Crossing Assessment for the Sandy Neck Barrier Beach System Area of Critical Environmental Concern (ACEC)

Suggested Citation: Duffey, S.M. and A.L. Pappal. 2019. Crossing Assessment for the Sandy Neck Barrier Beach System Area of Critical Environmental Concern (ACEC). Massachusetts Office of Coastal Zone Management, Boston, MA.

This report was developed as part of a National Oceanic and Atmospheric Administration (NOAA) Coastal Management Fellowship project. It is a publication of CZM pursuant to the National Oceanic and Atmospheric Administration Award No. NA18NOS4190023. This publication is funded (in part) by a grant/cooperative agreement from NOAA. The views expressed herein are those of the author(s) and do not necessarily reflect the views of NOAA or any of its sub-agencies. This information is available in alternate formats upon request. All photos are by CZM unless otherwise noted.

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Background

This report is one component of a vulnerability assessment conducted for the Sandy Neck Barrier Beach System Area of Critical Environmental Concern (Sandy Neck ACEC), in fulfillment of a National Oceanic and Atmospheric Administration (NOAA) Coastal Management Fellowship project hosted by the Massachusetts Office of Coastal Zone Management (CZM). The vulnerability assessment included a review of potential climate change impacts to the coastal habitats within the Sandy Neck ACEC, in addition to other anthropogenic threats and stressors on coastal habitat health. A technical advisory committee (TAC) with members from multiple state agencies, including CZM, the Department of Conservation and Recreation (DCR), and the Department of Fish and Game's Division of Ecological Restoration (DER) informed the development of the assessment. Through the vulnerability assessment process, crossings that restrict flow of tidal or freshwater to the Sandy Neck ACEC were identified as a significant threat to coastal habitat resilience, both in the present and with future climate change impacts.

Introduction

Transportation infrastructure (roads, railroads, trails, etc.) is critical for facilitating the movement of people, goods, and services. In many communities, transportation infrastructure crosses over hydrographic features such as rivers, creeks, and streams. At these crossings, structures like bridges and culverts allow water to move under the roadway or railway. Crossings over waters influenced by regular or periodic tidal flow are referred to as tidal crossings.

Historically, crossing designs focused on efficiency, structural integrity, and cost effectiveness and not necessarily on the ecology of the surrounding area. As a result, many crossings restrict water flows necessary for ecosystem functioning (Levine 2013; Massachusetts Division of Ecological Restoration 2012). Adequate water flow through crossing structures is crucial for fish and wildlife passage, habitat connectivity and function, natural sedimentation processes, nutrient and hydrological dynamics, and habitat diversity (Findlay and Houlahan 1997; Jackson 2003). Regular tidal flow from estuaries into salt marshes is necessary to maintain the growth and seed supply of plants that reside within the marsh and also to bring sediments to build the marsh both horizontally and vertically. When tidal flows are restricted by a crossing structure, the upstream portion of the marsh can become less saline, disturbing the natural ecology and facilitating the encroachment of the invasive common reed (*Phragmites australis*), which thrives in fresher marshes (Saltonstall et al. 2005). In addition, these upstream marshes have less opportunity to receive sediments from tidal flow and can be at a much lower elevation than an unrestricted marsh (Bowron et al. 2009; Burdick et al. 1997; Haltiner et al. 1997). The elevation of the salt marsh is critically important for resiliency and persistence through time, as rising sea levels will begin to flood lower elevation areas more regularly—essentially drowning the marsh if it cannot keep pace. Tidal crossings that restrict flow can also interfere with effective drainage of upstream areas, contributing to excessive ponding of water and the degradation of the marsh through time.

In Massachusetts, there is an ongoing effort to remediate the impacts crossings have on surrounding ecosystems by upgrading and replacing structures and restoring adequate water flow. Prior to any restoration effort, information related to the crossing and the surrounding ecosystem must be collected to determine the degree of restriction and appropriate course of action. This information is critical for identifying crossings that restrict water flow, assessing the severity of that restriction, and prioritizing sites in need of restoration given limited resources available.

This report documents the results of an assessment of crossings within the Sandy Neck ACEC and watershed, as part of a wider ecological vulnerability assessment. The goals of the assessment were to: 1) collect data to characterize water flow restriction at a select number of crossing sites; 2) aid in the identification and prioritization of restoration opportunities; and 3) encourage and facilitate restoration at the Sandy Neck ACEC. The report details valuable information on the degree of water flow restriction and observed ecological impacts at crossing sites in the towns of Sandwich, Barnstable, and Yarmouth on Cape Cod, Massachusetts. Coastal planners, managers, municipalities, restoration practitioners, and others can use the information provided to pursue restoration opportunities at identified sites.

Methodology

Crossings located both in the Scorton Creek and Barnstable Harbor watersheds within the greater Sandy Neck ACEC watershed were considered for assessment. For the purposes of this report, tidal crossings refer to sites that have been identified as restrictive of tidal water flow based on measurements and observations both on the ground and through remote sensing. Non-tidal crossings refer to sites that were not found to be tidally influenced, based on professional judgment and field and remote-sensing measurements. While not the sole focus, non-tidal crossings were included in the report for three reasons: 1) the crossing is located in either the Scorton Creek or Barnstable Harbor watershed and was accessible for field assessment; 2) the site supports either a current or historical anadromous fish run; and/or 3) the site may become tidal with future sea level rise based on model predictions (CZM in prep).

A total of 18 crossings were assessed: seven crossings are located in the town of Sandwich, seven are located in the town of Barnstable, and four are located in the town of Yarmouth (Figure 1). Sites were chosen based on location within the Scorton Creek or Barnstable Harbor watersheds, road and land ownership, accessibility, and other site attributes. Input from local officials from the towns of Sandwich, Barnstable, and Yarmouth was also incorporated into the selection of crossing sites. For more information on the site selection process, see Appendix A.

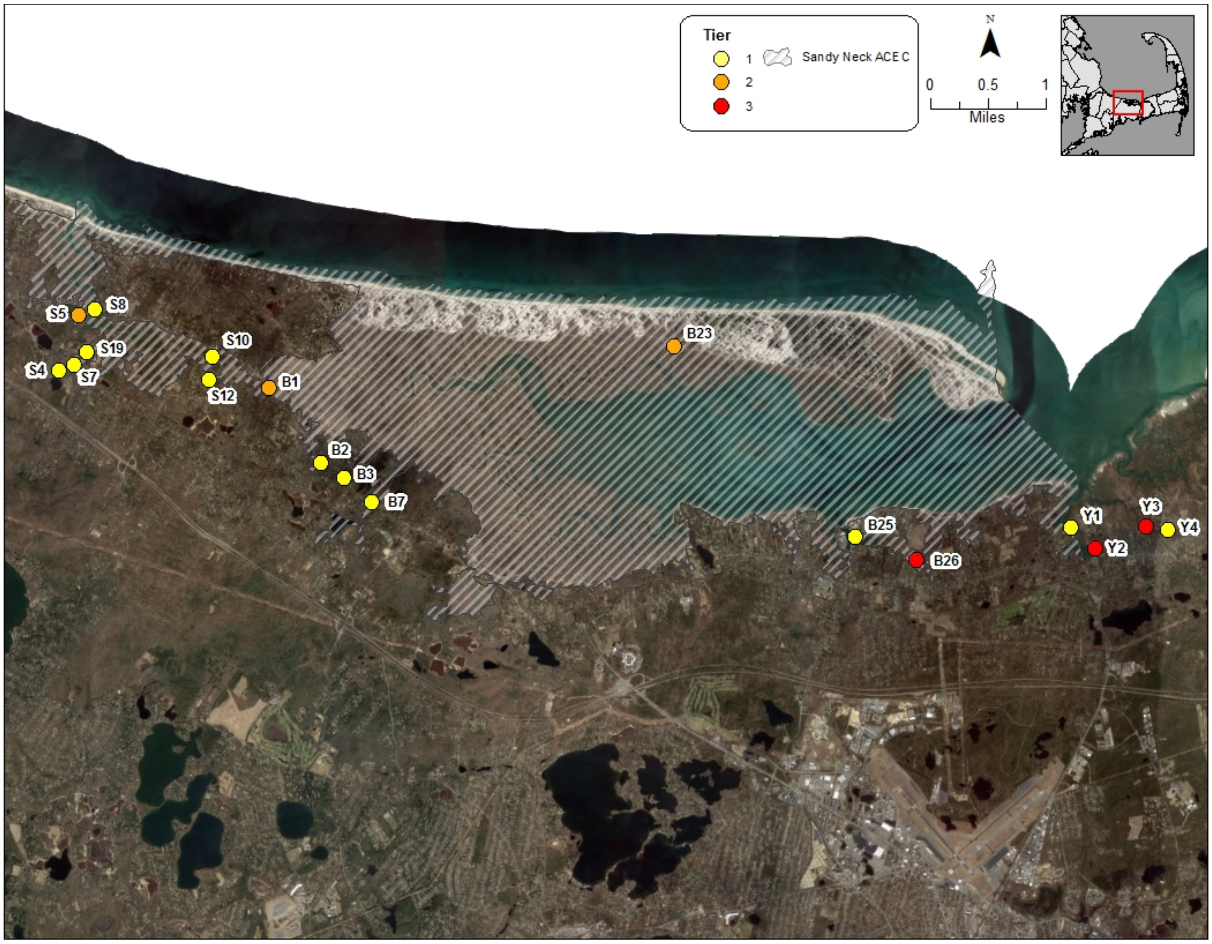

Figure 1: Crossings within the Sandy Neck ACEC watershed included in the assessment. Crossings were given an ID consisting of a letter and number, using the first letter of the town in which it is located, and then numbering consecutively from west to east (unless a new crossing was identified that was not in any of the reviewed sources, like S19).

Crossings were first given an ID consisting of a letter and number, using the first letter of the town in which it is located and then numbered consecutively moving from west to east (unless a new crossing was identified that was not in any of the reviewed sources, like site S19). For an explanation of why the sites are not presented in sequential numerical order, see Appendix A. A tiered approach was then used to assess water flow restriction and associated ecological impacts at each of the 18 crossings. Crossings were prioritized initially by the Tier 1 assessment results prior to proceeding further in the evaluation process. This approach provided the opportunity to collect additional information for the crossings that were selected for Tier 2 and subsequently Tier 3 assessments. All 18 sites were investigated in Tier 1, which led to the prioritization of six sites for Tier 2, culminating in a total of three sites selected for Tier 3. The methods used in each step of the tiered evaluation are summarized briefly below.

Tier 1

The goals of the Tier 1 assessment were to: determine the feasibility of the additional data collection needed for Tier 2 field assessments for each site, collect observations to suggest whether the site was tidally influenced, and establish a baseline of the degree of water flow restriction and associated ecological impacts using visual indicators. Tier 1 consisted of both a field component and GIS desktop analysis and was informed by the Cape Cod Atlas of Tidally Restricted Salt Marshes (Justus et al. 2001), the Tidal Stream Crossing Field Data Form Instruction Guide from the North Atlantic Aquatic Connectivity Collaborative (NAACC) (Jackson 2017), and the New Hampshire Tidal Restriction Protocol (Steckler et al. 2017).

Observations on vegetation community, salinity, and other physical habitat attributes were obtained in the field as close to low tide as possible at all 18 crossings. The condition of the crossing structure itself was recorded using the following options: New; OK; Poor; Failing; Unknown. The presence of visible utilities either above or through the crossing or marked on the roadway was noted. Any obstructions that would limit future data collection (width/depth of creek, height, barriers) were also noted.

Potential flooding impacts to low-lying infrastructure upstream of each site (if flow were to be restored by replacing the existing culvert) were determined by comparing sea level rise results with assessor's parcels in GIS. In addition, CZM Sea Level Affecting Marshes Model (SLAMM) products were used to determine marsh migration potential (areas adjacent to salt marshes where topography, elevation, and slope indicate suitable conditions for conversion) and predict marsh microhabitat community change with sea level rise (Appendix B) (CZM in prep).

A scoring system was used to rank the crossings assessed in Tier 1 based on the visual indicators addressed in the field assessment and the results from the GIS analysis. The priority rankings, along with considerations of physical access for additional field data collection, were used to select six crossings for the Tier 2 assessment. For more information on the Tier 1 assessment methods, scoring system, and field datasheet see Appendix B.

Tier 2

The goal of Tier 2 assessments was to further determine the degree and severity of flow restriction at each of the six priority crossings established in Tier 1. Data for this effort were collected both in the field and also using remote sensing (satellite imagery and GIS). Methods were primarily adapted from Jackson (2017), with a few minor additions from Steckler et al. (2017). All field measurements were taken as close to low tide as possible with average high tide elevation determined based on indicators such as water marks and wrack lines.

Height, width, and length measurements of each crossing structure were collected on both the upstream and downstream sides in the field. The alignment of the upstream opening of the structure with the creek or stream and degree of perch—the distance between the bottom of the opening of the crossing structure (i.e., the bottom of a culvert) and the water surface at both low and high tide—were measured. Substrate within the culvert itself was observed to visually ascertain the similarity to surrounding creek bed substrates. Creek width was measured on the ground and the width of larger features (i.e. scour pools) were calculated using satellite imagery in ArcGIS (Jackson

2017). Data were analyzed using the NAACC Aquatic Passability Scoring System for Tidal Stream Crossings (Jackson 2018). Using this scoring system, a value between 0-100 was calculated for all six crossings reflecting the severity of water flow restriction at each site. These scores were used to rank the crossings from most restrictive to least restrictive, and then were presented to a technical team within the Massachusetts Department of Fish and Game's Division of Ecological Restoration (DER). Input from DER staff and the crossing restriction scores were used to prioritize the top three crossings in terms of flow restriction and restoration potential, for which additional data were collected through the Tier 3 assessment. See Appendix C for the Tier 2 assessment field datasheet.

Tier 3

The Tier 3 assessment focused on further refinement of flow restriction identified in the previous Tier 1 and Tier 2 efforts through the collection of tide levels using a short-term deployment of water level loggers. Water levels on both the upstream and downstream sides of the crossing were collected at each of the three prioritized sites using Onset HOBO data loggers. The loggers were tested prior to deployment and installed in the upstream and downstream portions of the creek based on methods described in Kennedy et al. (2018), which were adapted from Curdts (2017). An additional data logger was housed in an upland site to measure barometric pressure, which is used in the water level calculations. Using a Trimble Real Time Kinematic (RTK) unit, the elevations of the PVC housings for the water level loggers were recorded and surveyed to NAVD88. The tidal range for the upstream and downstream portions of each site were calculated from the elevation measurements and water level data collected over the 13 day deployment period. The elevations of the top of the culvert and the marsh surface were recorded for both the upstream and downstream sides and surveyed to NAVD88 to compare to the tidal data. See Appendix D for the Tier 3 assessment field datasheet.

Results

The results for each crossing are summarized in the following pages. The crossings located on Mill Creek in the town of Sandwich (S4, S7, and S19) are presented first and organized from upstream to downstream, while the remaining crossings are organized based on their location from west to east. The information presented for each crossing depends on whether the site was assessed only in Tier 1, or received additional assessment in Tier 2 and Tier 3. A description of the assessment results is provided for each site, along with a map displaying upstream wetland types (salt marsh; shallow marsh, meadow, or fen; and shrub swamp) based on the Massachusetts Department of Environmental Protection (MassDEP) Wetlands layer. Assessed crossings that are either upstream or downstream of the featured crossing are identified with their corresponding page numbers for cross reference purposes. The upstream affected areas (outlined in blue on the following maps) were delineated using the United States Geological Survey (USGS) Streamstats tool (USGS 2018). Whether the site was originally assessed in the Cape Cod Atlas of Tidally Restricted Salt Marshes (Justus et al. 2001) was also noted.

Sandwich Crossings

Old County Road Crossing at Nye Pond

Site ID: S4
Town: Sandwich
Tidal: No
Assessment Level: Tier 1
This site was not assessed in the Cape Cod Atlas of Tidally Restricted Salt Marshes.

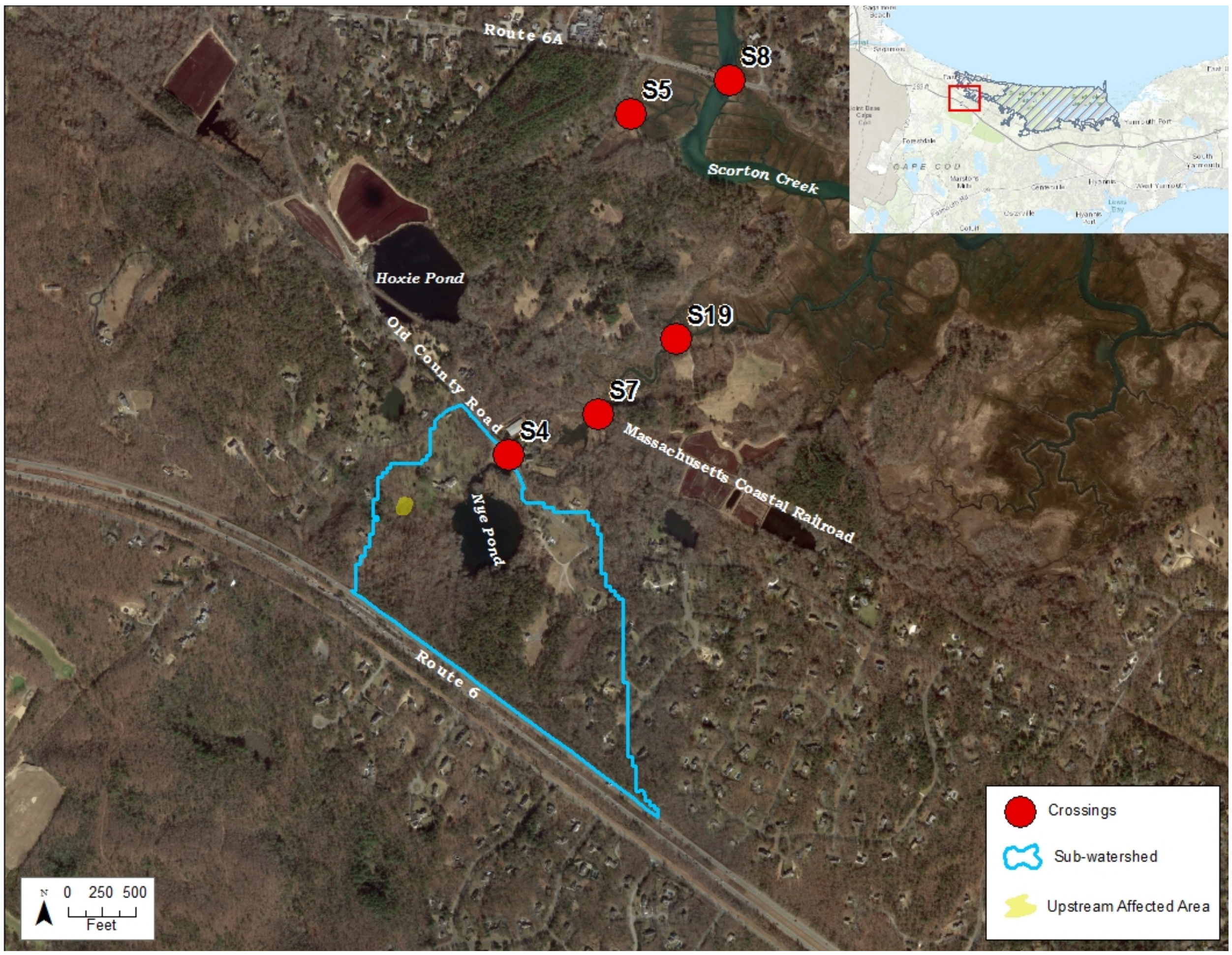

Figure 2: Site S4 is located at 41.7288°N 70.4318°W in Sandwich. Upstream Affected Area (as shown in the pea-green shaded area): Salt Marsh, none; Shallow Marsh, Meadow or Fen, none; Shrub Swamp, 0.32 acres (based on the MassDEP Wetlands layer). Crossings S7 (pg. 12), S19 (pg. 14), S5 (pg.16) and S8 (pg. 19) are located downstream.

Tier 1 Analysis

Located on Old County Road just downstream of Nye Pond, this crossing consists of multiple small dam/spillway structures on the upstream side, with an open-bottom stone culvert on the downstream side. Water entering the dam/spillway structures flows through a corrugated metal pipe under the road and toward the downstream. The downstream is part of the Mill Creek tributary to

Scorton Creek. The crossing appears to be in OK condition. Visible utilities include overhead electrical wires and an underground natural gas line. Crossings S7 (pg. 12), S19 (pg. 14), S5 (pg. 16), and S8 (pg. 19) are located downstream. The downstream crossings could be contributing to the restriction at this site by impairing flow and drainage, and therefore should be considered with any restoration efforts at S4. The downstream area is on the property of the Nye Family of America Homestead and Museum, and the upstream area is divided among multiple private landowners. The vegetation on both sides is very different, with primarily lawn present on the downstream side and aquatic vegetation consistent with a freshwater pond on the upstream side. This system was once an active alewife run, and the Town of Sandwich has expressed interest in restoring it to allow anadromous fish passage. None of the visual indicators of a tidal restriction are evident at this site, as data collected at the time of this report suggest that this is a freshwater crossing. Since this site is a known former fish run, it may be appropriate to investigate further the feasibility of restoration for that use.

Figure 3: Concrete dam/spillway structures controlling water levels on the upstream side of site S4.

Figure 4: The downstream area of site S4 which falls on the Nye Family of America Homestead and Museum property.

Massachusetts Coastal Railroad Crossing of Mill Creek

Site ID: S7
Town: Sandwich
Tidal: Yes
Assessment Level: Tier 1
This site was not assessed in the Cape Cod Atlas of Tidally Restricted Salt Marshes.

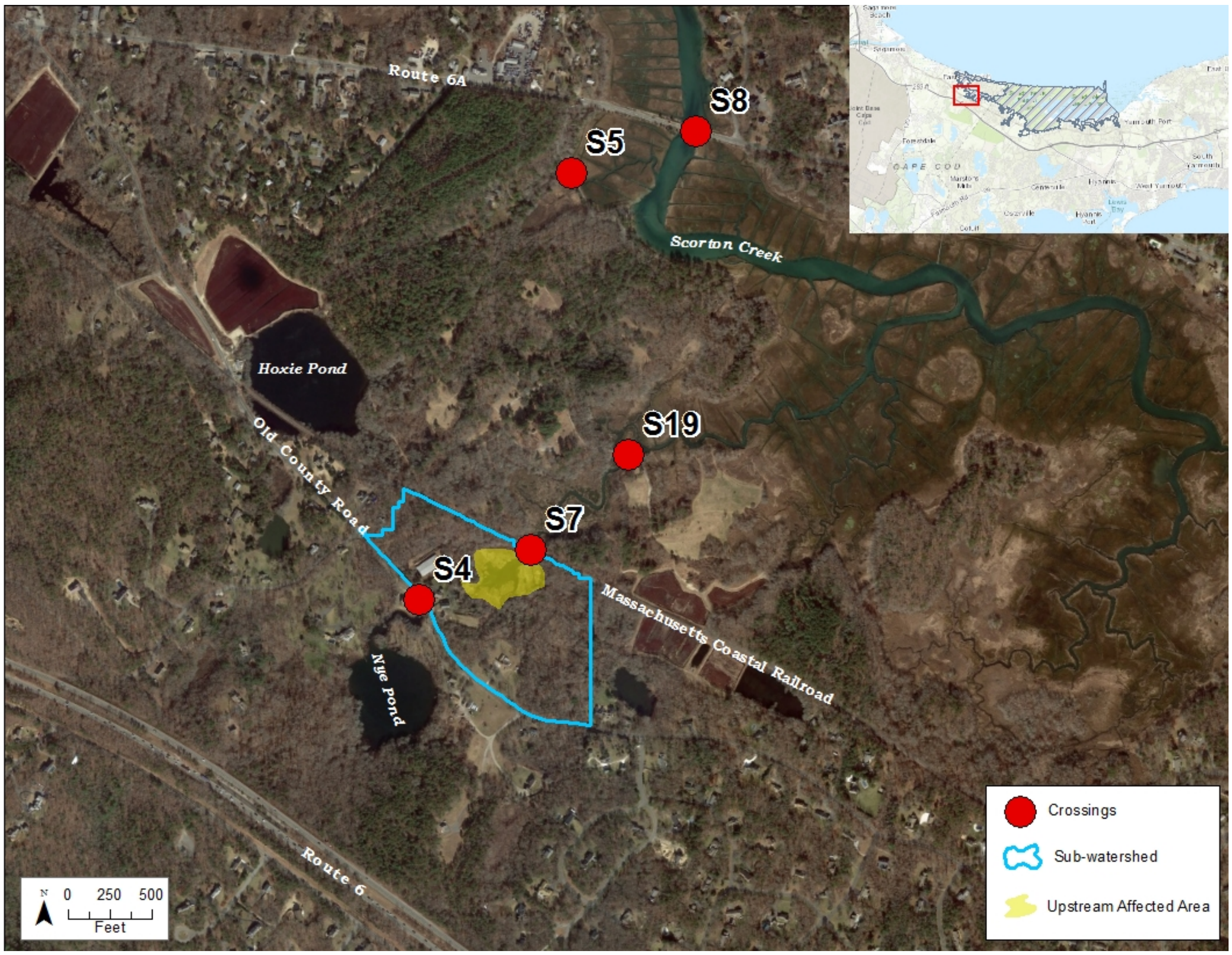

Figure 5: Site S7 is located at 41.7296°N 70.4294°W in Sandwich. Upstream Affected Area (as shown in the pea-green shaded area): Salt Marsh, none; Shallow Marsh, Meadow, or Fen, 2.68 acres; Shrub Swamp, none (based on the MassDEP Wetlands layer). Crossing S4 (pg. 10) is located upstream and crossings S19 (pg. 14), S5 (pg. 16), and S8 (pg. 19) are located downstream.

Tier 1 Analysis

Mill Creek flows beneath the Massachusetts Coastal Railroad through a concrete bottomless culvert at this site. The crossing appears to be in poor condition. No visible utilities are present at the site. Crossing S4 (pg. 10) is located upstream and crossings S19 (pg. 14), S5 (pg. 16), and S8 (pg. 19) are located downstream. The downstream crossings could be contributing to the restriction at this site by impairing flow and drainage, and therefore should be considered with any restoration efforts at

S7. Both the upstream and downstream areas are currently owned by the Massachusetts Department of Fish and Game (DFG) and leased to the Thornton Burgess Society. The vegetation upstream and downstream is moderately different, with freshwater wetland plants on the upstream side and more brackish wetland plants on the downstream side. Visual indicators of a restriction include the formation of a scouring basin on both the upstream and downstream sides and evidence of submergence of the downstream structure at high tide. The invasive common reed (*Phragmites australis*) is present on both the upstream and downstream sides of the crossing. In the Tier 1 assessment, the presence of *P. australis* on both sides of the crossing is not considered an indicator of a tidal restriction (see Table B1 for the vegetation-based scoring matrix). Due to accessibility issues, this crossing was not assessed further for this report, but the Town of Sandwich has expressed interest in restoring Mill Creek for anadromous fish passage. Therefore, it is recommended that additional assessment is conducted to investigate the potential for flow restoration at this site.

Figure 6: The upstream box culvert structure at site S7.

Figure 7: The area immediately downstream of site S7. Notice the invasive common reed (*Phragmites australis*) in the foreground.

Game Farm Driveway Crossing of Mill Creek

Site ID: S19
Town: Sandwich
Tidal: Yes
Assessment Level: Tier 1
This site was not assessed in the Cape Cod Atlas of Tidally Restricted Salt Marshes.

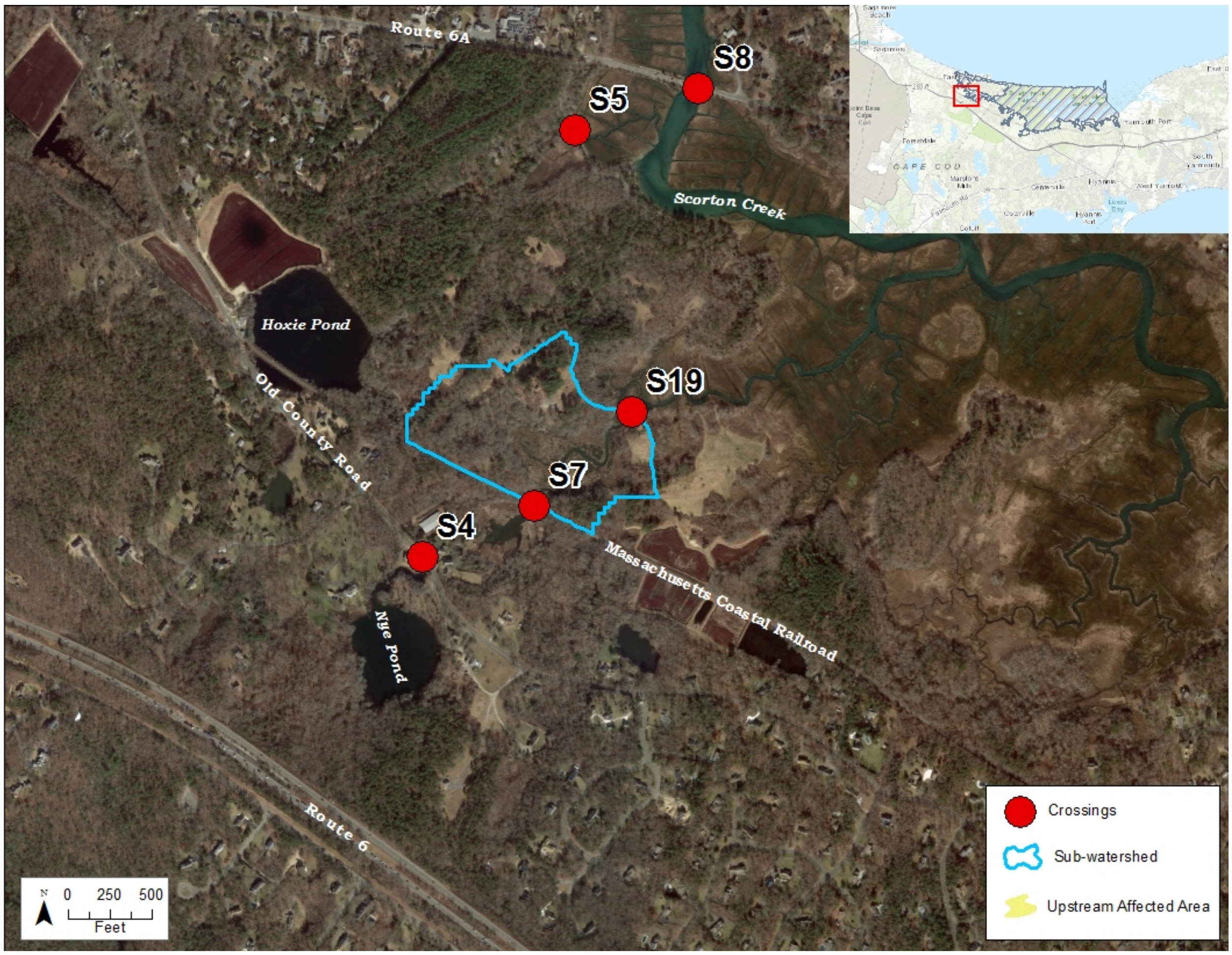

Figure 8: Site S19 is located at 41.7311°N 70.4272°W in Sandwich. The upstream affected area is considered Deep Marsh by the MassDEP Wetlands layer, resulting in 0 acres of upstream Salt Marsh, Shallow Marsh, Meadow, or Fen, or Shrub Swamp. Crossings S4 (pg. 10) and S7 (pg. 12) are located upstream and crossings S5 (pg. 16) and S8 (pg. 19) are located downstream.

Tier 1 Analysis

At this site, the Game Farm Driveway crosses Mill Creek by a bridge with side slopes and abutments. The portion of the creek flowing below the bridge is lined with stone and rip rap. The bridge was built in 2004 after the old concrete weir was removed and appears to be in new condition. No visible utilities are present at the site. Crossings S4 (pg. 10) and S7 (pg. 12) are located upstream of this crossing, while crossings S5 (pg. 16) and S8 (pg. 19) are downstream. Site S8 could be contributing to the restriction at this site by impairing flow and drainage, and therefore should be considered with any restoration efforts at S19. Both the downstream and upstream areas are owned by the Massachusetts Department of Fish and Game (DFG) and leased to the Thornton Burgess Society. The vegetation upstream and downstream is moderately different, with a brackish plant community upstream and *Spartina* spp. the dominant species downstream. Visual indicators of a restriction include scour pool formation both upstream and downstream of the crossing, as well as a higher proliferation of the invasive common reed (*Phragmites australis*) on the upstream side. Some bank erosion is evident but seems to be caused by stormwater runoff from the road and/or bridge. The Town of Sandwich has expressed interest in restoring the once active anadromous fish run in Mill Creek, and there appears to be no barrier to fish passage at this crossing.

Figure 9: The wetland area immediately upstream of site S19. Notice the invasive common reed (*Phragmites australis*) stands along the creek bank.

Figure 10: The salt marsh habitat immediately downstream of site S19.

Game Farm Driveway Crossing of Scorton Creek

Site ID: S5
Town: Sandwich
Tidal: Yes
Assessment Level: Tier 1 and Tier 2
This site was assessed in the Cape Cod Atlas of Tidally Restricted Salt Marshes (Site SA-11).

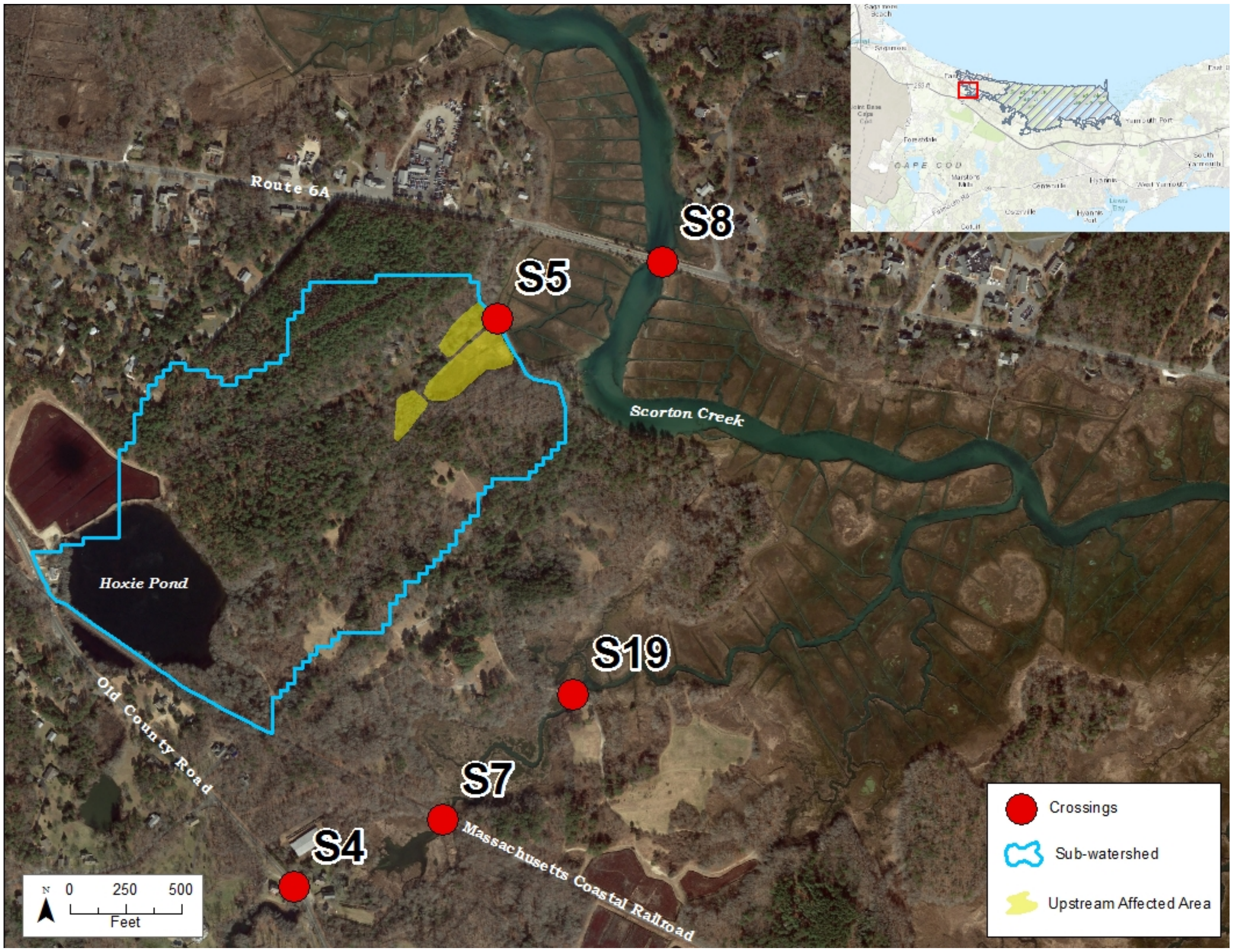

Figure 11: Site S5 is located at 41.7354°N 70.4279°W in Sandwich. Upstream Affected Area (as shown in the pea-green shaded area): Salt Marsh, 1.37 acres; Shallow Marsh, Meadow, or Fen, none; Shrub Swamp, 1.06 acres (based on the MassDEP Wetlands layer). Crossing S8 (pg. 19) is located downstream.

Tier 1 Analysis

Located on the Game Farm Driveway in East Sandwich, this restriction is on a small unpaved road that leads to a parking lot owned by the Massachusetts Department of Fish and Game (DFG). The structure at S5 was reconstructed in 2012. Prior to replacement, the crossing was reported to be in poor condition with a broken corrugated metal pipe and clogged with debris (Justus et al. 2001). At the time of the current assessment, a plastic corrugated pipe with a metal tide gate within a stone headwall on the downstream side severely restricts flow to the upstream side. The structure is in new condition. No visible utilities are present at the site. Crossing S8 (pg. 19) is located downstream and could be contributing to the restriction at this site by impairing flow and drainage, and therefore should be considered with any restoration efforts at S5. The property is currently owned by DFG and leased to the Thornton Burgess Society. The vegetation on the downstream and upstream sides is very different, with the downstream area consisting of *Spartina* spp., while the upstream area is dominated by the invasive common reed (*Phragmites australis*). It is unclear whether this channel or the area leading up to the tide gate serve as an anadromous fish run. A clear tidal restriction is present at this site; observations indicate the flap gate structure significantly restricts saltwater flow upstream of the crossing at all stages of the tide. Visual indicators of a restriction include the dominance of *P. australis* in the upstream affected area, ponded water and a scouring basin at the downstream tide gate, and slumping of the marsh surrounding the downstream structure.

Figure 12: The flap gate on the downstream side of site S5 presents a tidal restriction, shown here at low tide.

Figure 13: The area immediately upstream of site S5 consists of a dense stand of the invasive common reed (*Phragmites australis*).

Tier 2 Analysis

This site was selected for Tier 2 assessment based on Tier 1 results (indicating a restriction at the site) and its accessibility for the Tier 2 assessment measurements (Table 1).

Two different creeks converge at the crossing on the upstream side of the restriction—one that runs directly into the culvert and another that runs south at a 90° angle to the culvert. There is no substrate in the pipe, while the creek bottom is mud and sand. The slope of the crossing structure seems to be comparable to the natural creek, although water flow velocities are high from upstream to the downstream side of the crossing because of the perch of the downstream culvert at low tide. There is a significant scour pool on the downstream side of the crossing, and observations indicate this may be due to the height of the crossing structure, water velocity exiting the downstream side, and restricted water flow against the stone headwall. Debris in the upstream creek creates a minor barrier to flow before water reaches the culvert. Based on the presence of the flap gate, it is assumed that no aquatic organism passage is possible through the structure toward the upstream side.

Table 1: Measurements taken at site S5 during the Tier 2 assessment. Measurements were taken on both the downstream and upstream portions of the stream and structure. See Appendix C to view the Tier 2 assessment datasheet.

Site S5		
	Downstream	**Upstream**
Stream		
Channel width (m)	2.87	1.00
Pool width (m)	7.16	1.00
Tidal range (m)	1.00	0.00
Alignment	-	Aligned
Structure		
Width (m)	0.46	0.46
Height (m)	0.46	0.46
Substrate/Water width (m)	0.27	0.27
Water depth (m)	0.03	0.03
High tide water depth (m)	Above structure	-
Spring tide water depth (m)	Above structure	-
Low tide perch (m)	0.27	0.00
High tide perch (m)	0.00	0.00
Length (m)	9.14	
Road fill height (m)	1.89	

Figure 14: The upstream culvert at site S5 shown at high tide.

Figure 15: The downstream flap gate at site S5 shown at high tide.

Route 6A Crossing of Scorton Creek (Sandwich)

Site ID: S8
Town: Sandwich
Tidal: Yes
Assessment Level: Tier 1
This site was assessed in the Cape Cod Atlas of Tidally Restricted Salt Marshes (Site SA-10).

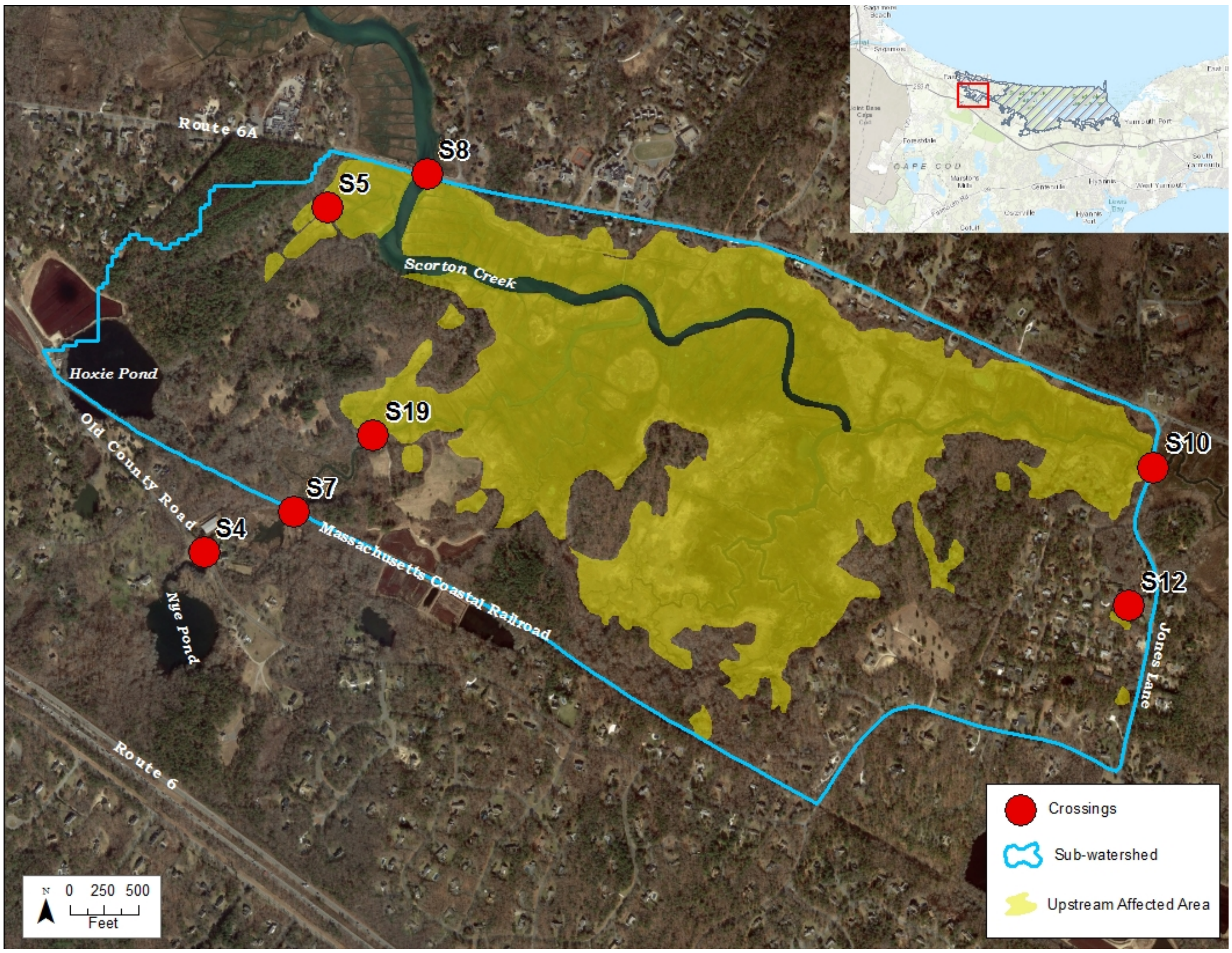

Figure 16: Site S8 is located at 41.7364°N 70.4257°W in Sandwich. Upstream Affected Area (as shown in the pea-green shaded area): Salt Marsh, 195.29 acres; Shallow Marsh, Meadow, or Fen, 21.37 acres; Shrub Swamp, 11.57 acres (based on the MassDEP Wetlands layer). Crossings S4 (pg. 10), S7 (pg. 12), S19 (pg. 14), S5 (pg. 16), and S10 (pg. 21) are located upstream.

Tier 1 Analysis

This crossing is located where Route 6A crosses Scorton Creek. It is a stone and concrete bridge with two cells separated by a center column and appears to be in OK condition. Visible utilities include overhead electrical wires and a water/sewer pipe in the ground. This bridge is the furthest downstream crossing of Scorton Creek, with crossings S4 (pg. 10), S7 (pg. 12), S19 (pg. 14), S5 (pg. 16), and S10 (pg. 21) all located upstream. Much of the immediate upstream marsh habitat is owned by the Massachusetts Department of Fish and Game (DFG), and the downstream area is privately owned. In 2001, the Cape Cod Atlas of Tidally Restricted Salt Marshes noted visual indicators of a restriction including scouring and erosion on both the upstream and downstream sides, as well as significant marsh slumping and vegetation die-back seaward of the crossing (Justus et al. 2001). In the current assessment, the vegetation between the upstream and downstream areas was observed to be very similar, with *Spartina* spp. the dominant species. Significant marsh slumping, bank erosion, and vegetation die-back on the creek banks was noted on both sides of the crossing along with large scouring basins. These indicators are likely a result of high velocity water flow through the crossing caused by both tides and storm events. The Town of Sandwich has expressed interest in restoring the once active anadromous fish run up Scorton Creek and through Mill Creek to Nye Pond, which passes through this crossing as well as S4, S7, and S19. Based on observations from the current assessment, this crossing does not appear to inhibit aquatic organism passage.

Figure 17: The upstream side of site S8 shown at low tide.

Figure 18: View from site S8 of the salt marsh habitat upstream of the crossing. Notice the marsh slumping and erosion present on either side of the creek.

Jones Lane Crossing of Scorton Creek

Site ID: S10
Town: Sandwich
Tidal: Yes
Assessment Level: Tier 1
This site was assessed in the Cape Cod Atlas of Tidally Restricted Salt Marshes (SA-12).

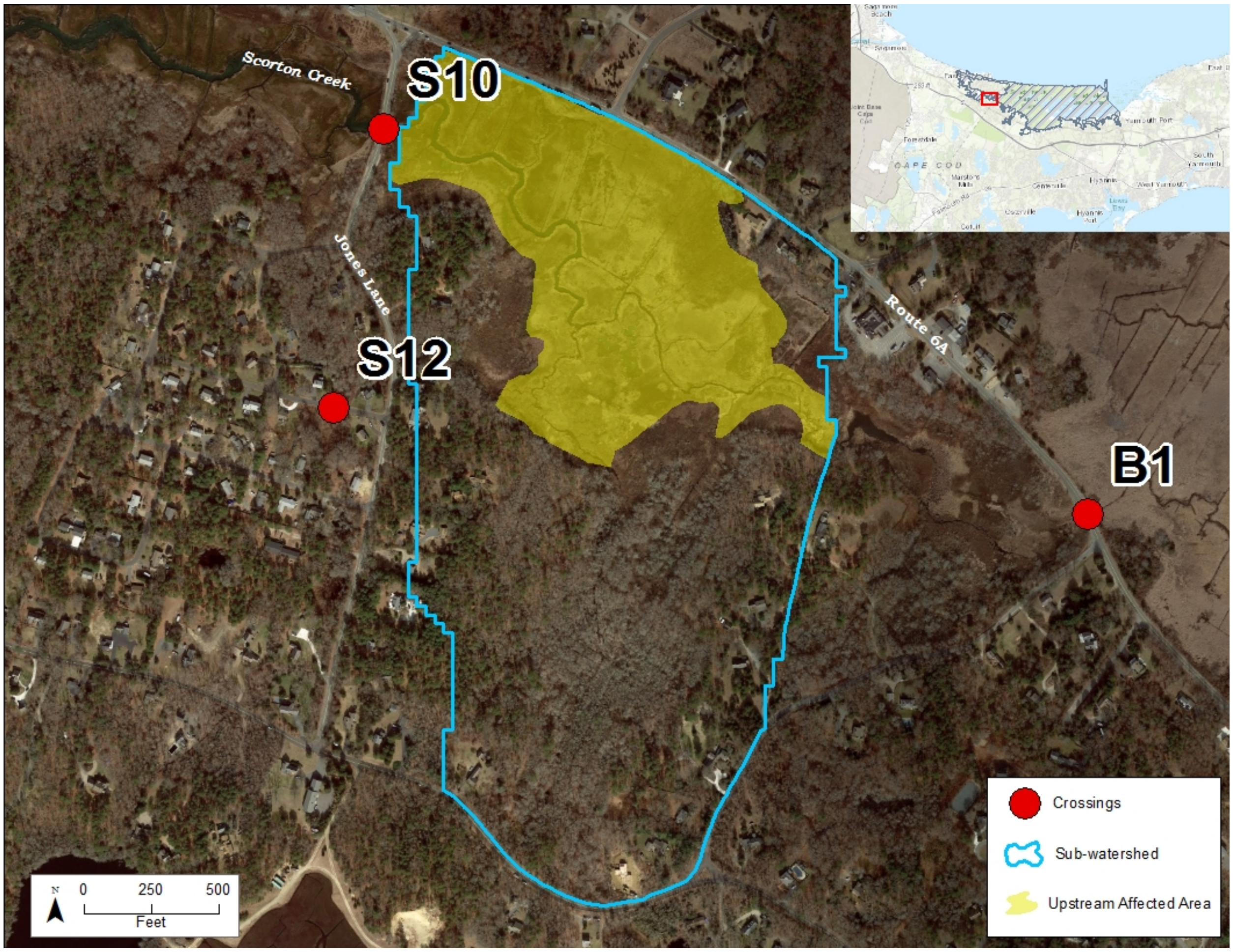

Figure 19: Site S10 is located at 41.7303°N 70.4061°W in Sandwich. Upstream Affected Area (as shown in the pea-green shaded area): Salt Marsh, 16.84 acres; Shallow Marsh, Meadow, or Fen, 9.41 acres; Shrub Swamp, 1.29 acres (based on the MassDEP Wetlands layer). Crossing S8 (pg. 19) is located downstream.

Tier 1 Analysis

A concrete box culvert facilitates the flow of Scorton Creek under Jones Lane. The culvert was replaced and widened in 1998 and appears to be in OK condition. Overhead electrical wires are visible at the site. Crossing S8 (pg. 19) is located downstream and could be contributing to the restriction at this site by impairing flow and drainage, and therefore should be considered with any restoration efforts at S10. The downstream area is owned by the Town of Sandwich, with the upstream area split between the Sandwich Conservation Trust and private ownership. Upstream of this crossing the waterway joins the portion of Scorton Creek that drains into Barnstable Harbor. Consequently, the upstream area of this crossing merges with the upstream area for B1 (pg. 25). In the Cape Cod Atlas of Tidally Restricted Salt Marshes, some visual indicators of a restriction were identified in 2001 including scouring, erosion, and marsh slumping on the downstream side of the crossing (Justus et al. 2001). In the current assessment, the vegetation between the upstream and downstream areas was observed to be very similar, with *Spartina* spp. the dominant species. Visual indicators of a restriction include marsh slumping and bank erosion occurring both upstream and downstream of the crossing. The invasive common reed (*Phragmites australis*) is present both upstream and downstream of the site, but far enough away that it is unlikely that its presence is related to this crossing. Scorton Creek has historically supported anadromous fish runs according to the Cape Cod Atlas of Tidally Restricted Salt Marshes (Justus et al. 2001), and this crossing does not appear to contain structures that would impede fish passage.

Figure 20: The salt marsh habitat immediately upstream of site S10. Stands of the invasive common reed (*Phragmites australis*) can be seen in the distance.

Figure 21: The downstream box culvert with wingwalls at site S10. Stone has been placed around both the upstream and downstream structures to help armor the crossing and minimize erosion.

Betty Avenue Stream Crossing

Site ID: S12
Town: Sandwich
Tidal: No
Assessment Level: Tier 1
This site was not assessed in the Cape Cod Atlas of Tidally Restricted Salt Marshes.

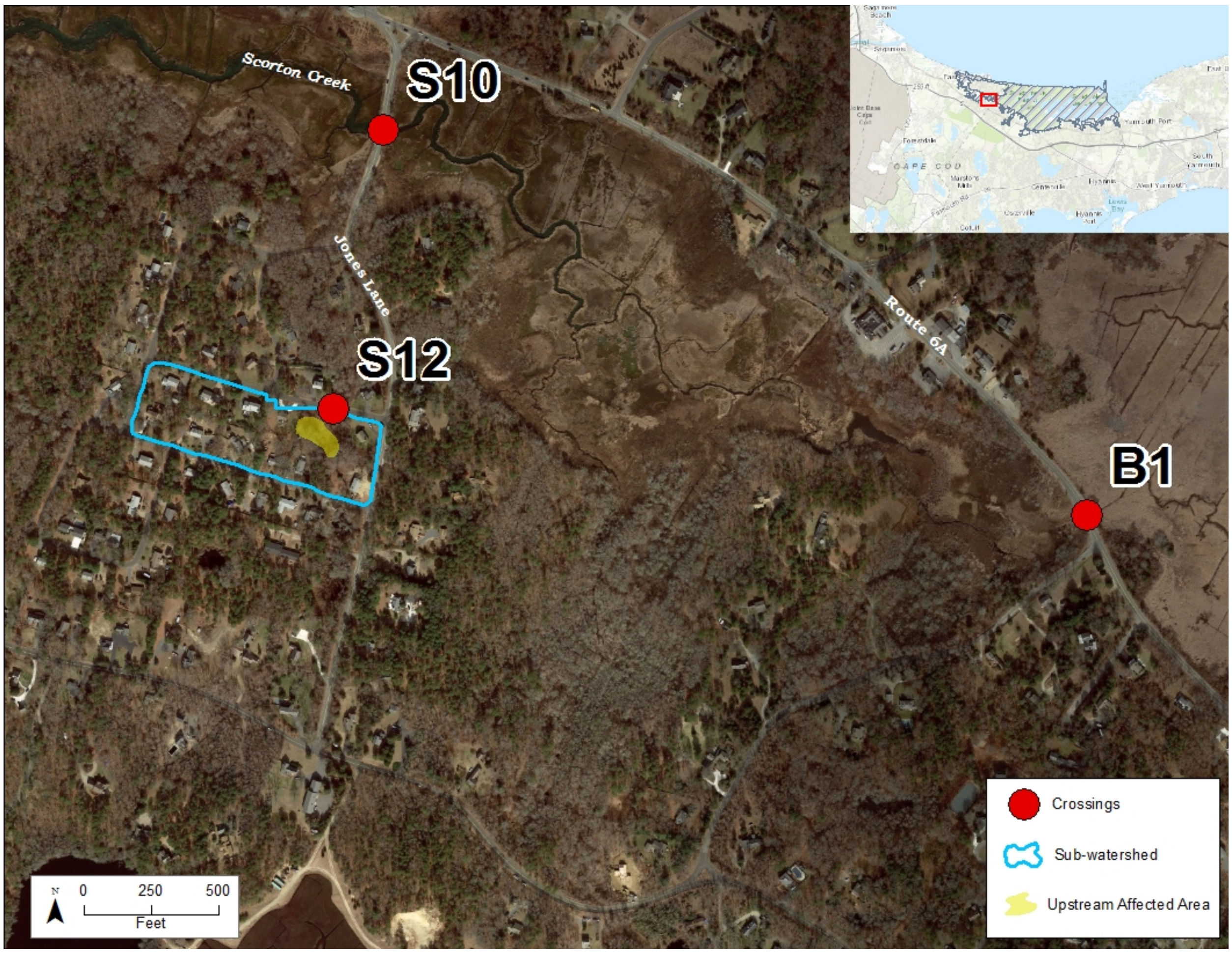

Figure 22: Site S12 is located at 41.7274°N 70.4068°W in Sandwich. Upstream Affected Area (as shown in the pea-green shaded area): Salt Marsh, none; Shallow Marsh, Meadow, or Fen, none; Shrub Swamp, 0.30 acres (based on the MassDEP Wetlands layer). There are no crossings located upstream or downstream.

Tier 1 Analysis

A small, corrugated metal pipe culvert facilitates the movement of this small stream under Betty Avenue, which connects with Scorton Creek downstream. The pipe appears to be in OK condition. A cable line and other unknown underground utilities (possibly natural gas lines) were observed at the site. There are no known crossings upstream or downstream. The parcel of land directly upstream of the crossing is owned by the Town of Sandwich, but the crossing itself is located in a residential area, and many of the surrounding parcels are privately owned including the parcel immediately downstream. The vegetation is similar on both sides of the crossing, composed primarily of woody species consistent with a freshwater wetland. Site features indicate that this is a freshwater stream crossing and not tidally influenced at the time of this report. The invasive common reed (*Phragmites australis*) is present on the upstream side.

Figure 23: The downstream corrugated metal pipe culvert at site S12.

Figure 24: The area immediately downstream of site S12, consisting of woody, freshwater wetland species.

Barnstable Crossings

Route 6A Crossing of Scorton Creek (Barnstable)

Site ID: B1
Town: Barnstable
Tidal: Yes
Assessment Level: Tier 1 and Tier 2
This site was assessed in the Cape Cod Atlas of Tidally Restricted Salt Marshes (Site SA-13/BA-1).

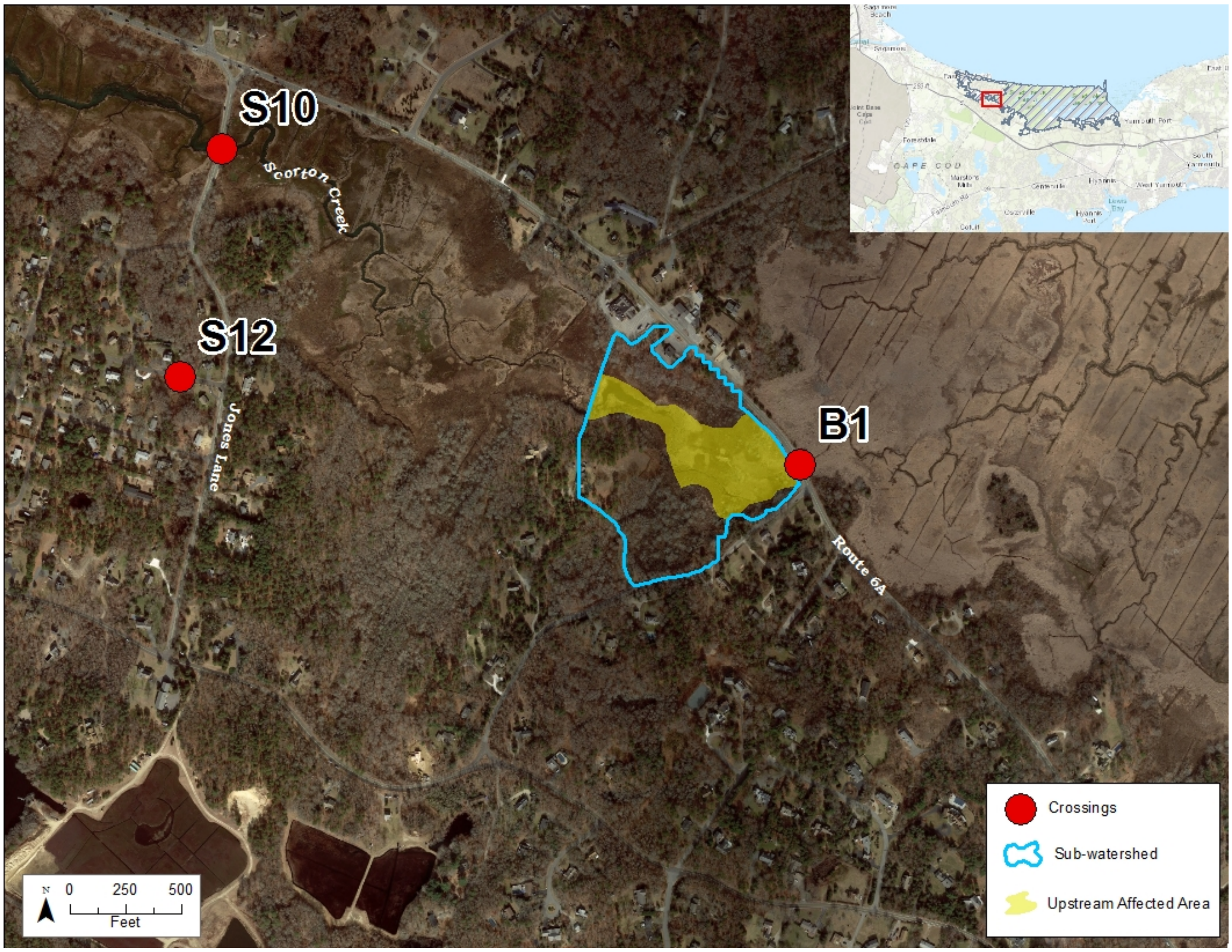

Figure 25: Site B1 is located at 41.7263ºN 70.3966ºW in Barnstable. Upstream Affected Area (as shown in the pea-green shaded area): Salt Marsh, 0.55 acres; Shallow Marsh, Meadow, or Fen, 4.28 acres; Shrub Swamp, 0.41 acres (based on the MassDEP Wetlands layer). There are no assessed crossings located upstream or downstream.

Tier 1 Analysis

At this location, Scorton Creek flows underneath Route 6A and into Barnstable Harbor. The crossing consists of a concrete pipe that appears to be in poor condition. Overhead electrical wires are visible at the site. This site falls on the boundary between the Town of Sandwich and the Town of Barnstable, with the two towns splitting ownership of the downstream area. The upstream area is split among multiple private landowners. Upstream of this crossing the waterway joins the portion of Scorton Creek that drains into Cape Cod Bay. Consequently, it is here that the upstream area of this crossing merges with the upstream area of S10 (pg. 21). In the Cape Cod Atlas of Tidally Restricted Salt Marshes, the pipe is identified as being in good condition and unclogged in 2001. Fringing invasive common reed (*Phragmites australis*) was also documented on the upstream side (Justus et al. 2001). In the current assessment, however, the structure was observed to be at least partially clogged, as evidenced by very little active water flow through the structure. The vegetation upstream is moderately different from downstream; both sides are indicative of a brackish to freshwater wetland, but *P. australis* is much more prevalent on the upstream side. Visual indicators of a restriction include ponded water, scouring basins, vegetation die-back on both sides, and bank erosion on the upstream side. The higher prevalence of *P. australis* on the upstream side may also be evidence of a restriction at the site, as it prefers less saline waters. Based on observations from the current assessment, the structure may need to be unclogged to allow better flow through the culvert.

At the time of the field assessment for Tier 1 (spring 2018), there was a high amount of wrack covering the culvert and surrounding marsh area (Figures 26, 27, 28, and 29). This may be the result of major storms in the winter of 2018, including a blizzard in January that resulted in the highest high tide ever recorded (15.16 feet) at the National Oceanic and Atmospheric Administration (NOAA) tide gauge station in Boston (NOAA, 2018). Several northeasters in March 2018 also significantly impacted this site and Massachusetts coast-wide. Local officials in the Town of Sandwich stated that the road was flooded and impassable during these storm events (D. DeConto, personal communication). These reoccurring storm impacts may warrant further assessment into restoration feasibility this site.

Figure 26: The downstream culvert is covered in wrack, indicative of how the structure was impacted by the blizzard in January 2018 and northeasters in March 2018 at site B1.

Figure 27: The invasive common reed (*Phragmites australis*) dominates the area immediately upstream of site B1, with stands present further upstream as well.

Tier 2 Analysis

This site was selected for Tier 2 assessment based on Tier 1 results (indicating a restriction at the site) and its accessibility for the Tier 2 assessment measurements (Table 2).

The upstream structure is not in alignment with the creek, which may be contributing to the pooling water on the upstream side. The structure contains natural material (viewed from the opening of both sides of the culvert) that is comparable to the stream. In the Tier 2 scoring system, substrate coverage through the crossing structure was used as a parameter to calculate the score for each crossing (Jackson 2018). Using best professional judgment, it was determined that the substrate covers 25-50% of the length of the pipe, although this was difficult to determine because of the turbidity of the water within the pipe. The slope of the crossing structure is comparable to that of the natural creek. There is evidence of scour and erosion both upstream and downstream of the culvert, degrading the condition of the culvert itself and the surrounding stone supports. Water infiltrating around and under the culvert was also observed on both sides. Based on the information presented above, it is likely that the structure restricts tidal water flow, which makes the culvert at the site vulnerable to degradation and reduces connectivity for fish and wildlife.

Table 2: Measurements taken at site B1 during Tier 2 assessment. Measurements were taken on both the downstream and upstream portions of the stream and structure. See Appendix C to view the Tier 2 assessment datasheet.

Site B1		
	Downstream	**Upstream**
Stream		
Channel width (m)	1.62	1.68
Pool width (m)	1.62	1.68
Tidal range (m)	0.40	0.03
Alignment	-	Skewed
Structure		
Width (m)	1.25	1.25
Height (m)	1.31	1.25
Substrate/Water width (m)	1.25	1.25
Water depth (m)	0.52	0.46
High tide water depth (m)	0.90	0.49
Spring tide water depth (m)	Above structure	0.64
Low tide perch (m)	0.00	0.00
High tide perch (m)	0.00	0.00
Length (m)	15.24	
Road fill height (m)	0.91	

Figure 28: The culvert on the upstream side of site B1 is also covered with wrack, likely a result of high tides and storm surge from the blizzard in January 2018 and two northeasters in March 2018.

Figure 29: The downstream area of site B1 is characterized by broadleaf cattail (*Typha latifolia*), invasive common reed (*Phragmites australis*), and other species indicative of a brackish wetland.

Route 6A Crossing of Smith Creek

Site ID: B2
Town: Barnstable
Tidal: No
Assessment Level: Tier 1
This site was not assessed in the Cape Cod Atlas of Tidally Restricted Salt Marshes.

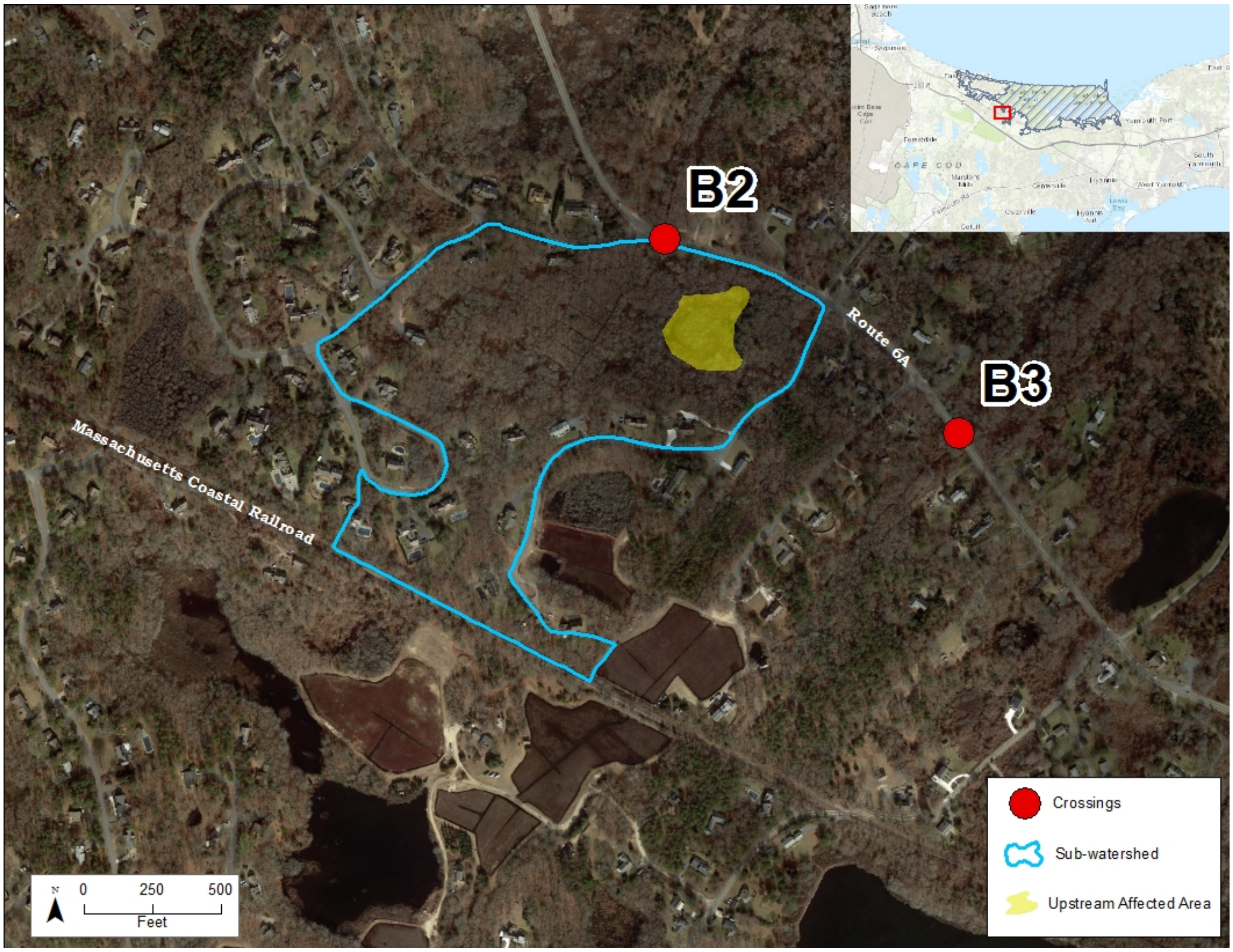

Figure 30: Site B2 is located at 41.7168°N 70.3880°W in Barnstable. Upstream Affected Area (as shown in the pea-green shaded area): Salt Marsh, none; Shallow Marsh, Meadow, or Fen, none; Shrub Swamp, 1.56 acres (based on the MassDEP Wetlands layer). There are no assessed crossings located upstream or downstream.

Tier 1 Analysis

Smith Creek flows under Route 6A through a round concrete culvert on the upstream side to a stone box culvert with a synthetic bottom on the downstream side. The crossing structure appears to be in OK condition, though erosion of the substrate and structure above the crossing (likely from stormwater flow from the road) was observed. Overhead electrical wires are visible at the site. There are no known crossings upstream or downstream of this structure. Both the areas upstream and downstream of the crossing are privately owned. The vegetation upstream and downstream of the structure is similar, with plant communities indicative of a freshwater wetland present. Site observations indicate this is a freshwater crossing, currently not influenced by tidal flow. Downstream erosion of the bank and the road due to stormwater runoff could compromise the structure in the future and may warrant further assessment.

Figure 31: The downstream box culvert at site B2 does not have a stone bottom, but does contain an artificial bottom that is not connected to the structure. Notice the erosion occurring directly above the culvert opening from road runoff.

Figure 32: The vegetation on the downstream side of site B2 crossing is indicative of a freshwater wetland.

Route 6A Crossing of Unnamed Stream

Site ID: B3
Town: Barnstable
Tidal: No
Assessment Level: Tier 1
This site was not assessed in the Cape Cod Atlas of Tidally Restricted Salt Marshes.

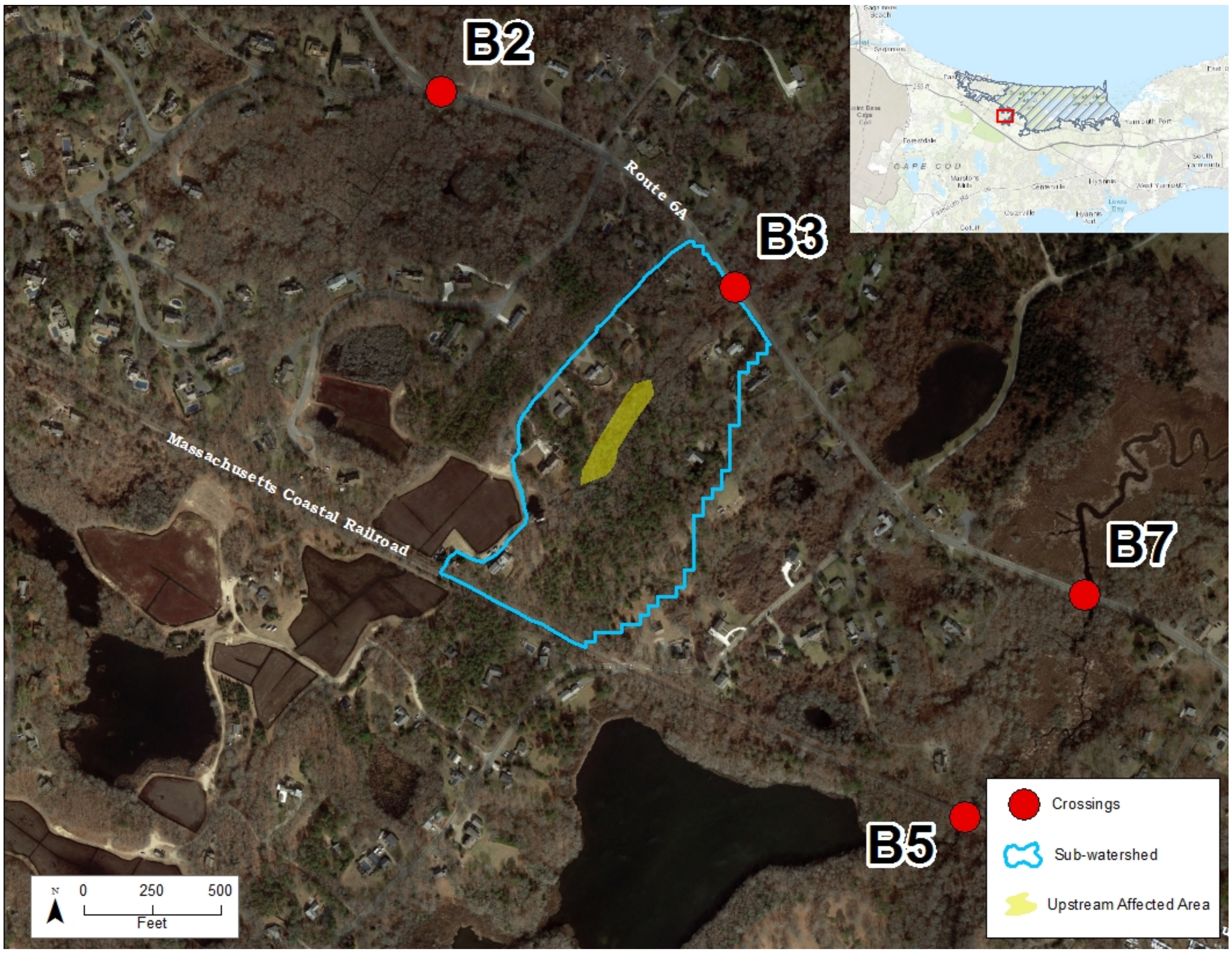

Figure 33: Site B3 is located at 41.7148°N 70.3842°W in Barnstable. Upstream Affected Area (as shown in the pea-green shaded area): Salt Marsh, none; Shallow Marsh, Meadow, or Fen, none; Shrub Swamp, 0.78 acres (based on the MassDEP Wetlands layer). There are no assessed crossings located upstream or downstream.

Tier 1 Analysis

An unnamed stream passes under Route 6A through a small stone opening on the upstream side to a round metal pipe on the downstream side. The crossing appears to be in OK condition, with no obvious signs of degradation. Visible utilities include overhead electrical wires and underground water/sewer pipes. There are no known crossings upstream or downstream of this crossing. The parcels on both the upstream and downstream sides of the crossing are privately owned. The vegetation of the upstream and downstream areas is very similar, composed of freshwater wetland species. Visual indicators of a restriction include a clogged upstream structure and ponded water on the upstream side of the crossing. Site observations indicate the site is not currently influenced by tidal flow. The downstream structure is slightly perched during typical low flow conditions, which may impede the movement of aquatic organisms.

Figure 34: The downstream structure of site B3 is a small metal culvert that is slightly perched during typical low flow conditions.

Figure 35: The upstream plant community at site B3 is indicative of a freshwater wetland.

Route 6A Crossing of Boat Cove Creek

Site ID: B7
Town: Barnstable
Tidal: Yes
Assessment Level: Tier 1
This site was not assessed in the Cape Cod Atlas of Tidally Restricted Salt Marshes.

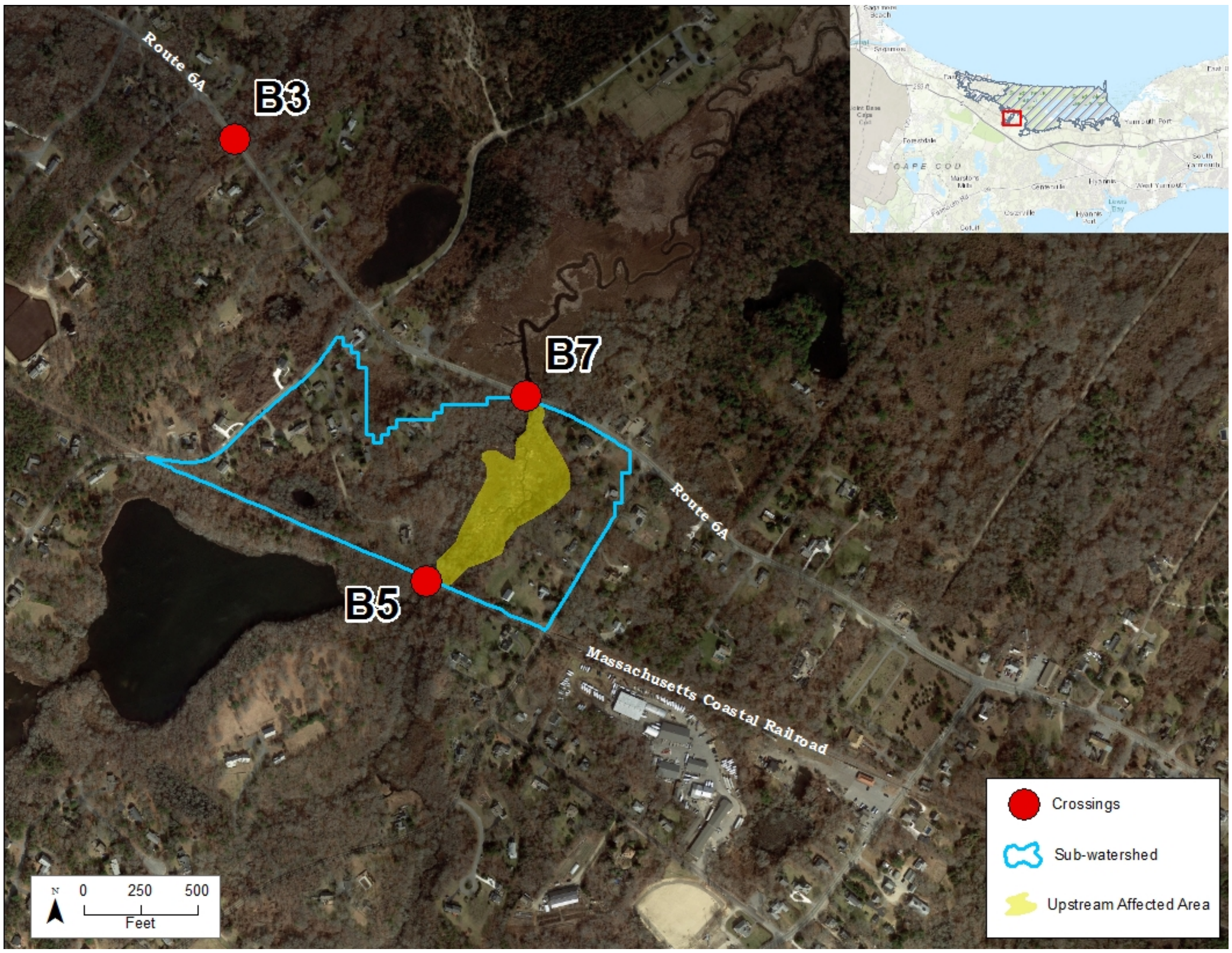

Figure 36: Site B7 is located at 41.7117°N 70.3796°W in Barnstable. Upstream Affected Area (as shown in the pea-green shaded area): Salt Marsh, none; Shallow Marsh, Meadow, or Fen, none; Shrub Swamp, 4.19 acres (based on the MassDEP Wetlands layer). Crossing B5 (not assessed) is located upstream.

Tier 1 Analysis

A bottomless, concrete box culvert facilitates the movement of Boat Cove Creek under Route 6A at this crossing. The crossing appears to be in poor condition, with some signs of structural degradation. Visible utilities include overhead electrical wires and underground water/sewer pipes. There are no known crossings downstream of B7, but B5 (which is where the Massachusetts Coastal Railroad intersects with Boat Cove Creek right before it connects with Mill Pond) is located upstream. Due to accessibility constraints, B5 was not assessed in the field for this report; however it may be worth pursuing if the crossing at B7 is identified for further assessment. The upstream area is spilt among multiple private landowners, while the downstream area is both privately and publicly owned (the Town of Barnstable owns two small parcels). The vegetation on the upstream and downstream sides is moderately different, with the downstream community consisting of predominantly freshwater herbaceous species, and the upstream containing both herbaceous and woody freshwater vegetation. Visual indicators of a restriction include debris clogging both the upstream and downstream sides of the crossing, as well as ponded water on the upstream side. The invasive common reed (*Phragmites australis*) is present on both the upstream and downstream sides of the crossing. In the Tier 1 assessment, the presence of *P. australis* on both sides of the crossing is not considered an indicator of a tidal restriction (see Table B1 for the vegetation-based scoring matrix).

Figure 37: A large mass of peat is partially blocking flow on the downstream side of site B7, most likely rafted up during the blizzard in January 2018 or the northeasters in March 2018.

Figure 38: The upstream area of site B7 is a mix of herbaceous and woody vegetation, with a large accumulation of debris at the structure and on the banks. A stand of the invasive common reed (*Phragmites australis*) is present on the creek bank on the right side of this photo.

Although observations from this assessment indicate this site is not tidally influenced on a daily basis, this structure is clearly impacted at the very least by storm events. High accumulations of wrack were observed in the downstream area, and a large mass of peat was rafted right up to (and partially blocking) the downstream structure opening (Figure 37). This material was likely deposited during the major storms in the winter of 2018, including a blizzard in January that resulted in the highest high tide ever recorded (15.16 feet) at the National Oceanic and Atmospheric Administration (NOAA) tide gauge station in Boston (NOAA 2018), as well as several northeasters in March 2018 that also significantly impacted this site and Massachusetts coast-wide.

In 2019, the Town of Barnstable stocked Mill Pond with river herring in an effort to restore the anadromous fish run in Boat Cove Creek between Barnstable Harbor and the Pond. The large mass of peat on the downstream side (which may cause both a physical barrier and contribute to higher water flow velocities moving out of the structure) and clogging of the upstream side of the crossing by high amounts of debris may be impeding the movement of anadromous fish at this site. The

Town of Barnstable's efforts to restore anadromous fish as well as the repeated storm impacts may warrant further assessment of restoration feasibility at this crossing and at site B5.

Figure 39: View from the roadway showing the high accumulation of wrack on the downstream side of site B7.

Marsh Trail Crossing of Wells Creek at the Sandy Neck Park

Site ID: B23
Town: Barnstable
Tidal: Yes
Assessment Level: Tier 1 and Tier 2
This site was assessed in the Cape Cod Atlas of Tidally Restricted Salt Marshes (Site BA-7).

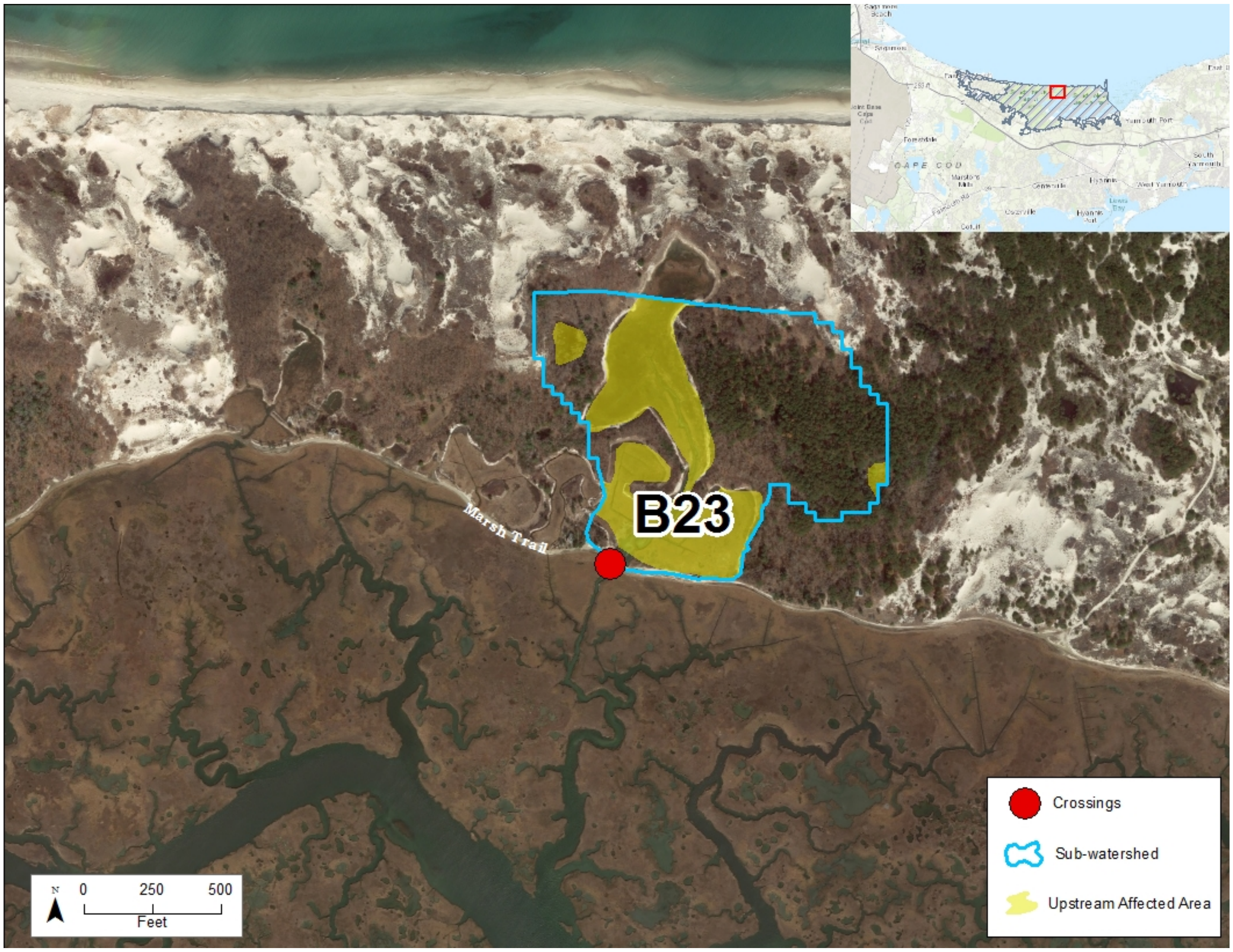

Figure 40: Site B23 is located at 41.7309°N 70.3285°W in Barnstable. Upstream Affected Area (as shown in the pea-green shaded area): Salt Marsh, 7.37 acres; Shallow Marsh, Meadow, or Fen, none; Shrub Swamp, 0.46 acres (based on the MassDEP Wetlands layer). There are no assessed crossings located upstream or downstream.

Tier 1 Analysis

The unpaved marsh trail at the Sandy Neck Park is part of an extensive trail system that traverses much of the Sandy Neck Barrier Beach. This trail closely follows the boundary between the extensive salt marsh system of Barnstable Harbor and the dune system of the park. Wells Creek intersects the trail at this site and flows through a concrete box culvert. The culvert appears to be in OK condition and was installed in 2000. There are no visible utilities at the site. There are also no crossings upstream or downstream. The area both upstream and downstream of the crossing is owned by the Town of Barnstable, with two parcels immediately upstream of the structure leased to a private landowner. In the Cape Cod Atlas of Tidally Restricted Salt Marshes, scouring and erosion were identified as visual indicators of a restriction at the site (Justus et al. 2001). Observations from the current assessment indicate vegetation downstream and upstream of the structure is comparable, with *Spartina* spp. abundant both in the downstream area and upstream of the crossing, shifting to a plant community indicative of a dune system further upstream. Visual indicators of a restriction include minor scouring basins and erosion on both the upstream and downstream sides of the crossing. There are no apparent barriers to aquatic organism passage at this site. Due to its location in such a complex coastal system, the marsh trail regularly floods with higher high tides, including the portion of the trail located at this site. Yearly improvements and repairs to the trail system are executed by park staff to alleviate the impacts from storms and large precipitation events, which may become even more common with climate change.

Figure 41: The upstream side of site B23. The structure is in good condition and rock retaining walls have been put in place around the opening to limit erosion and washout of the trail.

Figure 42: The upstream area of site B23 shows a transition from a salt marsh to a dune community, and the creek consists of predominantly sandy sediment.

Tier 2 Analysis

The site was selected for Tier 2 assessment based on its accessibility for the Tier 2 assessment measurements (Table 3).

The structure is aligned with the natural creek. The substrate within the crossing is comparable to the natural creek and covers the entire length of the structure. The slope between the structure and the creek is also comparable. As mentioned previously, the structure appears to allow the passage of aquatic organisms, and there are no additional barriers to passage either upstream or downstream of the crossing.

Table 3: Measurements taken at site B23 during Tier 2 assessment. Measurements were taken on both the downstream and upstream portions of the stream and structure. See Appendix C to view the Tier 2 assessment datasheet.

Site B23		
	Downstream	**Upstream**
Stream		
Channel width (m)	4.57	4.72
Pool width (m)	4.57	4.72
Tidal range (m)	1.16	1.04
Alignment	-	Aligned
Structure		
Width (m)	2.44	2.44
Height (m)	1.07	1.07
Substrate/Water width (m)	2.07	2.07
Water depth (m)	0.09	0.09
High tide water depth (m)	0.98	0.98
Spring tide water depth (m)	Above structure	Above structure
Low tide perch (m)	0.00	0.00
High tide perch (m)	0.00	0.00
Length (m)	4.57	
Road fill height (m)	0.00	

Figure 43: The downstream area of site B23 is part of the expansive Barnstable Great Marsh.

Millway Crossing of Maraspin Creek

Site ID: B25
Town: Barnstable
Tidal: Yes
Assessment Level: Tier 1
This site was assessed in the Cape Cod Atlas of Tidally Restricted Salt Marshes (Site BA-5).

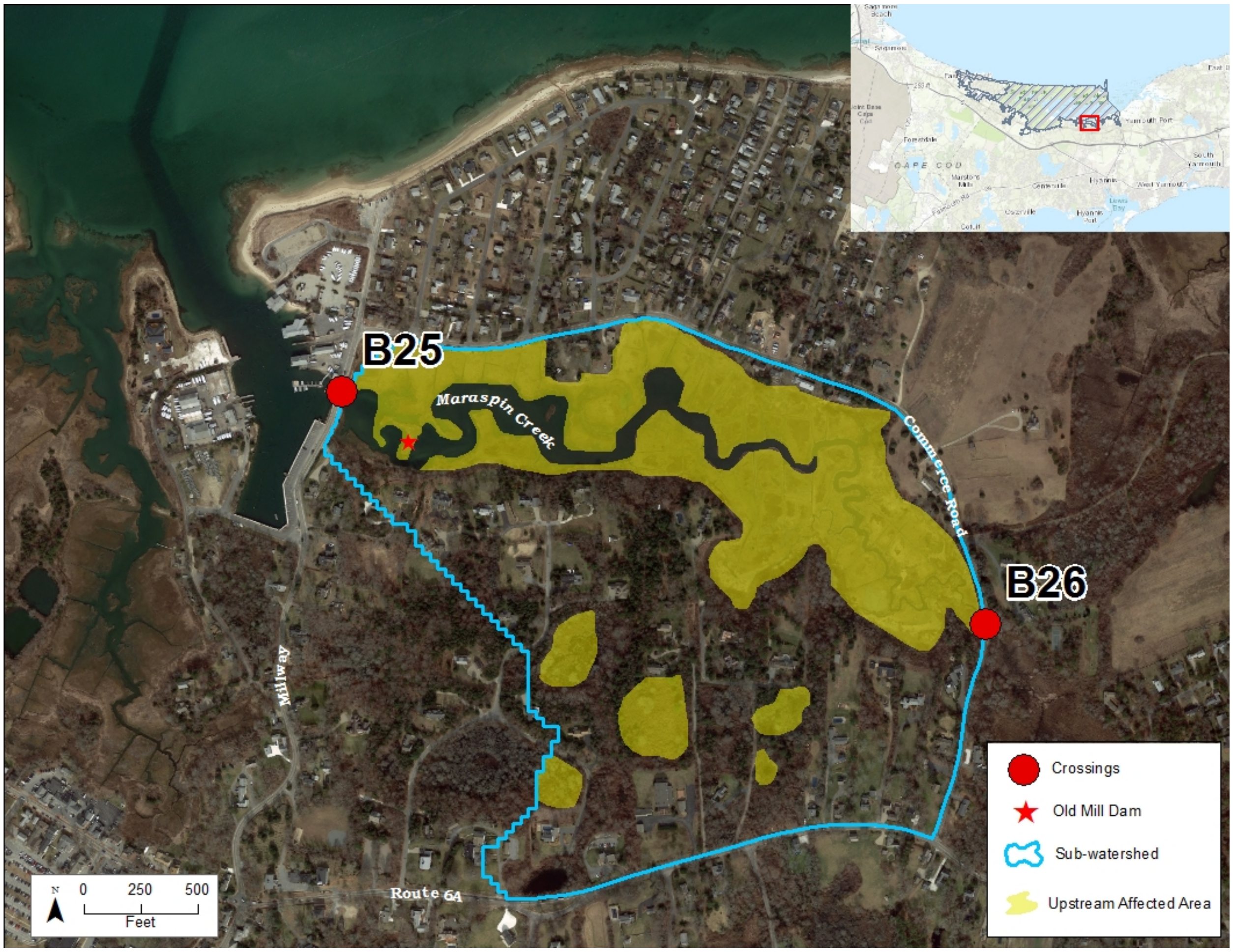

Figure 44: Site B25 is located at 41.7065°N 70.2984°W in Barnstable. Upstream Affected Area (as shown in the pea-green shaded area): Salt Marsh, 31.77 acres; Shallow Marsh, Meadow, or Fen, none; Shrub Swamp, 5.32 acres (based on the MassDEP Wetlands layer). Crossing B26 (pg. 41) is located upstream.

Tier 1 Analysis

The concrete and stone bridge of Millway Road crosses Maraspin Creek at this site. The bridge appears to be in OK condition, and the upstream and downstream sides of the bridge are lined with large rocks for armoring. Overhead electrical wires are present at the site. This site is located downstream of crossing B26 (pg. 41). The upstream side of the crossing has a mix of ownership among private landowners, the Massachusetts Audubon Society (Mass Audubon), and the Barnstable Land Trust. The downstream side is owned by the Town of Barnstable and Millway

Marina, Inc. In the Cape Cod Atlas of Tidally Restricted Salt Marshes, a rise in elevation from the downstream to upstream side is noted. The remnants of an old mill dam on one of the many channels flowing through the upstream salt marsh were also observed (Justus et al. 2001). These characteristics were also observed in the current assessment, as well as rip rap on the upstream side of the crossing. The vegetation on the upstream side is very different from the downstream, as the upstream side is a salt marsh dominated by *Spartina* spp. while the downstream side is a public marina with no vegetation. Visual indicators of a restriction include marsh slumping, bank erosion, and ponded water on the upstream side of the crossing. There is no invasive common reed (*Phragmites australis*) at the bridge, but there are significant stands further upstream into Maraspin Creek. The perch created by the rip rap located in the creek may impede the movement of aquatic organisms at low tide. The elevation change, old mill dam, and rip rap should all be taken into account if this site is considered for restoration.

The Town of Barnstable recently contracted with the Woods Hole Group (WHG) to conduct a Hydrologic and Hydraulic (H&H) assessment of Maraspin Creek, including modeled scenarios of impacts from flooding and sea level rise with the current culvert and a widened culvert at site B26 (pg. 41). Water level data collected by WHG also indicate a tidal restriction exists between the downstream and upstream sides of the bridge at site B25 (Shultz et al. 2019). The results from the current assessment and the WHG study should be used to inform any restoration activity at this site as well as at site B26 (pg. 41).

Figure 45: View of the bridge from the downstream marina. Notice the perch created by the rip rap located on the upstream side of site B25.

Figure 46: The upstream area at site B25 is salt marsh habitat, where water must flow through multiple channels to move upstream, including through the site of an old mill dam.

Commerce Road Crossing of Maraspin Creek

Site ID: B26
Town: Barnstable
Tidal: Yes
Assessment Level: Tier 1, Tier 2, and Tier 3
This site was assessed in the Cape Cod Atlas of Tidally Restricted Salt Marshes (Site BA-6).

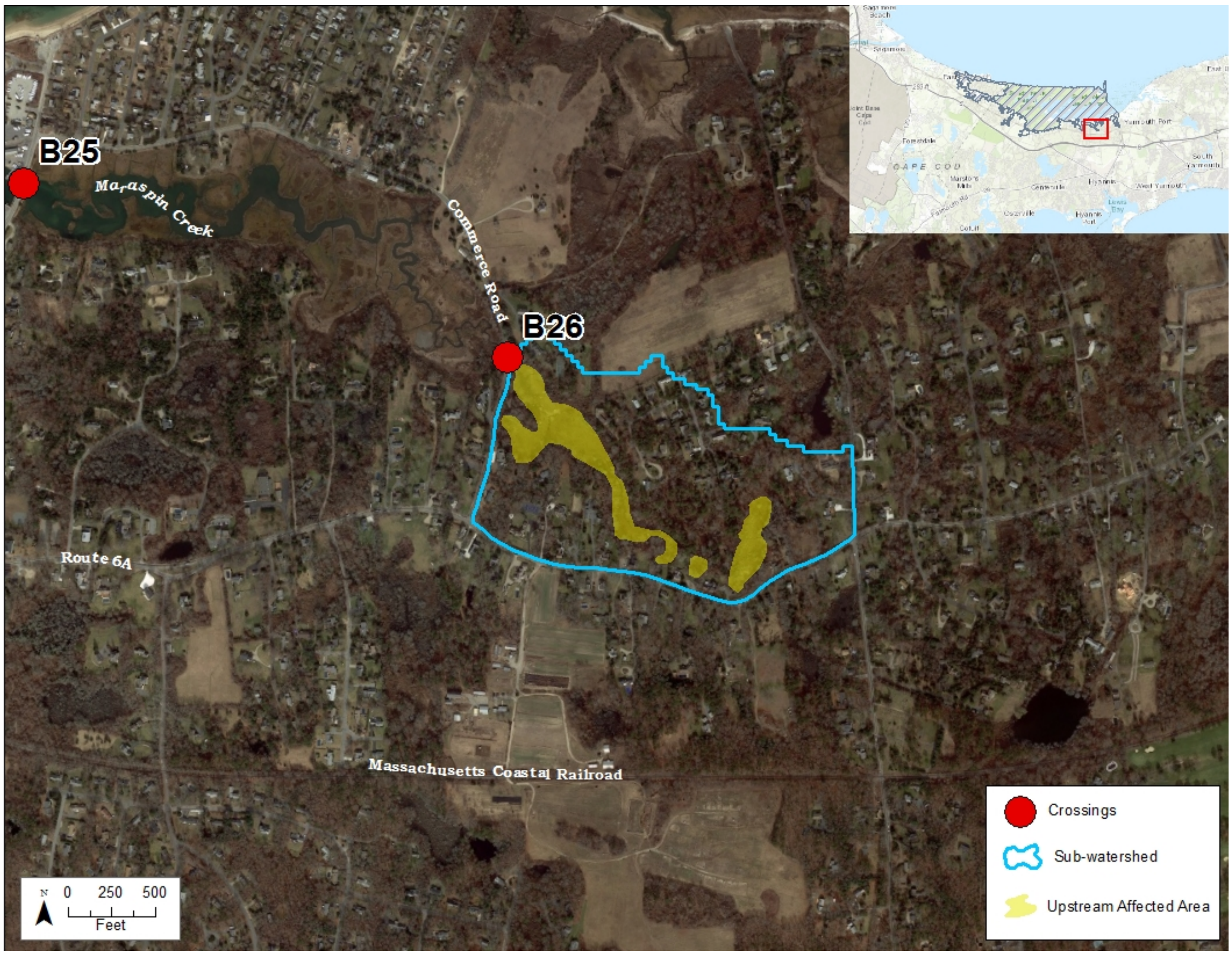

Figure 47: Site B26 is located at 41.7026°N 70.2882°W in Barnstable. Upstream Affected Area (as shown in the pea-green shaded area): Salt Marsh, none; Shallow Marsh, Meadow, or Fen, 1.57 acres; Shrub Swamp, 5.77 acres (based on the MassDEP Wetlands layer). Crossing B25 (pg. 39) is located downstream.

Tier 1 Analysis

At this location, Maraspin Creek flows under Commerce Road through a corrugated metal pipe. The pipe appears to be in poor condition and is partially collapsed on both the upstream and downstream sides of the culvert. Visible utilities at the site include overhead electrical wires and underground water/sewer pipes. Crossing B25 (pg. 39) is located downstream and could be contributing to the restriction at this site by impairing flow and drainage, and therefore should be considered with any restoration efforts at B26. There is a mix of ownership on both the upstream and downstream sides of the crossing. The Barnstable Land Trust owns significant parcels on both sides of the crossing, the Massachusetts Audubon Society (Mass Audubon) owns a portion of the downstream area, and small parcels on both sides of the crossing are held by private landowners. In the Cape Cod Atlas of Tidally Restricted Salt Marshes, the upstream culvert is identified as elliptical in shape due to the weight of the concrete above it. Scour, erosion, and the presence of the invasive common reed (*Phragmites australis*) were identified as visual indicators of a restriction (Justus et al. 2001). In the current assessment, vegetation on the upstream side was observed to be moderately different than the downstream side. A mix of freshwater species is located on the upstream side and *Spartina* spp. and brackish water species are present on the downstream side. *Phragmites australis* is present on both the upstream and downstream sides of the crossing. In the Tier 1 assessment, the presence of *P. australis* on both sides of the crossing is not considered an indicator of a tidal restriction (see Table B1 for the vegetation-based scoring matrix). Visual indicators of a restriction at the site include minor scouring and erosion on the downstream side of the crossing.

Figure 48: The metal culvert is partially collapsed on both sides of site B26. Shown here is the upstream side of the pipe, which is more profoundly collapsed than the downstream side.

Figure 49: The upstream side of site B26 is a mix of freshwater wetland species, with a dead tree overhanging the creek. A stand of the invasive common reed (*Phragmites australis*) is observable on the left side of this photo, and is more prevalent further upstream.

Tier 2 Analysis

The site was selected for Tier 2 assessment based on Tier 1 results (indicating a restriction at the site) and its accessibility for the Tier 2 assessment measurements (Table 4).

The crossing structure is aligned with the natural meandering of the creek, and the slope of the crossing is comparable. There is no substrate observed in the structure. There is a layer of rip rap extending away from both sides of the crossing in the creek bed, which could act as a potential barrier to aquatic organism movement. The downstream side of the culvert is also perched above the rip rap at low tide, which may further impede aquatic organism passage.

Table 4: Measurements taken at site B26 during Tier 2 assessment. Measurements were taken on both the downstream and upstream portions of the stream and structure. See Appendix C to view the Tier 2 assessment datasheet.

Site B26		
	Downstream	**Upstream**
Stream		
Channel width (m)	2.83	2.13
Pool width (m)	2.83	2.13
Tidal range (m)	-	-
Alignment	-	Aligned
Structure		
Width (m)	0.94	0.94
Height (m)	0.64	0.58
Substrate/Water width (m)	0.91	0.64
Water depth (m)	0.15	0.09
High tide water depth (m)	-	-
Spring tide water depth (m)	-	-
Low tide perch (m)	0.34	0.00
High tide perch (m)	0.34	0.00
Length (m)	9.45	
Road fill height (m)	1.07	

Figure 50: A dense stand of the invasive common reed (*Phragmites australis*) dominates the immediate downstream area at site B26.

Figure 51: The downstream creek has an area of rip rap that is creating a cascade from the culvert and resulting in increased water flow velocity at site B26.

Tier 3 Analysis

Additional data were collected at site B26 because the score using the NAACC tidal protocol and input from restoration experts indicated the possible presence of a restriction (Jackson 2018). This additional analysis consisted of installing Onset HOBO data loggers both upstream and downstream of the crossing to measure water levels from November 20 through December 3, 2018 (approximately 13 days). These data were used to further identify the presence and degree of flow restriction at this site.

During this time period, the crossing at site B26 caused a restriction of the water level on the upstream side (Figure 52). The mean tidal range was 1.31 meters on the downstream side and 0.56 meters on the upstream side indicating that the upstream side of the crossing site receives, on average, 43% of the tidal flow compared to the downstream side. The highest tide recorded at the site occurred on November 25 with a height of 2.43 meters NAVD88 on the downstream side and 2.07 meters NAVD88 on the upstream side, with a delay of 1 hour between downstream and upstream (this was the largest delay of high tide during the deployment period; 12:45 p.m. on the downstream side and 1:45 p.m. on the upstream side). The maximum tidal restriction of 0.36 meters NAVD88 was also recorded at this time. Elevation of the downstream marsh surface and culvert were measured at 1.09 meters and 1.17 meters NAVD88 respectively. Based on the logger measurements and these elevations, the water level reached a height greater than the top of the culvert for some duration during every tidal cycle measured during this time period.

A precipitation event on November 25 resulted in 3.76 centimeters (about 1.5 inches) of rainfall in the Town of Barnstable (NOAA 2018). The high freshwater inflow from the precipitation event as well as tidal flow contributed to the high water levels observed on this date (Figure 52). Due to the restriction at site B26, the upstream side of the culvert may not efficiently drain these stormwater and tidal inputs. This could result in water backing up on the upstream side, which could ultimately lead to flooding. Expected climate change effects such as increased precipitation and sea level rise will exacerbate these impacts at this site and others that restrict water flow.

The Town of Barnstable recently contracted with the Woods Hole Group (WHG) to conduct a Hydrologic and Hydraulic (H&H) assessment of Maraspin Creek, including modeled scenarios of impacts from flooding and sea level rise with the current culvert and a widened culvert at site B26. Water level data collected by WHG also indicate a tidal restriction exists between the downstream and upstream sides of the culvert at site B26 (Shultz et al. 2019). The results from the current assessment and the WHG study should be used to inform any restoration activity at this site as well as at site B25 (pg. 39).

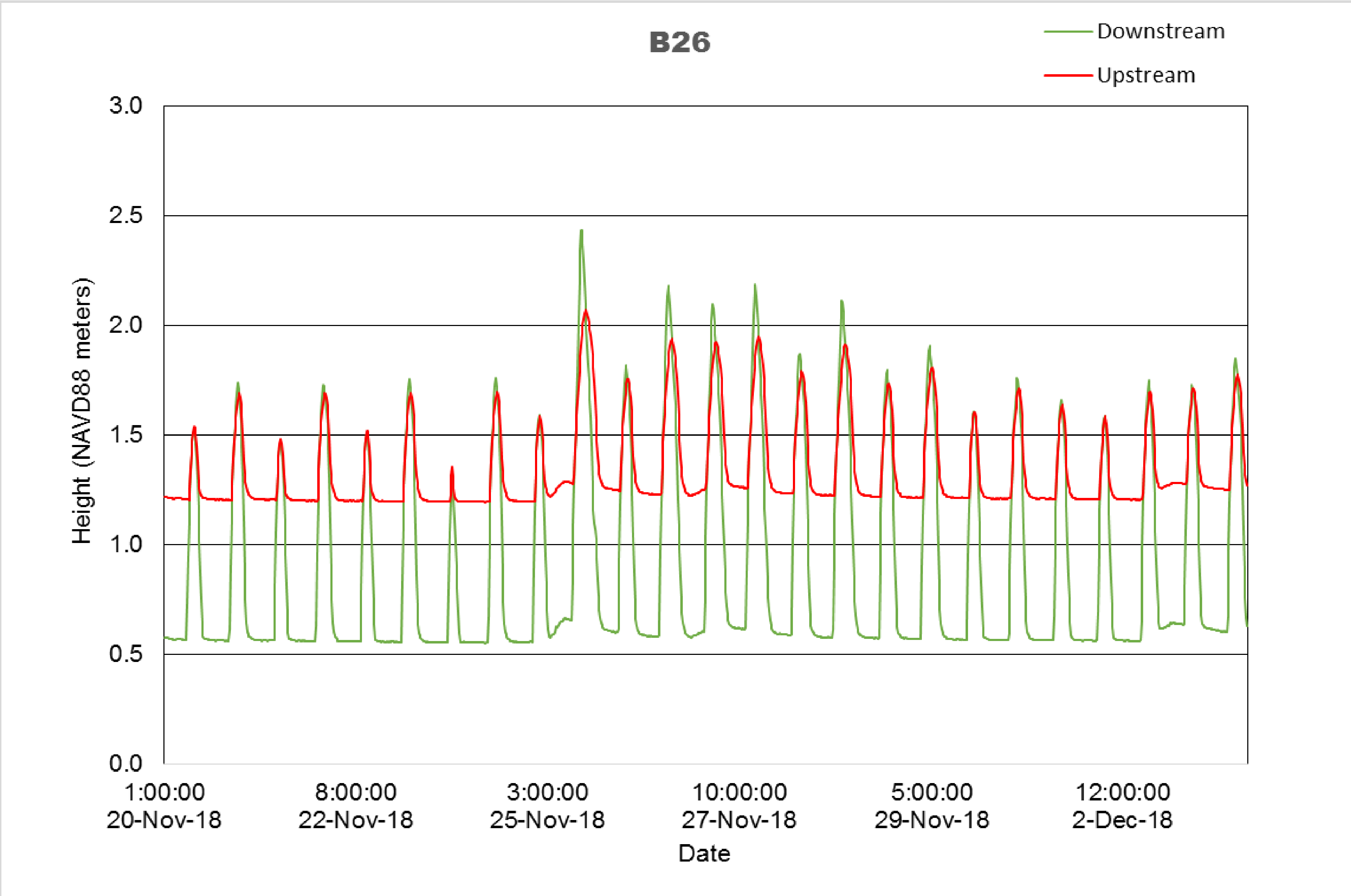

Figure 52: Hydrograph for Site B26 from 11/20/18 to 12/3/18. Data were measured with Onset HOBO data loggers. The green (downstream) and red (upstream) lines represent the fluctuation in water height (NAVD88 meters) during the measured time period. The pulse seen on November 25 is due to a precipitation event that resulted in 3.76 centimeters (about 1.5 inches) of rainfall (NOAA 2018).

Yarmouth Crossings

Keveney Lane/Mill Lane Crossing of Mill Creek and Hallets Mill Pond

Site ID: Y1
Town: Yarmouth
Tidal: Yes
Assessment Level: Tier 1
This site was assessed in the Cape Cod Atlas of Tidally Restricted Salt Marshes (Site BA-8/YA-1).

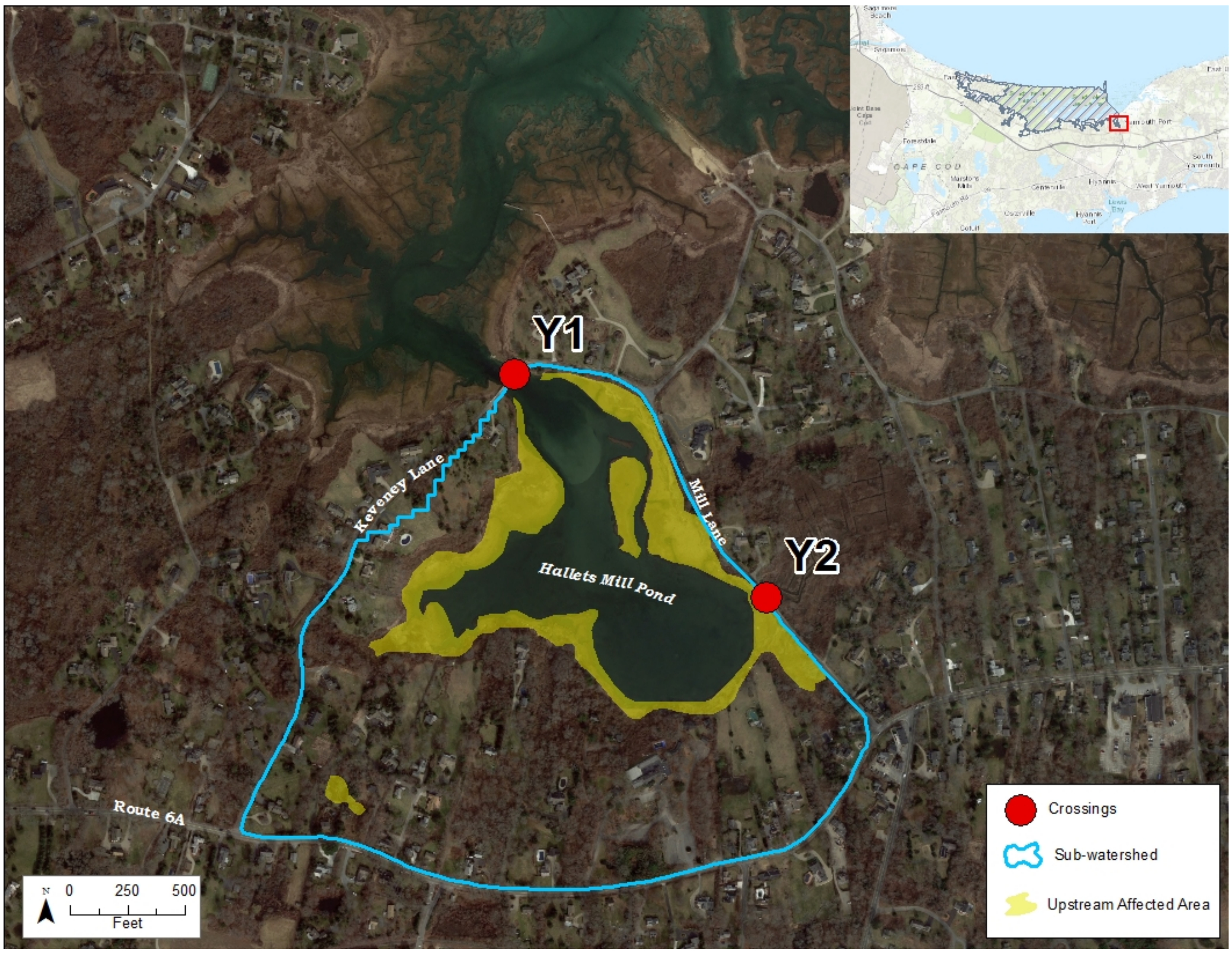

Figure 53: Site Y1 is located at 41.7074ºN 70.2622ºW in Yarmouth. Upstream Affected Area (as shown in the pea-green shaded area): Salt Marsh, 12.56 acres; Shallow Marsh, Meadow, or Fen, 0.57 acres; Shrub Swamp, 0.30 acres (based on the MassDEP Wetlands layer). Crossing Y2 (pg. 48) is located upstream.

Tier 1 Analysis

The Keveney Lane/Mill Lane Bridge crosses Mill Creek where it intersects with Hallets Mill Pond. The bridge is made of stone and appears to be in OK condition. Both sides of the crossing are heavily armored with large stones. Underground water/sewer pipes are present at the site and overhead electrical wires are visible on either end but do not cross over the bridge. Crossing Y2 (pg.

48) is located upstream. This site falls on the boundary of the Towns of Barnstable and Yarmouth. The upstream area is owned by various private landowners, while the downstream area is owned in part by private landowners and the Barnstable Land Trust. In the Cape Cod Atlas of Tidally Restricted Salt Marshes, the bridge was reported in good condition, and a rise in elevation from the downstream to the upstream side due to rocks under the bridge was observed (and is still present) (Justus et al. 2001). In the current assessment, the vegetation between the upstream and downstream areas was observed to be very similar, with *Spartina* spp. the dominant species on both sides. Bank erosion, marsh slumping, and vegetation die-back were observed on both sides of the crossing. These indicators are likely a result of high velocity water flow through the crossing as a result of both tides and storm events. The invasive common reed (*Phragmites australis*) is present on both the upstream and downstream sides of the crossing. In the Tier 1 assessment, the presence of *P. australis* on both sides of the crossing is not considered an indicator of a tidal restriction (see Table B1 for the vegetation-based scoring matrix). The heavy armoring in the channel and elevation change between the upstream and downstream creek may inhibit the movement of aquatic organisms, especially at low tide. Ponded water on the upstream side is also indicative of water flow restriction.

Figure 54: A stone support splits the bridge opening into two passageways for water flow and the bridge is heavily armored with large rocks on both sides at site Y1.

Figure 55: The downstream saltmarsh at site Y1 shows signs of bank erosion, marsh slumping, and vegetation die-back.

Mill Lane Crossing of Hallets Mill Pond

Site ID: Y2
Town: Yarmouth
Tidal: Yes
Assessment Level: Tier 1, Tier 2, and Tier 3
This site was assessed in the Cape Cod Atlas of Tidally Restricted Salt Marshes (Site YA-2).

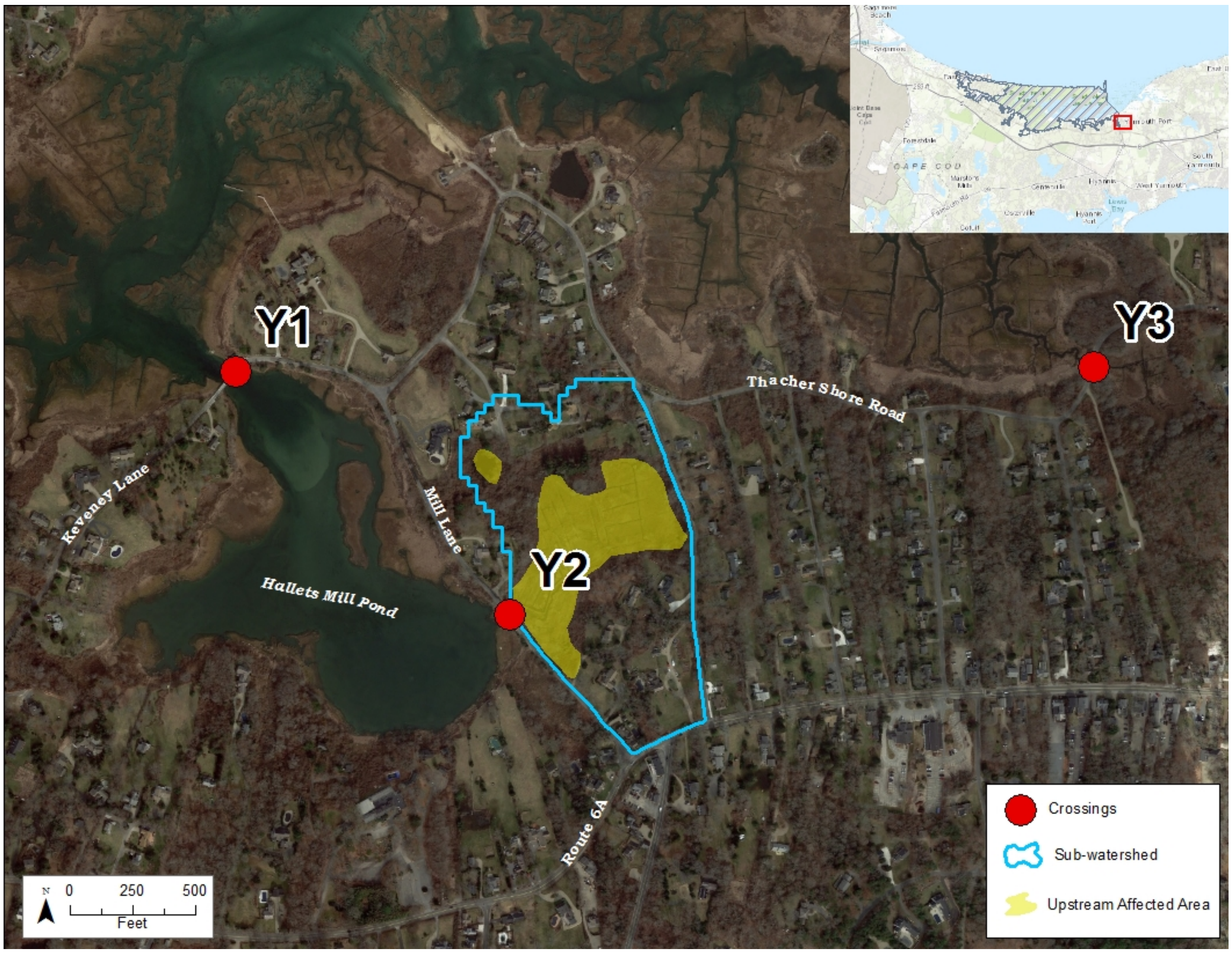

Figure 56: Site Y2 is located at 41.7047°N 70.2582°W in Yarmouth. Upstream Affected Area (as shown in the pea-green shaded area): Salt Marsh, 2.55 acres; Shallow Marsh, Meadow, or Fen, 3.53 acres; Shrub Swamp, 0.24 acres (based on the MassDEP Wetlands layer). Crossing Y1 (pg. 46) is located downstream.

Tier 1 Analysis

A small creek connected to Hallets Mill Pond is restricted by Mill Lane at this site. The creek passes under Mill Lane through a round concrete culvert. Stones are placed on the lateral sides of both the upstream and downstream sides of the crossing to help prevent erosion and scouring around the structure. The upstream structure extends out from a concrete "sleeve," and erosion was observed around this extended structure, likely from stormwater runoff from the road. The culvert appears to be in OK condition. Overhead electrical wires are visible at the site. Crossing Y1 (pg. 46) is located downstream and could be contributing to the restriction at this site by impairing flow and drainage, and therefore should be considered with any restoration efforts at Y2. The downstream area is owned by multiple private landowners, while the upstream is owned by both the Town of Yarmouth and private landowners. In the Cape Cod Atlas of Tidally Restricted Salt Marshes, the downstream culvert was identified as perched one foot above the streambed, and scouring and erosion were observed on both the downstream and upstream sides of the crossing (Justus et al. 2001). In the current assessment, the vegetation between the upstream and downstream sides is moderately different. Both sides of the crossing are composed of *Spartina* spp., but the invasive common reed (*Phragmites australis*) is abundant in the upstream area. Visual indicators of a restriction include minor scouring and erosion on the downstream structure as well as marsh slumping on both sides of the crossing. There is also ponded water on the upstream side and evidence of submergence at high tide on both sides of the culvert. Water was observed flowing from an unknown source just north of the downstream culvert. The Town of Yarmouth has expressed interest in addressing the restriction present at this site, so further assessment may be warranted.

Figure 57: The invasive common reed (*Phragmites australis*) is abundant on the upstream side of site Y2 with minor abundance on the downstream side.

Figure 58: The upstream culvert extends out from a "sleeve" at the foot of the road fill at site Y2.

Tier 2 Analysis

The site was selected for Tier 2 assessment based on Tier 1 results (indicating a restriction at the site) and its accessibility for the Tier 2 assessment measurements (Table 5).

The upstream culvert is not in-line with the natural meandering of the creek. There is no substrate within the structure itself, and the slope of the structure is comparable to the slope of the creek. The downstream structure is perched at low tide, likely impeding aquatic organism passage and restricting water flow. A layer of stone is laid horizontally across the creek bed on the downstream side of the crossing, which may also impede the passage of water flow and aquatic organisms.

Table 5: Measurements taken at site Y2 during Tier 2 assessment. Measurements were taken on both the downstream and upstream portions of the stream and structure. See Appendix C to view the Tier 2 assessment datasheet.

Site Y2		
	Downstream	**Upstream**
Stream		
Channel width (m)	4.76	1.40
Pool width (m)	4.76	1.40
Tidal range (m)	0.85	0.58
Alignment	-	Skewed
Structure		
Width (m)	0.61	0.61
Height (m)	0.58	0.64
Substrate/Water width (m)	0.37	0.34
Water depth (m)	0.02	0.06
High tide water depth (m)	0.49	0.58
Spring tide water depth (m)	Above structure	Above structure
Low tide perch (m)	0.46	0.00
High tide perch (m)	0.00	0.00
Length (m)	15.54	
Road fill height (m)	1.22	

Figure 59: The downstream area of site Y2 is predominantly Hallets Mill Pond, with an associated salt marsh dominated by *Spartina* spp.

Figure 60: The downstream structure is armored with stone and is perched above the creek at low tide at site Y2.

Tier 3 Analysis

Additional data were collected at site Y2 because the score using the NAACC tidal protocol and input from restoration experts indicated the possible presence of a restriction (Jackson 2018). This additional analysis consisted of installing Onset HOBO data loggers both upstream and downstream of the crossing to measure water levels from November 20 through December 3, 2018 (approximately 13 days). These data were used to further identify the presence and degree of flow restriction at this site.

During this time period, the crossing at site Y2 caused a restriction of the water level on the upstream side (Figure 61). The mean tidal range was 1.68 meters on the downstream side and 0.69 meters on the upstream side, indicating that the upstream side of the crossing receives, on average, 41% of the tidal flow compared to the downstream side. The highest tide recorded at the site occurred on November 25 with a height of 2.54 meters NAVD88 on the downstream side and 1.99 meters NAVD88 on the upstream side, with a delay of 1 hour and 30 minutes (this was the largest delay of high tide during the deployment period; 12:30 p.m. on the downstream side and 2:00 p.m. on the upstream side). The maximum tidal restriction of 0.55 meters was also recorded at this time.

Elevation of the downstream side marsh surface and culvert were measured at 1.22 meters and 1.50 meters NAVD88 respectively. Based on the logger measurements and these elevations, the water level reached a height greater than the top of the culvert for some duration during all but one tidal cycle measured during this time period. The upstream marsh surface and culvert were measured at 1.29 meters and 1.83 meters NAVD88 respectively, with the water level reaching a height above the top of the upstream side of the culvert during five of the recorded tidal cycles.

A precipitation event on November 25 resulted in 3.76 centimeters (about 1.5 inches) of rainfall in the Town of Yarmouth (NOAA 2018). The high freshwater inflow from the precipitation event as well as tidal flow contributed to the high water levels observed on this date (Figure 61). Due to the restriction at site Y2, the upstream side of the culvert may not efficiently drain these stormwater and tidal inputs. This could result in water backing up on the upstream side, which could ultimately lead to flooding. Expected climate change effects such as increased precipitation and sea level rise will exacerbate these impacts at this site and others that restrict water flow.

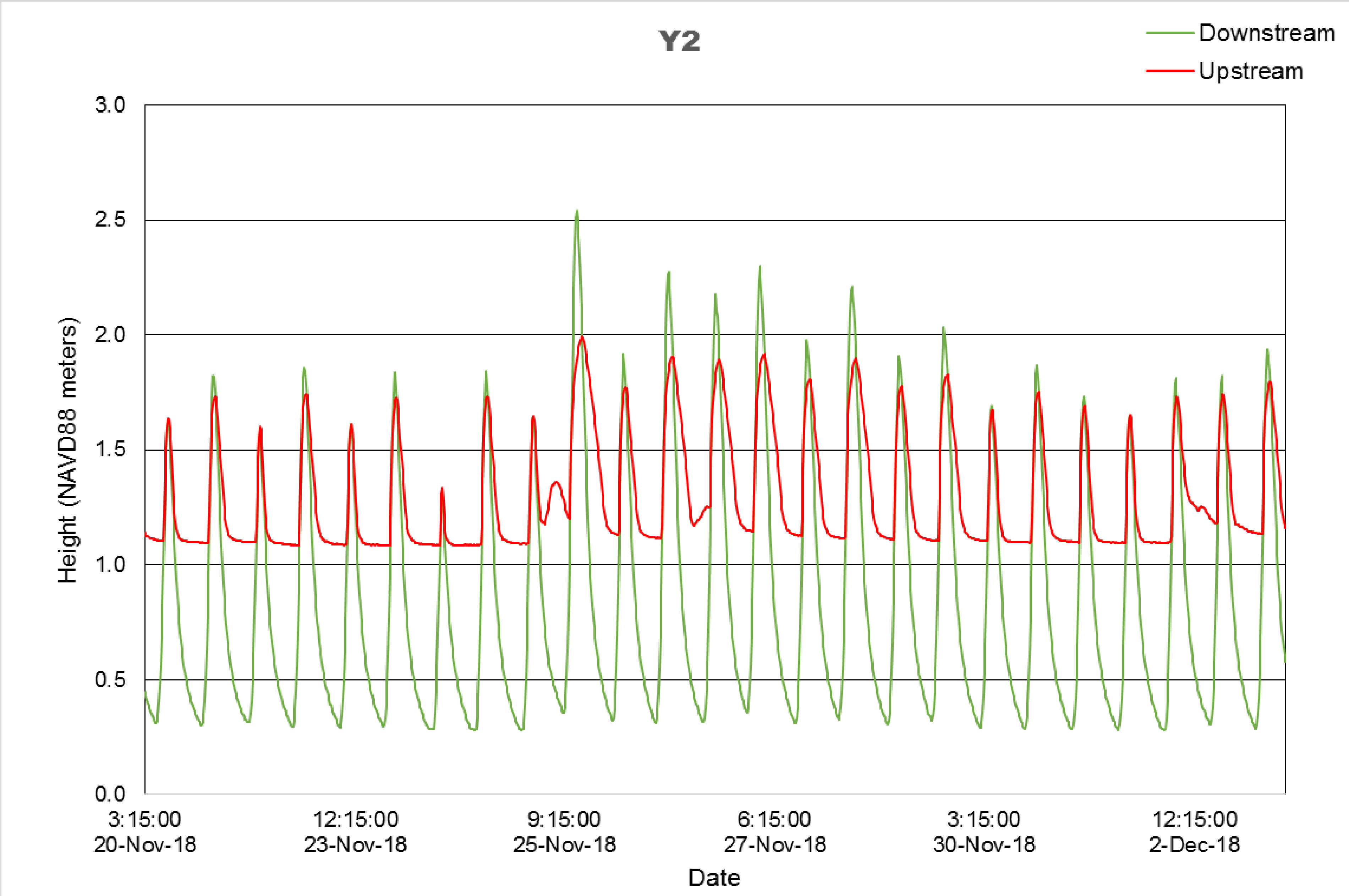

Figure 61: Hydrograph for Site Y2 from 11/20/18 to 12/3/18. Data were measured with Onset HOBO data loggers. The green (downstream) and red (upstream) lines represent the fluctuation in water height (NAVD88 meters) during the measured time period. The pulse seen on November 25 is due to a precipitation event that resulted in 3.76 centimeters (about 1.5 inches) of rainfall (NOAA 2018).

Thacher Shore Road Crossing of Short Wharf Creek

Site ID: Y3
Town: Yarmouth
Tidal: Yes
Assessment Level: Tier 1, Tier 2, and Tier 3
This site was assessed in the Cape Cod Atlas of Tidally Restricted Salt Marshes (Site YA-3).

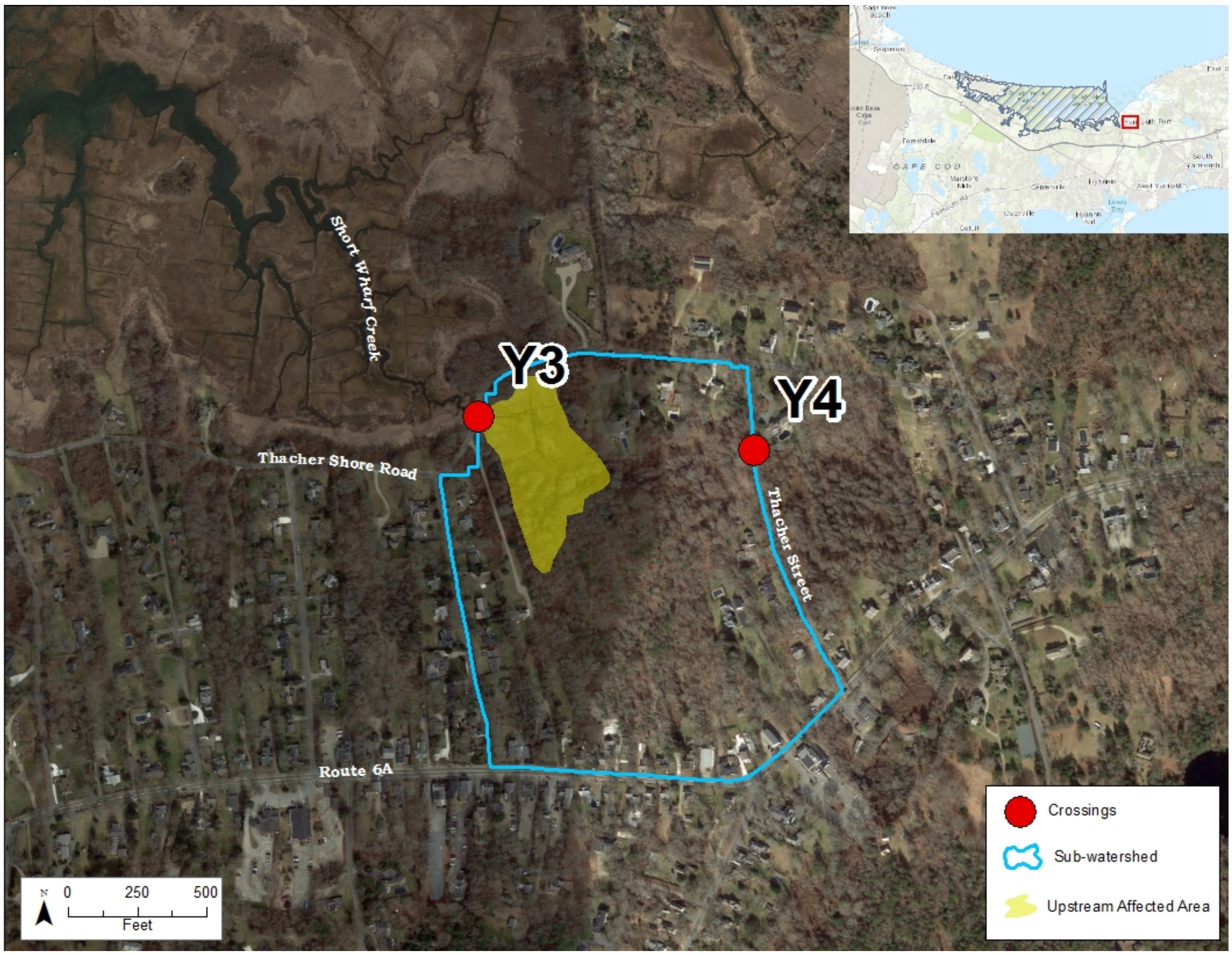

Figure 62: Site Y3 is located at 41.7073°N 70.2497°W in Yarmouth. Upstream Affected Area (as shown in the pea-green shaded area): Salt Marsh, 2.89 acres; Shallow Marsh, Meadow, or Fen, none; Shrub Swamp, 1.02 acres (based on the MassDEP Wetlands layer). Crossing Y4 (pg. 59) is located upstream.

Tier 1 Analysis

Short Wharf Creek flows under Thacher Shore Road through a round concrete culvert that is in poor condition. Both the upstream and downstream culvert structures are damaged as scouring seems to have broken down portions of both sides of the culvert, evidenced by exposed rebar on the downstream side of the culvert. A rock headwall surrounds both the upstream and downstream structures. Utilities at the site include overhead electrical wires and a potential underground gas line (based on markings on the roadway). Crossing Y4 (pg. 59) is located upstream. The downstream area is publicly owned by the Town of Yarmouth, while the immediate upstream area is held by private landowners. In the Cape Cod Atlas of Tidally Restricted Salt Marshes, scour, erosion, marsh slumping, and vegetation die-back were observed on the downstream side and identified as indicators of a water-flow restriction (Justus et al. 2001). In the current assessment, the vegetation between the downstream and upstream areas was observed to be moderately different. *Spartina* spp. are intermixed with brackish and freshwater species like broadleaf cattail (*Typha latifolia*) on the downstream side and a higher abundance of brackish and freshwater species on the upstream side. Marsh elder (*Iva frutescens*) is growing on the creek bank on the upstream side, which may be indicative of the deposition of sediment from mosquito ditching efforts in the creek. There is also a stand of the invasive common reed (*Phragmites australis*) a distance upstream from the crossing. Visual indicators of a restriction include evidence of structure submergence at higher high tides, scouring on the downstream side of the crossing, and marsh slumping on both the upstream and downstream sides. The stand of *P. australis* located upstream of the crossing may also be caused by restricted tidal flow at the crossing.

At the time of the field assessment for Tier 1 (spring 2018), there was a high amount of wrack covering the culvert and surrounding marsh area (Figure 64). This was the result of major storms in the winter of 2018, including a blizzard in January that resulted in the highest high tide ever recorded (15.16 feet) at the National Oceanic and Atmospheric Administration (NOAA) tide gauge station in Boston (NOAA 2018). Several northeasters in March 2018 also significantly impacted this site and Massachusetts coast-wide. The town of Yarmouth has had to repair the roadway on the upstream side multiple times because of the recurrence of a sink hole, with the most recent repair coming after the northeasters in March of 2018. These repeated storm impacts and repair efforts may warrant further assessment for restoration feasibility as this site.

Figure 63: The downstream side of site Y3 is composed of *Spartina* spp. as well as broadleaf cattail (*Typha latifolia*) (shown on the left side of the image), giving way to salt marsh habitat further downstream.

Figure 64: The downstream culvert was covered in wrack and is perched above a cascade caused by rip rap placed directly beneath the structure and continuing for some distance downstream at site Y3.

Tier 2 Analysis

The site was selected for Tier 2 assessment based on Tier 1 results (indicating a restriction at the site) and its accessibility for the Tier 2 assessment measurements (Table 6). The structure is in-line with the natural meandering of the creek. There is no substrate within the culvert, and the slope of the structure is comparable to the natural creek. The downstream culvert is perched at low tide above a layer of rip-rap, creating a cascade that results in increased water-flow velocity. A layer of rip rap also continues in the creek bed for some distance away from the culvert on the downstream side. Although the rip rap may dissipate water velocities that may scour the downstream culvert, it may also be impeding aquatic organism passage.

Table 6: Measurements taken at site Y3 during Tier 2 assessment. Measurements were taken on both the downstream and upstream portions of the stream and structure. See Appendix C to view the Tier 2 assessment datasheet.

Site Y3		
	Downstream	**Upstream**
Stream		
Channel width (m)	2.23	1.19
Pool width (m)	2.23	1.19
Tidal range (m)	0.27	0.12
Alignment	-	Aligned
Structure		
Width (m)	0.61	0.61
Height (m)	0.64	0.64
Substrate/Water width (m)	0.27	0.40
Water depth (m)	0.03	0.06
High tide water depth (m)	0.30	0.18
Spring tide water depth (m)	Above structure	0.40
Low tide perch (m)	0.40	0.00
High tide perch (m)	0.00	0.00
Length (m)	13.72	
Road fill height (m)	1.43	

Figure 65: The creek on the upstream side of site Y3 has marsh elder (*Iva frutescens)* growing on the creek bank, which may be indicative of legacy mosquito ditching impacts. A stand of the invasive common reed (*Phragmites australis*) is also present upstream.

Figure 66: The upstream culvert has stone placed around the opening, and is beginning to deteriorate, especially the lower half of the structure at site Y3.

Tier 3 Analysis

Additional data were collected at site Y3 because the score using the NAACC tidal protocol and input from restoration experts indicated the possible presence of a restriction (Jackson 2018). This additional analysis consisted of installing Onset HOBO data loggers both upstream and downstream of the crossing to measure water levels from November 20 through December 3, 2018 (approximately 13 days). These data were used to further identify the presence and degree of flow restriction at this site.

During this time period, the crossing at site Y3 caused a restriction of the water level on the upstream side (Figure 67). The mean tidal range was 1.99 meters on the downstream side and 0.79 meters on the upstream side, indicating that the upstream side of the crossing receives, on average, 39% of the tidal flow compared to the downstream side. The highest tide recorded at the site occurred on November 25 with a height of 2.61 meters NAVD88 on the downstream side and 2.26 meters NAVD88 on the upstream side, and a delay of 1 hour (12:30 p.m. on the downstream side and 1:30 p.m. on the upstream side). The maximum tidal restriction of 0.35 meters NAVD88 was recorded at this time. Elevation of the downstream side marsh surface and culvert were measured at 1.41 meters and 1.51 meters NAVD88 respectively. Based on the logger measurements and these elevations, the water level reached a height greater than the top of the culvert for some duration during all but one tidal cycle measured during this time period.

A precipitation event on November 25 resulted in 3.76 centimeters (about 1.5 inches) of rainfall in the Town of Yarmouth (NOAA 2018). The high freshwater inflow from the precipitation event as well as tidal flow contributed to the high water levels observed on this date (Figure 67). Due to the restriction at site Y3, the upstream side of the culvert may not efficiently drain these stormwater and tidal inputs. This could result in water backing up on the upstream side, which could ultimately lead to flooding. Expected climate change effects such as increased precipitation and sea level rise will exacerbate these impacts at this site and others that restrict water flow.

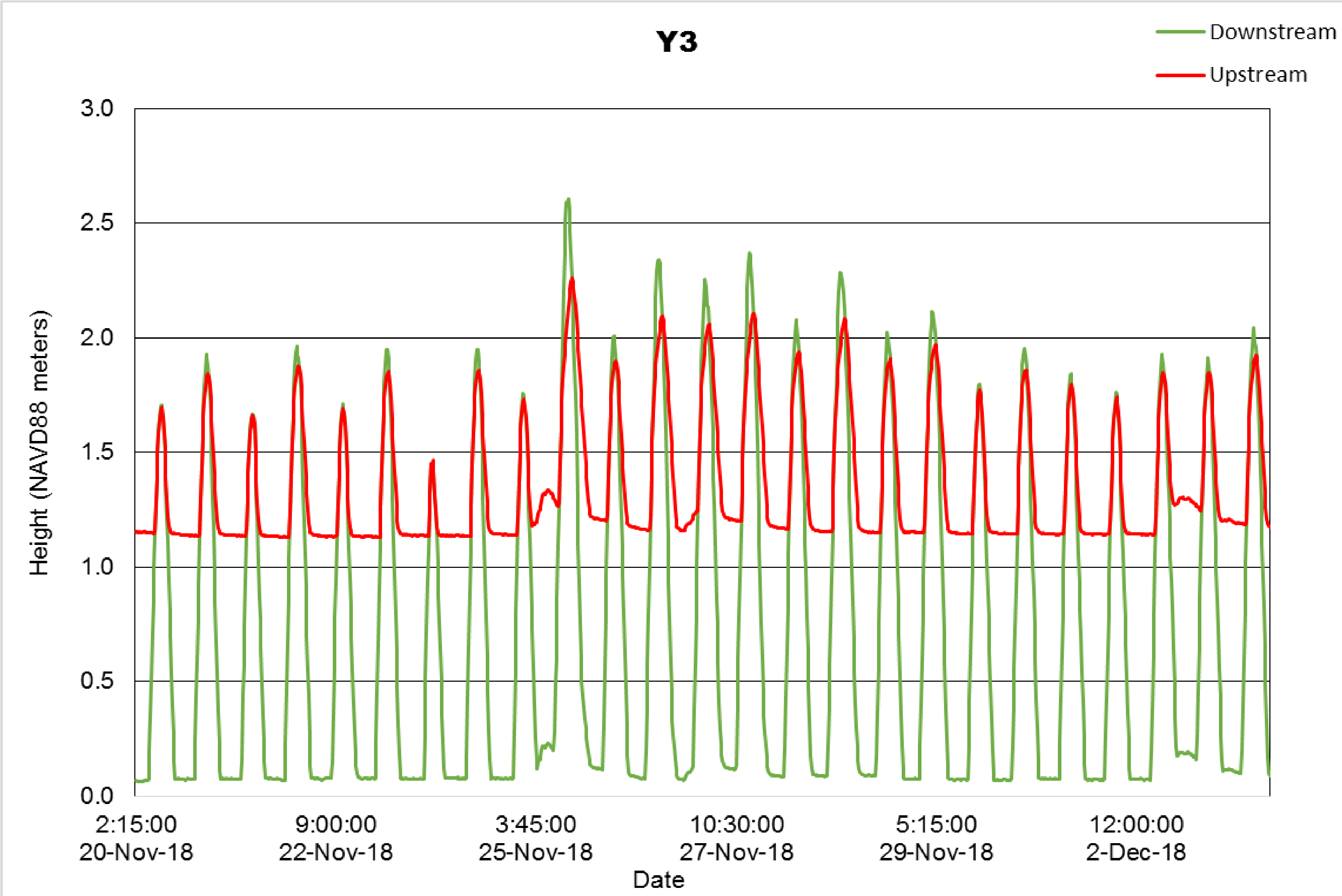

Figure 67: Hydrograph for Site Y3 from 11/20/18 to 12/3/18. Data were measured with Onset HOBO data loggers. The green (downstream) and red (upstream) lines represent the fluctuation in water height (NAVD88 meters) during the measured time period. The pulse seen on November 25 is due to a precipitation event that resulted in 3.76 centimeters (about 1.5 inches) of rainfall (NOAA 2018).

Thacher Street Crossing of Short Wharf Creek

Site ID: Y4
Town: Yarmouth
Tidal: No
Assessment Level: Tier 1
This site was not assessed in the Cape Cod Atlas of Tidally Restricted Salt Marshes.

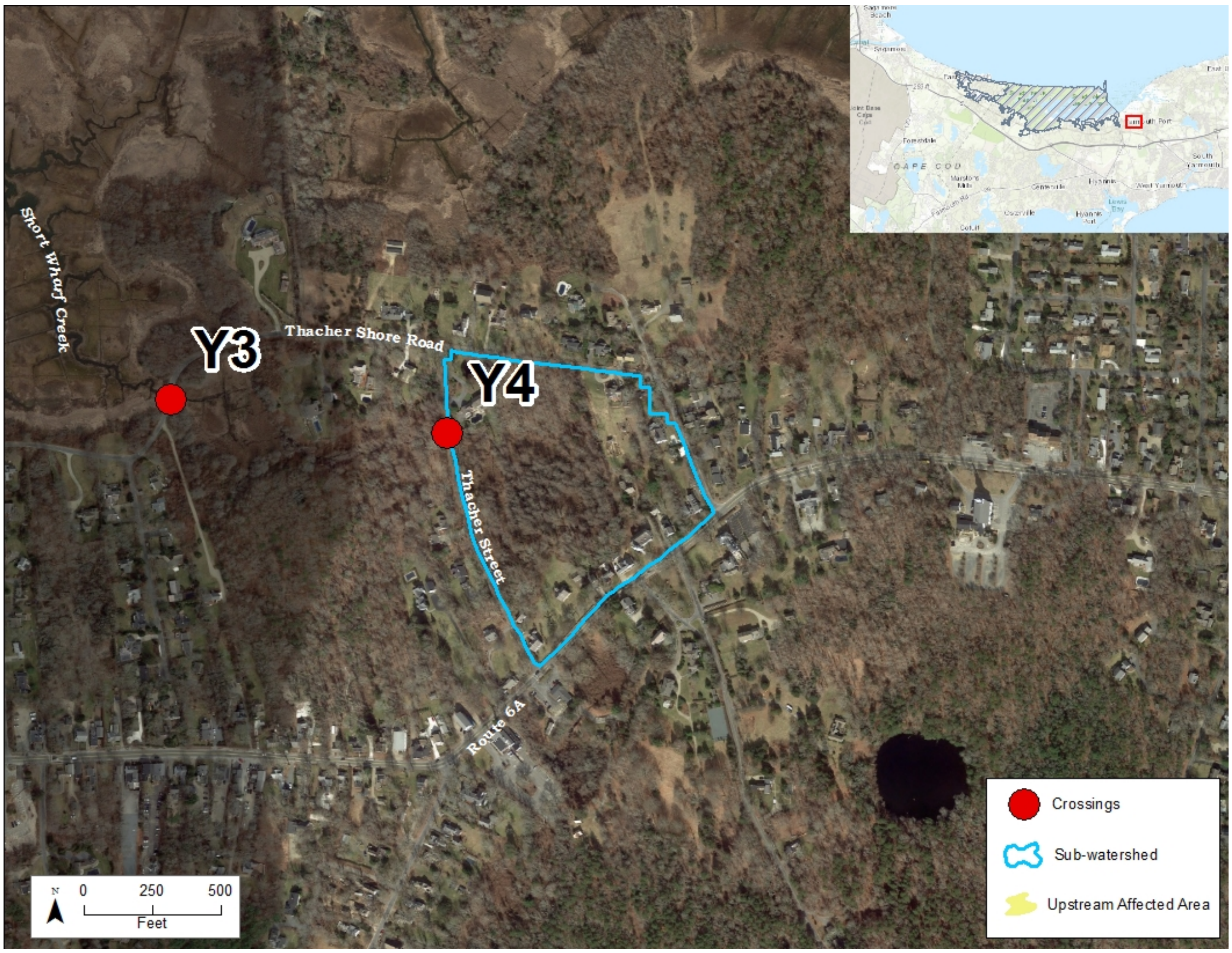

Figure 68: Site Y4 is located at 41.7069°N 70.246°W in Yarmouth. There is no Salt Marsh, Shallow Marsh, Meadow, or Fen, or Shrub Swamp in the upstream affected area. Crossing Y3 (pg. 53) is located downstream.

Tier 1 Analysis

Thacher Street crosses Short Wharf Creek at this site. The type of crossing is unknown because it is covered by stone placed around both the upstream and downstream sides. It is possible that the structure is at least partially collapsed and failing, evidenced by the very minimal observed water flow through the structure. No visible utilities are present at the site. Crossing Y3 (pg. 53) is located downstream and could be contributing to the restriction at this site by impairing flow and drainage, and therefore should be considered with any restoration efforts at Y4. The area downstream is owned by several different private landowners and ownership of the upstream area is split between the Town of Yarmouth and a private landowner. The vegetation between the upstream and downstream is moderately different, although both sides are composed of both herbaceous and woody vegetation indicative of a freshwater wetland. Field observations indicate the crossing is not tidally influenced at this time. There are, however, some visual indicators of a flow restriction at the site, including evidence of a clogged structure and ponded water on both the upstream and downstream sides. Debris accumulating at the upstream structure may also be impeding water flow and aquatic organism passage at this site.

Figure 69: Field observers were unable to identify what kind of structure was covered by the stone at site Y4, shown here on the upstream side. Due to the small opening beneath the stone, debris has accumulated at the crossing.

Figure 70: Much like the upstream structure, there is stone covering the downstream opening at site Y4. At the time that the crossing was assessed, very minimal water flow was observed through the structure.

Conclusion

This report provides information on water flow restriction and associated ecological impacts at 18 crossings within the Sandy Neck ACEC and greater watershed. These findings can be used as a baseline to identify and inform future restoration projects. For sites identified as priorities for restoration, next steps may include: 1) creating a hydrologic and hydraulic model to understand the hydrodynamics at a site under current and future conditions and with improved crossing structures (such as the Woods Hole Group study conducted for Maraspin Creek, sites B25 [pg. 39] and B26 [pg. 41] in Barnstable); 2) soliciting buy-in and input from property abutters when exploring the feasibility of a restoration project; and 3) pursuing funding options for further assessment and restoration efforts.

The characteristics of a tidal crossing (daily fluctuations in tides, mixture of salt and freshwater, coastal flooding, and sea level rise) make these sites complex and can potentially increase the impact a crossing has on ecological function. The sites assessed in Tier 3 should be a higher priority for further assessment of restoration feasibility, given that the data from this report indicate that they constrict tidal flow. Sites not assessed in Tier 3 should be targeted for water level logger installation, as hydrograph data are crucial to setting a baseline for the level of tidal flow restriction and establishing restoration priorities. This report provides important information to help prioritize future data collection efforts, especially for sites selected for Tier 2 assessment and identified as needing more information (such as sites S7 [pg. 12] and B7 [pg. 33]).

Accessibility was an extremely important factor when selecting crossings for further assessment. The ability to take measurements of both the creek and the crossing was crucial for the Tier 2 data collection, so an inability to access the structure and/or creek ruled out Tier 2 assessment at a crossing. For future assessment efforts, the use of chest waders and kayaks should be considered when attempting to collect the type of quantitative data collected in the Tier 2 and Tier 3 assessments. These pieces of equipment may be useful for accessing crossings that were inaccessible using only knee boots as part of this study.

Prioritizing the replacement of crossings that impede water flow makes sense from an ecological perspective but also to improve the resiliency of transportation infrastructure. Degraded and undersized crossing structures can result in increased erosion as water pools around instead of moving through the crossing, which over time can lead to major structural damage of the crossing itself and surrounding roadway. Aging structures also are more likely to clog or fail, which can lead to major damage, and undersized crossings increase the risk of flooding to roadways and surrounding properties, especially during storm events (Levine 2013; Steckler et al. 2017). These effects may be further exacerbated with climate change impacts, such as sea level rise and increased precipitation (Horton et al. 2014; Resilient MA 2017).

Coordination with municipal decision makers and transportation officials should be incorporated into any assessment or restoration planning process. Linking transportation infrastructure improvement projects and crossing restoration work can be a good way to leverage funding and can provide an avenue for projects that not only improve public safety but also improve ecological functioning at a crossing. Local officials should also carefully document the costs of repairs required at crossings for comparison when design and restoration costs are considered for particular sites. Comparing the cost of restoration versus the current, repeated costs of repairs can be critical when determining the feasibility of a restoration project.

The field component of this assessment was conducted in the spring and fall of 2018, following a blizzard in January 2018 that resulted in the highest high tide ever recorded (15.16 feet) at the National Oceanic and Atmospheric Administration (NOAA) tide gauge station in Boston (NOAA, 2018), as well as several northeasters in March 2018. The serendipitous timing of the assessment resulted in the opportunity to observe and record the impacts these storms had on crossings within the Sandy Neck ACEC and greater watershed. The effects of these storms on crossings and the surrounding ecology may also reflect future conditions with sea level rise, increasing precipitation and coastal flooding, and other climate change impacts. Therefore, it is critical that climate change is considered when investigating the feasibility of restoration at a crossing site.

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Appendices

Appendix A: Identification of Crossing Sites

Multiple sources for potential crossings were used to identify assessment sites for this report. These sources included the Cape Cod Atlas of Tidally Restricted Marshes (Justus et al. 2001), the Massachusetts Bays National Estuary Program (MassBays) Estuarine Delineation and Assessment 2.0 (MassBays 2017), and the North Atlantic Landscape Conservation Cooperative's (NALCC) North Atlantic Aquatic Connectivity Collaborative (NAACC) Data Center (www.naacc.org/naacc_data_center_home.cfm). Crossing sites from all three sources were combined into a Geographic Information System (GIS) format, and clipped to the watersheds of Scorton Creek and Barnstable Harbor using ArcGIS Desktop version 10.5.1. The watershed delineations were downloaded from the Cape Cod Commission (CCC) GIS open data hub (Reynolds 2018). Through this process, over 60 crossings were identified for the Sandy Neck ACEC. Crossings were given an ID consisting of a letter and number, using the first letter of the town in which it is located, and then numbering consecutively from west to east (unless a new crossing was identified that was not in any of the reviewed sources). These sites were then narrowed down to the 18 crossings assessed in this report using the following methods.

In the MassBays Estuarine Delineation and Assessment (2017), tidal crossings were identified as intersections of a road and stream that fall within salt marsh habitat as defined by the MassGIS DEP Wetlands layer, which can be found on the MassGIS website (www.mass.gov/orgs/massgis-bureau-of-geographic-information). Crossings that were classified as tidal through this process were given preferential consideration when identifying sites for this assessment. To narrow down the sites to a number that was feasible for assessment for this project, all sites were filtered based on whether they were located on a publically owned road. Next, sites were filtered based on the presence of at least one publically owned surrounding parcel. This filtering process narrowed the number of crossings to 25. Officials from the towns of Sandwich, Barnstable, and Yarmouth were then consulted to help identify sites that were either priorities for the town or had issues that could impede assessment. Sites that presented potential issues for assessment were removed from consideration. The Bridge Creek salt marsh restoration site, which consisted of culvert replacements on the Massachusetts Coastal Railroad in 2003 and Route 6A in 2005, was also removed from consideration. Through this process, a total of 18 crossings were selected for assessment.

Appendix B: Tier 1 Assessment Protocol, Scoring System, and Field Datasheet

Field Assessment Protocol

The protocol for the Tier 1 field assessment was adapted predominantly from the Cape Cod Commission (CCC) Atlas of Tidal Restricted Marshes (Justus et al. 2001), and the North Atlantic Aquatic Connectivity Collaborative (NAACC) Tidal Stream Crossing Field Data Form Instruction Guide (Jackson 2017). The information below describes the protocol used for field assessment of the Tier 1 crossings.

The following attributes were recorded using a GIS prior to field sampling:

- The associated NAACC crossing code
- Road name
- Affected waterbody

Assessments were conducted as close to low tide (+/- 2 hours) as possible. The GPS coordinates for each crossing were recorded using a handheld GPS unit. The degree of accessibility of the structure for visual inspection and physical measurement was assessed for each site, especially to inform Tier 2 assessment work.

Using a refractometer, the salinity was recorded for both the upstream and downstream portions of the crossing.

The following photos were taken:

- Upstream area from the crossing
- Downstream area from the crossing
- Upstream crossing structure
- Downstream crossing structure

The following information was collected based on the crossing structure and upstream and downstream areas (based on Jackson 2017).

- Crossing type (Culvert; Multiple culvert; Bridge; Bridge adequate; Ford; Buried stream; No crossing; Removed crossing; No upstream channel; Other)
- Crossing condition (New; OK; Poor; Failing; Unknown)
- Number of culverts/bridge cells
- Upstream structure type (Using the "Structure Type Definitions" provided below on pages 68 and 69 and adapted from Jackson 2017)
- Upstream structure material
- Downstream structure type (Using the "Structure Type Definitions" provided below on pages 68 and 69 and adapted from Jackson 2017)
- Downstream structure material
- Vegetation above vs. below the structure (Using the rubric provided below on page 69 and adapted from Jackson 2017)

If more than one culvert/bridge cell was present at a site, the structure type and material for each structure was recorded. Structures were numbered from left to right while looking downstream toward the upstream side of the structure.

The following attributes were scored from 1 to 5 (1= Dominant, 2= Significant, 3= Moderate, 4= Minor, 5= None.) for both the upstream and downstream sides of the crossing (based on the Cape Cod Atlas of Tidally Restricted Salt Marshes).

- Clogged structure
- Structure submerged at high tide
- Ponded water at the structure
- Scouring basin
- Bank erosion
- Prevalence of *Phragmites australis*
- Vegetation die-back
- Marsh slumping

Structure Type Definitions (adapted from Jackson 2017)

Round Culvert- This is a circular pipe. It may or may not have substrate inside. It may be compressed slightly in one dimension, and should be considered round unless it is truly squashed so that it reflects a *pipe arch/elliptical culvert* shape described below.

Pipe Arch/Elliptical Culvert- This is essentially a squashed *round culvert*, where the lower portion is flatter, and the upper portion is a semicircular arch, or more of a pure ellipse. It may or may not have substrate inside.

Open Bottom Arch Bridge/Culvert- This structure will often look like a *round culvert* on the top half, but it will not have a bottom. There will be some sort of footings to stabilize it, either buried metal or concrete footings, or concrete footings that rise some height above the channel bottom. There will be natural substrate throughout the structure. To distinguish between an embedded *pipe arch culvert* and an *open bottom arch*, note that the sides of the *pipe arch* curve inward in their lower section, while the sides of the *open bottom arch* will run straight downward into the streambed substrate or to a vertical footing. Beware of confusion between an *open bottom arch* and an embedded *round culvert*; *open bottom arches* tend to be larger than most *round culverts*. This shape could also be selected for certain bridges that have a similar arched shape and are not well represented by other bridge types.

Box Culvert- These structures are usually made of concrete or stone, but sometimes of corrugated metal with a slightly arched top. Typically, they have a top, two sides, and a bottom. A box culvert *without* a bottom, called a bottomless box culvert, should be classified as a *box/bridge with abutments*. If you cannot tell if the structure has a bottom, classify it as a *box/bridge with abutments*.

Bridge with Side Slopes- This is a bridge with angled banks up to the bottom of the road deck. This type will have no obvious abutments, though they may be buried in the road fill.

Box/Bridge with Abutments- This is a bridge or bottomless box culvert with vertical sides.

Bridge with Side Slopes and Abutments- This is a bridge with sloping banks and vertical abutments (typically short) that support the bridge deck.

Ford- A ford is a shallow, open stream crossing that may have a minimal structure to stabilize where vehicles drive across the stream bottom.

R*emoved*- Select this option when the structure is no longer present.

Unknown- Select when a structure's shape is unidentifiable for any reason. Typically, the inlet shape may be unidentifiable because it is submerged or completely blocked with debris.

Clogged/Collapsed/Submerged- Select this option if the structure outlet is either full of debris, collapsed, or completely underwater (not usually all three). This may be found in places where beavers or debris have plugged a structure inlet so completely that water has backed up and covered the outlet, or where a crossing has collapsed to the point that it cannot be measured at its outlet.

Vegetation Above Versus Below Definitions (adapted from Jackson 2017)

The vegetative communities above and below the crossing were compared and the most appropriate characterization from the list below was chosen based on vegetative structure (trees, shrubs, and herbaceous plant) and species composition. Transitions from saltwater to freshwater plants were considered particularly significant.

Comparable: Vegetative structure and species composition are not noticeably different.

Slightly different: Differences in vegetative structure and species composition are evident, but small.

Moderately different: Differences in vegetative structure and species composition are obvious and substantial, but similarities remain.

Very different: Vegetative structure and species composition are so different that different vegetative communities occur above and below the crossing. This typically occurs where there is a salt marsh below and a freshwater wetland above the crossing.

Unknown: Choose this option if it is impossible to assess vegetation above and/or below the crossing, due to time of year or lack of a vantage point for observations.

GIS Assessment Protocol

The GIS component of the Tier 1 assessment was adapted from New Hampshire's Tidal Crossing Assessment Protocol (Steckler et al. 2017). The analysis consisted of calculating the size of the potential salt marsh migration area and number of potentially adversely impacted low-lying properties in the upstream affected area of each crossing. The upstream affected area was calculated using the United States Geological Survey (USGS) StreamStats tool, which calculates sub-watersheds for user-selected points on streams (www.usgs.gov/mission-areas/water-resources/science/streamstats-streamflow-statistics-and-spatial-analysis-tools?qt-science_center_objects=0#qt-science_center_objects). Using the Sea Level Affecting Marshes Model (SLAMM) that was run in 2016 for the state of Massachusetts, the potential salt marsh migration acreage for the upstream affected area was calculated with 1.385 meters of sea level rise by 2100. The SLAMM model provides results that indicate the change in coastal wetland coverage with varying user-defined sea level rise scenarios, which can be used to predict potential salt marsh migration. A rise in sea level of two feet was then applied to the upstream affected area and the number of impacted properties was calculated for each crossing. For the adverse impacts to low-lying infrastructure calculation, the sea level rise and property data were acquired from the NOAA Coastal Inundation and Standardized Assessor's Parcels datasets available on the MassGIS website (www.mass.gov/orgs/massgis-bureau-of-geographic-information). A sea level rise of two feet was used for the adverse impacts to infrastructure calculation because it was the closest scenario to the 1.7 feet scenario used in Steckler et al. (2017). This value was chosen because "it hedges against extreme rises and accounts for low and moderate rises at a relevant time-scale" (Steckler et al. 2017). The results from this analysis were used in the ranking of the Tier 1 crossings, based on the scoring system described below.

Scoring System

A scoring system to rank the 18 crossings assessed in Tier 1 was created using a combination of field data and GIS analysis results. The field data that was incorporated into the scoring system was based on the visual indicators and the comparison between the upstream and downstream vegetation. Using the 1-5 scale for each visual indicator described above and adapted from Justus et al. (2001), a numerical score was calculated for each crossing, with a high score of 80. Using this system the higher the score, the lower the level of restriction caused by the crossing resulting in fewer impacts to ecological functioning at the site. Therefore, the crossings with low scores were determined to be higher priorities for further assessment in Tier 2.

The vegetation comparison upstream versus downstream was used to score each site based on methods used in Steckler et al. (2017). Using the vegetation comparison options defined in the Field Assessment Protocol, each crossing was given a score based on Table B1 on page 72. Based on this matrix, the higher a crossing's score, the higher the likelihood that it is causing a restriction. Therefore, the crossings with high scores were determined to be higher priorities for Tier 2 assessment.

The two components of the GIS analysis were assigned scores based on the system used in Steckler et al. (2017). Based on the size of the potential salt marsh migration acreage in the upstream affected area, scores were assigned to each crossing based on the criteria in Table B2 on page 72. A score was also given to each crossing using the criteria in Table B3 on page 73, based on the number of impacted properties in the upstream affected area. For both of these parameters, higher scores indicate greater potential restoration area and feasibility of restoration, resulting in higher Tier 2 assessment rankings.

The visual indicator, vegetation comparison, and GIS analysis scores were all considered in the selection of sites for assessment in Tier 2. The scores were not combined to form a composite score, but were compared across the 18 crossings to determine the ecological impact, acreage of potential salt marsh restoration, and restoration feasibility at each site. This approach helped to create a holistic view of the restoration potential at each site, which in addition to accessibility, provided key information in the prioritization of sites for further assessment.

Table B1. The vegetation comparison matrix associated with the vegetation evaluation parameter. Adapted from Steckler et al. (2017).

Vegetation Comparison Matrix			
	The plant community appears to be the same on both sides of the crossing; both sides are occupied by tidal marsh vegetation of similar species and structure	The upstream and downstream plant communities appear different (i.e., two different expressions of tidal marsh on either side of the crossing)	The upstream and downstream plant communities differ; one side is tidal marsh, while the other side is unvegetated, open water, un-naturally modified (i.e., armored, or channeled), or occupied by a completely different structure or suite of plants
Native plant species only	1 point	3 points	5 points
Invasive plants are prevalent over a wide area of the marsh plain on both sides of the crossing*	No Score	No Score	No Score
Invasive plants are present within the marsh plain near one side of the crossing, and absent (or present in a constricted area close to the crossing) on the other side	3 points	4 points	5 points
* If invasive species are prevalent in the plant community on both sides of the crossing, the crossing may not be the only issue affecting the vegetation. Under these conditions a vegetation comparison is unlikely to clearly inform the evaluation of inundation and salinity conditions at a site.			

Table B2. The evaluation scores and criteria for the salt marsh migration parameter. Adapted from Steckler et al. (2017).

Evaluation Score	Evaluation Criteria
1	0-1 acres of potential salt marsh increase
2	1-2 acres of potential salt marsh increase
3	2-5 acres of potential salt marsh increase
4	5-10 acres of potential salt marsh increase
5	>10 acre potential salt marsh increase

Table B3. The adverse impacts evaluation scores and criteria. Adapted from Steckler et al. (2017).

Evaluation Score	Evaluation Criteria
1	>5 impacts identified
2	3-5 impacts identified
3	2 impacts identified
4	1 impact identified
5	No impacts identified

Field Datasheet

Tier 1 Tidal Stream Crossing Assessment Datasheet

Crossing ID _____________ **Crossing Code (NAACC)** _______________________________

Lat. ____________________________________ **Lon.** ____

Tidal Conditions Low Mid/Low Mid Mid/High High **AND** Incoming Outgoing Slack

Observer(s) ____ **Town** ____________ **Date Observed** __________

Start Time ________ **End Time** ________ **Road Name** _________________ **Affected Waterbody** _________________

Road Type: □ Multilane □ 1 or 2 lane paved □ Unpaved road □ Driveway □ Trail □ Railroad

Visible Utilities: □ None □ Overhead wires □ Water/sewer pipe □ Gas line □ Other ____________________

Accessible: □ Yes □ No

Crossing Type: □ Culvert □ Multiple Culvert □ Bridge □ Bridge adequate □ Ford □Buried stream

□ No crossing □ Removed crossing □ No upstream channel □ Other (explain) _______________________

Crossing Condition: □ New □ OK □ Poor □ Failing □ Unknown **Number of culverts/bridge cells:** ____________

Upstream Structure Type: □ 1 □ 2 □ 3 □ 4 □ 5 □ 6 □ 7 □ Ford □ Removed □ Clogged/Collapsed/Submerged

□ Unknown

Upstream Structure Material: □ Concrete □ Stone □ Wood □ Metal-smooth □ Metal-corrugated □ Plastic smooth

□ Plastic-corrugated □ Other (explain) __________________

Downstream Structure Type: □ 1 □ 2 □ 3 □ 4 □ 5 □ 6 □ 7 □ Ford □ Removed □ Clogged/Collapsed/Submerged

□ Unknown

Downstream Structure Material: □ Concrete □ Stone □ Wood □ Metal-smooth □ Metal-corrugated □ Plastic smooth

□ Plastic-corrugated □ Other (explain) __________________

Vegetation Above/Below: □ Comparable □ Slightly different □ Moderately different □ Very different □ Unknown

Salinity (ppt) __________

Visual Indicators*	Upstream	Downstream
Clogged Structure		
Structure Submerged at High Tide		
Ponded Water at Restriction		
Scouring Basin		
Bank Erosion		
Phragmites australis		
Vegetation Die-Back		
Marsh Slumping		

*Score 1-4. 1= Dominant. 2= Significant. 3= Moderate. 4= Minor 5= None.

Photo File #s: Upstream Structure _______________ Upstream _______________ Downstream Structure _______________

Downstream _______________ Other ____

Comments: ____

Appendix C: Tier 2 Field Datasheet (adapted from Jackson 2017 and Steckler et al. 2017)

Tier 2 Tidal Stream Crossing Assessment Datasheet

General Information

Crossing Code ______________________________ **Local ID** ______________________

Date observed ____________________ **Start time** ______________ **End time** ________________

Tide stage: ☐ Low slack tide ☐ Low ebb tide ☐ Low flood tide ☐ Unknown ☐ Other ____________

Tide prediction: Time of nearest low tide ______________ Tide chart ________________________

Flow conditions: ☐ Dewatered ☐ Unusually low ☐ Typical low flow ☐ Moderate flow ☐ High flow

Observer(s) ____

Crossing Data

Stream type: ☐ Salt marsh creek ☐ Salt/brackish flow-through stream ☐ Freshwater tidal

Accessible for Tier 3 Assessment: ☐ Yes ☐ No

Alignment: ☐ Flow aligned ☐ Skewed (> 45∘) **Road Fill Height** ______ **Road flooded at high tide**: ☐ Yes ☐ No

Downstream: Channel width ______________ Pool width ______________ Tidal range ________________

Upstream: Channel width ______________ Pool width ______________ Tidal range ________________

Crossing Notes/Comments:____

____

____

____

____

____

Structure # ___________ *of* _____________

Downstream structure dimensions: A. Width __________ B. Height _________C. Substrate/Water Width______________

D. Water Depth_________ E. Abutment Height (Type 7 bridges) ________High Tide Water Depth__________
Spring Tide Water Depth ___________

Downstream structure perch: Low tide______________ High tide __________

Downstream side armoring: ☐ None ☐ Not extensive ☐ Extensive

Upstream structure dimensions: A. Width _______B. Height________ C. Substrate/Water Width ________
D. Water Depth_______ E. Abutment Height (Type 7 bridges) __________High Tide Water Depth _________
Spring Tide Water Depth ___________

Upstream structure perch: Low tide __________ High tide __________

Upstream side armoring: ☐ None ☐ Not extensive ☐ Extensive

Structure length (upstream structure to downstream structure):____

Structure substrate: ☐ None ☐ Muck/silt ☐ Sand ☐ Gravel ☐ Cobble ☐ Boulder ☐ Bedrock ☐ Unknown

Substrate matches stream: ☐ None ☐ Comparable ☐ Contrasting ☐ Not appropriate (e.g. rip rap) ☐ Unknown

Substrate coverage: ☐ None ☐ 25-50% ☐ 50-75% ☐ 75-99% ☐ 100% ☐ Unknown

Scour at Downstream Structure: ☐ None ☐ Culvert ☐ Footer ☐ Wingwalls ☐ Abutment ☐ Headwall ☐ Armoring

Severity of Downstream Scour: ☐ None ☐ Low ☐ Medium ☐ High

Scour at Upstream Structure: ☐ None ☐ Culvert ☐ Footer ☐ Wingwalls ☐ Abutment ☐ Headwall ☐ Armoring

Severity of Upstream Scour: ☐ None ☐ Low ☐ Medium ☐ High

Scour in Structure: ☐ None ☐ Culvert ☐ Footer ☐ Abutment ☐ Channel ☐ Armoring

Severity of Scour in Structure: ☐ None ☐ Low ☐ Medium ☐ High

Structure slope (relative to channel): ☐ Comparable ☐ Substantially flatter ☐ Substantially steeper

Other barrier type: ☐ None ☐ Sediment blockage ☐ Debris ☐ Fencing ☐ Pipes ☐ Deformation ☐ Freefall

☐ Other (describe) ____

Other barrier severity: ☐ None ☐ Minor ☐ Moderate ☐ Severe ☐ No aquatic passage

Dry passage for terrestrial wildlife: ☐ Yes ☐ No **Height above dry passage** __________________________

Structure Notes/Comments:____
____
____
____

Appendix D: Tier 3 Field Datasheet (adapted from Kennedy et al. 2018 and Curdts 2017)

Tidal Crossing Assessment Water Level Loggers Data Sheet SITE: ______________ STAFF: ___________________

Upstream Logger

Hobo Serial #	
Housing Label	
Distance from reference to hole (m)	
Type:	**U20L or U20-ti**
Deployment Date/Time	
Retrieval Date/Time	
Reference & Salinity	
Date/Time	
Salinity (ppt)	
Reference (m)	

Notes/Location Description:

Downstream Logger

Hobo Serial #	
Housing Label	
Distance from reference to hole (m)	
Type:	**U20L or U20-ti**
Deployment Date/Time	
Retrieval Date/Time	
Reference & Salinity	
Date/Time	
Salinity (ppt)	
Reference (m)	

Notes/Location Description:

General Info

Launch date/time (DLT GMT-4)	
sampling interval (min)	15
Bucket Test date/time and depth (m)	
pre-deployment	
post-retrieval	

General notes: