal gauge verified water level data for the same dates, we can see that MHW was 0.30 feet (9.1 cm) lower, and the maximum tide was 0.74 feet (22.6 cm) lower in East Saugus as compared to Boston Harbor Tides in the NAI 2014 study. The VHB 2018 study had slightly different results, with MHW being 0.54 feet (16 cm) lower and maximum tide 0.96 feet (29 cm) lower in East Saugus as compared to Boston Harbor. These results reveal the tidal restriction effect of the downstream bridges in the Pines River estuary, which will continue, even if the I-95 embankment is fully removed.

The NAI 2014 and VHB 2018 studies accurately reflect the tidal datums of MHW and MHHW at that period, as they were for a full tidal cycle. All these studies had their maximum observed elevations close to or above 6.1 feet NAVD88. In their extensive studies, the USACE formerly reported that the entire marsh is flooded at elevation 7.0 feet NGVD29. This is approximately elevation 6.1 feet NAVD88. This level of flooding, which the USACE formerly observed, would only occur once or twice a year, is now happening at least once to several times a month, during new and full moon spring tides. This level and frequency of tidal flooding has resulted in stunting of *Phragmites australis* and *Iva frutescens* in the marsh, as well as the expansion of low salt marsh species in the former high salt marsh.

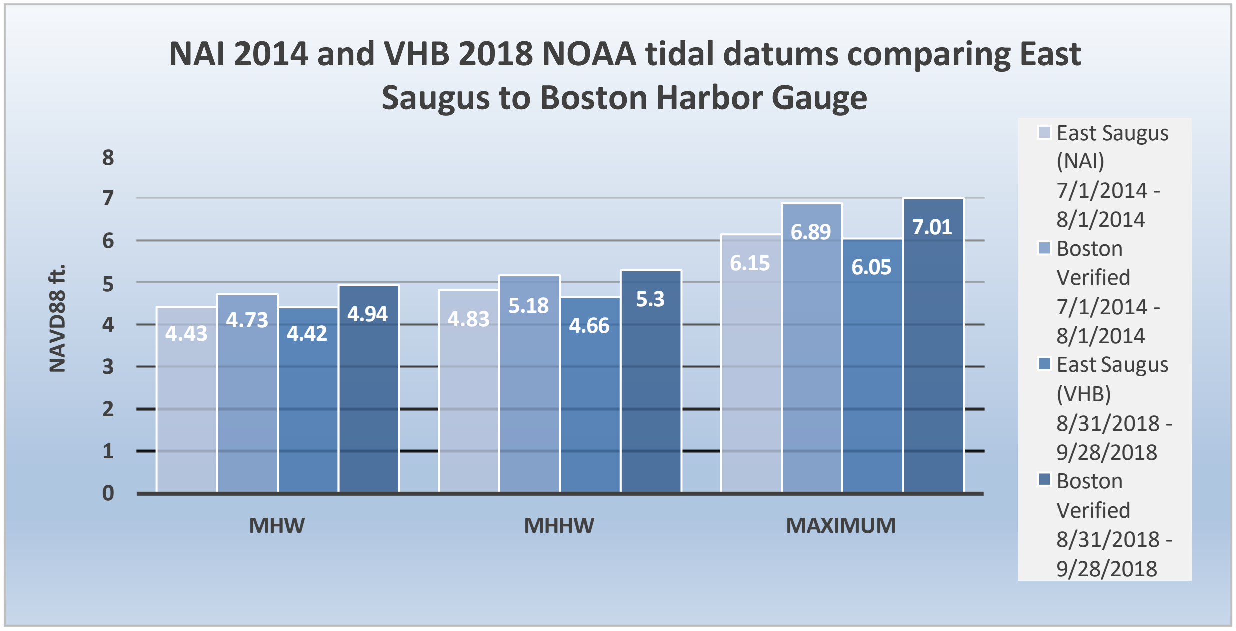

Figure 27. *Calculated NOAA tidal datums from NAI 2014 and VHB 2018 conducted in East Saugus compared to tidal datums from the Verified Boston Harbor gauge for the same periods. Elevations are in feet NAVD88.*

Vegetation Survey

Figure 28 is a box chart depicting the elevation ranges of the dominant vegetation species observed in the East Saugus Marsh from five days of survey in 2021. Additional information from this survey is provided in Appendix D. The data reveal a typical pattern of salt marsh plant zonation in the marsh consistent with the increased tides caused by the Route 107 bridges reconstruction. A significant observation from our survey data was the finding of stunted *Phragmites australis* and *Iva frutescens* growing at similar elevations as *Distichlis spicata* and *Spartina patens* (around elevation 4.8 - 5.2 feet NAVD88). It appeared that many of the stands of *Iva* in the high marsh were stunted in height and had an understory of *Spartina patens* and/or *Distichlis spicata.* This indicates that the tidal inundation frequency is sufficient to cause to cause stunting. Figure 29 is a photograph depicting stunted *Phragmites* in the East Saugus Marsh.

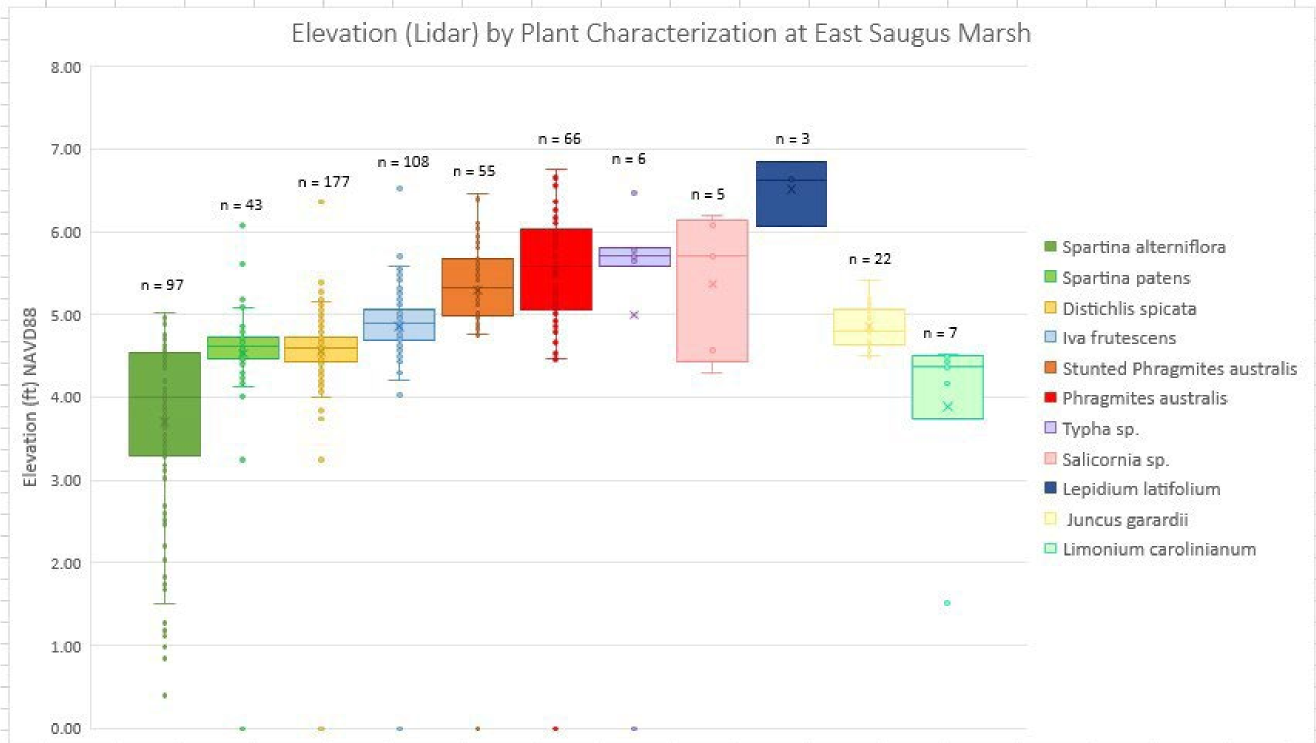

Figure 28. *Box chart depicting elevation data ranges based on Lidar data for vegetation species observed in the East Saugus Marsh.*

Figure 29. *Stunted Phragmites is less than two feet tall in this area of the East Saugus Marsh due to the increased tides. Photo credit Ed Reiner.*

Storm Surge Evaluation

The most significant threat of flooding for the project area is from tidal surges that may occur during spring high tide periods. Storm or tidal surges occur due to low pressure weather systems such as cyclones. It is measured as the rise of water level above the normal tidal level where actual tides exceed predicted tides. To evaluate if the abandoned I-95 embankment reduces tidal flooding during storm surges, photographic evidence of numerous tidal flooding events as it impacts one property along the East Saugus Marsh shoreline was reviewed.

The photographic evidence provided in Appendix C shows that storm surges, which produced 0.3-to-3.4-foot higher tides than predicted at the Boston Harbor tide gauge, flood the marsh as well as the low-lying streets in East Saugus. EPA estimated the flood levels in East Saugus by first obtaining the elevation of a fence along a residential property using Trimble GPS receivers to obtain X/Y coordinates, and subsequently obtaining those points' elevations over Light Detection and Ranging (LiDAR) terrain data (*MassGIS*, 2013-2014; vertical accuracy 18.13 cm). Using Massachusetts GIS Lidar data from the average of 13 points along the fence, EPA estimates the fence ground elevation is 5.6 feet NAVD88.

Based on the photographic evidence and fence measurements, EPA estimates these tidal flood events resulted in water levels reaching elevation 6.4 to 7.5 feet NAVD88 (Appendix C). This evidence is presented to support the position that the I-95 embankment is not providing a reduction of flooding in East Saugus. Figure 30 is a chart comparing Boston Harbor verified high tide elevations compared to the estimated East Saugus high tide elevations. The results show East Saugus highest tides are lower than Boston tides, due to the tidal restrictions associated with the downstream bridges. The photographs provide a means to check these estimates with future accurate ground surveys.

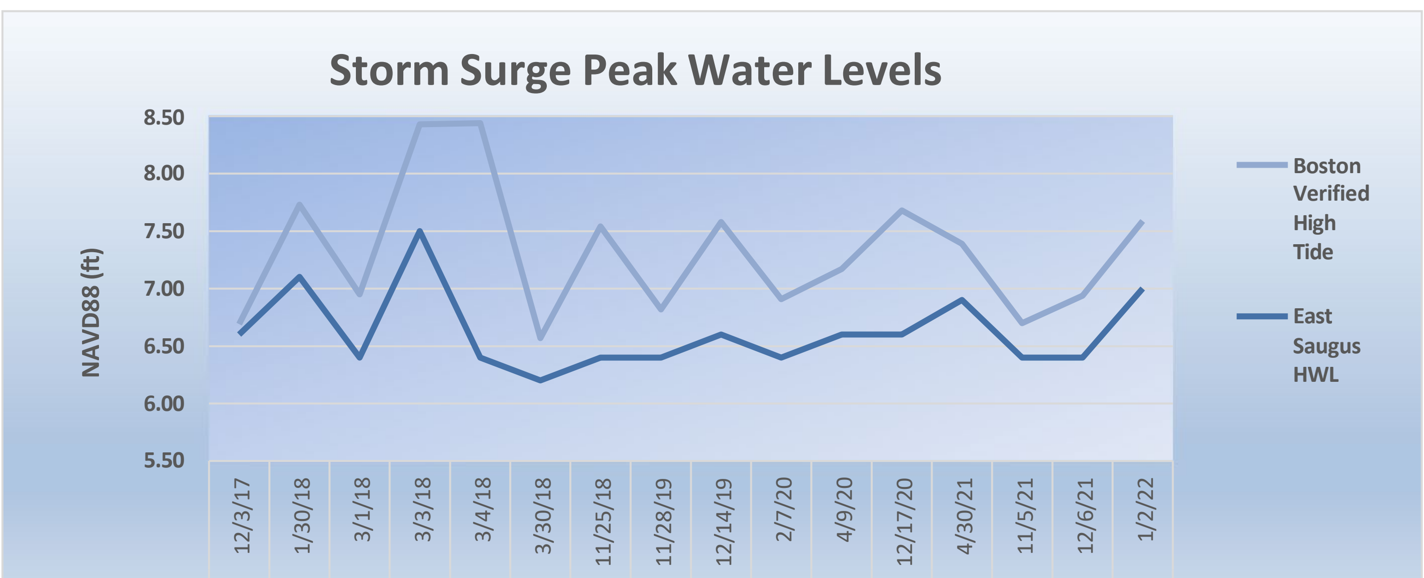

Figure 30. *Chart comparing Boston Harbor verified high tide elevations to the estimated East Saugus high tide elevations, shows that tides are typically slightly lower in East Saugus, due to the tidal restriction at the downstream bridges.*

Some of the highest tidal events were not captured photographically as they occurred during nighttime. In addition, some tidal events required evacuation for safety. Figure 31 is a chart of the predicted and verified water levels from the Boston Harbor tide gauge for the March 1-6, 2018. On March 2, 2018, the verified water level in Boston was 3.4 feet higher than the predicted tide of 5.87 feet, producing a 9.17-foot-high water level. This water level is approximately the 1% chance storm tide, or 100-year flood plain event. During the five-day period starting March 1, 2018, there were 10 consecutive tides that were higher than 6.0 feet NAVD88.

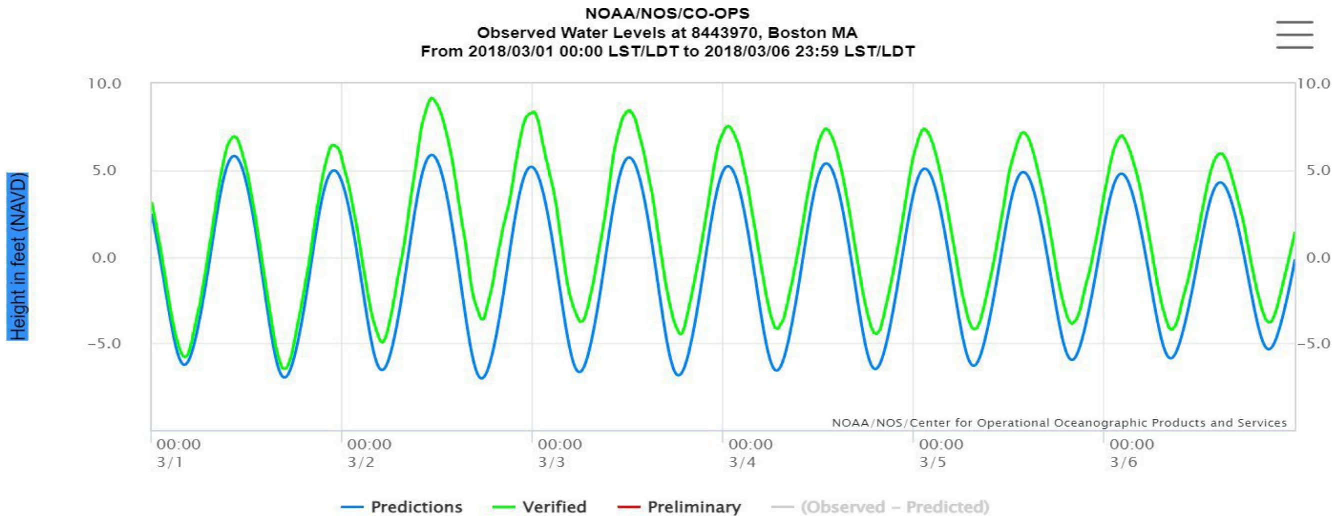

Figure 31. *Boston Harbor predicted and verified tides for the period from March 1-March 6, 2018, shows ten consecutive tides exceeding elevation 6.0 feet due to storm surge conditions.*

Sea Level Rise

While the NOAA 1983-2001 National Tidal Datum Epoch (NTDE) for MHW for the area is 4.3 feet, our study found MHW during the study period was 4.8 feet NAVD88. This 0.5-foot difference represents the change to local sea level in the last 40 years. At the Boston Harbor NOAA tide gauge, sea level trends show an increase of about 0.11 inches/year (2.87 +/- 0.15 mm/yr).[37] NOAA estimates sea level rise of 1.54 feet in Boston by 2050. NOAAs 2022 Sea Level Rise Technical Report containing projections of sea level rise through 2150 is available at https://oceanservice.noaa.gov/hazards/sealevelrise/sealevelrise-tech-report.html.

The Lynn Municipal Vulnerability Plan is using 40 inches (1.02 m) rise by 2070 for their planning.[38] Sea level rise projections indicate that by the end of the century, average sea level in the project area is expected to increase by between 4 feet (low projection) and 10.2 feet (high projection) with an intermediate projection of 5 feet.[39] Climate change projections indicate that by 2100, sea level at the Boston tide gauge is “likely” to rise by 1.5 to 4.0 feet and could be as high as 9.7 feet (NECASC, 2018). While the significant change in tidal hydrology in the Pines River estuary is clearly attributable to the Route 107 bridges reconstruction, a portion of the change is due to sea level rise between the study periods.

[37] https://tidesandcurrents.noaa.gov/sltrends/sltrends_station.shtml?id=8443970
[38] https://www.ediclynn.org/mvp%20page.html
[39] https://resilientma.mass.gov/changes/sea-level-rise

The USACE studies from 1989 and 1990 found MHW above the abandoned I-95 embankment was at elevation 4.7 NGVD29. Using the National Geodetic Survey (NGS) Coordinate Conversion and Transformation Tool (NCAT)[40], we can convert elevation 4.7 NGVD29 by adding -0.91 feet to equal 3.8 feet (NAVD88). Comparing the 1989 USACE data to the 2014 NAI and 2018 VHB data, MHW for the area upstream of the embankment has increased from around elevation 3.8 to 4.4 feet NAVD88, an increase of 0.6 feet (15 cm).

The USACE 1989 studies reported Mean High Water in the Pines River downstream of the abandoned I-95 embankment as elevation 5.0 feet NGVD29, which is approximately 4.1 feet NAVD88. MHW according to our 2019 study is now approximately elevation 4.8 feet NAVD88, revealing an increase of around 0.7 feet (15 cm).

NOAA currently uses the 1983-2001 National Tidal Datum Epoch (NTDE).[41] Sea level rise is not included in tidal datums. However, as tidal datums are also a "mean", for purposes of calculating sea level rise since the NTDE, the values are assumed to be for the "middle date" of that period - June 1992. Sea level rise in Boston is calculated to be a rate of 2.87 mm per year.[42] For the period of 1992 to 2021, at that average rate, sea level rise would be approximately 83.23 mm or 3.27 inches. The USACE 1989 studies, however, used data from NOAA's superseded 1960-1978 epoch. USACE used a MHW value of 5.0 feet NGVD29 based on the 1960-1978 National Ocean Survey Tidal Epoch Boston Harbor tidal datums. Since these values are an average over that period, the middle date of that period would be June 1969 and the rise in sea level from 1969 to 2019 using Boston Harbor long-term sea level trends would be approximately 50 x 2.87mm +/- 0.15 mm/year or 143.5 mm or 5.65 +/- 0.3 inches.

This epoch is now undergoing revision and will be replaced by the fifth iteration of the NTDE. Measurements for the update will be based on water level data spanning the years 2002-2020.
Since 1950, sea level rose by about eight inches (20 cm) in Boston. Scientists predict that sea level may rise by another six inches (15 cm) in the next 15 years.[43] It is now accepted science that the rate of sea level rise is increasing. This study did not address considerations of future sea level rise, which will increase flooding from present levels.

Tidal flooding can come from the Saugus River side of the estuary as well as the Pines River side. The marshes were historically connected; however, the historic wetland fill for landfills and commercial development now restricts the tidal water movement to a partially obstructed ditch along the upstream side of the railroad track, and the tide gate at Ballard Street on the upstream side of Route 107. Tidal water levels which exceed the elevation of Ballard Street in East Saugus will flood across the road to the Ballard Street Salt marsh, providing an additional source of flooding for the East Saugus neighborhood.

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[40] https://geodesy.noaa.gov/NCAT/
[41] NOAA Tides Datums for 8443970, Boston MA
[42] https://tidesandcurrents.noaa.gov/sltrends/sltrends_station.shtml?id=8443970
[43] https://sealevelrise.org/states/massachusetts/

The current tidal flooding, as experienced throughout the Pines and Saugus River estuary, already produces street and yard flooding during new and full moon high spring tides (Appendix C). Flooding problems in the estuary will increase with expected sea level rise. If a storm surge occurs during a spring tide period, within any of the ranges of expected sea level rise in the future, low lying areas in the community are at risk of flooding. This flooding, however, is virtually unaffected by the embankment. Figure 32 is a photograph of a commuter train crossing the marsh on March 3, 2018, showing tidal water levels approaching the top of the railroad embankment. On March 2, this storm produced one of the highest tides recorded at the Boston Harbor tide gauge, with a reading of 9.17 NAVD88 as shown in figure 31 above. This elevation is essentially equal to the 100-year flood or 1% tidal flooding event.

The MBTA is replacing the railroad bridge over the Saugus River. Mitigation plans for the unavoidable loss of intertidal areas and salt marsh involve the removal of additional fill material from the abandoned I-95 embankment to restore salt marsh in Saugus.[44]

Figure 32. *Photograph taken March 3, 2018, shows tidal water levels approaching the top of the railroad embankment at Rumney Marsh. Photo credit, Geoffrey Wilson, Northeast Wetland Restoration.*

[44] USACE # NAE-2018-00339, MA DEP Transmittal # X286945

CONCLUSIONS AND RECOMMENDATIONS

This study aimed to determine if the abandoned I-95 embankment could be removed or breached without increasing flooding problems in the upper marsh area. In the past, efforts to pursue embankment removal were opposed because the embankment was believed to restrict tides.

The three Route 107 bridges that were reconstructed between 2009 to 2012 increased normal tides and bi-monthly spring tides throughout the Pines River estuary, revealing that the abandoned I-95 embankment does not reduce tidal flooding as previously believed. EPA's 2019 water level study results reveal that the reconstructed Route 107 bridges removed most of the former tidal restriction previously documented by the USACE. Route 107, as well as the further downstream railroad bridge, will continue to slightly lower the highest tides in the estuary, even if the embankment were to be fully removed.

Our data showed the time to the maximum tide in East Saugus on the upstream side of the embankment was delayed more than one hour. The tides start to ebb in the lower Pines River while the upper marsh is still flooding. The USACE formerly observed a two-hour lag time for high tide in the upper Pines River and noted their observations that the embankment restricts drainage by acting as a dam at extreme low tides, not allowing the upstream area to drain completely (USACE, 1989c). This impairment to drainage is important since increasing frequency and duration of tidal inundation controls vegetation in a salt marsh, shifting high marsh species to low marsh species which are better adapted to survive periods of inundation. With sea level rise, the concern is that the high marsh may not be able to maintain itself vegetatively.

The preservation of high salt marsh is particularly important for the saltmarsh sparrow (*Ammodramus caudacutus*) which nests in high marsh areas. Listed as a Species of Special Concern under the Massachusetts Endangered Species Act (MESA) in 2020, the sparrow is currently being considered for federal listing under the United States Endangered Species Act.

Increased tides can result in high salt marsh areas formerly vegetated with *Spartina patens* and *Distichlis spicata* shifting to short form *Spartina alterniflora*. Ponding of tidal waters in salt marshes results in plant die-off and marsh subsidence. Increasing sea level can also drown low marsh containing *Spartina alterniflora*, resulting in further degradation of salt marsh and conversion to unvegetated tidal flats.

Appendix C provides photographic documentation of tidal storm surge flooding events where the majority of the East Saugus Marsh is flooded, as well as streets and yards, at estimated elevations around 6.4 -7.3 feet NAVD88. Compared to Boston Harbor verified tidal heights, the East Saugus marsh for most of these events had lower peak tides, likely due to the downstream bridges. Since the Route 107 bridges will continue to be the primary tidal restriction to flow in the Pines River estuary, embankment removal and breaching, to restore the severed drainage patterns across the marsh, will not increase flooding to the developed property upgradient of the embankment.

Sea level rise projections indicate that by the end of the century, average sea level in the project area is expected to increase by between 4 feet (low projection) and 10.2 feet (high projection) with an intermediate projection of 5 feet.[45] Alternative retreat, flood proofing, raising building elevations, or flood control berms or walls will be needed along the East Saugus shoreline, as well as the Saugus River side, since flooding already is experienced in these areas. Berms or walls, however, do not solve all problems as groundwater also rises with sea level, and interior drainage would need to be accommodated.

Solving the larger estuary and regional flooding problem will likely require a new analysis of the formerly proposed Saugus River and Tributaries Flood Damage Reduction Project, which would construct a closable flood gate barrier at the mouth of the Saugus River.[46] Regardless of any larger flood control projects that may be needed in the future to address sea level rise, continued removal of embankment fill to appropriate elevations can restore salt marsh and intertidal mudflat habitat, create additional flood storage in the marsh, and improve drainage for the East Saugus community.

The removal of the abandoned I-95 embankment is one of the greatest opportunities to restore coastal aquatic habitat north of Boston, Massachusetts, with the potential to restore up to 50 additional acres (20.2 hectares) of salt marsh and intertidal areas. Additional wetland acreage can be restored by using some of the excavated material to fill in portions of the eroding drainage channel that was constructed on the upstream side of the embankment in Saugus.

Restoration of the former creek systems that were once severed by the embankment would then provide improved drainage for 444 acres (180 hectares) of up-gradient marsh. Removal of the embankment would decrease water velocity, decrease erosive conditions along marsh edges, restore and improve fish and wildlife habitat, and increase sediment accumulation across the marsh surface. All this would, in turn, increase marsh resiliency to sea level rise and help to protect nesting habitat for the saltmarsh sparrow.

I-95 Embankment Removal and Breaching

Figure 33 depicts the I-95 abandoned embankment with locations of the formerly filled tidal creeks. Two creeks, depicted along the Saugus peninsula of the embankment fill, were cut off by the embankment fill and relocated to a constructed channel. A third creek is shown along the Revere peninsular of the embankment. Tidal restrictions and high velocity waters continue to contribute to erosion along the constructed Pines River channel (Figure 13) and elsewhere in the marsh. Flowing water erodes the salt marsh peat, undermining overhanging pieces, which break off and fall into the creek (salt marsh calving). Due to the continued erosion of the embankment fill, the Pines River channel is filling with sediment, exposing intertidal areas at low tide. Removing the I-95 embankment would reduce tidal current velocity and help to lessen salt marsh losses from continued erosion processes.

[45] https://resilientma.mass.gov/changes/sea-level-rise
[46] https://apps.dtic.mil/dtic/tr/fulltext/u2/a217016.pdf

The embankment could be fully removed to marsh grades to restore salt marsh, intertidal habitat, and the drainage that was severed and impaired by the embankment fill. The suggested priority embankment removal area (Figure 8) would restore 3,200 linear feet of sheet flow across the high marsh. Restoring sheet flow would improve marsh resiliency by increasing the opportunity for the settlement of organics over the marsh surface.

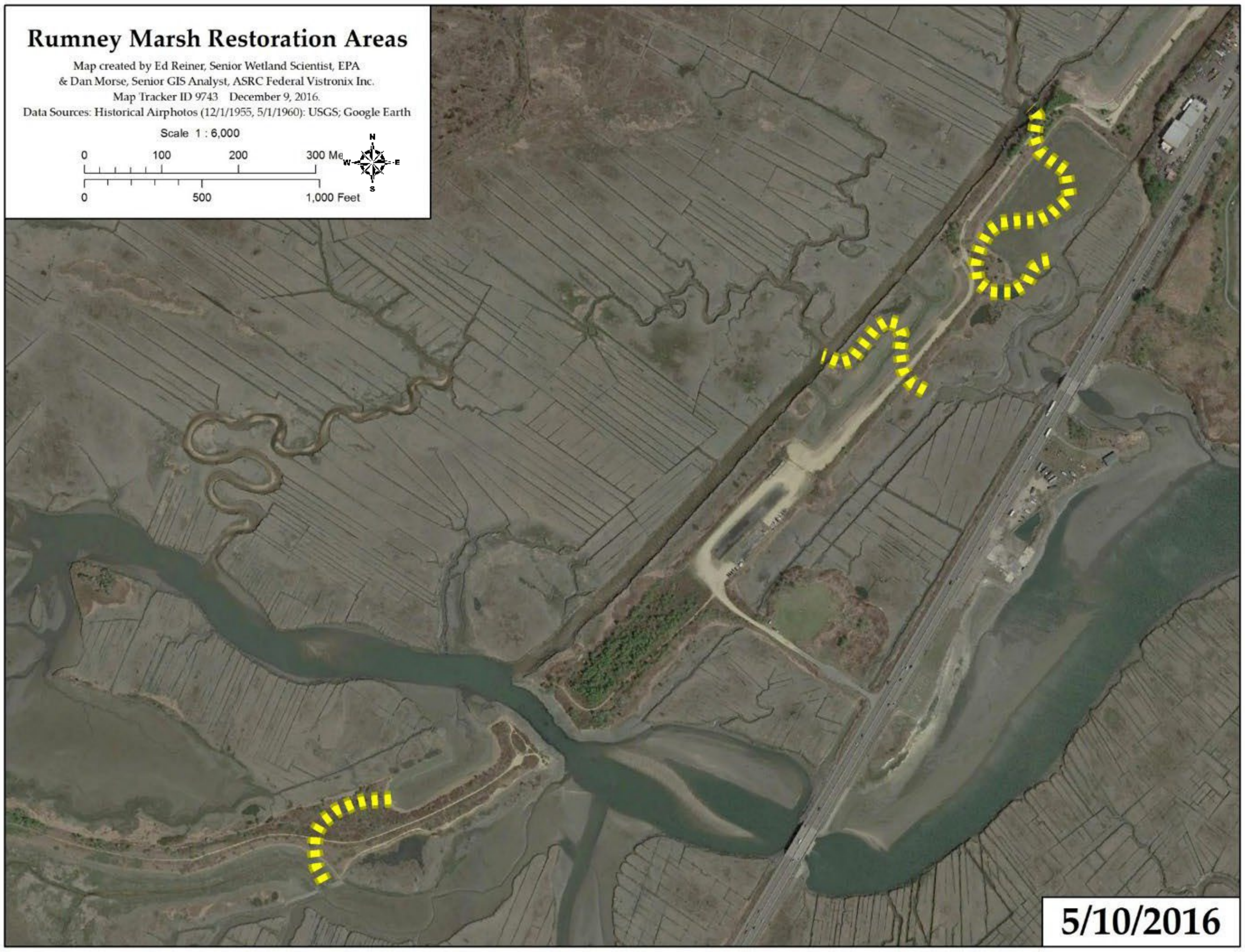

Figure 33. *Aerial photo taken May 10, 2016, highlighting the locations of former channels which were filled along the abandoned I-95 embankment in Revere and Saugus, Massachusetts.*

Beneficial Use of Embankment Sands and Gravel

Robert Hunt, retired USACE project manager for the Saugus River Floodgate project, estimated that some 15 acres of wetlands bordering four mitigation sites can be restored by removing about 200,000 cubic yards along the abandoned I-95 embankment.[48] Figure 8 depicts a berm removal focus area along three of the mitigation sites which would remove about 3,200 linear feet of embankment. We estimate this would require approximately 113,000 cubic yards of excavation. Some of this excavated material could potentially be used to restore salt marsh to sections of the constructed drainage channel that are no longer needed after restoring the former creeks (Figure 13). Embankment soils may also be useful for partial construction of flood control berms or a public trail around the upland edge of the marsh. Flood control berms, however, would normally require a clay core or other impermeable structure to prevent water seepage.

Off-site beneficial use of the embankment soils could include use for dune improvements at Point of Pines, sand dune creation and walkovers at Revere Beach, and continued beach nourishment use at Revere Beach or Winthrop Shore Reservation. The material may also be suitable for other road construction projects or living shoreline stabilization projects. In this sense, the sand and gravel soils have value which can reduce project costs and provide a dual benefit of marsh restoration.

Permit and Funding Considerations

Removal of the abandoned I-95 embankment and restoration of the marsh were specifically included as a goal in the 1988 designation of the marsh as an Area of Critical Environmental Concern. Since then, restoration has been promoted and sought out and has only been constrained by the mistaken belief that the embankment provided flood protection by reducing the tides.

While the 37 acres of salt marsh and intertidal area habitat restoration completed to date by embankment removal was done as permittee responsible mitigation efforts, the Compensatory Mitigation Rule[47] and Corps of Engineers Mitigation Guidance[48] now favor the use of mitigation banks or In-Lieu Fee (ILF) programs. Potential projects to restore aquatic habitat can seek funding through the Massachusetts ILF program. The I-95 embankment removal and restoration of hydrology at the East Branch of the Pines River would also be an excellent candidate for wetland habitat restoration grant funding or a Supplemental Environmental Project.[49]

Additional Considerations for Marsh Restoration

The USACE, in their 1989 and 1991 studies, documented that the upper marsh rarely flooded. However, flooding frequency in the upper marsh has dramatically increased due to the reconstructed Route 107 bridges. The more frequent flooding is also resulting in retained water on the high marsh surface because of ditch and dike effects that historically elevated portions of the marsh. The increased tidal inundation to the high marsh favors short form *Spartina alterniflora* which can tolerate the longer inundation periods, however, retained water in a high marsh typically results in vegetation die-off.

Geoffrey Wilson, with the Bear Creek Wildlife Sanctuary in Saugus, while working in Rumney Marsh, discovered evidence of colonial era agricultural embankment systems that had been constructed throughout the marsh. These embankment systems were used to reduce or cut off the tides and freshen the soils for the growth of salt marsh hay, English hay, and a slightly salt-tolerant livestock forage beet called Mangelwurzel. The embankment systems have since been reduced in height by decomposition of

[47] https://www.ecfr.gov/cgi-bin/text-idx?c=ecfr&tpl=/ecfrbrowse/Title33/33cfr332_main_02.tpl

[48] https://www.nae.usace.army.mil/portals/74/docs/regulatory/Mitigation/2016_New_England_Compensatory_Mitigation_Guidance.pdf

[49] https://www.epa.gov/enforcement/supplemental-environmental-projects-seps

the organic soils used to construct the embankments, and, as the marsh has grown upward, keeping pace with sea level rise over the centuries. The remnant embankments, however, continue to alter the tide sheds in the marsh, sometimes resulting in extensive water ponding on the marsh surface. Persistent flooding of high marsh vegetation causes a die-off of salt marsh plants that cannot tolerate the lack of oxygen in the soils. The Bear Creek Wildlife Sanctuary, together with local environmental community partners, are working on developing plans to address the drainage impairments and water ponding problems that are being observed in the upper marsh area.

One technique being used to address shallow ponding water in the high marsh is the creation of shallow ditches called runnels.[50] Originally developed in Australia in the 1980s to control mosquitoes by draining standing water, runnels construction has been used in several Rhode Island and Massachusetts salt marsh restoration projects.[51,52] Runnels successfully drained off surface ponding and colonized with vegetation along the Narrow River in Narragansett, Rhode Island (Perry et. al. 2022). Another technique involves ditch remediation where mosquito ditches are restored to salt marsh to restore single creek hydrology to individual tide sheds (Burdick et. al. 2020, 2021).[53]

EPA funded research undertaken by the University of Massachusetts Amherst, in cooperation with MassDEP and MA CZM, is evaluating the use of unoccupied aerial systems (drones and sensors) to collect multi-spectral, multi-temporal data for mapping plant communities and physical characteristics of salt marshes and evaluating salt marsh condition. While this work is not yet being conducted at Rumney Marsh, the development of this assessment method has great potential for evaluation of marsh condition everywhere.

If project funding can be found, and permit plans agreed upon, restoration of improved tidal flows to the Ballard Street salt marsh in Saugus would allow for an additional 34.5 acres (14 hectares) of wetland restoration. Around 3,000 feet of the embankment at the northern end near Ballard Street was left at the original height of approximately 26 feet NAVD88 (8 meters), due to community concerns related to noise and views of the nearby waste-to-energy facility. It is unlikely that further removal of the embankment would occur at this area due to these concerns.

Solving the larger estuary and regional flooding problem will likely require a new analysis of the formerly proposed Saugus River and Tributaries Flood Damage Reduction Project, which would construct a closable flood gate barrier at the mouth of the Saugus River.[56] Regardless of any larger flood control projects that may be needed in the future to address sea level rise, continued removal of embankment fill to appropriate elevations can restore salt marsh and intertidal mudflat habitat, create additional flood storage in the marsh, and improve drainage for the East Saugus community. The removal of the abandoned I-95 embankment would be one of the greatest opportunities to restore coastal aquatic

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[50] https://www.Woodwellclimate.Org/Assessing-New-Salt-Marsh-Restoration-Technique-In-Buzzards-Bay/

[51] https://doi.org/10.1007/s12237-021-01028-8 https://www.ediclynn.org/mvp%20page.html

[52] https://www.savebuzzardsbay.org/wp-content/uploads/2020/03/RunnelWorkshopMasterPresentation.pdf

[53] https://link.springer.com/article/10.1007/s12237-019-00656-5.

habitat north of Boston, Massachusetts, with the potential to restore up to 50 additional acres (20.2 hectares) of salt marsh and intertidal area and improve tidal flow and drainage to 444 acres (180 hectares) of additional coastal wetlands.

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APPENDIX A - Bathymetry Study

As stated in the report, this project was conducted to provide bathymetric data of the Pines River as it flows through three tidal restrictions (the railroad crossing, the Rt. 107 crossing, and the Pines River/I-95 embankment armored channel). The data collected in this study illustrated the locations of scour holes and showed the effects erosion and sedimentation within the Pines River and the Pines River channel. It also provides useful information that could be added to the USACE model of the estuary. Essentially, the goal of the bathymetry is to provide accurate information that will help inform those making decisions about Rumney Marsh and the protection of the East Saugus community.

Methods

A bathymetry study was undertaken in 2018 to document the depth along the Pines River as it passes the railroad bridge, Route 107 Pines River Bridge, and the I-95 embankment. Depth along the East Branch of the Pines River as well as the Pines River channel was also measured. Due to the low vertical clearance at the railroad bridge and Route 107 bridges, this study was done by kayak. Depth measurements were obtained using a depth gauge (H22PX – HawkEye® Handheld Sonar System) to log depth of the water paired with a GPS device to log location at a meter accuracy level. The depth measurements were manually input to the GPS device to create a record with time, depth, and position.

These GPS records were post-processed with Trimble Pathfinder Office to a mean horizontal accuracy of less than one meter. While the soundings were collected as feet below the survey vessel, the local tidal range of almost ten feet required that we adjust these depths using NOAA tidal measurements, by correlating their time stamps. We converted the surveyed depths to NAVD88, the datum of most other local data.

Results

This study revealed significant scour holes at the Railroad crossing, Route 107 bridge and the I-95 embankment opening along the Pines River. Scour holes typically form at bridges or culverts due to the increased flows through undersized structures. Bottom elevations measured at:

Location	I-95 crossing	Route 107	Railroad
Upstream	26.5	23.6	22.3
Downstream	32.7	38.3	46.9

Figure 12 below provides a visualization of a comparison of the bottom elevations upstream and downstream at the three tidal restrictions.

Figure A-1 shows the results from the 2018 bathymetry study. The shallowest areas are shown in red with deeper areas in yellow, and the deepest areas shown in increasing shades of blue to black. Depths were sampled according to the methods described above. The samples were collected in GPS with coordinates and time stamps for the height of tide at each location; depth soundings were corrected by tidal elevation for actual depth.

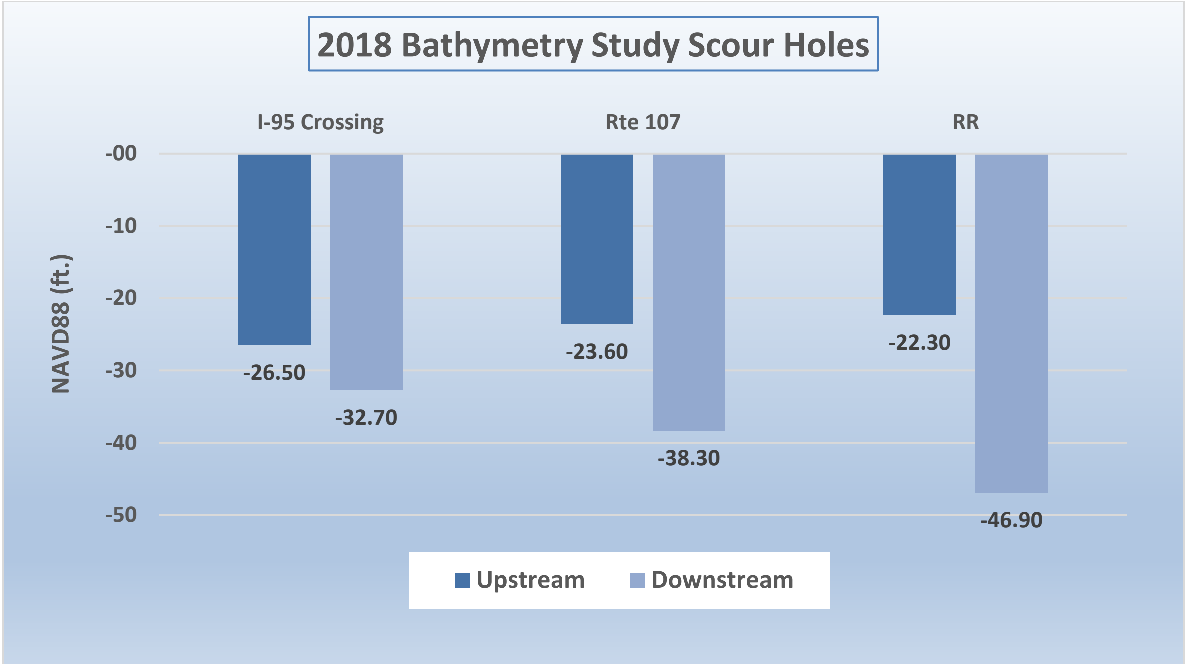

Figure 12 *(same as in the main body of the report)*. *Depth of scour holes at three tidal restrictions in Rumney Marsh.*

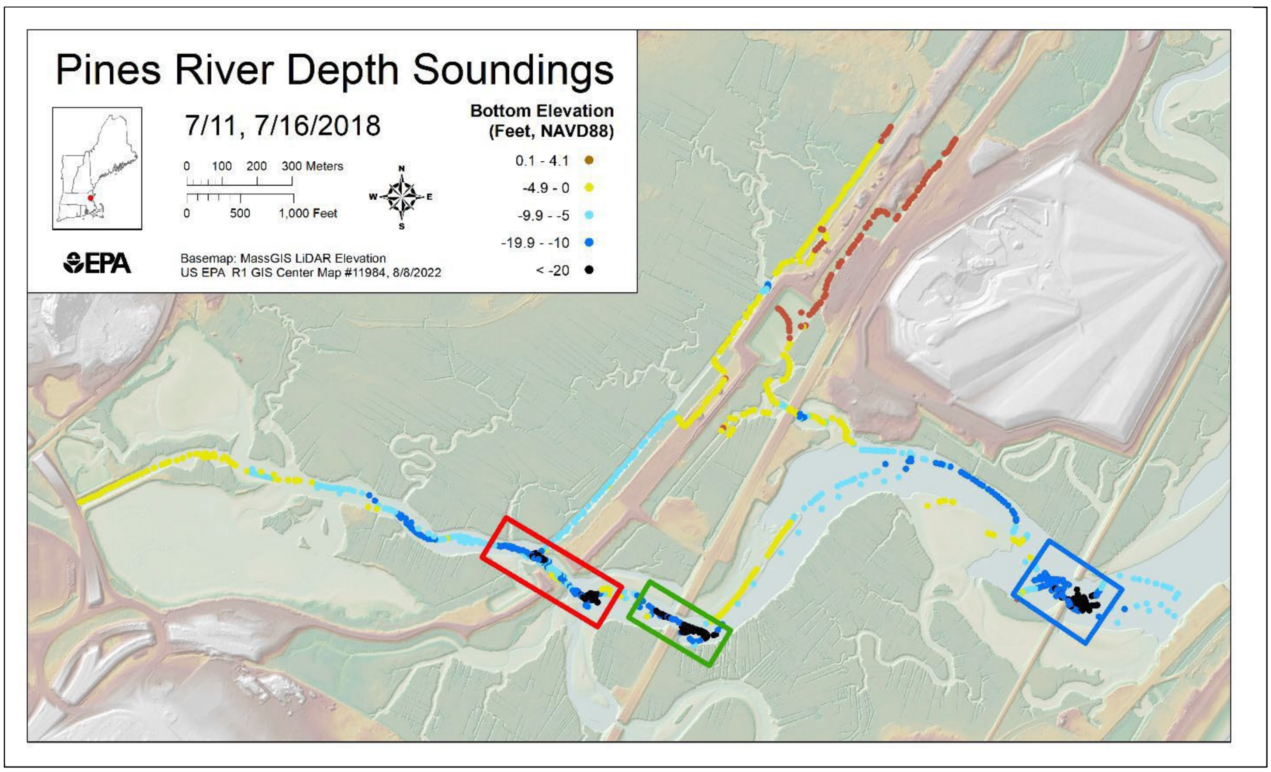

Figure A-1. *July 2018 results from Bathymetry study Pines River, Pines River channel and East Branch Pines River in Saugus and Revere, Massachusetts. The rectangles on this map identify the border colors in the figures below as follows: red is the I-95 crossing, green is the Route 107 crossing, and blue is the railroad crossing.*

The bathymetric surface models shown below were interpolated from the depth sample points. Figure A-2 depicts significant scour holes at the Railroad Bridge and Route 107 crossing of the Pines River.

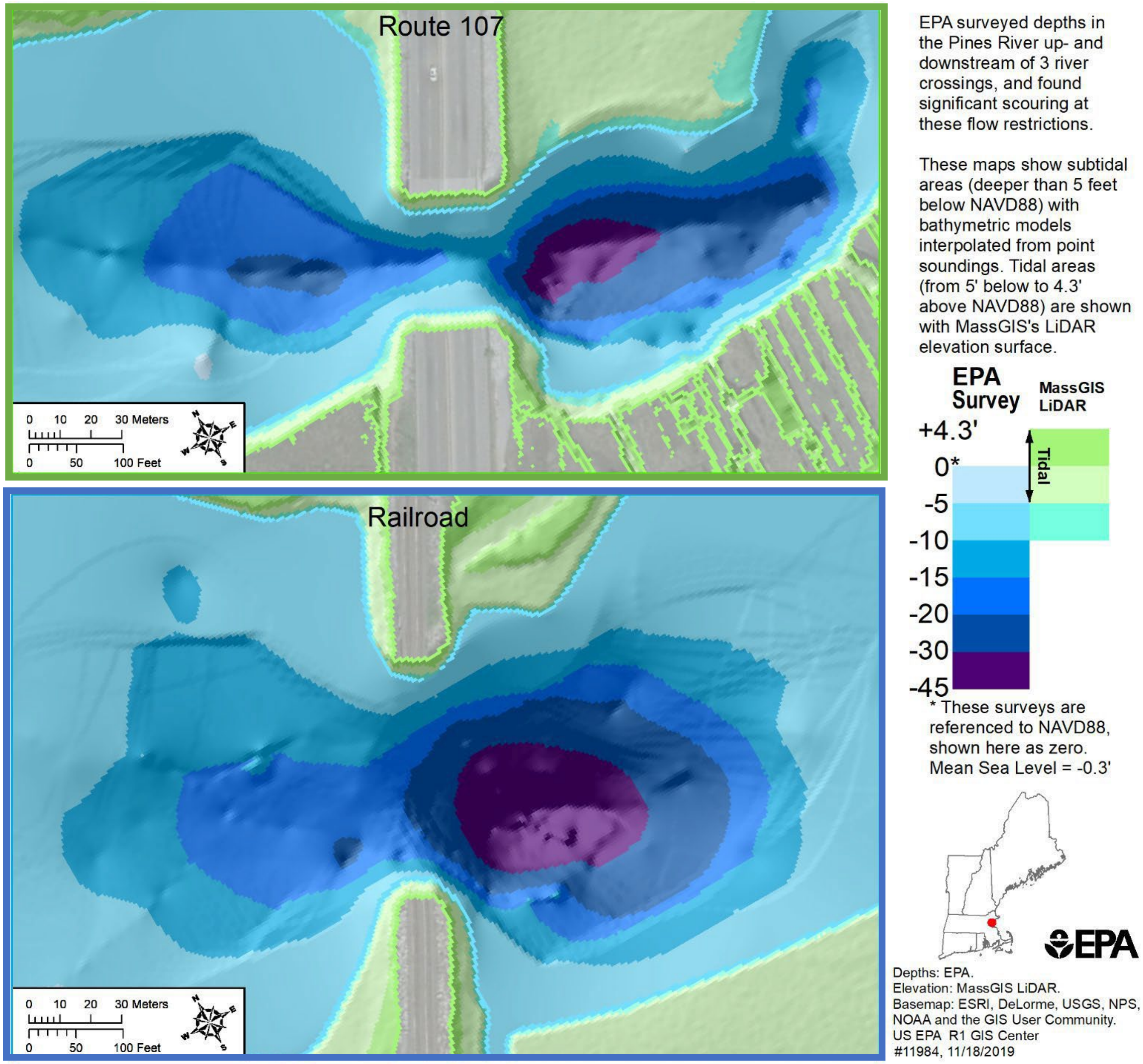

Figure A-2. *Bathymetry maps showing significant scour holes at the Railroad Bridge and Route 107 crossing of the Pines River.*

Figure A-3 contains an inset map of the samples taken at the I-95 crossing, with their depths labeled in feet NAVD88. The upstream scour hole had a maximum depth at -25 feet, whereas the downstream scour hole was -32 feet deep. The deeper downstream scour hole is indicative of an ebb dominant flow pattern due to the faster draining higher velocity water. The actual crossing is armored with a bottom depth of -9 to -10 feet NAVD88.

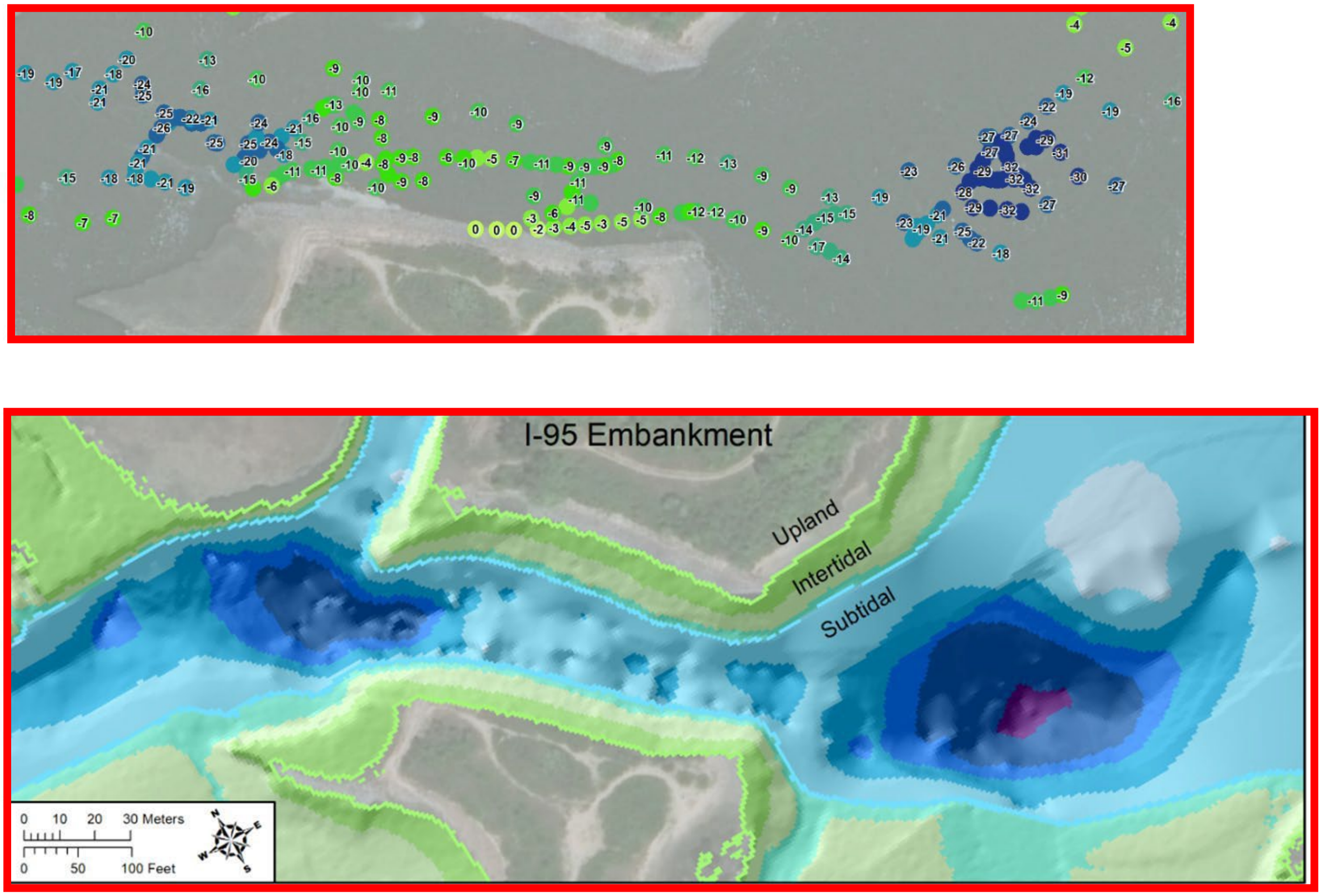

Figure A-3. *Top figure shows depth in feet NAVD88 at the Pines River crossing of the abandoned I-95 embankment. Bottom figure is a model which interpolated the depth between the samples.*

The abandoned I-95 embankment forms a continuous berm across the width of the marsh, with only one opening for tidal flow and drainage purposes. This opening, which was intended to be spanned by a bridge, is armored with rock in a trapezoidal fashion. Figure A4 (Figure 6 from the main report) is a plan sheet from the Corps of Engineers September 1966 revised permit for the relocated Pines River crossing. This plan shows that the crossing has a bottom width of 15 feet (4.7 meters) and depth set at -10 feet below Mean Sea Level (NGVD29). This narrow opening increases the velocity of the current sufficiently to result in significant scour holes of the bottom substrate at both sides of the crossing.

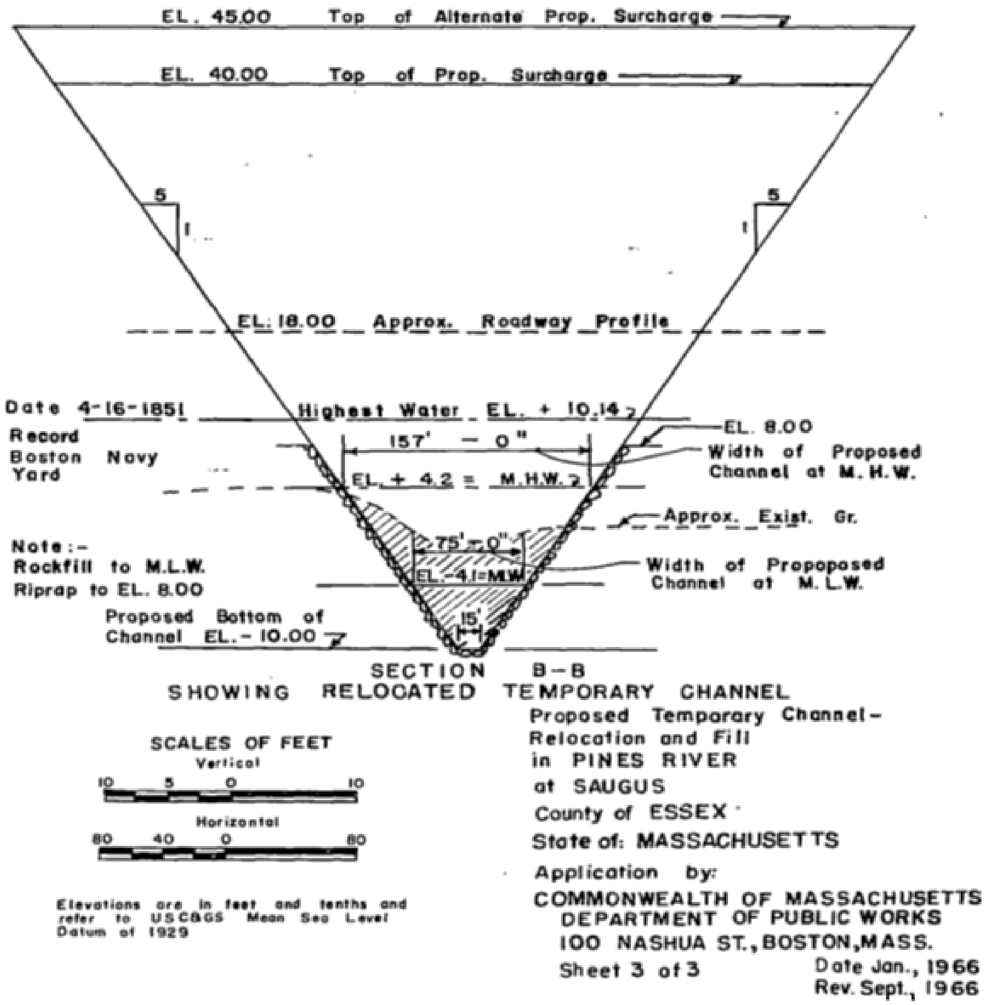

Figure A-4 also figure 6 in the main report. *Corps permit plan for the relocated Pines River shows the armored crossing dimensions and depth. Elevations are in feet and tenths and refer to US&GS Mean Sea Level Datum of 1929.*

APPENDIX B - Rumney Marsh Restoration Areas and Tidal Restrictions

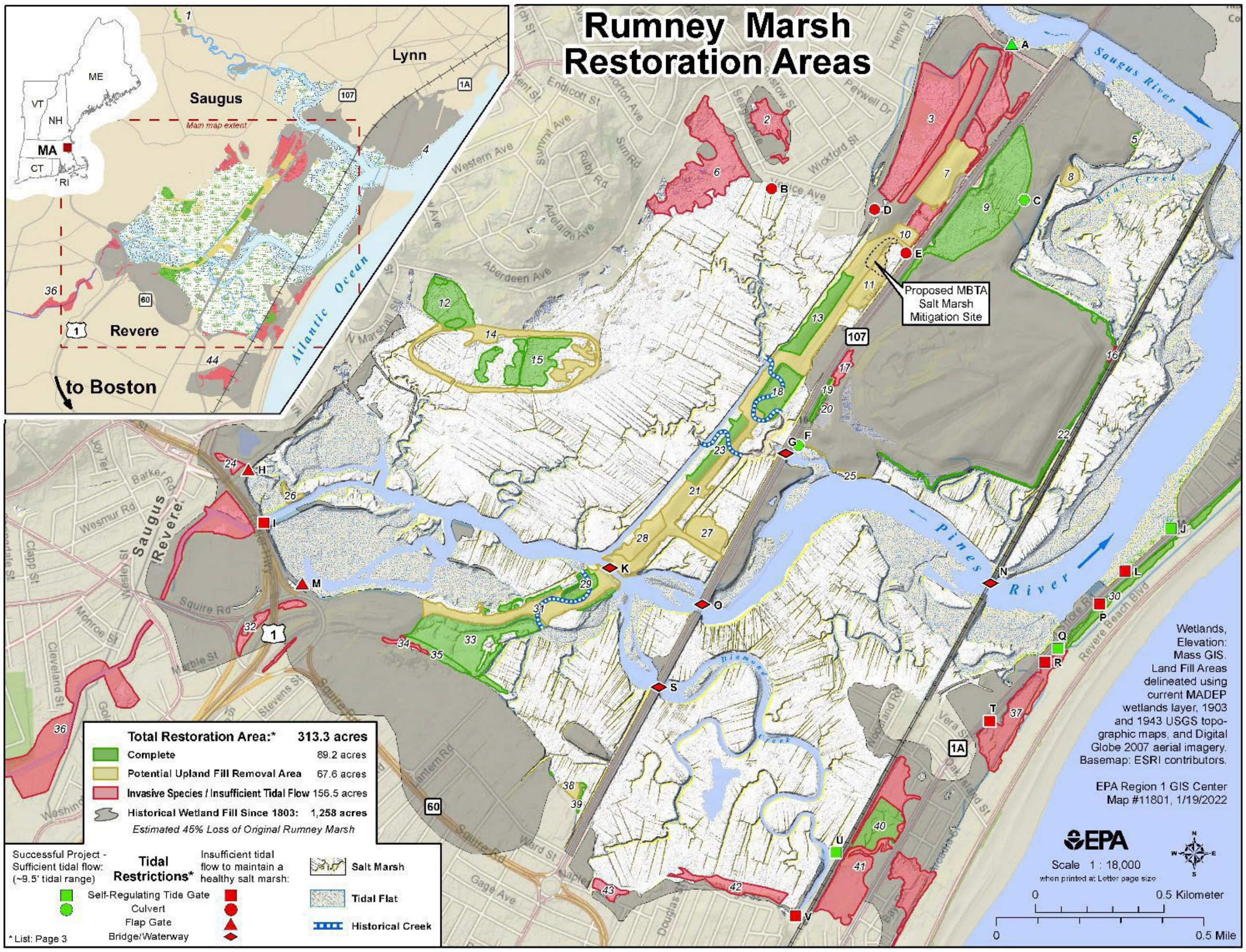

Figure B-1 also Figure 7 from main report. *EPA Rumney Marsh Restoration Areas map depicts locations and status of various fill removals, restoration projects, and tidal restrictions; detail for each area can be found in the following tables. The locations of the former tidal channels that were altered by embankment construction are depicted in the blue dotted lines*

Below is the acreage of restoration areas and their status and a chart of the tidal restrictions from EPA's Rumney Marsh Web Page [Rumney Marsh Restoration Area and Tidal Restrictions.]

Restoration Areas					
ID	**Name**	**Acres**	**Status**	**Phragmites**	**Notes**
1	National Park Service	2.9	Complete		*See locus map
2	Seagirt Ave Marsh	3.4	Insufficient Tidal Flow	Yes	
3	Ballard St Restoration	34.5	Insufficient Tidal Flow	Yes	
4	Potential Lynn South Harbor Shoreline Restoration	2.0	Potential Upland Fill Removal Area		Potential living shoreline *See locus map
5	GE Salt Marsh Mitigation	0.2	Complete		

Restoration Areas (cont.)					
ID	**Name**	**Acres**	**Status**	**Phragmites**	**Notes**
6	Saugus Ave Marsh	16.4	Insufficient Tidal Flow	Yes	
7	I-95 Salt Marsh Restoration Area 6	7.0	Potential Upland Fill Removal Area		Peat from original marsh
8	RESCO Salt Marsh Restoration Area	1.0	Potential Upland Fill Removal Area		
9	Crescent Marsh	22.8	Complete	Yes	MA DOT installed new culvert February, 2021
10	I-95 Salt Marsh Restoration Area 5	1.3	Potential Upland Fill Removal Area		
11	I-95 Salt Marsh Restoration Area 4	3.6	Potential Upland Fill Removal Area		Peat from original marsh
12	Park Street Marsh Restoration Area	6.1	Complete		Overflooded marsh needs some drainage
13	Massport Logan Airport Mitigation	4.7	Complete		Plantings installed 2017
14	Saugus Racetrack	10.3	Potential Upland Fill Removal Area		
15	Saugus Racetrack Open Marsh Water Mgmt. (OMWM)	8.6	Complete		Overflooded marsh needs some drainage
16	Landfill Salt Marsh Restoration Area	0.1	Insufficient Tidal Flow	Yes	Large wood debris blocking tidal flow
17	Route 107 Wetland	1.2	Insufficient Tidal Flow	Yes	
18	Saugus River Navigation Project Mitigation	5.1	Complete		
19	DOT Route 107 Bridges Mitigation	0.6	Complete		
20	Saugus Landfill Wetland	0.1	Complete	Yes	Invasive species dominated
21	I-95 Salt Marsh Restoration North	24.0	Potential Upland Fill Removal Area		
22	Landfill Salt Marsh Restoration Area	2.9	Complete		
23	DCR Nahant Causeway Mitigation	4.2	Complete		Natural colonization only
24	Linden Brook Restoration	0.8	Insufficient Tidal Flow	Yes	
25	Dewey Daggett Landfill Shoreline Stabilization	0.2	Complete	Yes	Eroding landfill edge stabilized with riprap
26	Pines River Channelization Upland Fill	0.6	Potential Upland Fill Removal Area		
27	DCR Salt Marsh Restoration Area	3.5	Potential Upland Fill Removal Area		Fill was found to be contaminated
28	I-95 Salt Marsh Restoration Area 1	3.5	Potential Upland Fill Removal Area		
29	Corps Roughans Point Mitigation Area	2.2	Complete		

Restoration Areas (cont.)					
ID	**Name**	**Acres**	**Status**	**Phragmites**	**Notes**
30	Route 1A Tide gates #1-4 Marsh	5.4	Complete		Maintenance needed to tide gates for proper function
31	I-95 Salt Marsh Restoration South	9.9	Potential Upland Fill Removal Area		
32	Copeland Circle Wetlands	2.4	Insufficient Tidal Flow	Yes	
33	Central Artery Marsh Restoration	16.0	Complete		
34	Caruso Marsh Restoration Phragmites Zone	0.7	Insufficient Tidal Flow	Yes	
35	Caruso Marsh Restoration	1.7	Complete		
36	Townline Brook Marsh Restoration	39.0	Insufficient tidal flow	Yes	
37	Route 1A Tide gates #5-6 Marsh	9.5	Insufficient Tidal Flow	Yes	
38	DCR Salt Marsh Restoration Area 2	0.8	Potential Upland Fill Removal Area	Yes	
39	BJ's Salt Marsh Restoration	0.3	Complete		
40	Oak Island Marsh Restoration	5.5	Complete		
41	Oak Island Marsh Restoration & Eastern County Ditch	20.7	Insufficient Tidal Flow	Yes	
42	Hastings Street Salt Marsh	6.5	Invasive species	Yes	
43	Naples Road Marsh	1.3	Invasive species	Yes	
44	Central County Ditch Marsh Restoration	22.9	Insufficient Tidal Flow	Yes	Tide gate needs bottom float install *See locus map

Tidal Restrictions						
ID	**Name**	**Type**	**Functioning**	**Status**	**Phragmites**	**Notes**
A	Ballard St Tide gate	Flap Gate	Yes	Complete	Yes	
B	Seagirt Ave Marsh Tide gate	Culvert	No	Potential project	Yes	Obstructed 18-inch culvert and ditch
C	Crescent Marsh Culvert	Culvert	Yes	Complete	Yes	MA DOT culvert replacement
D	Bristow St Culvert #2	Culvert	No	Potential project	Yes	obstructed ditch; 18-inch culvert
E	Bristow St Culvert #1	Culvert	No	Potential project	Yes	Obstructed culvert and ditch
F	Route 107 Bridges Mitigation	Culvert	Yes	Functioning salt marsh		Failed culvert replaced to restore salt marsh

Tidal Restrictions (cont.)						
ID	**Name**	**Type**	**Functioning**	**Status**	**Phragmites**	**Notes**
G	Route 107 E Branch Pines River	Bridge	Yes	Complete		Bridge was replaced, with higher and wider structure
H	Linden Brook Tide gate	Flap Gate	No	Potential project	Yes	Old wooden flap gate
I	Townline Brook Tide gates (3)	SRT	No	Repairs needed	Yes	Three SRTs are not being operated per permit conditions. three bottom floats missing
J	Route 1A Tide gate #1	SRT	Yes	Repairs needed		Missing top floats need replacement for flood control
K	I-95 Embankment	Waterway	Yes	Potential Project	No	Armored crossing of Pines River restricts flow and drainage across marsh
L	Route 1A Tide gate #2	SRT	No	Repairs needed		Missing top floats need replacement; obstructed culvert
M	Copeland Circle Tide gate	Flap Gate	No	Potential project	Yes	Cast iron flap gate only supports salt marsh from leakage
N	Pines River Railroad Crossing	Bridge	Yes	Potential Project	No	Limited vertical clearance at high tide - due to low bridge structure
O	Route 107 Pines River	Bridge	Yes	Complete		Bridge was replaced, with higher and wider structure
P	Route 1A Tide gate #3	SRT	No	Repairs needed		Crushed culvert outlet and stolen grated vault cover need replacement
Q	Route 1A Tide gate #4	SRT	Yes	Repairs needed		Stolen grated vault cover needs replacement
R	Route 1A Tide gate #5	SRT	No	Potential project	Yes	Replace 24" culvert with larger size. 48" SRT stolen grated vault cover needs replacement
S	Route 107 Diamond Creek	Bridge	Yes	Complete		Bridge was replaced, with higher and wider structure
T	Route 1A Tide gate #6	SRT	No	Repairs needed	Yes	Completely obstructed 600-foot-long culvert. Stolen grated vault cover needs replacement
U	Oak Island Tide gate	SRT	Yes	Under restoration		New combo gate (2013). Portions of salt marsh restored with muted tidal hydrology
V	Central County Ditch Tide gate	SRT	No	Repairs needed	Yes	Not being operated properly to maximize restoration; needs bottom float installation

APPENDIX C - Coastal Flooding Photos of East Saugus Marsh

This appendix provides photographs in chronological order of tidal flooding in East Saugus. Fae Saulenas, a long-term Saugus resident, allowed EPA to use her fence and yard which abuts the salt marsh to measure flood levels. The pictures below depict flooding at 26 Beachview Avenue in East Saugus unless otherwise specified. EPA estimated the flood levels by first obtaining the location of a fence along the property using Trimble GPS receivers to obtain X/Y coordinates, and subsequently obtaining those points' elevations over Light Detection and Ranging (LiDAR) terrain data (*MassGIS*, 2013-2014; vertical accuracy 18.13 cm). Using Massachusetts GIS Lidar data from the average of 13 points along the fence, EPA estimates the fence ground elevation is at elevation 5.6 feet NAVD88. This elevation correlates closely to our measurement during a king tide event on October 19, 2020, when we observed the highest tide at the MassPort tide gauge, and then measured the fence height based on that flood level. We compared the East Saugus estimated water levels to verified water levels from the Boston Harbor NOAA tide gauge.

Figure C-1, which is labeled Figure 30 in the main report, plots Boston Harbor verified high tides and estimated high tides in East Saugus, Massachusetts. The East Saugus estimated high water levels were typically lower than Boston Harbor highest tides due to the tidal restriction at the downstream bridges.

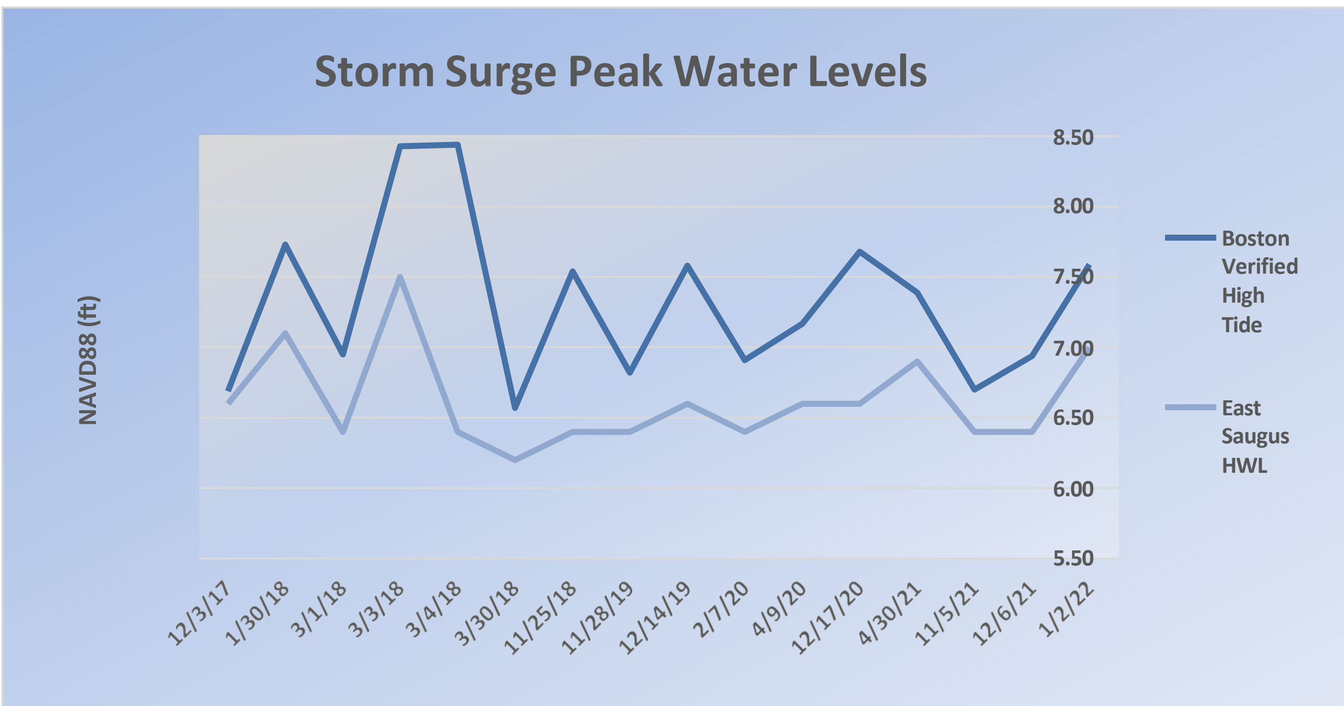

Figure C-1 also Figure 30 in the main report. *Chart comparing Boston Harbor verified high tide elevations to the estimated East Saugus high tide elevations, shows that tides are typically slightly lower in East Saugus, due to the tidal restriction at the downstream bridges.*

Figure C-2. *High tide debris from January 2, 2022, storm surge measures 16.5 inches from ground level or elevation 7.0 feet NAVD88. Photo credit Fae Saulenas.*

Figure C-3. *January 2, 2022, street flooding estimated at elevation 7.0 feet NAVD88. Photo credit Fae Saulenas.*

Figure C-4. *January 2, 2022, flooding estimated at elevation 7.0 feet NAVD88. Photo credit Fae Saulenas.*

Figure C-5. *December 6, 2021, estimated water level 6.4 feet NAVD88. Photo credit Fae Saulenas.*

Figure C-6. *December 6, 2021, estimated water level 6.4 feet. Photo credit Fae Saulenas.*

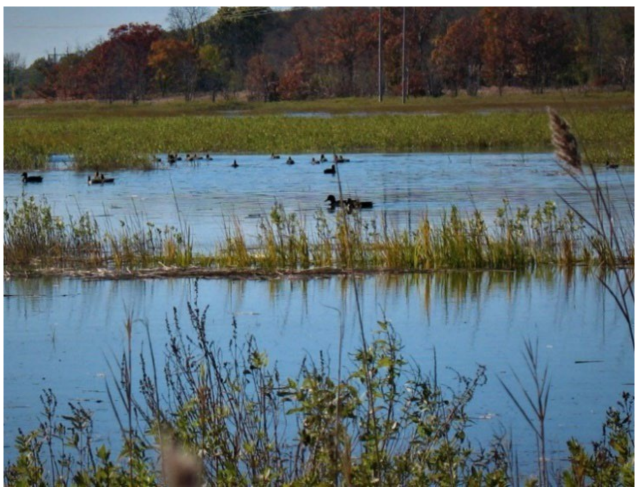

Figure C-7. *November 5, 2021, estimated water level 6.4 feet NAVD88. Photo credit Fae Saulenas.*

Figure C-8*. April 30. 2021. Debris on fence 16 inches high estimated at elevation 6.9 feet NAVD88. Photo credit Fae Saulenas.*

Figure C-9. *December 17, 2020, high water estimated at 6.6 feet NAVD88. Photo credit Fae Saulenas.*

Figure C-10. *April 9, 2020, high water estimated at elevation 6.6 feet NAVD88. Photo credit Fae Saulenas.*

Figure C-11. April 9, 2020, *Beachview Ave high water at 2:20 p.m. estimated at 6.6 feet NAVD88. Photo credit Fae Saulenas.*

Figure C-12. *February 7, 2020, high water estimated at elevation 6.4 feet NAVD88. Photo credit Fae Saulenas.*

Figure C-13. *December 14, 2019, tidal flooding at 4:11 PM estimated at 6.6 feet NAVD. Photo credit Fae Saulenas.*

Figure C-14. *November 28, 2019, high tide estimated at 6.4 feet NAVD88. Photo credit Fae Saulenas.*

Figure C-15. *November 28, 2019, high tide estimated at elevation 6.4 feet NAVD88. Photo credit Fae Saulenas.*

Figure C-16. *November 25, 2018, high water level estimated at elevation 6.4 feet NAVD88. Photo credit Fae Saulenas.*

Figure C-17. *November 25, 2018, Beachview Ave estimated water elevation 6.4 feet NAVD88. Photo credit Fae Saulenas.*

Figure C-18. *November 25, 2018, tidal flooding estimated at 6.4 feet NAVD88. Photo credit Fae Saulenas.*

Figure C-19. *November 25, 2018, tidal flooding Belair Street estimated at 6.4 feet NAVD88. Photo credit Fae Saulenas.*

Figure C-20. *November 25. 2018 high tide estimated at 6.4 feet NAVD 88. Photo credit Fae Saulenas.*

Figure C-21. *March 30, 2018, high tide estimated at elevation 6.2 feet NAVD88. Photo credit Fae Saulenas.*

Figure C-22. *March 4, 2018, high tide estimated at elevation 6.4 feet NAVD88. Photo credit Fae Saulenas.*

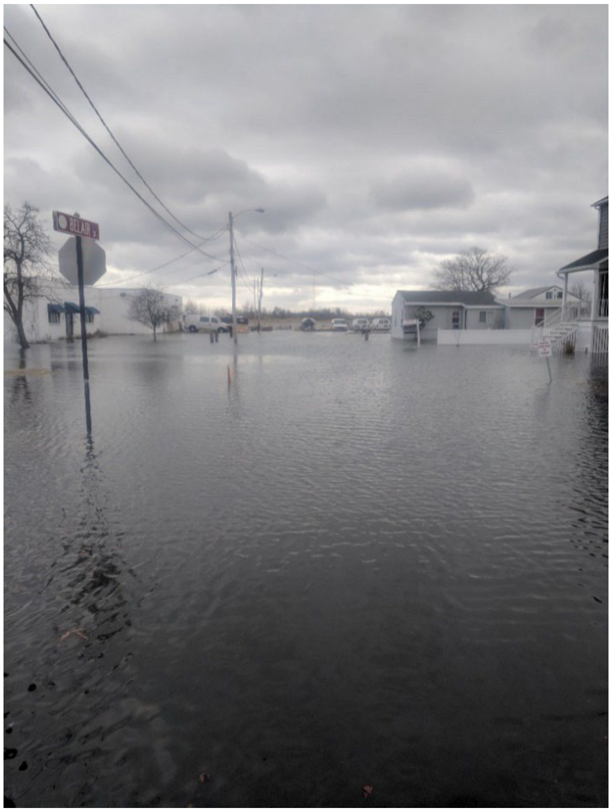

Figure C-23. *March 3, 2018, high tide on Belair street estimated at 7.5 feet NAVD88. Photo credit Ed Reiner.*

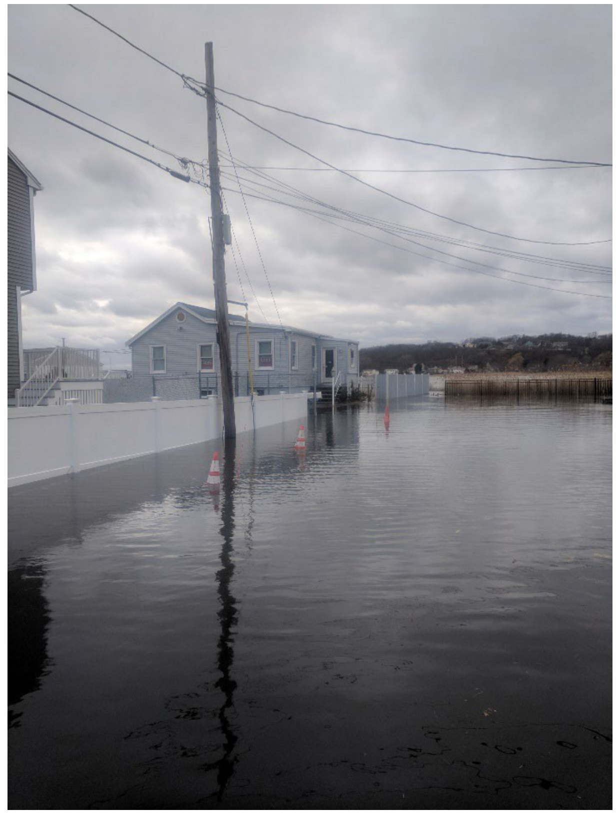

Figure C-24. *March 3, 2018, high tide on Beachview Ave estimated at 7.5 feet NAVD88. Photo credit Ed Reiner.*

Figure C-25. *March 1, 2018, high tide at 2:04 pm estimated at elevation 6.4 Feet NAVD88. Photo credit Fae Saulenas.*

Figure C-26*. January 30. 2018 high tide debris 18-inches high estimated elevation 7.1 feet NAVD88. Photo credit Fae Saulenas.*

Figure C-27. *December 3, 2017, high tide on Beachview Ave estimated at elevation 6.6 feet NAVD88. Photo credit Fae Saulenas.*

APPENDIX D – Vegetation and Elevation Survey in the East Saugus Marsh

Salt marsh vegetation is distinguished from freshwater wetland vegetation due to adaptations that allow inundation with salt water. Vegetation sorts itself, based on the ability to tolerate frequency and duration of inundation with salt water. In general, low salt marsh typically below MHW is dominated by *Spartina alterniflora*, a plant that can tolerate twice daily flooding. High salt marsh vegetation generally grows on the relatively flat high marsh platform above the vertical plain of MHW. High salt marshes only flood during full and new moons which are referred to as spring tide periods.

The USACE formerly mapped the wetland boundaries in Rumney Marsh and found that the whole marsh would flood in a 7.0-foot NGVD29 water level which is approximately 6.12 feet NAVD88. With the increased tides caused by the Route 107 bridges reconstruction, as well as sea level rise, the vegetation in the salt marsh is subject to more frequent and longer periods of inundation. This is particularly evident where the salt marsh may have lost elevation through subsidence due to the former tidal restriction. In many New England salt marshes, the normally dry high salt marsh is transforming into wetter marshes dominated by short form *Spartina alterniflora.*

Principal investigator Ed Reiner surveyed a portion of the East Saugus Marsh to obtain information on vegetation in the marsh. Data was collected during five visits to the marsh on February 23 and 24, March 2, August 11, and August 12, 2021. Trimble GeoXH GPS was used to obtain X/Y coordinates for the identified vegetation species sampling those points' elevations over Light Detection and Ranging (LiDAR) terrain data (*MassGIS*, 2013-2014; vertical accuracy 18.13 cm).

Figure D-1 depicts box plots of the elevation ranges found for the sampled vegetation using the Massachusetts GIS Lidar data layer. Figure D-2 is a map of the sampled vegetation color coded for the identified species. A typical zonation pattern of salt marsh plants was found. The most significant observation from this data was the finding of stunted *Phragmites australis* and *Iva frutescens* growing at similar elevations as *Distichlis spicata* and *Spartina patens* around elevation 6.0 feet NAVD88. It appeared that many of the stands of *Iva* in the high marsh were stunted in height and had an understory of salt marsh plants. This indicates that frequent enough inundation at these elevations is occurring to cause stunting. *Salicornia sp*., a pioneering salt marsh species was found in some low-lying yard areas revealing the occasional tidal inundation to developed property at the edge of the salt marsh. Also, *Typha angustifolia* was observed growing in the northwestern part of the East Saugus Marsh, indicating a more brackish water condition, possibly affected by colonial era dikes constructed for farming hay near and above elevation 6.0 feet NAVD88. Taller *Phragmites australis* is prevalent in the northwestern corner of the marsh near Saugus Avenue, likely due to the freshened salinity conditions from groundwater discharge and runoff affected by the colonial era dikes.

The vegetation survey results provide corollary evidence of higher tides upstream of the abandoned I-95 embankment, compared to before the Route 107 bridges reconstruction project. The presence of stunted *Phragmites* at elevations near 6.0 feet NAVD88 and above is an indication that these areas are being inundated frequently enough with salt water to stunt vertical growth. From the water level data, monthly spring tides during new and full moon periods are near or just above elevation 6.0 NAVD88. The increased tides on the upstream side of the abandoned I-95 embankment are causing a reduction of the height, density, and presence of both *Phragmites* and *Iva frutescens*.

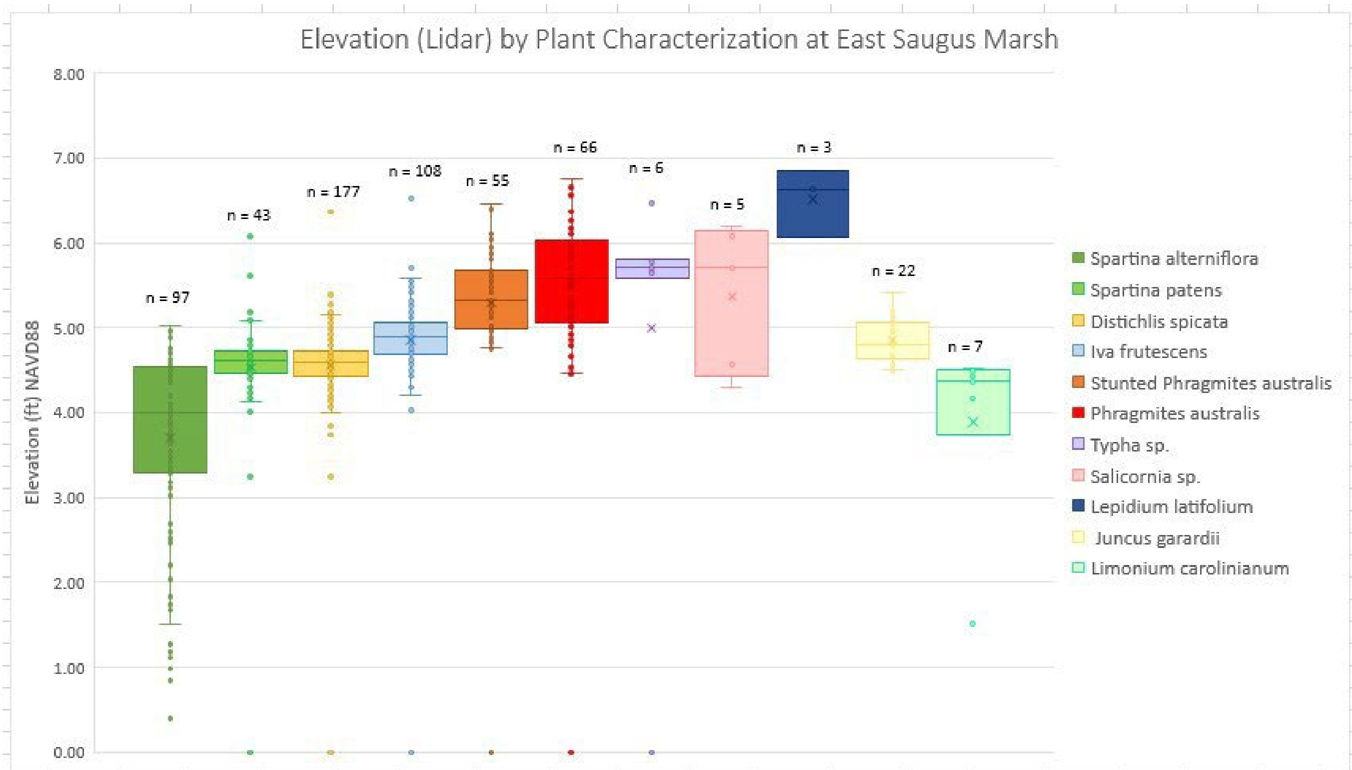

Figure D-1. *Box chart depicting elevation data ranges based on Lidar data for vegetation species observed in the East Saugus Marsh.*

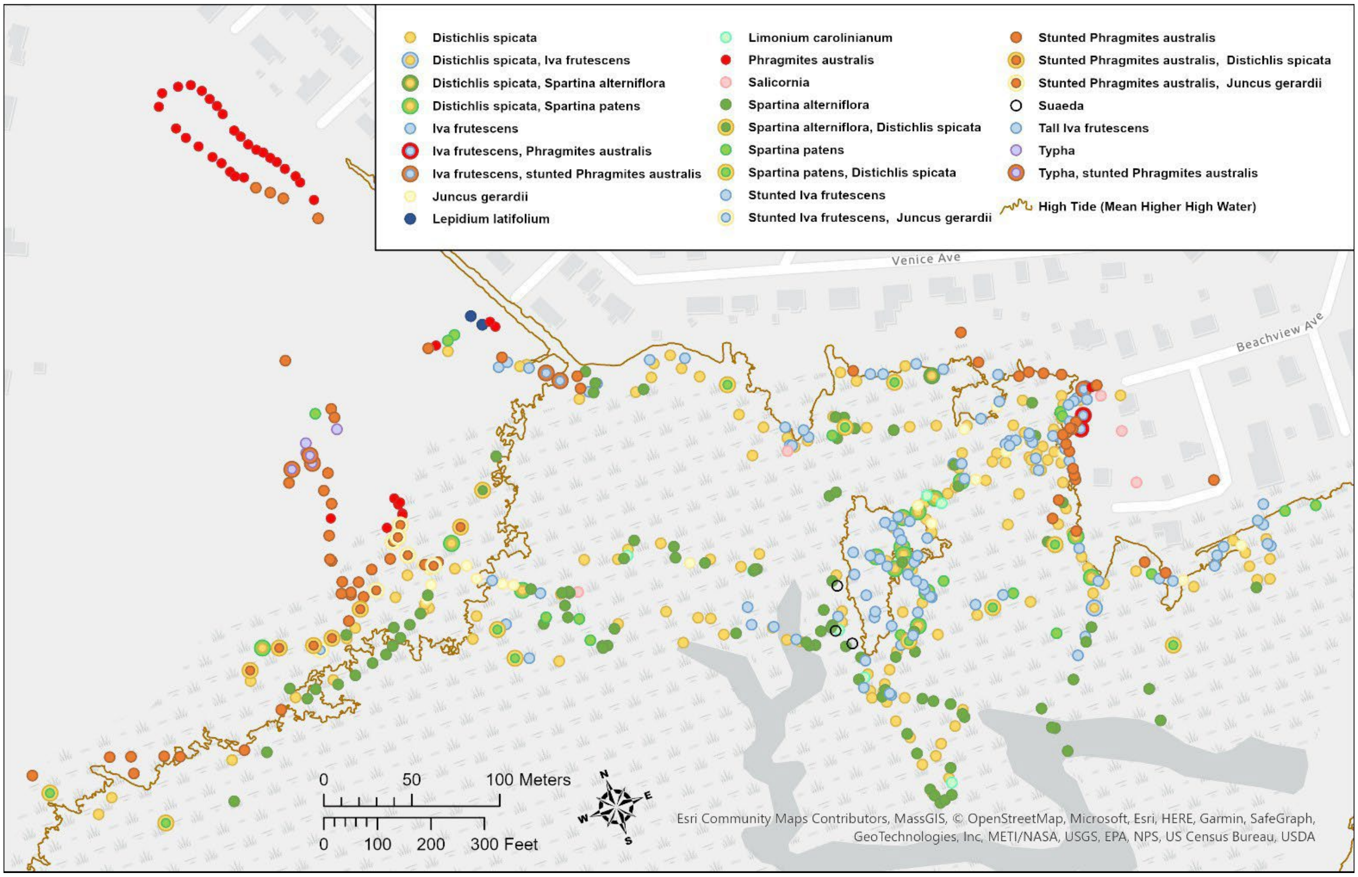

Figure D-2. Map of vegetation species identified in the East Saugus Marsh, 2021.

APPENDIX E - Additional Graphs of the Study Results

Figure E-1 shows the peak daily tide (MHHW) for the entire 142-day study period. A number of comparisons of the peak daily water levels (MHHW) were made to assess the tidal restrictions at each of the three crossings. The peak daily water levels of the Lower Pines versus Upstream Railroad were compared to determine if the railroad bridge is a tidal restriction. The data shows virtually identical peak water levels as the tide passes under the railroad bridge, except at the highest tides of the month which shows a slight tidal restriction (Figure E-2). The peak daily water levels of Upstream I-95 and East Saugus were also compared. This data shows nearly identical peak water levels for the two stations upstream of the abandoned I-95 embankment (Figure E-3).

Then the peak daily water levels of East Saugus and Upstream Railroad were compared. This data shows the highest water levels in East Saugus are slightly lower than Upstream Railroad, which reveals a slight tidal restriction associated with the Route 107 bridges (Figure E-4)**.** Comparing the East Saugus peak daily water level with Upstream Route 107 also shows slightly reduced peak daily tides on the upstream side of Route 107 at the highest tides (Figure E-5). Comparing the East Saugus peak daily water level (MHHW) with Upstream Route 107 shows nearly equal water levels, except during neap tides where tidal water levels are slightly higher on the upstream side of Route 107 (Figure E-6). This data suggests that both the railroad bridge and Route 107 bridges cause a tidal restriction at the highest tides.

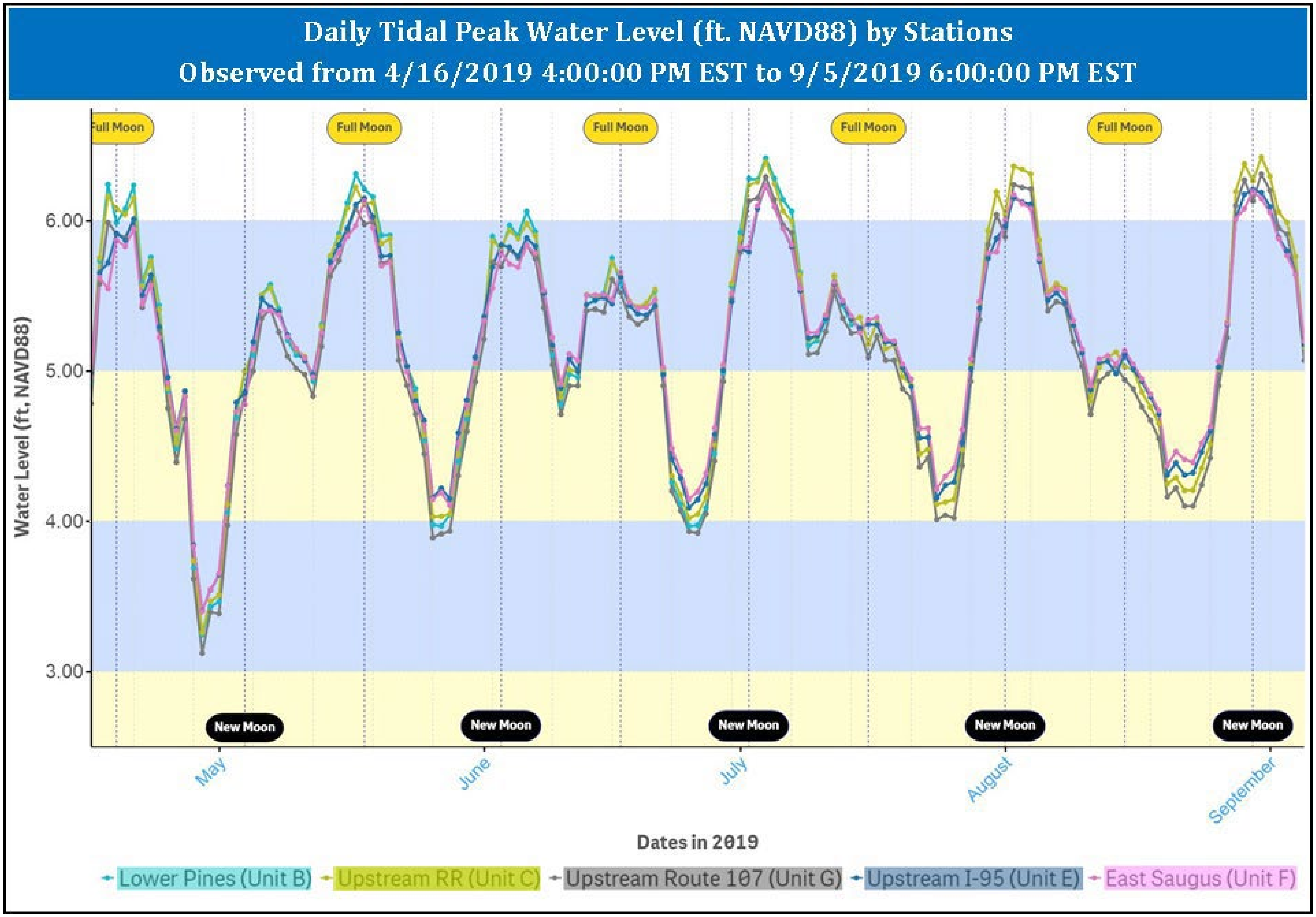

Figure E-1. Graph of peak daily water level (MHHW) from five stations along the Pines River in Saugus and Revere, Massachusetts for the 142-day period from April 16 -September 5, 2019.

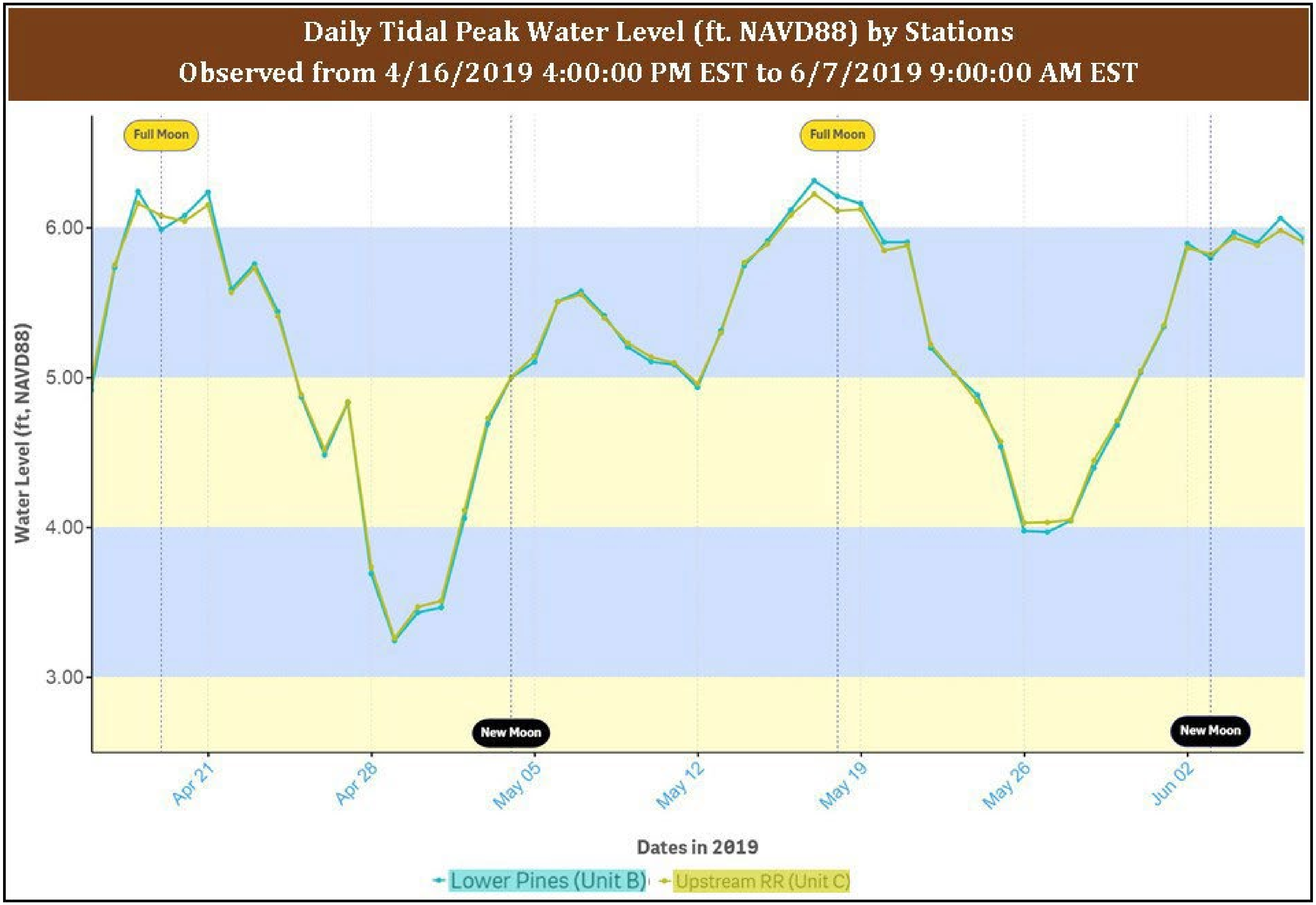

Figure E-2. Comparison of Lower Pines peak daily water level (MHHW) versus Upstream Railroad shows virtually identical peak water levels as the tide passes under the railroad bridge, except at the highest tides of the month which reveals a slight tidal restriction at the railroad bridge.

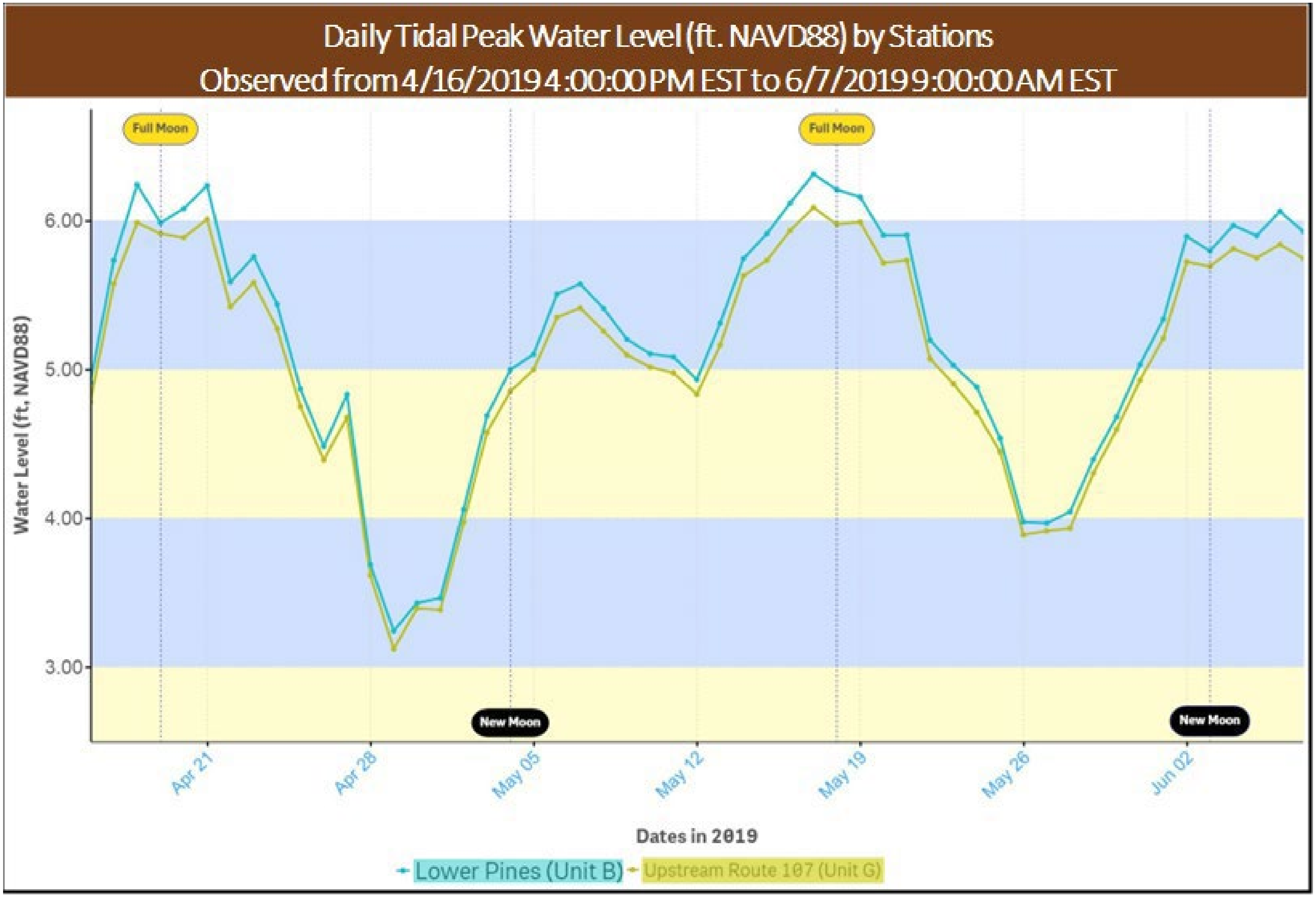

Figure E3. Comparison of Lower Pines peak daily water level with Upstream Route 107 shows consistently lower daily tides on the upstream side of Route 107 demonstrating a small tidal restriction at the highest tides.

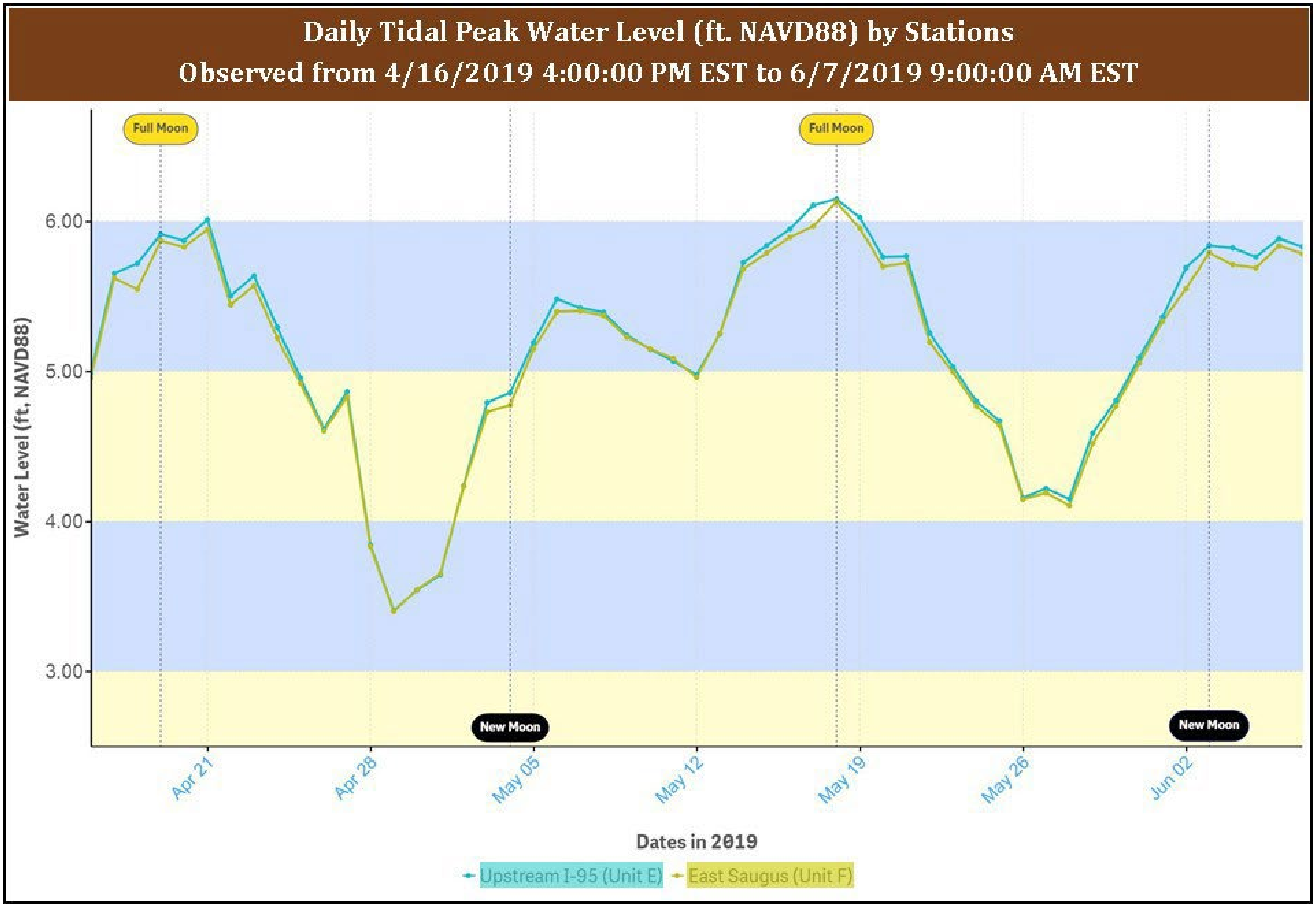

Figure E-4. Comparison of Upstream I-95 and East Saugus shows nearly identical peak water levels for the two stations upstream of the abandoned I-95 embankment.

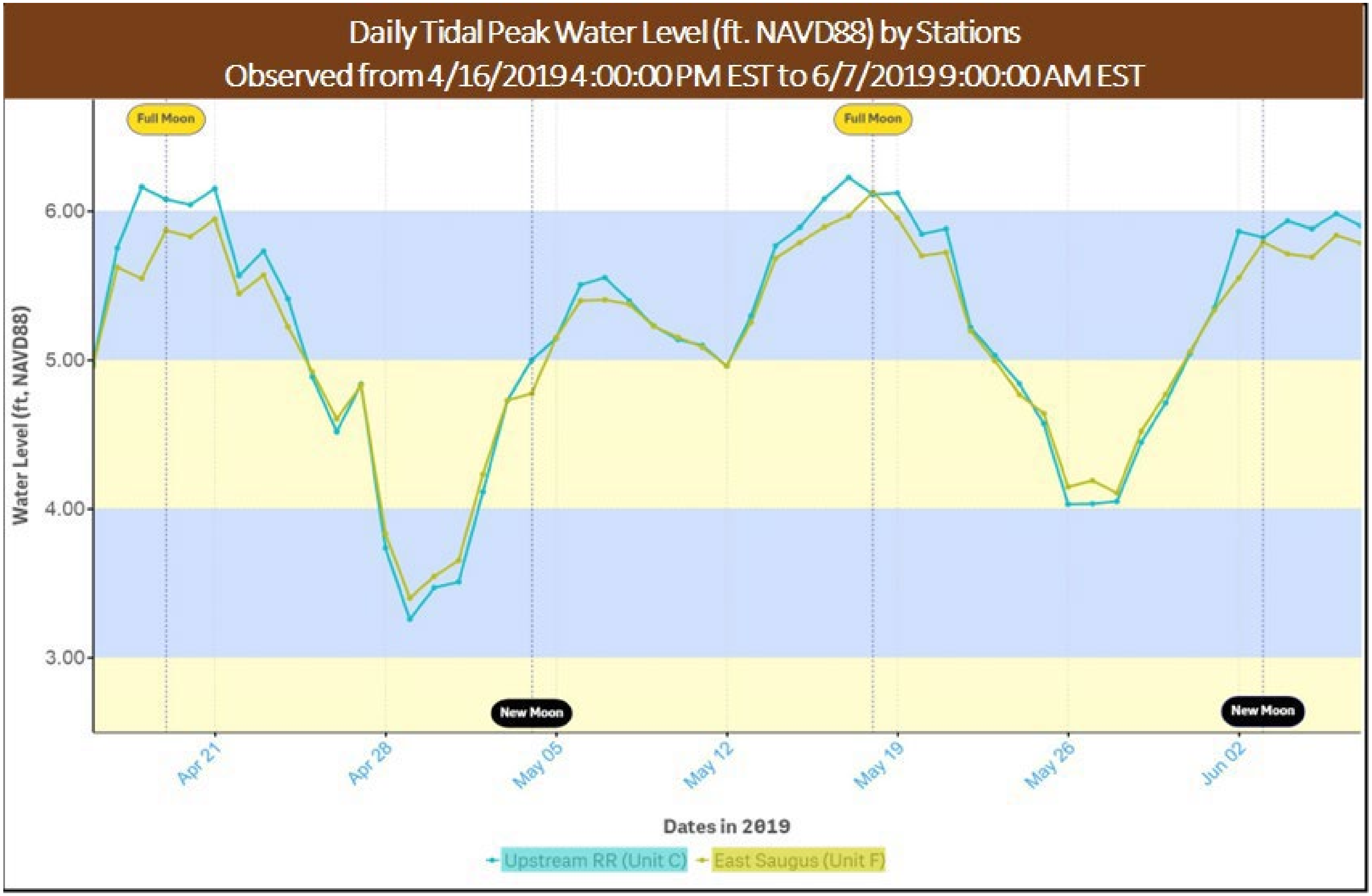

Figure E-5. Comparison of East Saugus with Upstream Railroad shows the highest water levels are slightly lower than Upstream Railroad, a result we attribute to the Route 107 Bridges Reconstruction Project.

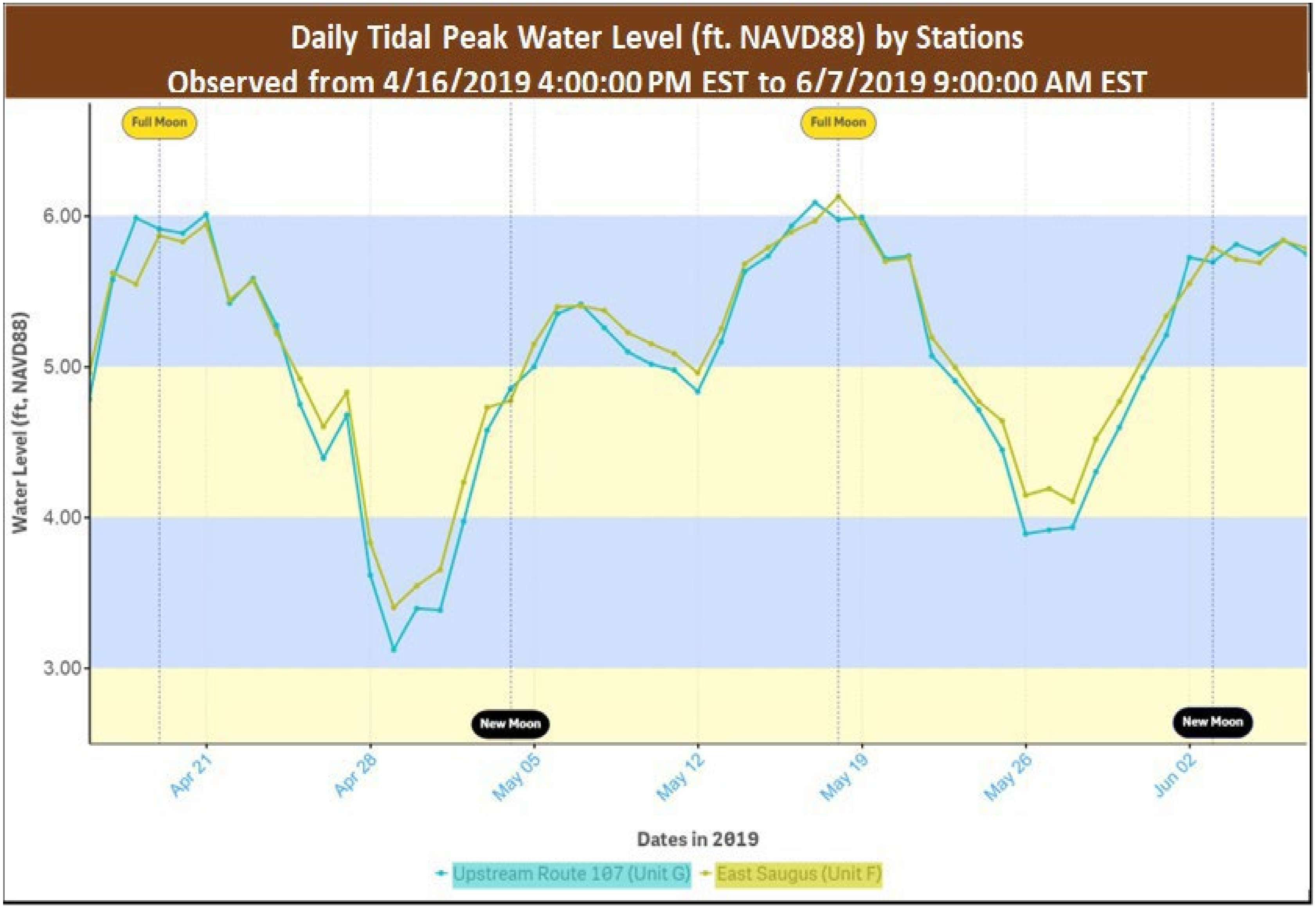

Figure E-6. Comparison of Upstream Route 107 with East Saugus shows the slightly reduced peak daily tides on the upstream side of Route 107.

APPENDIX F - Quality Assurance Project Plan

Available on request.