FINAL DRAFT DOCUMENT

WOODS HOLE GROUP FOR EARTH, FROM SPACE

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MEMORANDUM

DATE July 17, 2019

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Little Pamet River, Truro, MA– Sediment & Vegetation Assessment and Restoration of the Little Pamet River System

1. Introduction

Little Pamet River, which includes wetland areas upstream of Corn Hill Road in Truro, MA appears to have experienced changes over the last 10-15 years resulting in concerns from nearby residents and owners of the adjacent Perry Farm.

A cursory review of historical aerial imagery shows the channels within Little Pamet River between Corn Hill Road and Castle Road have been filling in with sediment and/or organic detritus, which has led to changes in vegetation and reduced drainage of the system. Anecdotal information provided by nearby landowners confirm these changes including: 1) the shallowing and disappearance of open water in the river channel, 2) no longer able to navigate the river by kayak, 3) spread of invasive vegetation, 4) loss of avian/terrestrial wildlife, and 5) impeded drainage which has caused flooding of agricultural lands adjacent to the marsh.

The Little Pamet River originates east of State Route 6 near the intersection of Long Nook Road and Atwood Road at Long Nook Meadows Farm and flows westward under Castle Road and then Corn Hill Road before draining into Pamet Harbor. A 280-foot long, 24-inch diameter pipe culvert connects the marsh upstream of Corn Hill Road to the salt marsh adjacent to Pamet Harbor. The downstream side of the culvert is equipped with a hinged steel flapper valve, which is intended to allow the marsh to freely drain into Pamet Harbor while restricting any tidal flow from entering the upstream, freshwater marsh system.

The Town recently conducted survey work and an aerial drone survey of the Little Pamet River system to obtain the latest elevations and imagery. Additionally, the Association to Preserve Cape Cod collected field data to inform an initial assessment of potential factors that may have caused changes within the Little Pamet River system (Horsely, Muramoto, DePuy, & Wobst, 2018). Their assessment showed the flap gate on the downstream side of the culvert connecting Little Pamet River to Pamet Harbor was failing and allowing saline water to infiltrate the freshwater marsh upstream of Corn Hill Road. Additionally, the field data confirmed the buildup of material upstream of the culvert and the continued spread of invasive species (*Phragmites australis*).

Of primary concern to the Town is the drainage restriction and failing flapper valve at Corn Hill Road. A hydrologic and hydraulics (H&H) study was conducted (Woods Hole Group, 2019) to assess potential culvert replacement/flow control alternatives at Corn Hill Road to allow better drainage over the lifetime of the structure. The culverts at the Castle Road and Route 6 crossings were also assessed as part of this investigation. This study showed:

1. The optimal culvert sizes at Corn Hill and Castle Road are 4-foot diameter pipes (or equivalent) to limit peak water levels and provide sufficient drainage during both extreme coastal and rainfall events with a replaced flapper valve at Corn Hill Road. Existing invert elevations can be maintained.

2. Aggradation of the channel between Corn Hill Road and Castle Road has limited flow conveyance creating a weir-like, perched effect on the upstream water levels, and is inhibiting drainage.

To further investigate the aggradation and changes that have occurred in the lower marsh between Corn Hill Road and Castle Road, the Town requested two (2) additional tasks including a sediment and vegetation assessment together with an evaluation of potential restoration alternatives. The potential for ecological restoration of previously existing habitat could be considered as a secondary benefit associated with the culvert replacement.

These additional tasks will better inform potential restoration alternatives and, with the establishment of restoration goals, help guide the Town with subsequent phases of the project and in selecting a preferred alternative for design and permitting.

This memorandum discusses the work conducted for these additional tasks and identifies potential restoration alternatives for the Town's consideration. The selection of a preferred restoration alternative will require further stakeholder involvement and consultation with the Town.

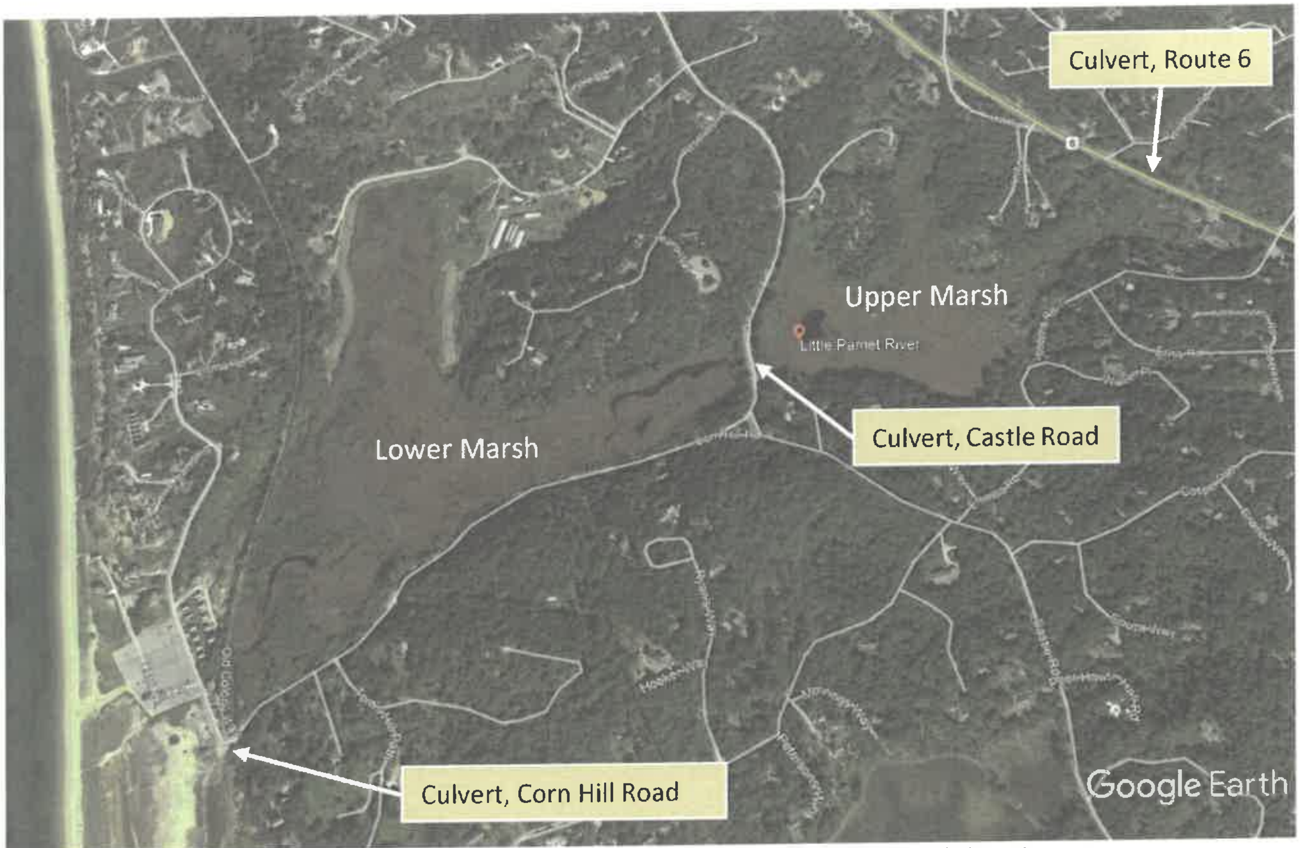

Figure 1.Aerial image of Little Pamet River (Date of imagery: 10/5/2018)

2. Sediment and Vegetation Assessment

As part of this assessment, Woods Hole Group conducted a field assessment to identify locations of sediment and vegetation that may be inhibiting or blocking flow in the Little Pamet River system. A desktop study was first conducted to analyze the aerial drone survey data provided by the Town and collected by the Provincetown Center for Coastal Studies (CCS) during the winter of 2018-2019 to identify locations of potential blockages and dense vegetative cover that would be visited in the field investigation. The locations identified for field investigations are shown in Figure 2.

The field verification included documenting debris locations and types of vegetation using GPS survey equipment and digital photographs. A Trimble R8 real-time kinematic (RTK) GPS was used to collect channel cross sections of the river bathymetry that the drone survey was not able to capture. The data derived from the field verification together with the drone survey were used to develop a vegetation map using ESRI ArcGIS and details of the blockages within the Little Pamet River System. An updated map of vegetation types verified during the field investigation is included in Figure 3.

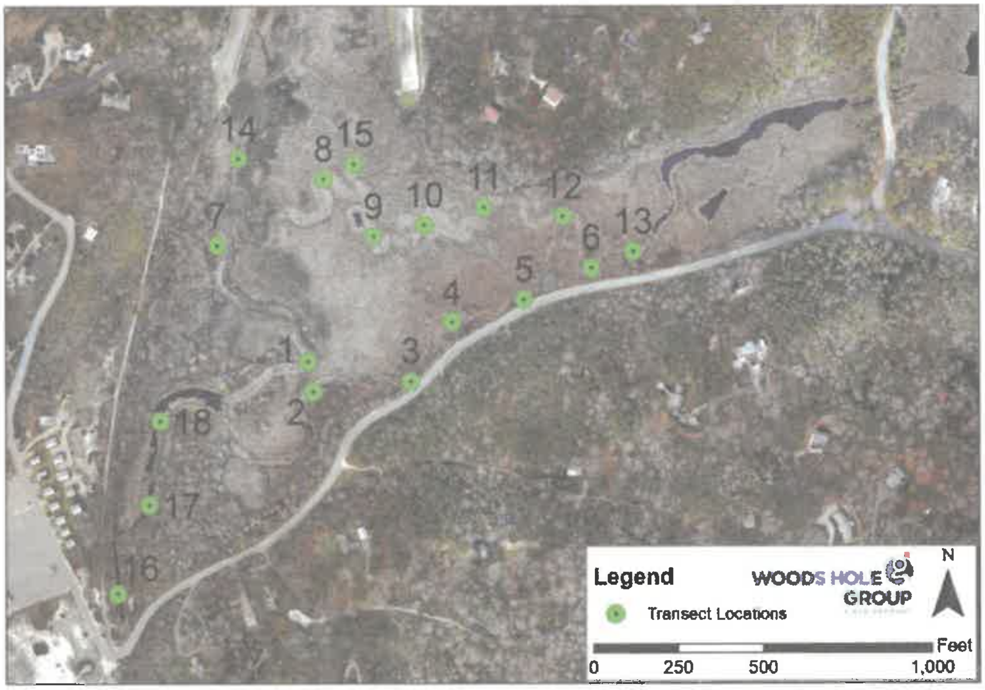

Figure 2. Locations identified for field investigation within lower marsh of Little Pamet River

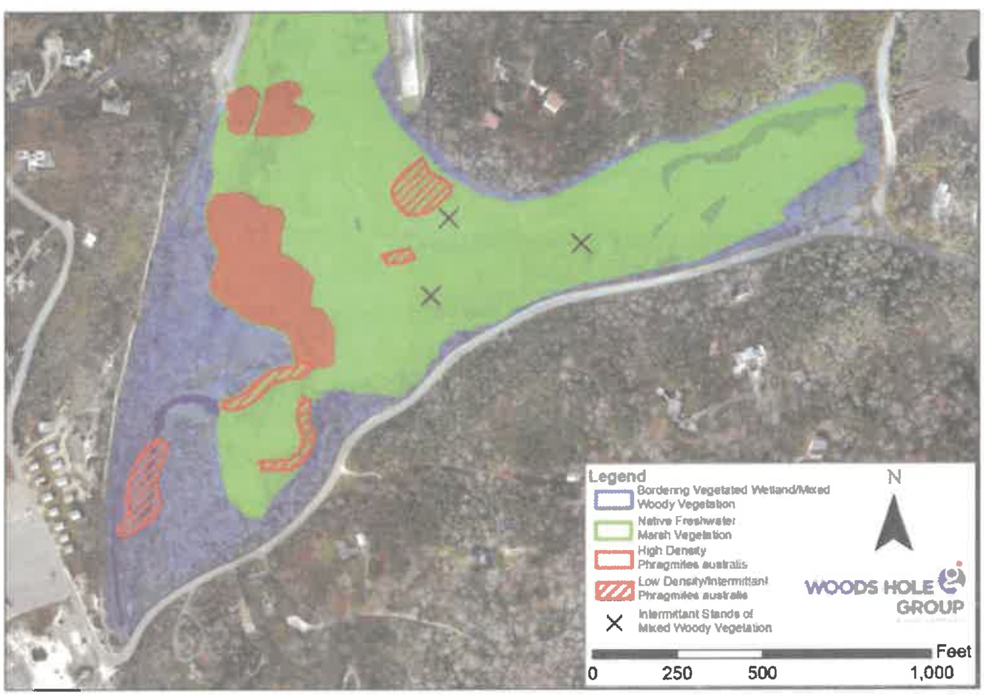

Figure 3. Updated vegetation mapping within the lower marsh of Little Pamet River

Table 1 lists the vegetation types identified during the field investigation and quantifies the acreage of each respective type of vegetation to serve as a baseline for future surveys and document for the permitting process. Additionally, a catalogue of conditions at each location visited in the field is included as Attachment A. This catalogue includes digital photographs and the surveyed channel cross-section at each location.

Table 1. Wetland vegetation types and areas within the lower marsh of Little Pamet River

Type of Vegetation Observed	Area (acres)
Phragmites australis (high density)	2.95
Phragmites australis (low density/intermittent)	1.40
Native Freshwater Marsh Vegetation	32.01
Bordering Vegetated Wetland / Native Mixed Woody Vegetation	12.91
Total	**49.27**

Figure 4 shows the 2005 USGS imagery for the lower marsh of Pamet River (top panel) and the historical channel extents (mapped from 2005 USGS imagery) for the main and secondary channels connecting to the upper portion of the marsh overlaid on the latest 2018-2019 aerial image acquired by CCS (bottom panel). Figure 4 also shows the RTK GPS surveyed channel cross-sections collected as part of this study. The change in channel extents and amount of infilling/vegetation growth over the last 10+ years is clearly evident in these images.

In order to better quantify the amount of aggradation within the channels and to help inform potential restoration alternatives, the collected channel survey data were used to develop the current-day bathymetry within the extents of the historical channel. Channel elevations were derived through linear interpolation of the collected channel cross-section data.

Based on the collected channel survey data, the existing channel invert elevations were determined. These are included in Table 2 along with the existing culvert invert elevations. The last column in Table 2 lists recommended target invert elevations for the channels within the lower marsh of Little Pamet, as well as downstream of the culvert at Corn Hill Road.

Table 2. Existing and recommended invert elevations for the lower marsh of Little Pamet River

Culvert/Channel	Downstream Invert Elevation (ft, NAVD88)	Upstream Invert Elevation (ft, NAVD88)	Existing Invert Elevation (ft, NAVD88)	Target Invert Elevation (ft, NAVD88)
Corn Hill Rd culvert	-1.3	-1.0	NA	NA
Castle Hill Rd culvert	-0.45	-0.45	NA	NA
Lower Little Pamet main channel	NA	NA	0.6	-0.6
Lower Little Pamet secondary channel	NA	NA	1.1	-1.0
Channel to Pamet Harbor, downstream of Corn Hill Road	NA	NA	0.4	-1.5

Figure 4. 2005 aerial image (top panel) and 2019 aerial image (lower panel) of the lower marsh of Little Pamet River. The lower panel shows the 2005 channel extents delineated in black and both panels show the surveyed cross sections.

Based on the characterization of vegetation and collected survey data, it is apparent that the lower basin of Little Pamet River is going through a natural succession to a freshwater wetland. With no tidal exchange and limited baseflow into the system, the channels are in-filling with deposited sediment and organic detritus. This has allowed for vegetation to migrate into and establish within the existing channels. With the change in seasons and vegetation die-off, there is a cyclical pattern allowing for build-up of organic matter and propagation of vegetation growth. Over time, and without intervention, it is likely that the Little Pamet River basins will allow for the establishment of higher densities of native woody vegetation and eventual succession to an Atlantic white cedar/red maple swamp.

3. Development of Restoration Alternatives

A set of restoration alternatives was developed with the primary goals of 1) facilitating drainage of the Little Pamet River system, and 2) reestablishing open water channels in the lower basin. These set of alternatives should be revisited upon receipt of stakeholder input and as restoration goals are further refined. Each alternative is detailed further below together with feasibility of construction, permitting, and required maintenance in Table 3. Figures 5 and 6 show the channel reaches identified for improvement in the different alternatives.

Alternative 1 – Replace culverts per H&H study recommendations & dredge outlet channel to Pamet Harbor
The H&H study (Woods Hole Group, 2019) conducted to assess the optimal culvert size at Corn Hill and Castle Road show 4-foot diameter pipes (or equivalent) would be required at both locations to limit peak water levels and provide sufficient drainage during both extreme rainfall events. Existing invert elevations can be maintained.

Alternative 2 – Replace culverts/dredge outlet channel & restore portion of main channel in lower Little Pamet
This alternative builds on Alternative 1 and includes restoring the channel to the northern reach of the lower Little Pamet basin to facilitate drainage of this area.

Alternative 3– Replace culverts/dredge outlet channel & restore portion of main channel & secondary channel in lower Little Pamet
This alternative builds on Alternative 2 and includes restoring the secondary channel that runs along the Corn Hill Road at the southern extent of the lower Little Pamet basin and connects to the upstream channel.

Alternative 4– Replace culverts/dredge outlet channel & restore all of main channel & secondary channel in lower Little Pamet
This alternative builds on Alternative 3 and includes restoring all of the main channel that connects to the upstream channel.

Alternative 5– Replace culverts/dredge outlet channel & regulate tidal flow into Little Pamet River
This alternative includes replacing the culvert structures at Corn Hill and Castle Road, and restoring tidal flow within the Little Pamet River system using an alternative tide gate control. A sluice-flap combination tide gate would regulate tidal flow under typical and coastal storm conditions to limit adverse flooding impacts while allowing the system to optimally drain (see Figure 7).

Table 3. Restoration Alternative Details – Little Pamet River

	Alternative 1	Alternative 2	Alternative 3	Alternative 4	Alternative 5
Components	• Replace Corn Hill Road culvert with 4-foot diameter concrete pipe, 255 feet in length. • Install flap gate at seaward end of Corn Hill Road culvert to prevent tidal flow. • Replace Castle Road culvert with 4-foot diameter concrete pipe, 60 feet in length. • Dredge outlet channel seaward of Corn Hill Road to -1.5 feet NAVD88 (approx. 1500 feet, 0.56 acres, with estimated volume of 1440 cubic yards).	• Alternative 1 components. • Clean out main channel to northwestern reach to -0.6 feet NAVD88 (approx. 825 feet, 0.8 acres. with estimated volume of 1500 cubic yards). • Treatment and removal of high density and intermittent phragmites. • Total amount of restored channel is 2325 feet, 1.35 acres, and 2950 cubic yards.	• Alternative 1 & 2 components. • Clean out secondary channel to -1.0 feet NAVD88 (approx. 2675 feet, 1.7 acres, with estimated volume of 3700 cubic yards). • Total amount of restored channel is 5000 feet, 3.0 acres, and 6650 cubic yards.	• Alternative 1, 2, and 3 components. • Clean out mid-upper portion of main channel to -0.6 feet NAVD88 (approx. 1850 feet, 1.5 acres, with estimated volume of 3165 cubic yards). • Total amount of restored channel is 6850 feet, 4.5 acres, and 9,800 cubic yards.	• Alternative 1 components. • Install a sluice-flap combination gate at the seaward end of Corn Hill Road culvert (rather than a flap gate) for an active solution that limits the entrance height of the culvert to regulate flow and flaps open to allow full culvert flow when the system is draining (Figure 7). • Treatment of high density phragmites.
Feasibility	• Likely feasible from a construction and permitting standpoint.	• Likely feasible from a construction and permitting standpoint, although within area mapped as a priority habitat of rare species by NHESP. • Requires review of appropriate and available construction methods to clean out channel & limit impacts on marsh.	• Similar to Alternative 2, although more impacts.	• Similar to Alternative 2, although less feasible from a construction and permitting standpoint as more impacts and hard to access this long interior channel reach	• Likely feasible from a construction and permitting standpoint. • Requires additional outreach and agreement with neighboring stakeholders.
Benefits	• Provides additional drainage capacity at road crossings, but marsh channels would still inhibit drainage of the overall system. • Does not provide for open water channels, lower basin will continue to infill with sediment/ organic matter, and convert to fresh water swamp.	• Provides additional drainage capacity at road crossings and northwest portion of the lower basin. Other marsh channels would still inhibit drainage of the overall system. • Staves off spread of *Phragmites australis*, an invasive species. • Does not provide for continuous open water channel through the lower basin. Other areas will continue to infill with sediment/ organic matter.	• Provides additional drainage capacity and connects to upstream basin to provide drainage of the overall system. • Staves off spread of *Phragmites australis*, an invasive species. • Provides continuous open water channel through the lower basin. Mid-upper portion of basin will continue to infill with sediment/ organic matter.	• Similar to Alternative 3, but more open-water channel with the mid-upper portion restored.	• Restoration of salt marsh habitat, with saline water helping to reduce spread of *phragmites australis*. • Increased flow and flushing would help water quality, create more open-water channels, and reduce the deposition of sediments & detritus material within the marsh channels.
Maintenance	• Continued regular clean out of culvert at Castle Hill Road, as sediment/organic matter builds up on the upstream side during periods when tide gate is closed.	• Continued regular clean out of culvert at Castle Hill Road, as sediment/organic matter builds up on the upstream side during periods when tide gate is closed. • Regular treatment of phragmites to stave off growth according to approved invasive plant management protocol. • Restored channel will likely need to be maintained on a regular interval (on order of 5-10 years).	• Similar to Alternative 2, although larger area of restored channels will need to be maintained on a regular interval.	• Similar to Alternative 2, although larger area of restored channels will need to be maintained on a regular interval.	• Tide gate will require regular inspection and maintenance. • Channels may require maintenance, after slowly reintroducing tidal flow and monitoring vegetation changes/natural channel evolvement.

Figure 5. Portion of outlet channel to Pamet Harbor identified for improvement to better drain Little Pamet River (included with Alternatives 1 through 5).

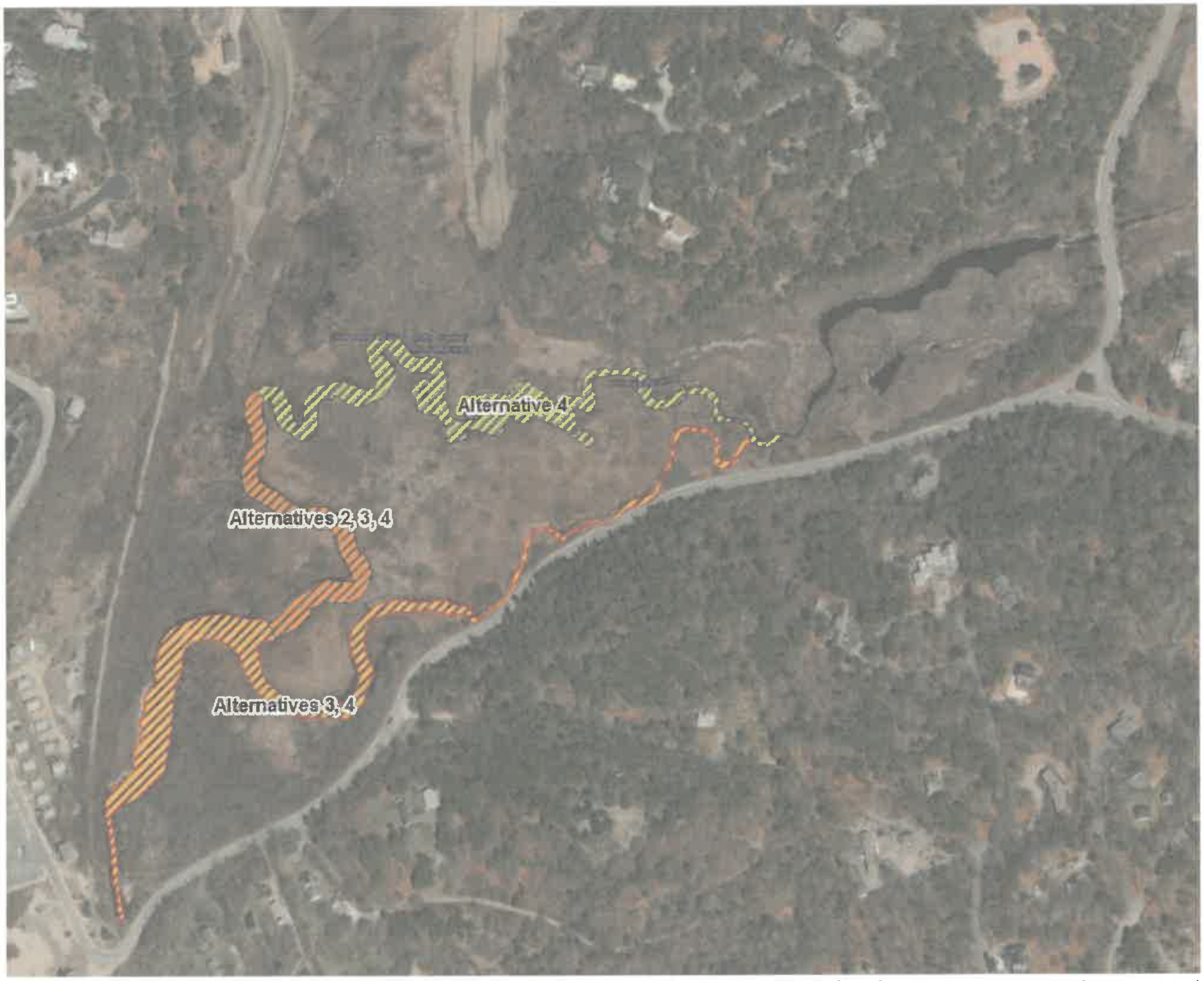

Figure 6. Different channel reaches within the lower marsh of Little Pamet River identified for improvements in the proposed restoration alternatives.

4. Summary and Recommendations

A sediment and vegetation assessment of the lower marsh basin within Little Pamet River was conducted to better understand the changes that have occurred over the last 10-15 years within the marsh system. The study was focused on assessing the channel aggradation and propagation of vegetation (both natural wetland and invasive species) that has led to a reduction in both drainage capacity and open water channels. This study supplements a prior H&H study (Woods Hole Group, 2019) which assessed the culvert structures at the Corn Hill and Castle Road crossings and provided recommendations for resizing when the Town decides to replace. Additionally, this study carried out some of the recommendations made in a preliminary ecological assessment by the Association to Preserve Cape Cod (Horsely, Muramoto, DePuy, & Wobst, 2018).

As part of this assessment, Woods Hole Group conducted a field investigation of sediment and vegetation material that is inhibiting or blocking flow in the Little Pamet River system at eighteen (18) identified locations. Vegetation species were classified, as well as the type of material found within the channels. The assessment also included the collection of bathymetry survey data at each channel location. This information was used to establish a baseline of existing conditions to help compare with future monitoring and for the development of potential restoration alternatives. Five (5) restoration alternatives were identified for the Town's consideration that include replacement of the culverts, channel improvements, and treatment of invasive species. These restoration alternatives were developed with the primary goals of reestablishing open-water channels and improving drainage capacity. Specific findings/recommendations from the study include:

- The channels in the lower marsh have accreted with sediment and organic detritus due to limited flow and drainage capacity.
- The propagation of vegetation within the channels can be attributed to the cyclical seasonal pattern of vegetation die-off, and accumulation of organic plant matter with minimal flow.
- The wetland over time, and without intervention, will likely succeed in to a Atlantic white cedar/ red maple swamp.
- The outlet channel seaward of the Corn Hill Road culvert has also filled in with sediment and is inhibiting drainage of Little Pamet River.
- Further discussion of restoration goals for Little Pamet River, and the involvement of relevant stakeholders will allow the Town to select a preferred, or set of preferred restoration alternatives for further evaluation.
- While Alternative 1 is likely the most feasible and least cost, it does not meet the overall goals of restoring open water channels and improving drainage in the lower marsh basin.
- Alternative 5 would create the most benefits in terms of increased flow within the lower marsh, habitat restoration, and improved water quality, however it is unclear whether the primary landowners would be amenable to such a solution and reintroducing tidal flow.

- Alternatives 2 through 4 all help meet the targeted restoration goals to a varying degree, but it is expected the channels will continue to infill and these will be short-term management alternatives that will require future maintenance.
- A likely next step in advancing restoration alternatives will be to conduct a feasibility study that will include: 1) sediment coring, sampling and analysis to identify disposal/reuse options and to support subsequent permitting, 2) supplemental wetland & resource delineation, 3) supplemental survey, 4) supplemental hydraulic modeling, 5) review of construction methodologies and identification of qualified contractor(s), 6) refined estimates of dredging volumes, 7) regulatory permitting requirements, and 8) order-of-magnitude cost for the design, permitting, and implementation of preferred alternative(s).
- Supplementary to identified alternatives, the Town should continue in their partnership with Barnstable County Mosquito Control and coordinate on needed maintenance of existing channels to ensure sufficient flow conveyance.

Figure 7. Golden Harvest GH-50 sluice-flap combination gate.

References

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FINAL DRAFT DOCUMENT

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MEMORANDUM

DATE March 8, 2019

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Little Pamet River Culverts and Tide Gate, Truro, MA–
Hydrologic & Hydraulic Assessment of the Little Pamet River System

1. Introduction

The Little Pamet River is a complex, tidally influenced wetland system connected to Pamet Harbor in Truro, MA. The Little Pamet River originates east of Route 6 near the intersection of Long Nook Road and Atwood Road at Long Nook Meadows Farm and flows westward under Castle Road and then Corn Hill Road before draining into Pamet Harbor. A 280-foot long, 24-inch diameter pipe culvert connects the marsh upstream of Corn Hill Road to Pamet Harbor. The downstream side of the culvert is equipped with a hinged steel flapper valve, which is intended to allow the marsh to freely drain into Pamet Harbor while restricting any tidal flow from entering the marsh system.

Surficial runoff from precipitation events and groundwater inflow from the Pamet River lens (Masterson & Portnoy, Potential Changes in Ground-Water Flow and their Effects on the Ecology and Water Resources of the Cape Cod National Seashore, Massachusetts, 2005) provide freshwater input into the headwaters of the Little Pamet River. Freshwater at the headwaters of the Little Pamet River flow approximately 1.5 river miles along a sinuous channel before emptying into Pamet Harbor. As the waters flow along the Little Pamet River, there are three (3) channel crossings: at Route 6, Castle Road, and Corn Hill Road where culverts convey flow under each of the roadways.

Woods Hole Group conducted a Hydrologic and Hydraulic (H&H) assessment of the system in support of the Town's efforts to: 1) increase and expedite the drainage of the upstream marsh following rainfall events, 2) mitigate the potential of stormwater impacts on the agricultural lands bordering the lower marsh reach between

Corn Hill Road and Castle Road, and 3) gain increased understanding of the effects of changes in groundwater inflows to the Little Pamet River system.

Increased tidal exchange and drainage in the system would likely help to improve water quality and restore the system to a more natural state, however fields adjacent to the marsh are being cultivated for agricultural use and are likely to preclude the beneficial impacts of marsh restoration in the near future. This assessment was conducted to determine the optimal culvert sizing and inverts that will facilitate drainage while limiting any adverse flooding impacts and potentially provide for future restoration of the upstream salt marsh.

This memorandum is divided into the following sections:

1. This Introduction,
2. Field Data Measurements of Existing Conditions,
3. Estuarine Culvert Model Development of Existing Conditions,
4. Alternative Evaluation and Effects on the Little Pamet River System,
5. Summary of Findings and Recommendations.

2. Field Data Measurements of Existing Conditions

In support of this assessment, Woods Hole Group deployed a system of four (4) AquaTroll data loggers to continuously measure temperature, salinity, and water level at key locations throughout the Little Pamet River estuarine system. The AquaTrolls collected data from November 30, 2018 through January 3, 2019 and were deployed at the locations shown in Figure 1. The instrument designated LPR1 was deployed on a piling at the Truro Harbormaster's office. The instrument designated as LPR2 was deployed on the upstream side of the Corn Hill Road culvert which connects the lower marsh reach of the Little Pamet River to Pamet Harbor. Instruments LPR3 and LPR4 were deployed on the downstream and upstream sides of the Castle Road culvert connecting the lower and upper marsh reaches, respectively. Finally, the Argonaut current meter, ARGO, was deployed on the downstream side of the Route 6 culvert connecting the upper marsh reach to the headwaters of the Little Pamet River.

Additionally, using a Trimble real-time kinematic (RTK) instrument, Woods Hole group surveyed channel depths, cross-sections, and culvert parameters both at Corn Hill Road and Castle Road, as well as the downstream invert of the Route 6 culvert. Collected elevations were referenced to the NAVD88 vertical datum.

Figure 1. Locus map of the Little Pamet River estuarine system. Call out boxes indicate the different reaches of the system and approximate locations of the AquaTroll data loggers and Argonaut current meter deployed in support of this study.

2.1 Water Levels in Little Pamet River System

The measured water levels in the estuarine system from the month-long deployment period (November 30, 2018 to January 3, 2019) are shown in Figure 2. The full tidal signal in Pamet Harbor at gauge LPR1 is shown as the black line, while the blue line shows measured water levels immediately upstream of the tide gate/culvert under Corn Hill Road at LPR2. Also shown in Figure 2 are water levels measured at gauge LPR3 (cyan line) and LPR4 (green line) during the deployment. At gauge LPR2, tides in Pamet Harbor appear to have a minor influence on the water levels, however there is no tidal influence at either LPR3 or LPR4. The water levels at LPR3, which is in the same lower marsh between Corn Hill and Castle Roads as LPR2, is consistently at or around 2 feet NAVD88. This indicates how aggradation of the channel between the two gauges in the lower marsh has limited flow conveyance and created a weir-like, perched effect on the upstream water levels.

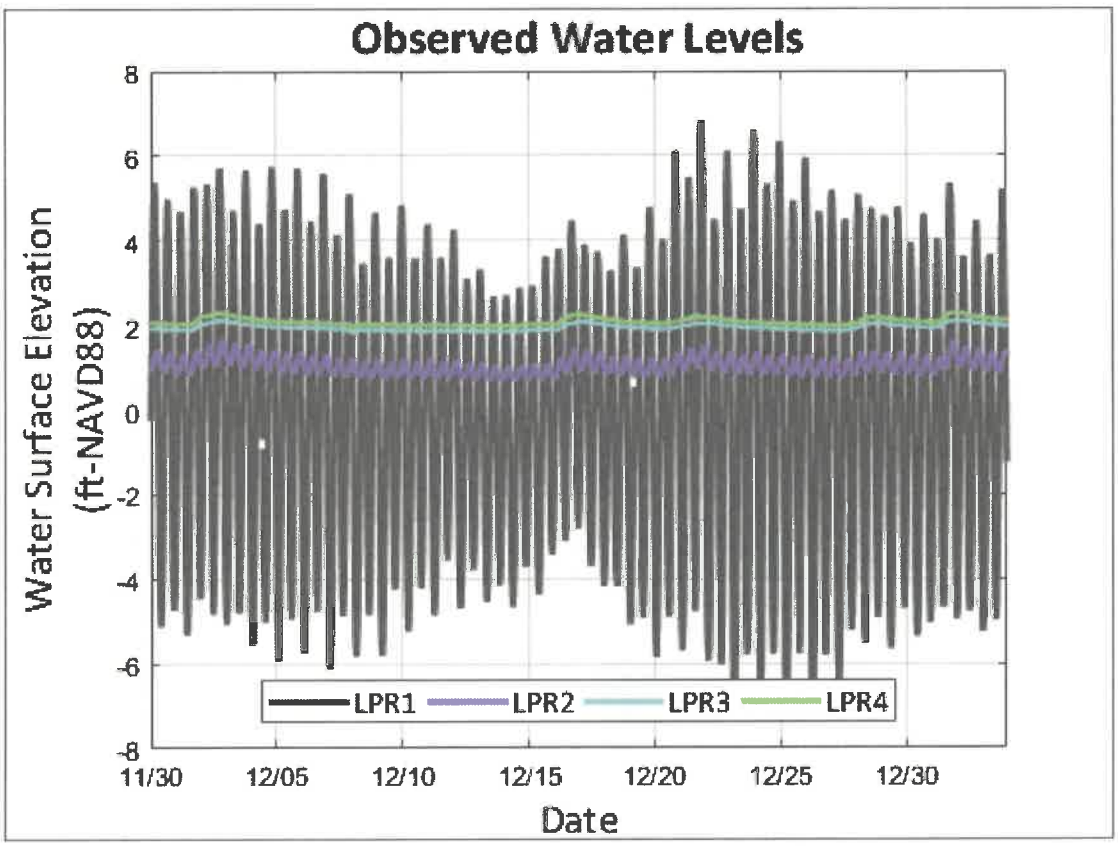

Figure 2. Observed water levels in the Little Pamet River system from November 30, 2018 through January 3, 2019.

2.2 Salinity in the Little Pamet River System

Time series of measured salinity in the Little Pamet River are shown in Figure 3. The measured salinity in the harbor (LPR1) is shown as a black line. Also, on the figure, the two gauges in the lower marsh, LPR2 and LPR3, are shown as blue and cyan lines respectively, with the time series from the gauge upstream of Castle Road in the upper marsh reach, LPR4, shown in green. In the harbor, the salinity typically varies from 25 PSU to 30 PSU, which is consistent with seawater from Cape Cod Bay mixing with the fresher water discharging from both the Pamet River and the Little Pamet River. Immediately upstream of the Corn Hill Road culvert, which is fitted with a clapper tide gate, the waters are primarily freshwater with observed salinities being typically less than 1 PSU. There are several incidences of increased salinity, specifically between 12/21/2018 and 12/28/2018 which could be indicative of poor tide gate performance or possibly an influx of saline water around the tide gate. The peaks in salinity at the LPR2 tide gauge appear to be coincident with the higher spring tide levels at LPR1 (seen in Figure 2) when water elevations in Pamet Harbor are close to or exceed 6 feet NAVD88. At both LPR3 and LPR4 located farther upstream, freshwater having salinity values at or less than 1 PSU is present during the entire deployment.

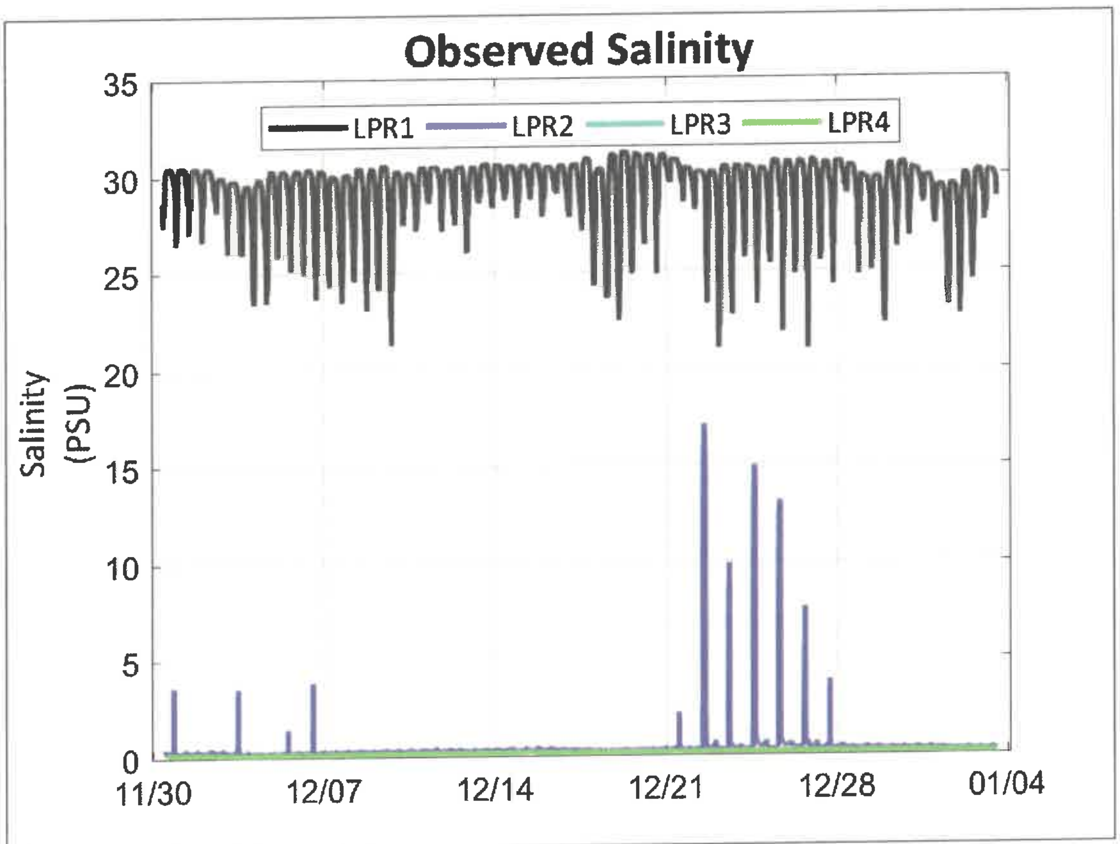

Figure 3. Observed salinities in the Little Pamet River system from November 30, 2018 through January 3, 2019.

3. Estuarine Culvert Model Development of Existing Conditions

The Little Pamet River was evaluated using the Estuarine Culvert Model (ECM) to simulate tidal flows and the effects of precipitation-induced surficial and groundwater inflows on the system. In addition to simulating typical conditions, the ECM was applied to assess the effects of low frequency surge and rainfall events on the Little Pamet River system. The Little Pamet River ECM uses the topography and bathymetry of the individual reaches that comprise the system, the geometry of the structures connecting each of the river reaches, together with the tidal boundary conditions at the harbor and freshwater inflows from the headwaters to simulate water levels throughout the system. The model is based on conservation of mass principles in propagating water fluxes through flow-control structures into basins described by their hypsometry (the relationship between the elevation and the surface area). Hypsometric analysis describes the elevation distribution across an area of land surface. It is an important tool to evaluate areas flooded and volumes of water with respect to specific water levels. The ECM is a proprietary model developed by Woods Hole Group.

The technical approach utilized by the ECM hypsometric model involves a simple procedure for calculating the tidal response in a marsh connected to the ocean by a fully or partially full opening. The assumptions are that the sea level in the marsh is independent of position, and that the flow through the culvert is described by a standard hydraulic head-loss relationship, depending on the type of flow control structure and depth of flow. Given the assumption of a horizontal sea surface within the marsh, the conservation-of-mass equation for the water in the marsh is

$$A(h_{marsh})\frac{dh_{marsh}}{dt} = Q_{culvert} + Q_{gw} + Q_{rain} \quad (1)$$

$$Q_{culvert} = -au \quad (2)$$

where t is time; $h_{marsh}\ (t)$ is the time-varying elevation of the water level in the marsh (NAVD88 feet); A is the surface area of the marsh, which is prescribed as a function of marsh h through the measured hypsometric relationship; $a(t)$ is the cross-sectional area of flow in the culvert; and $u(t)$ is the average flow velocity in the culvert. Velocity is defined as positive when flowing from the marsh toward the ocean (i.e., downstream). Q_{gw} and Q_{rain} are volumetric flow rates into the marsh resulting from groundwater input and surface water runoff, respectively. For circular pipe culverts, it is straightforward to calculate the relevant geometric parameters required to determine the velocity (cross-sectional area a, the wetted perimeter P, and hydraulic diameter $d_h = 4a/P$).

The quadratic head-loss relationship for the flow through a circular pipe culvert(s) is:

$$h_{marsh} - h_{ocean} = \left(K_{entrance} + K_{exit} + \frac{fl}{d_h}\right)\frac{u|u|}{2g} \quad (3)$$

where g is the acceleration due to gravity, entrance K and exit K are the dimensionless head-loss coefficients for the entrance and exit to the culvert, respectively, L is the length of the culvert, h d is the hydraulic diameter, and f is the empirical Darcy-Weisbach friction factor. The solution of (3) for the velocity u is

$$u = 2g \left(\frac{|h_{marsh} - h_{ocean}|}{K_{entrance} + K_{exit} + \frac{fL}{d_h}} \right)^{1/2} \frac{(h_{marsh} - h_{ocean})}{|h_{marsh} - h_{ocean}|} \qquad (4)$$

The friction factor, f varies depending roughness and flow velocity in the pipe and is calculated iteratively using the manning's n equation. The above equations are solved in time by means of standard first-order finite difference approach. Results of the computations include the water level time series in the marsh, time dependent water surface area in the marsh, and discharge volume through the culvert.

To account for potential overtopping of roadways that separate the basins in the model, as well as the weir effect in the channels due to aggradation, an additional overtopping flow can be specified in the model once a certain water elevation is reached. This flow is incorporated into the model using the broad crested weir equation (Equations 5 and 6).

$$Q_{weir} = CLH^{\frac{3}{2}} \quad (5)$$

$$C = \frac{2^{\frac{3}{2}}}{3} g^{\frac{1}{2}} \qquad (6)$$

Where Q_{weir} is the flow over the barrier, L is the width of the section over which water is flowing, H is the head difference between the water and the road, and g is the force of gravity.

2.1. Model Configuration

The Little Pamet River ECM was developed using tides measured in Pamet Harbor as a boundary, or forcing condition for three (3) interconnected basins, as shown in Figure 4. Pamet Harbor is connected to the lower marsh basin via a natural, earthen channel and a 240 ft long culvert equipped with a tide gate at Corn Hill Road. The lower marsh basin, which shows evidence of channel aggradation, is connected to the upper marsh basin via a second culvert under Castle Road. The final river basin, referred to as the headwaters, is connected to the upper marsh by a third culvert under Route 6. The headwaters basin was not fully incorporated into the Little Pamet ECM, but was instrumental in developing precipitation runoff and groundwater flows applied to the upper marsh basin.

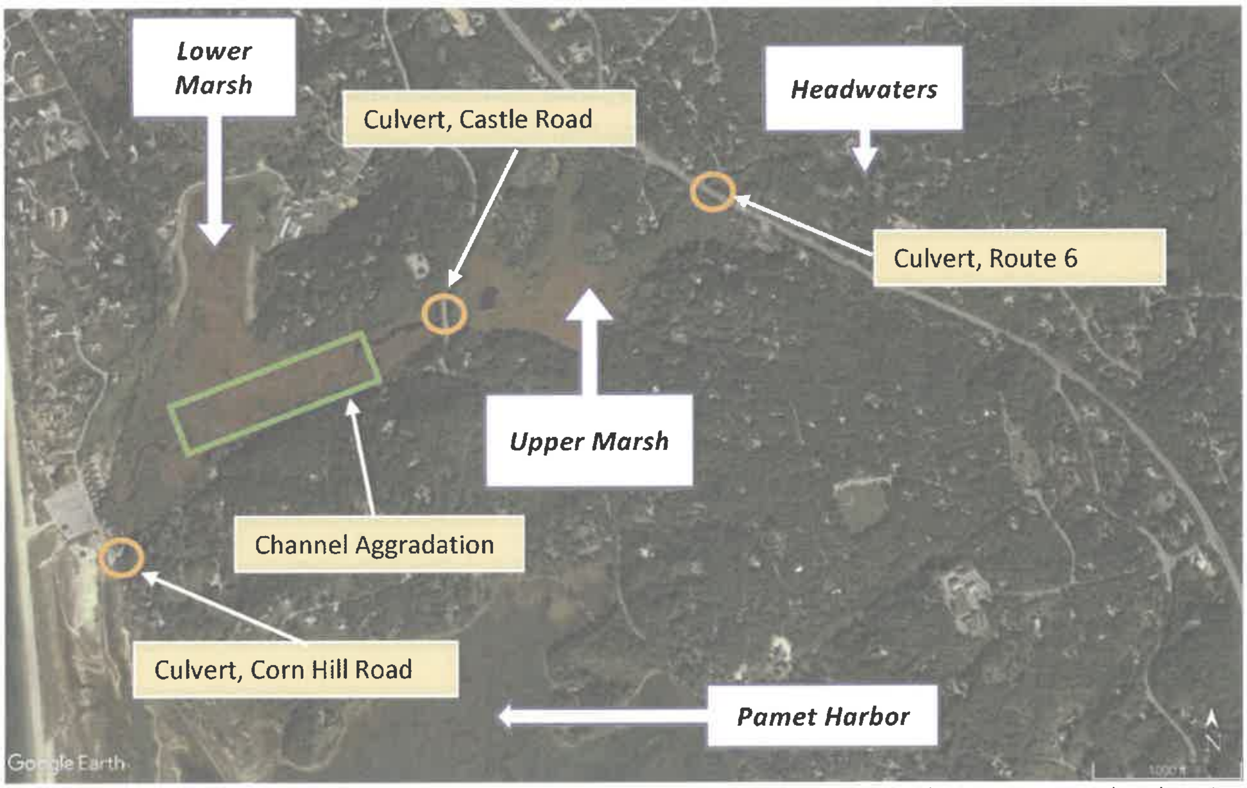

Figure 4. Aerial view of the Little Pamet River system showing the location of the tidal boundary at Pamet Harbor, locations of the flow control structures, and the upstream basins used in the Little Pamet ECM.

2.1.1. Topography/Bathymetry

The Little Pamet River estuary was subdivided into the 3 (three) computational marsh basins shown in Figure 4. The basin elevations were derived from the 2013-2014 USGS post-Sandy topobathy LiDAR shown as contours in Figure 5. The LiDAR dataset provided high density coverage over the extents of the study. Basin delineation between the lower and upper marshes was done using the roadway divisions and elevation gradients that define the watershed for each respective basin.

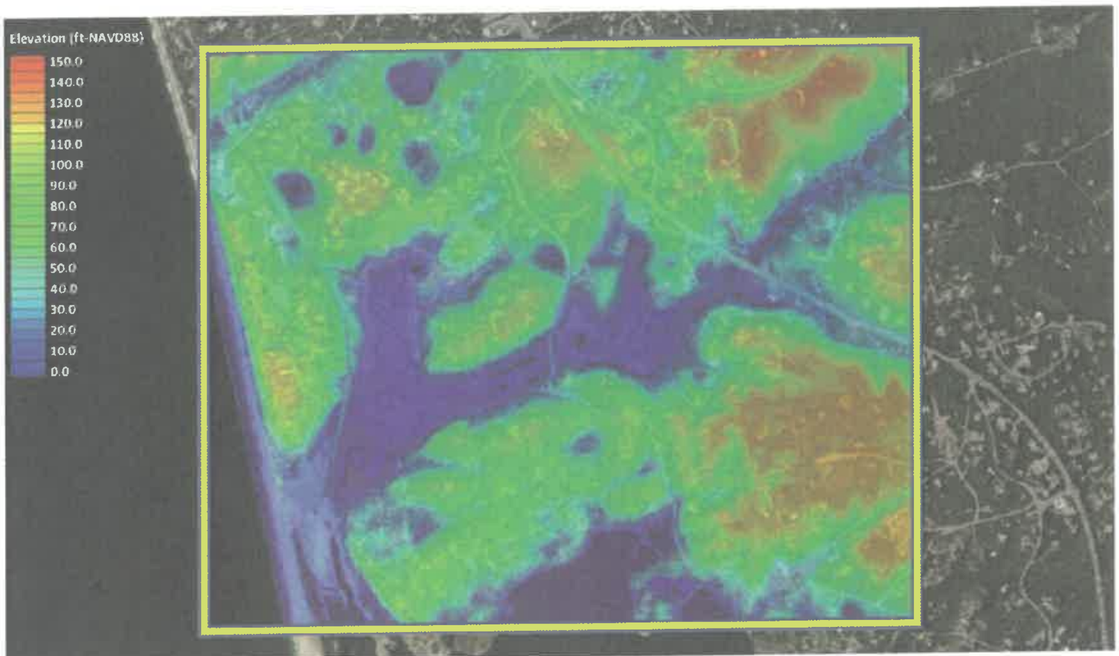

Figure 5. Aerial showing the extents of the USGS post-Sandy LiDAR dataset coverage used in developing the basin hypsometry for the Little Pamet River ECM. LiDAR is shown as colored contours within the yellow box overlaying the aerial image (USGS, 2019).

Figure 6 shows elevation contours for the lower marsh basin. The northern extent of the basin was defined by elevation gradients in the vicinity of High Ridge Road. Castle Road was used to define the eastern extent of the basin while the western extent was defined by the elevation gradient immediately west of Corn Hill Road. The hypsometric curve defining the relationship between the elevation and the surface area is shown as an inset on Figure 6. The lower marsh basin covers 240 acres, of which approximately 28 acres are below 3 ft-NAVD88.

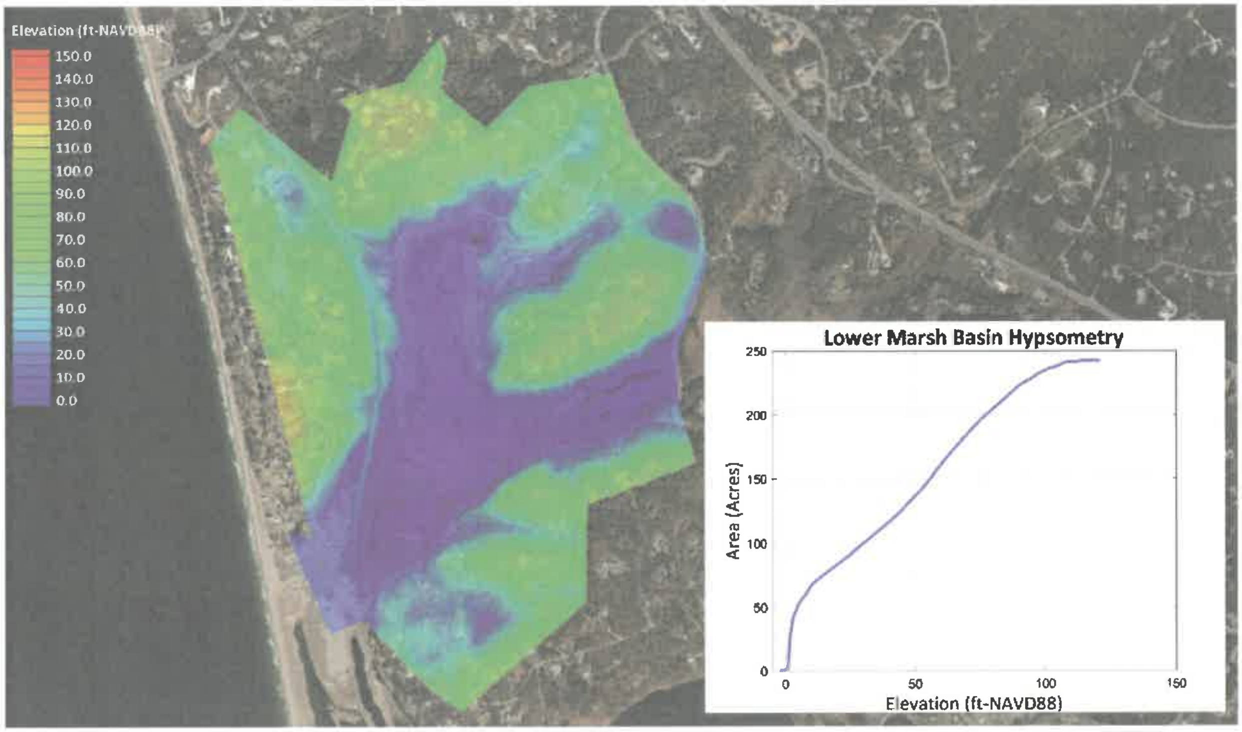

Figure 6. Computational grid of the lower marsh basin developed using the USGS post Hurricane Sandy LiDAR dataset. Inset shows the hypsometric curve for the basin.

Figure 7 shows elevation contours for the upper marsh basin with the hypsometric curve shown as an inset. Castle Road was used as the western extent and northern extents of this basin. The northeastern extent of the upper marsh basin was delineated using Route 6, while the southern extent was defined by the elevation gradient of the topobathy data at approximately Gospel Path. In total, the upper marsh basin covers approximately 180 acres, of which approximately 1.2 acres are at an elevation of 3 ft-NAVD88 or lower.

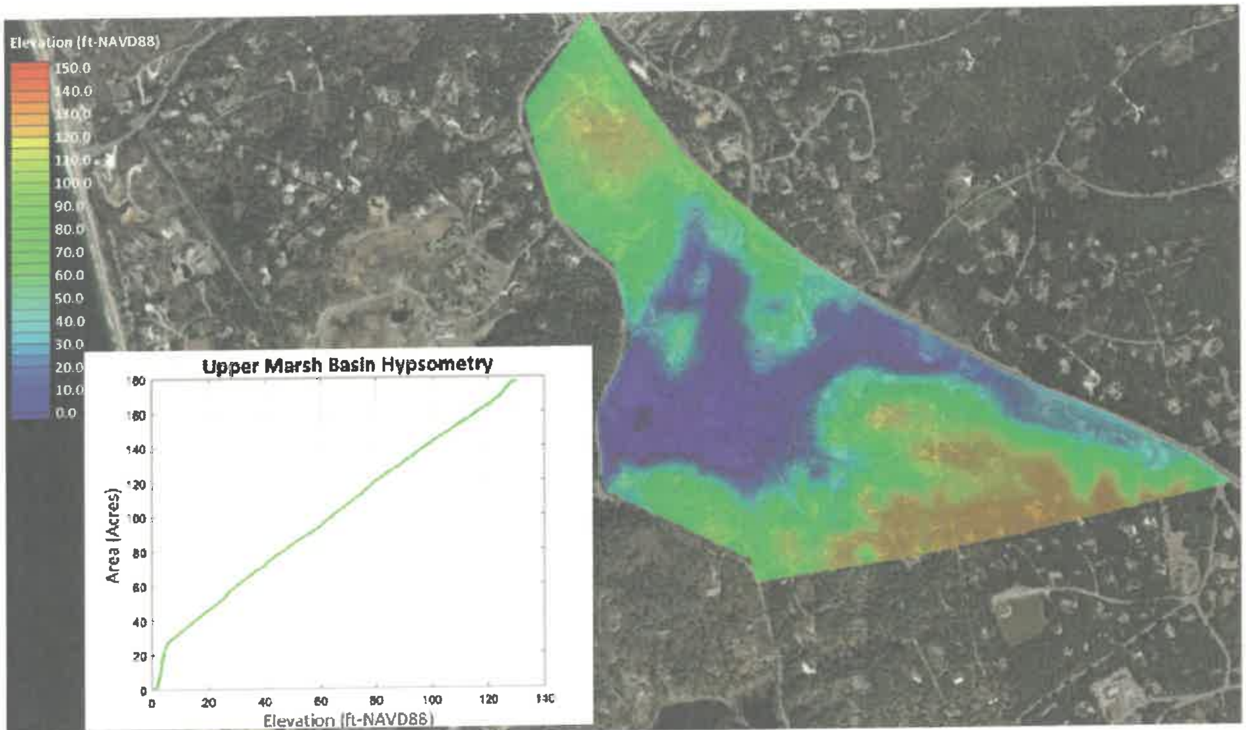

Figure 7 Computational grid of the upper marsh basin using the USGS LiDAR data. Inset shows the hypsometric curve for the basin.

Figure 8 shows elevations used to define the hypsometry for the headwaters basin used to inform the calculations for groundwater inflows and surficial runoff from precipitation events. Color contoured elevations are shown with the hypsometric curve line shown as an inset on the figure. The basin is separated from the upper marsh basin to the west by Route 6, while the remaining extents of the basin were determined by examination of the elevation contour gradients defining the watershed. The headwaters basin measured approximately 285 acres total.

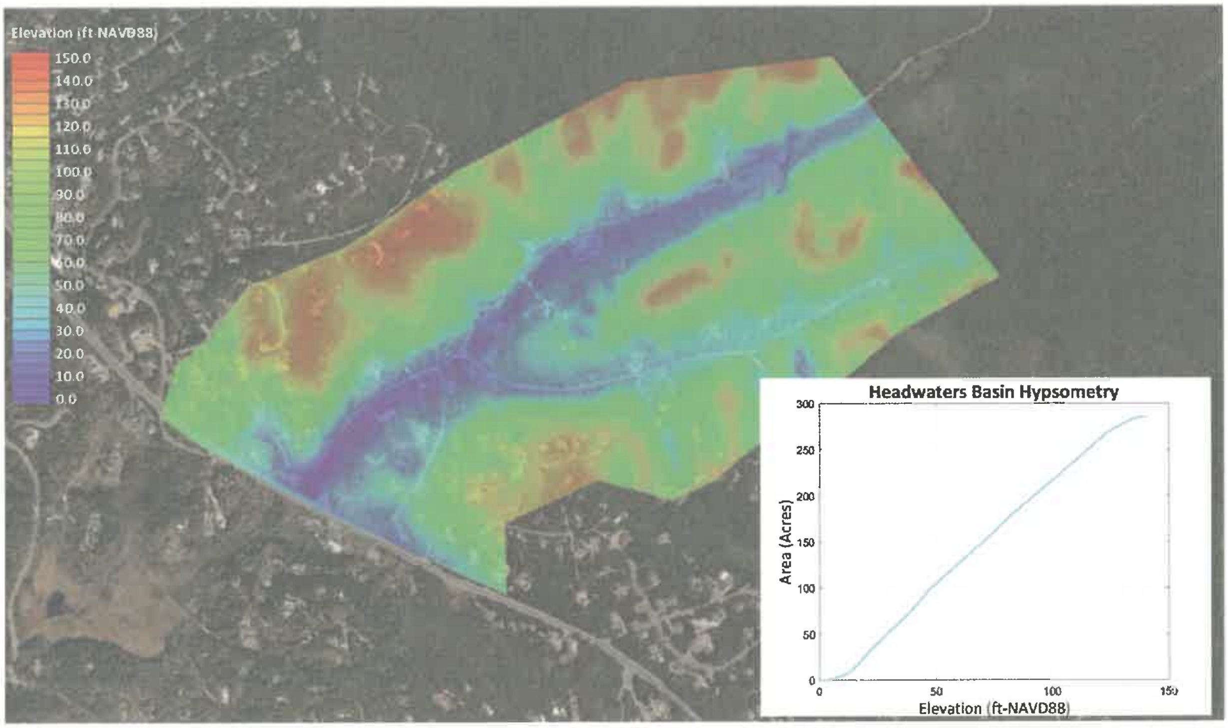

Figure 8. Computational grid of the Headwaters basin using the LiDAR data. Inset shows the hypsometric curve for the basin.

2.1.2. Boundary Conditions

Woods Hole Group developed boundary conditions for the Little Pamet River ECM to provide tidal and coastal storm forcing in the model simulations of both existing and proposed conditions. These boundary conditions consisted of: 1) typical tides developed from observed data, 2) projected sea level rise for 2070 superimposed with typical tides, and 3) low frequency storm events consisting of the 10% (10-year), 4% (25-year), 2% (50-year) and 1% (100-year) annual exceedance storm surge events. Additionally, Woods Hole Group developed freshwater inflows, both precipitation runoff and groundwater exfiltration, for the 10% (10-year), and 1% (100-year) annual exceedance precipitation events for application in the upper and lower marsh of the Little Pamet River model.

2.1.2.1. Typical Tides

Observed water levels in Pamet Harbor from the LPR1 gauge were used to develop a synthetic tidal signal for use in subsequent modelling. By analyzing the full record of observations in the harbor, the tidal signal was resolved into its component tidal frequencies and amplitudes using a series of functions developed for use in MATLAB (Pawlowicz, Beardsley, & Lentz, 2002). The tidal signal consisted of 35 constituent frequencies and associated amplitudes, of which the five largest are listed in Table 1. The synthetic tide, shown in the bottom panel of Figure 9, was used in conjunction with the low return frequency surge and precipitation events to develop a greater understanding of the effects each potential drainage alternative would have on the system.

Table 1. Dominant tidal constituents in Pamet Harbor

Constituent Symbol	Constituent Description	Period (hrs)	Amplitude (ft)
*M2	Main Lunar Semidiurnal	12.42	4.50
*N2	Elliptical Lunar Semidiurnal	12.66	1.01
*K1	Soli-lunar Diurnal	23.94	0.590
*S2	Main Solar Semidiurnal	12	0.576
*O1	Main Lunar Diurnal	25.82	0.350

2.1.2.2. Typical Tides with Sea Level Rise

In order to evaluate potential future conditions with projected increases in sea level, a tidal boundary condition was developed for a projected sea level rise (SLR) scenario. As this study is assessing the need for replacing existing culvert structures to optimize drainage, an SLR scenario were selected based on a typical culvert design life of 50 to 75 years. As such, the SLR scenario used was the intermediate-high scenario for year 2070 which gives a projected increase of 2.9 feet (Deconto & Kopp, 2017). The 14-day synthesized tide period was used as the basis for the SLR model simulations and Figure 10 shows the typical tidal conditions at present day (blue line) and projected sea levels accounting for SLR in 2070 (orange line).

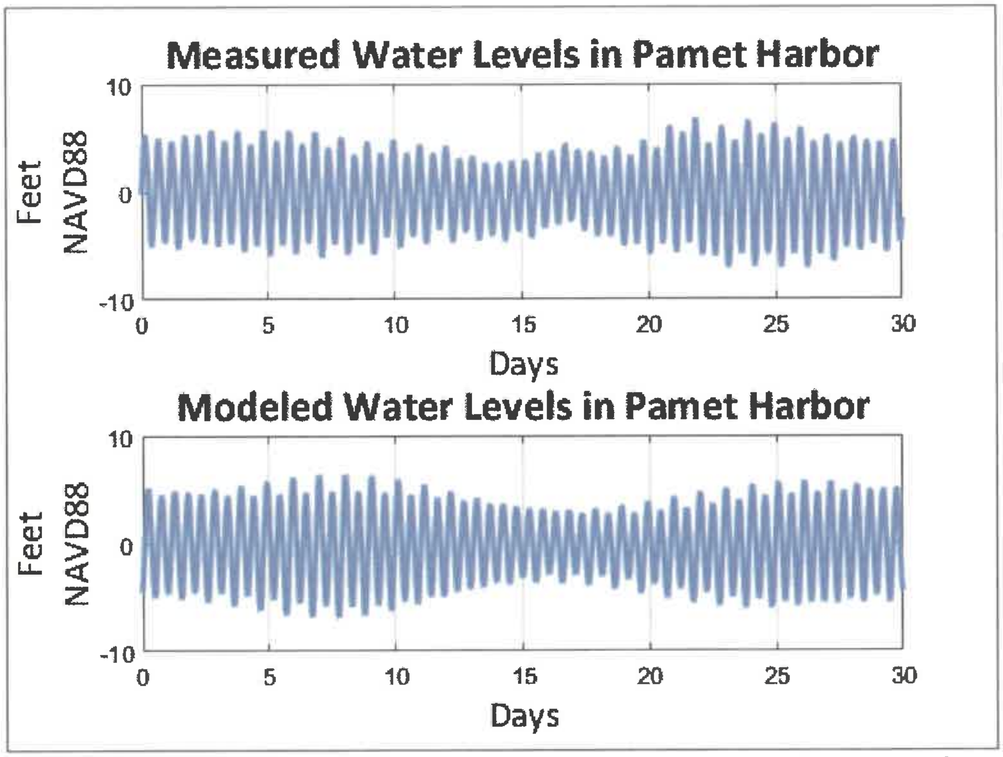

Figure 9. Tide measurements in Pamet Harbor (top) and the synthetic tide (lower panel) developed for use as the tidal boundary condition for Little Pamet River ECM model.

2.1.2.3. Coastal Storm Surge Event

Boundary conditions were also developed for model simulations of coastal storm surge events up to the 1%-annual-chance (100-year) level. The extreme storm surge elevations for the 10% (10-year), 2% (50-year) and 1% annual exceedance rate storms used in this study are from the preliminary Flood Insurance Study for Barnstable County (FEMA, 2018). These peak water levels were used to develop a water level for the 4% (25-year) storm event. Peak water levels for each of the low frequency storm events were then used to develop a synthetic storm surge hydrograph using methods detailed in the 2004 Federal Highway Administration Hydraulic Engineering Circular No. 25. The storm surge hydrographs developed using this procedure for each storm event occurring over 48 hours are shown in Figure 11. The 48-hour storm duration was chosen to be representative of the relatively long duration Nor'easter, or extratropical, events.

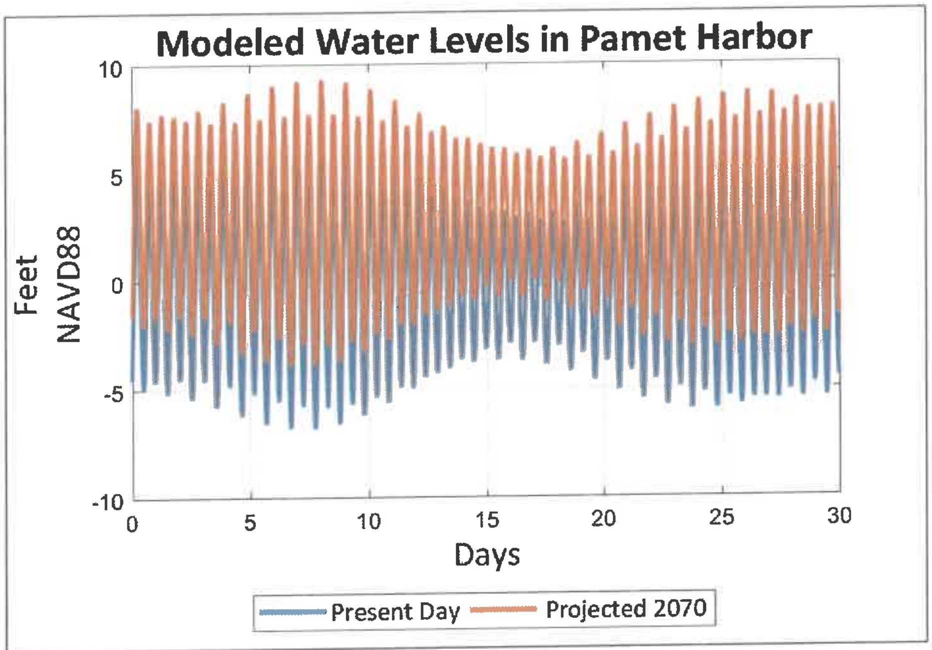

Figure 10. *Tidal conditions for Pamet Harbor at present sea levels (blue) and with projected sea level rise superimposed on the tidal forcing (orange). The 2070 scenario includes a sea level rise of 2.9 feet.*

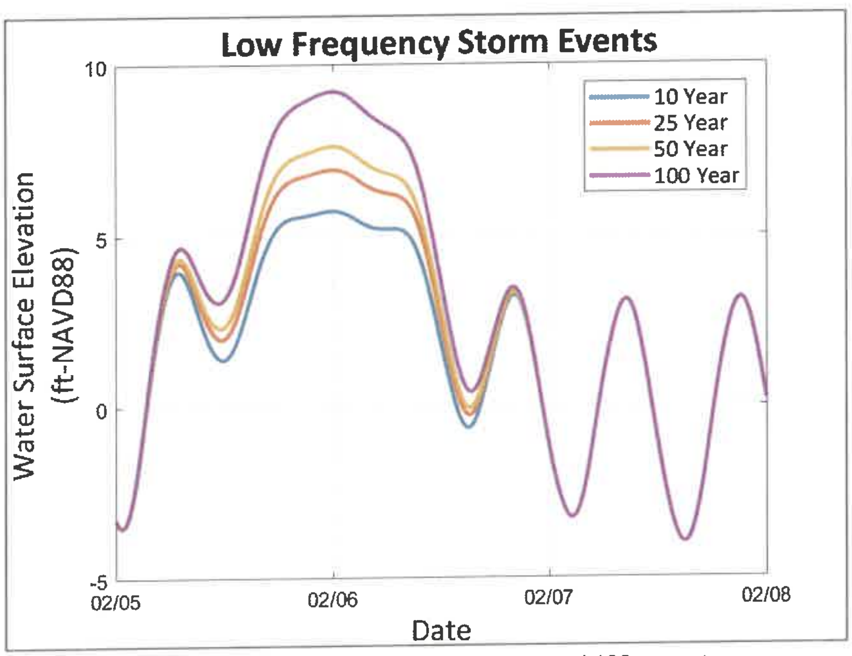

Figure 11. *Synthetic storm surge hydrographs for the 10-, 25-, 50-, and 100-year storm surge events*

2.1.2.4. Upstream Boundary Condition

Upstream model boundary conditions were developed for the base flow attributed to groundwater (applied at the upper marsh basin), and surface water runoff from rainfall for each of the basins. The upstream boundary condition included a constant input flow rate of 3.1 ft^3/s representing contribution from groundwater, which accounts for the majority of the 4.2 ft^3/s groundwater exfiltration into all streamways from the Pamet flow lens (Masterson, Simulated Interaction Between Freshwater and Saltwater and Effects of Ground-Water Pumping and Sea-Level Change, Lower Cape Cod Aquifer System, Massachusetts, 2004).

Additional freshwater inflows associated with surface water runoff were developed using hourly rainfall data collected at the Provincetown Airport. The established rational method was used to establish the surface water discharge, *Q*, using the following equation:

$$Q = C_R i A \qquad (7)$$

where C_R is a dimensionless runoff coefficient, *i* is the rainfall intensity, and *A* is the area of the watershed.

Inspection of the aerial photography of each of the basins in the Little Pamet ECM were used to develop the runoff coefficients for each basin listed in Table 2. Also listed in the table is the surface area for each of the basins and the time lag used distribute the rainfall contributions over a sufficient time to account for travel and infiltration/exfiltration. Surface areas were defined as the maximum surface area from the basin hypsometry as discussed in prior sections, while the value of the runoff coefficient used was selected to represent the composite land use of each basin (Chin, 2006). The appropriate time lag for surface and groundwater flows were developed based on the discharge flow rates computed at the ARGO station (see Figure 1) and throughout the model calibration process further discussed in Section 3.2.

Table 2. Parameters used for contribution of surface water and groundwater during precipitation events.

Basin	Surface Area (Acres)	Runoff Coefficient (C_R)	Time Lag for Surface Flows (hours)	Time Lag for Groundwater Flows (days)
Lower Marsh	242	0.10	0.25	N/A
Upper Marsh	177	0.40	16	2.5
Headwaters	285	0.50	52	14

Woods Hole Group also created boundary conditions for synthetic rainfall storm events based on the 10-year, 24-hour duration rainfall of 4.65 inches and the 100-year, 24-hour duration rainfall of 6.96 inches (NOAA, 2015). Both precipitation events were transformed into a rainfall hyetograph using the USGS Type III rainfall distribution, from which flow rates were defined using the rational method, with appropriate time delays, as described above. Figure 12 shows the volumetric surface flow rates developed for the 10-year storm in the upper panel, and 100-year rainfall event is shown in the lower panel. Figure 13 shows the groundwater contributions to the ECM model for the 10-year event in the upper panel, and the 100-year event in the lower panel. Groundwater contributions were only considered applicable for the headwaters and upper marsh basins.

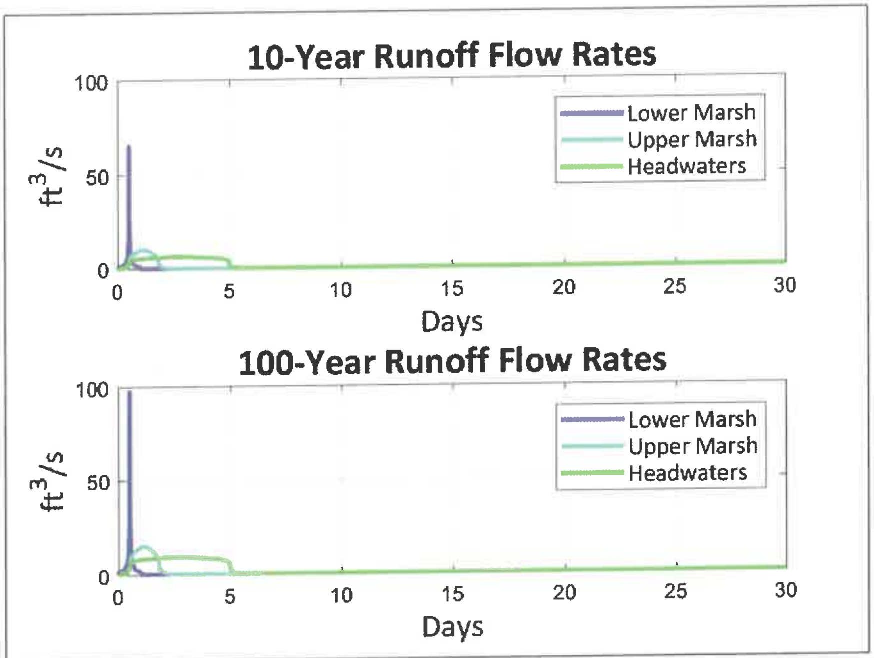

Figure 12. Surface water runoff flow rates developed for the 10- and 100-year rainfall event in each of the ECM basins using the rational method.

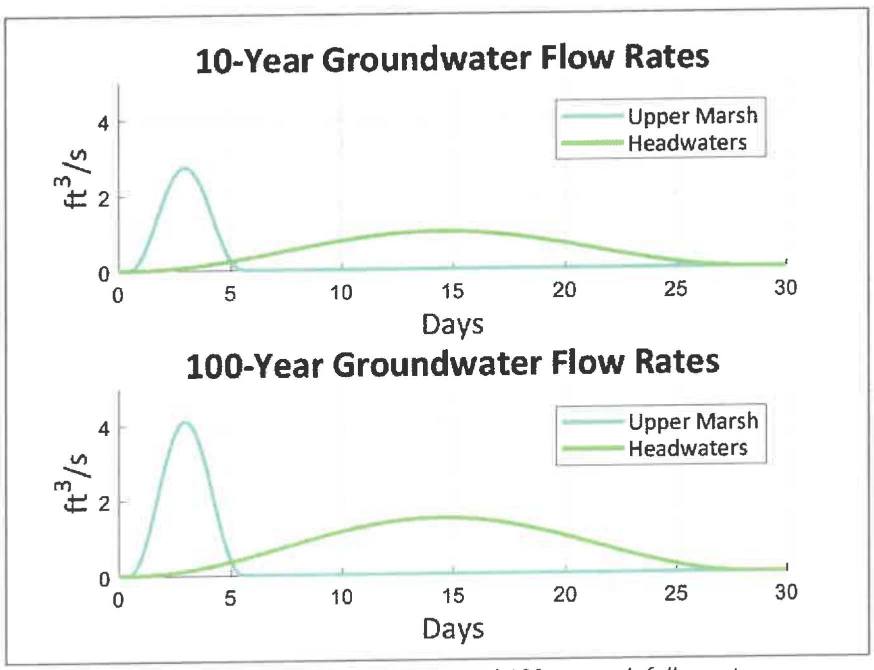

Figure 13. Groundwater flow rates developed for the 10- and 100-year rainfall events.

3.2 Model Calibration and Validation – Typical Tides

Model calibration refers to a comparison of model results with measured data, and refining the model parameters within reasonable values to improve the model skill and minimize uncertainties in the model results. To quantify model performance or the level of accuracy, error statistics are often computed. In evaluating the Little Pamet River ECM, two 'goodness of fit" statistics, bias and Root Mean Square Error (RMSE), were calculated using the model results at each basin within the system. This was done for multiple simulations until the model results and measurements were within reasonable agreement, and error statistics were minimal. After calibrating the model, a second validation period was simulated to determine the efficacy of the model to replicate observed results under similar, but differing conditions.

The calibration and validation simulations resulted in using the geometric variables listed in Table 3 for each of the culvert connections between individual basins. Culvert geometries were primarily derived from a combination of Woods Hole Group survey data collected during instrument deployment and the Little Pamet River Assessment plan provided by the town of Truro (Pajaron , 2017). As noted in the previous sections regarding the perching effect occurring in the lower marsh within the channel between the Corn Hill Road and Castle Road, a weir height of 1.95 ft-NAVD88 with a width of 20 feet was used to represent the aggradation/sill in the channel.

Table 3. Connection type, and geometric attributes of each of the basin connections modelled in the Little Pamet River ECM for existing conditions

Basin	Connection Type	Length (ft)	Width (ft)	Height (ft)	Downstream Invert Elevation (ft-NAVD88)	Upstream Invert Elevation (ft-NAVD88)	Entrance & Exit Loss Coefficient (K)	Manning's n
Corn Hill Road	Pipe Culvert	240	2	2	-1.3	-1.0	0.6	0.02
Castle Road	Pipe Culvert	60	2	2	-0.45	-0.45	0.7	0.033

The results of the Little Pamet River ECM and comparisons with measured data are shown in Figure 14 for the ten-day calibration period where the black line is the modeled water level and the observed values are shown in red. In the upper panel, the results of the ECM model in the lower marsh upstream of Corn Hill Road are compared with the measured water levels from tide gauge LPR2. Similarly, in the lower panel, the ECM results upstream of Castle Road are compared with measured water levels at gauge LPR4 in the upper marsh. At Corn Hill Road, during the ten-day calibration period, the bias is approximately 1/10th of an inch with an RMSE of slightly more than 1 inch. At Castle Road, the bias was slightly less than 4/10^{ths} of an inch with an RMSE value of less than ½ of an inch. The low bias and RMSE values at each of the modelled reaches suggest that the model setup is sufficiently skilled at replicating the observations.

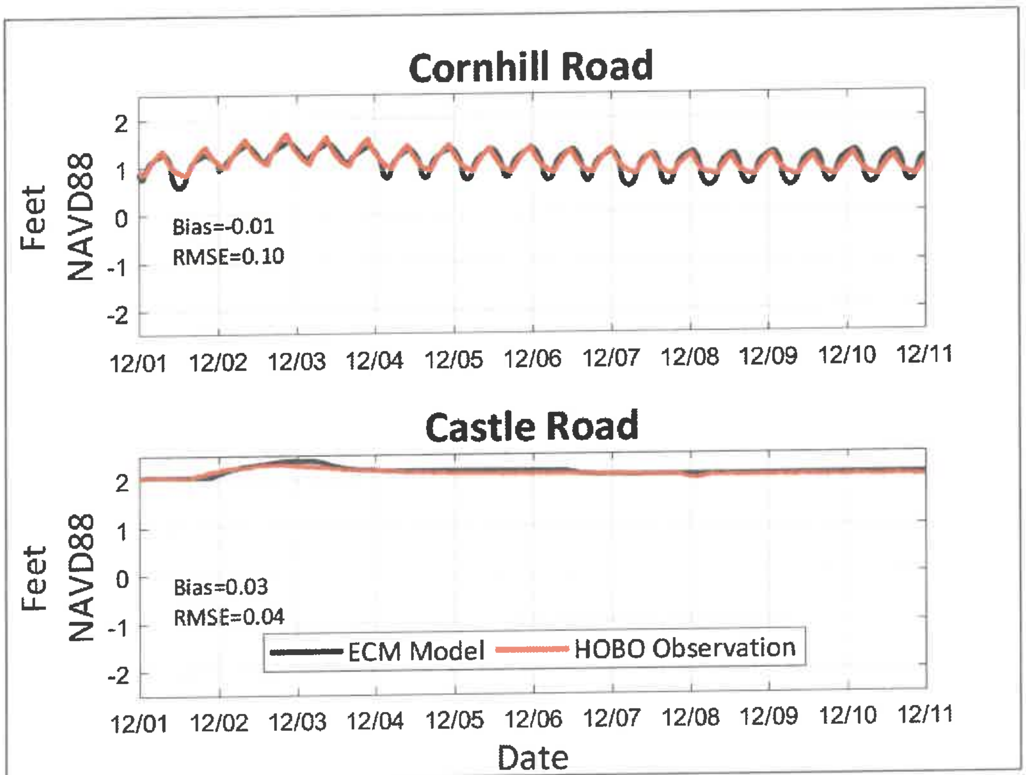

Figure 14. Comparison of the Little Pamet River ECM model results to the measured observations during the calibration period between 12/01/2018 and 12/11/2018.

Figure 15 shows the model results upstream of Corn Hill Road as a black line, and compared to the measured observations, shown as a black line, for the model validation period (12/11 – 12/21) in the upper panel. Upstream of Corn Hill Road, the ECM model shows a slightly higher range in elevations with lower water levels during ebb tides, and higher peak elevations. Over all, the bias was less than 0.7 inches, with a RMSE value of 1.4 inches. In the bottom panel, the time series of model results upstream of Castle Road are shown as a black line, and are compared with the measured observations (red line) for the same ten-day validation period. At Castle Road, the ECM model had a bias of less than ¼ of an inch, and a calculated RMSE of less than 0.5 inches.

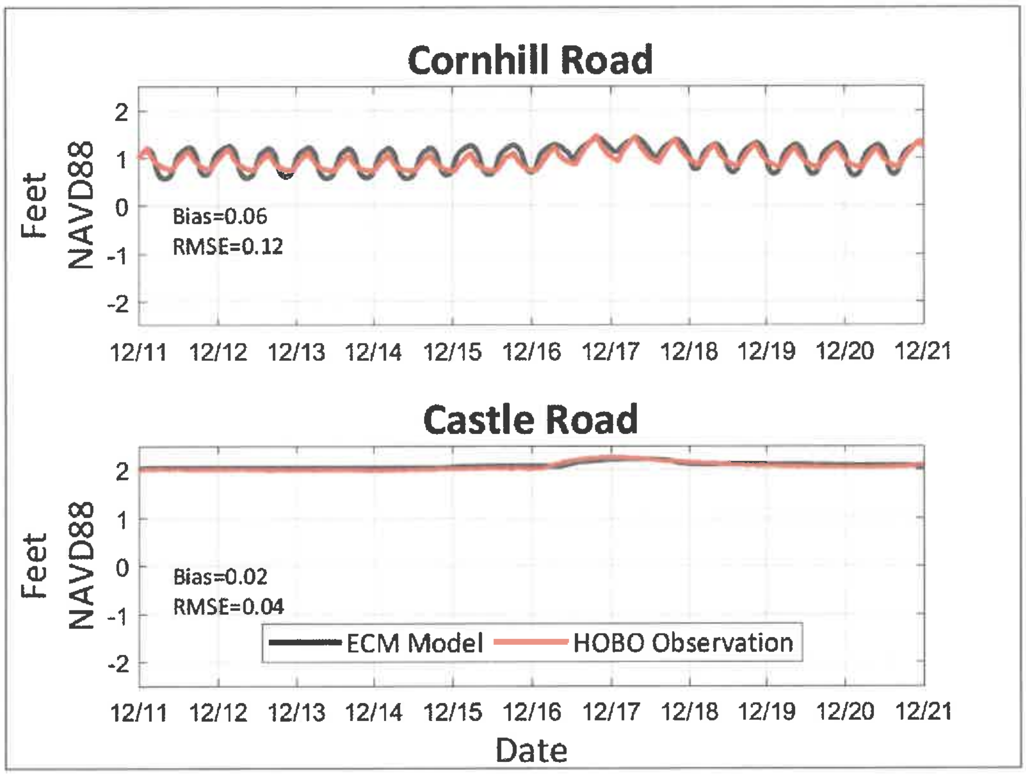

Figure 15. Comparison of the Little Pamet River ECM model results to the measured observations over the validation period between 12/11/2018 and 12/21/2018.

3.3 Additional Simulations of Existing Conditions

After the Little Pamet River ECM was calibrated and validated for typical tides, simulations of existing conditions were conducted in extreme coastal storm surge and rainfall events. Additional simulations were also conducted to assess the effects of sea level rise for the year 2070.

3.3.1. Projected Sea Level Rise in 2070

Figure 16 shows water levels within each modelled Little Pamet River reach under typical tides with projected 2.9 feet of sea level rise in 2070. The SLR model results are shown (black line) together with current-day water levels (red line). The model simulations of the existing culverts under typical tides with SLR indicate that the efficacy of the existing tide gate/culvert combination at Corn Hill Road is reduced as the higher water levels limit the amount of time the tide gate is actuated. The combination of reduced actuation time, with the restricted flow in the Corn Hill Road culvert results in a higher mean water level in typical conditions with SLR. Peak water elevations in the lower marsh basin approach 1.6 ft-NAVD88. Additionally, the low water level in the Lower Basin increases from 0.5 ft-NAVD88 under present sea level to an elevation of 0.65 ft-NAVD88 in 2070. Conversely, under normal tidal condition at both present day and projected 2070 sea levels, the upper marsh, shown in the bottom panel, remains unaffected.

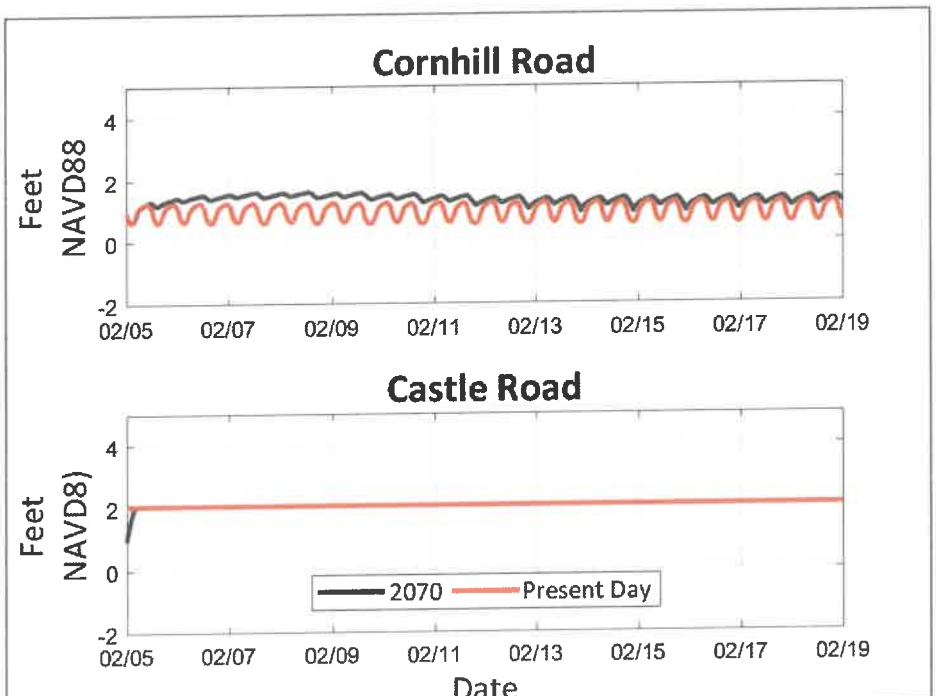

Figure 16. Time series of water levels in the Lower and upper marsh reaches of the Little Pamet River for existing conditions/typical tides with the current-day sea level (red), and with a projected sea level increase of 2.9 feet in 2070 (black).

3.3.2. Extreme-Coastal Storm Events

Modeled water levels within the Little Pamet River during a 10-year coastal storm surge event are shown in Figure 17 as a black line in each of the panels. The red lines in the Figure are typical (predicted) tides without storm surge and are shown as a basis for comparison. During the 10-year event, water levels in the upper marsh basin upstream of the Castle Road culvert are unaffected by the storm event as shown by the overlap of the red and black lines in the bottom panel of the figure. In the lower marsh basin (upper panel), however, the storm duration and raised water levels in the harbor are sufficient to prevent the tide gate from actuating and draining the basin for the duration of the storm. As such, during the storm, groundwater inflows back up at the culvert to elevations of almost 2 feet NAVD88 before returning its typical tidal behavior approximately 2.5 days after the start of the storm. The 25-year, 50-year, and 100-year storm events all exhibit similar trends in water levels as the minimum elevation of Corn Hill Road (approximately 9.2 ft NAVD88) is high enough to prevent surge water from overtopping into Little Pamet River during coastal storm events.

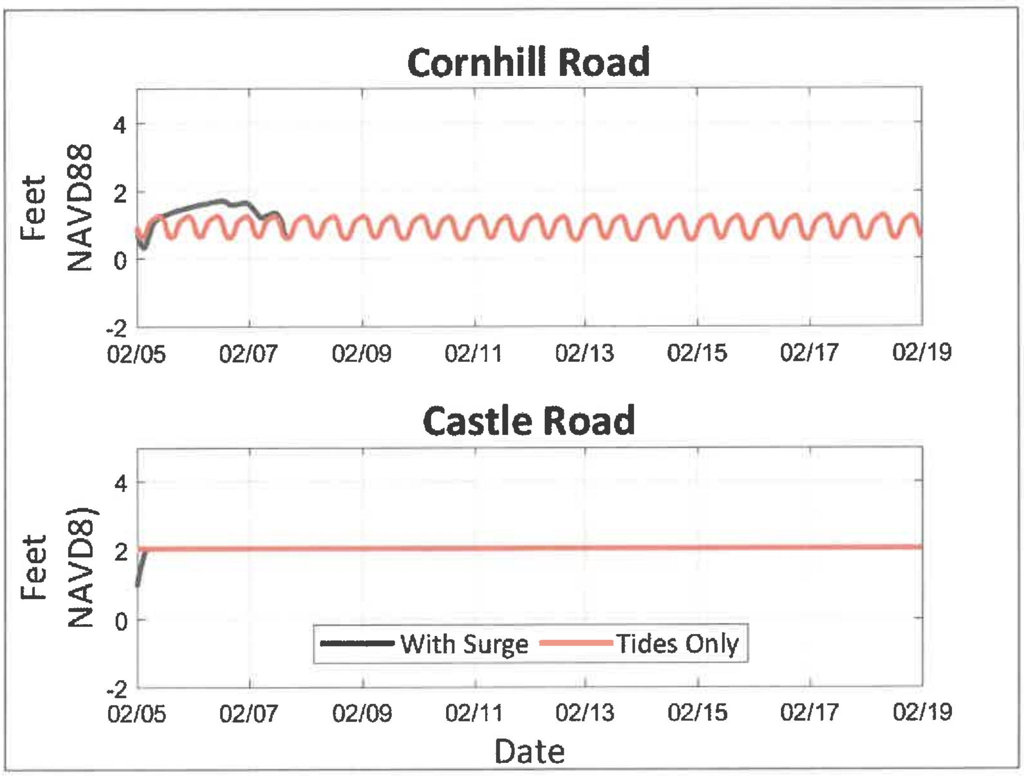

Figure 17. The 10-year storm surge event in Little Pamet River for existing conditions.

3.3.3. Extreme Precipitation Events

Figure 18 shows the effect of a 24-hour duration, 10-year rainfall event in the Little Pamet River system. In each panel, the black line shows the modelled water level with the contribution of the 10-year rainfall induced flow. The red lines in the Figure are typical conditions without rainfall and are shown as a basis for comparison. In a 10-year rainfall event, water is retained in the system above typical levels for approximately 6.5 days in the lower marsh, and 5.5 days in the upper marsh. Peak water levels upstream of the Corn Hill Road culvert (top panel) are slightly higher than 2 feet-NAVD88, and are just below 4 feet NAVD88 upstream of the Castle Road culvert (lower panel).

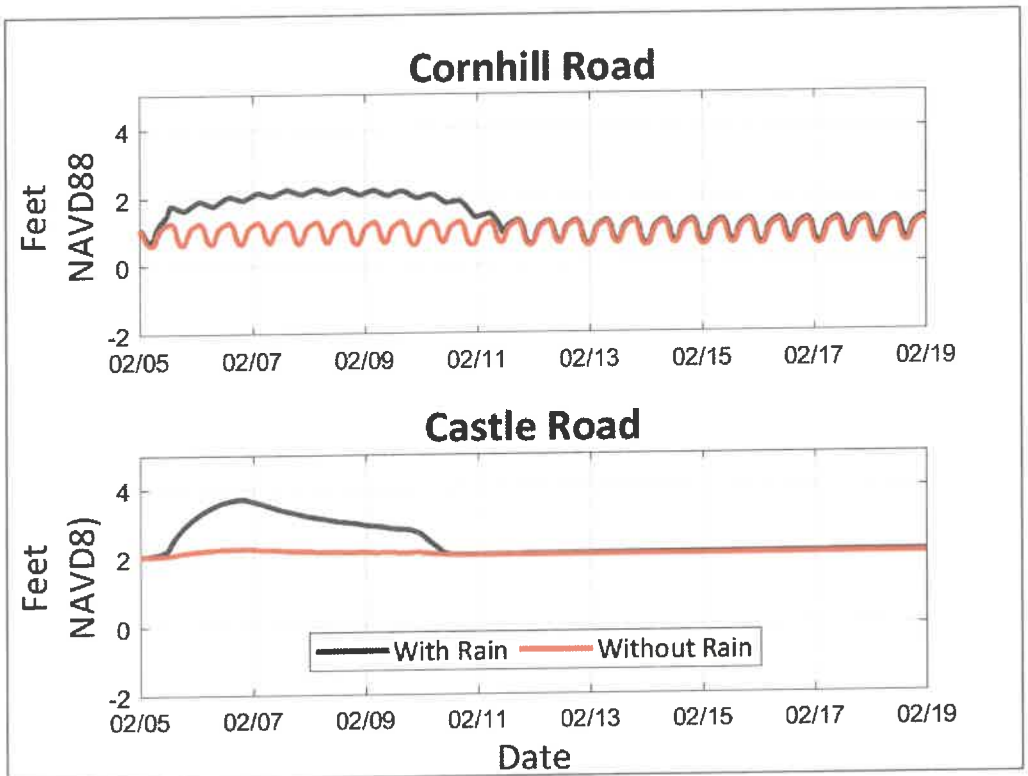

Figure 18. The 10-year rainfall event in the Little Pamet River system for existing channel conditions and culvert geometry.

Figure 19 shows the effect of the 24-hour duration, 100-year rainfall event in the Little Pamet River system. In each panel, the black line shows the modelled water level with the contribution of a 100-year rainfall event, while the red line shows the ECM modelled water level without any contribution from rain. In a 100-year rainfall event, water is retained in the system above typical levels for approximately 8.5 days in the lower marsh, and 7 days in the upper marsh. Peak water levels upstream of the Corn Hill Road culvert (top panel) are slightly lower than 3 feet-NAVD88, and are approximately 4.5 feet NAVD88 upstream of the Castle Road culvert (lower panel).

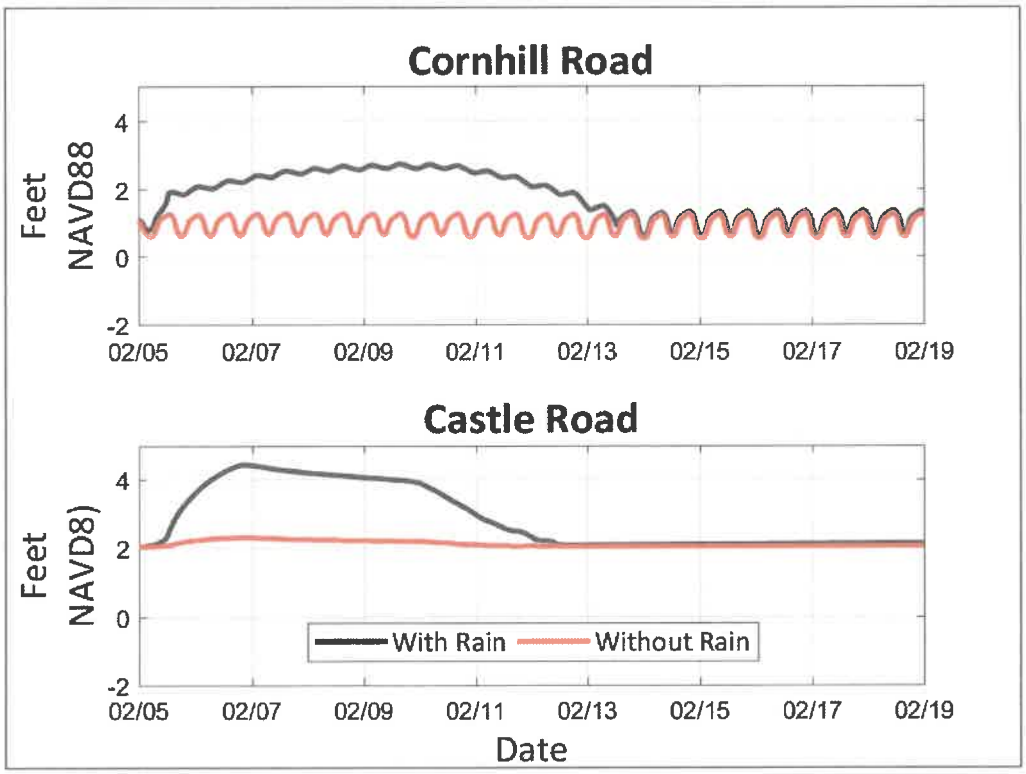

Figure 19. The 100-year rainfall event in the Little Pamet River system for existing channel conditions and culvert geometry.

4. Alternatives Evaluation and Effects on the Little Pamet River System

The water level observations collected in support of this study indicate that the long-term aggradation of the Little Pamet River is negatively impacting drainage of the upstream reaches. Additionally, the tide gate/culvert combination at the Corn Hill Road is likely not maximizing outflow from the riparian system during ebb tides. In order to optimize drainage of the system, and to mitigate potential flooding due to inadequate drainage, Woods Hole Group conducted a series of simulations with two primary alternatives based on the preliminary findings of the ECM model. The proposed alternative configurations included:

1) improving the main channel (i.e. dredging of shoaled areas) to remove any potential weir effects/restriction in the lower marsh, and
2) an optimized drainage configuration incorporating the channel improvements together with 4-foot diameter pipe culverts replacing the undersized 2-foot diameter culverts at both Corn Hill Road and Castle Road.

4.1 Typical Tides

A 14-day period was utilized to assess both proposed alternatives and effects on drainage in the Little Pamet River during typical tides. The modeled water levels with channel improvements are shown in Figure 20 as black lines and are compared to water levels with the existing channel geometry, shown as red lines. The channel improvements show noticeable benefits in improved drainage in both the lower marsh (top panel) and the upper marsh (bottom panel). The peak water level during flood tides, when the tide gate is closed, is similar under both channel configurations in the lower basin, but the improved channel has distinctly lower water levels as the tide gate is actuated and drainage occurs. Removal of the channel aggradations between Corn Hill Road and Castle Road also facilitates drainage of the upper basin with the mean water level being approximately 1.5 feet lower, upstream of Castle Road.

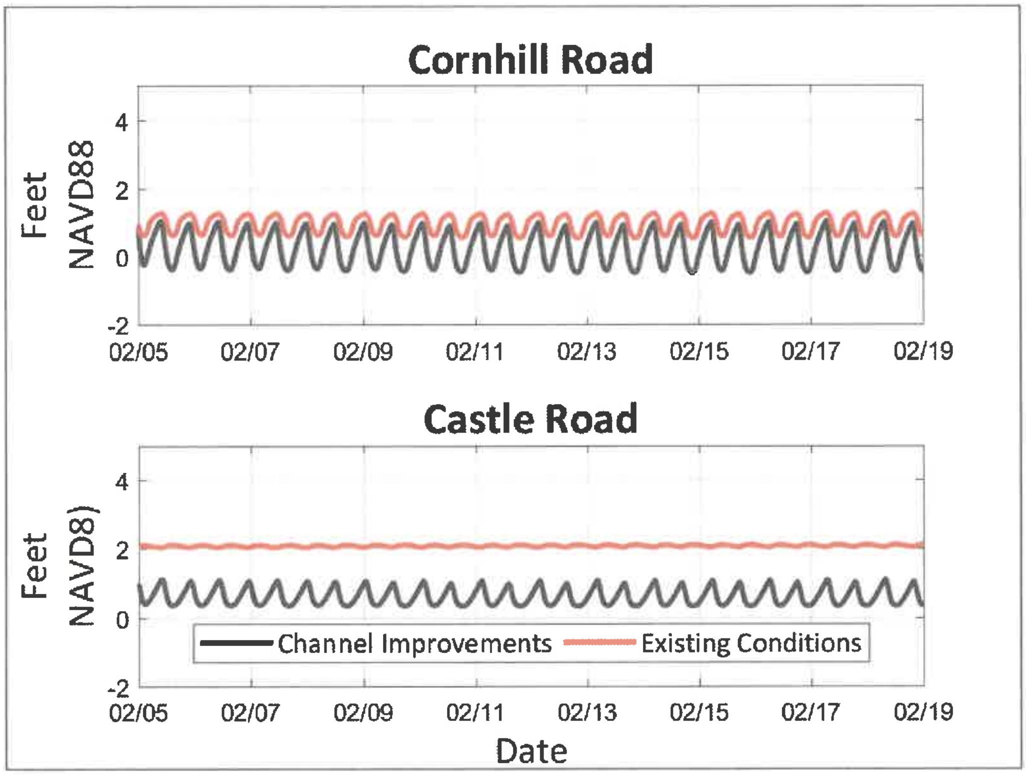

Figure 20. Effects of channel improvements on drainage of the system during typical tides.

Figure 21 shows the combined effects of channel improvements and increased culvert sizing. On the figure, existing channel conditions are shown as a red line on both the top panel (lower marsh) and bottom panel (upper marsh) for comparison with the optimized drainage alternative, shown on both panels as a black line. During typical tides, the increased culvert sizing does not show significant additional benefit in draining the system, in comparison to the previous alternative. The subsequent sections will look at the potential benefits during storm conditions, and how the increased capacity of the culverts provides additional drainage.

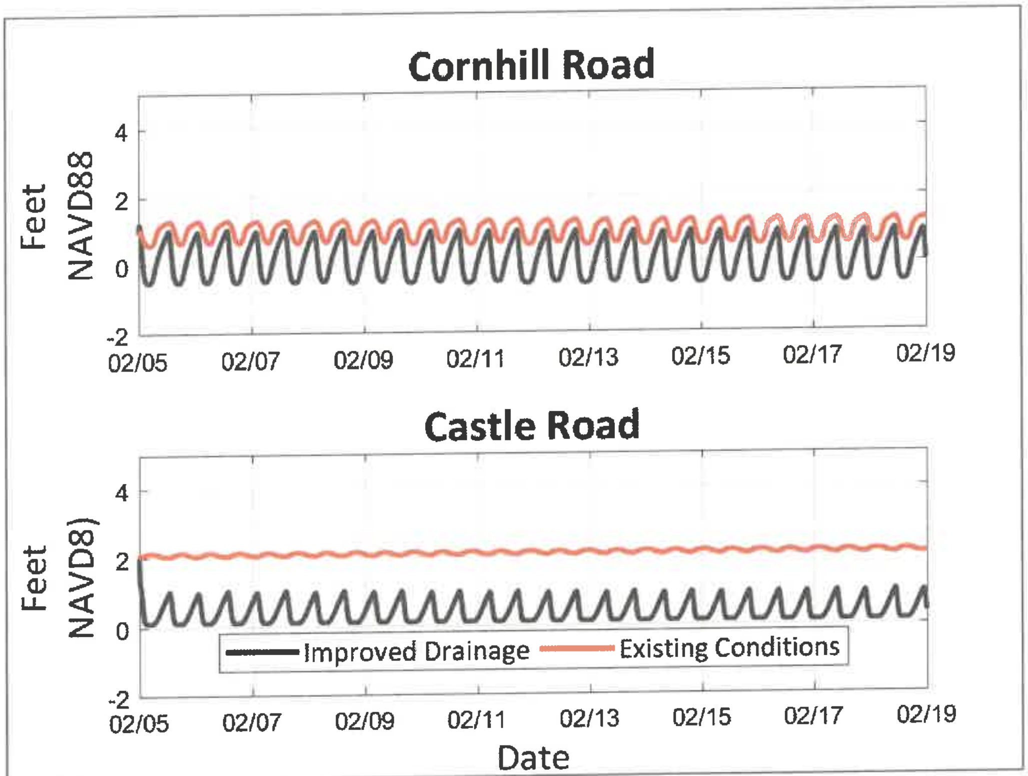

Figure 21. Effects of channel improvements and increased culvert sizing on drainage of the system during typical tides.

3.4 Sea Level Rise and 100-Year Storm Events

After assessing the alternatives in typical tides with the current-day sea level, additional simulations were conducted including: 1) typical tides in 2070, 2) a 100-year coastal storm surge event, and 3) a 100-year rainfall event.

4.2.1. Projected Sea Level Rise in 2070

Figure 22 shows the effects of channel improvements on water levels throughout the Little Pamet River system with projected 2.9 feet of sea level rise in the year 2070. Water levels with the proposed channel improvements are shown in black, while the water levels with the existing channel geometry are shown in red. At the start of the simulation, which corresponds with higher spring tides, channel improvements do not increase the drainage capacity of the lower marsh, as shown in the upper panel of Figure 22. The upper marsh shows a similar pattern to the lower marsh, as opposed to water being impounded by the channel aggradation. This is evident by the lowered water levels throughout the entire period. After 02/09, the lower high tide levels in the harbor allow for more outward-directed flow from Little Pamet through the Corn Hill Road culvert, and hence increased drainage throughout the entire system.

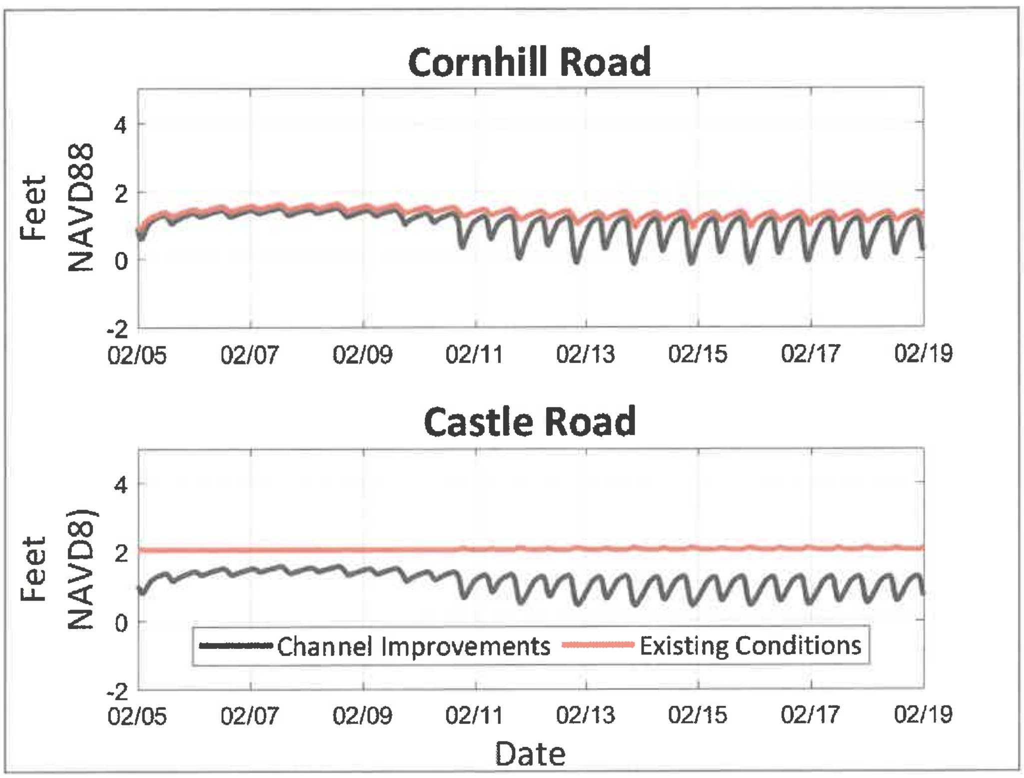

Figure 22. Effects of channel improvements in the Little Pamet River on drainage in the system during typical tides with sea level rise in 2070.

Figure 23 shows the effect on water levels throughout the Little Pamet River system with both culverts being optimized as 4-feet diameter concrete pipes together with channel improvements, for typical tides and 2.9 feet of sea level rise. Water levels in 2070 with the proposed drainage improvements are shown in black, while water levels with the existing culvert/channel geometry are shown in red. At the start of the simulation when there are higher spring tides, it can be seen how the increased culvert sizing allows for better drainage than with just the channel improvements alone. Water levels in the upper marsh show a similar pattern, and shows better drainage overall throughout the 14-day period.

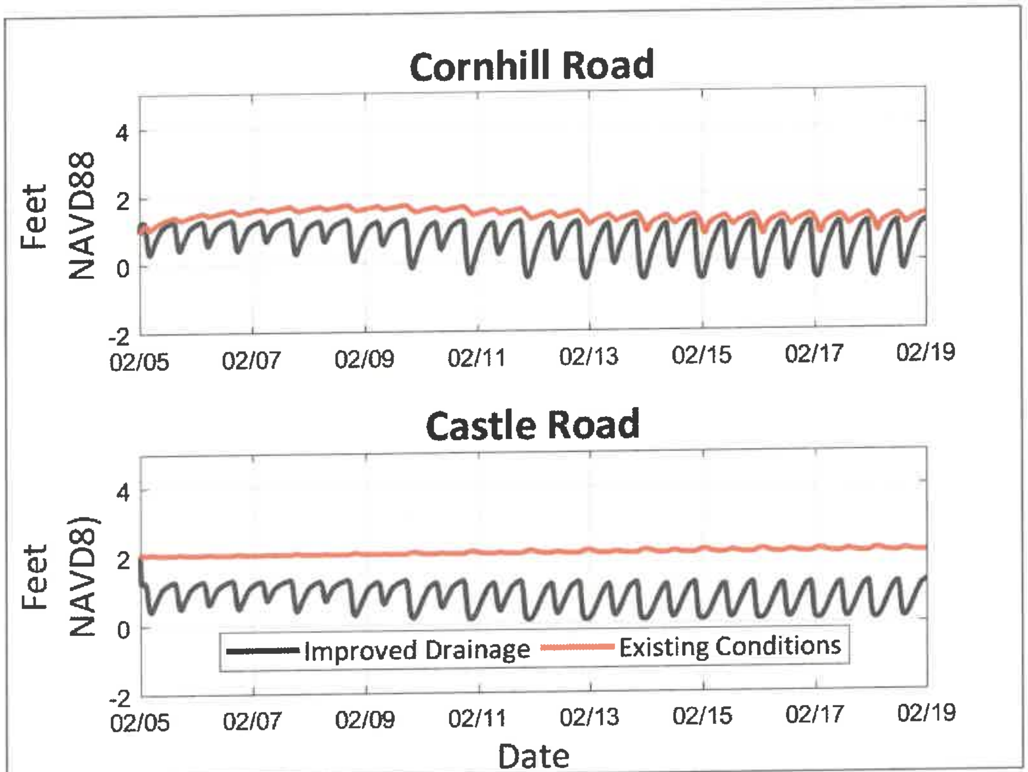

Figure 23. Effects of channel improvements and increased culvert size in the Little Pamet River on drainage in the system during typical tides with sea level rise in 2070.

4.2.2. 100-Year Storm Events

The 1%-annual-chance (100-year) storm surge event was simulated for both alternative drainage improvements in the Little Pamet River system. The resulting water levels are shown as black lines in Figure 24 for each of the sub-basins with channel improvements only, while Figure 25 shows the modelled results for the optimized drainage alternative including upsized culverts at both stream crossings. Both alternatives show an increase in water level during the storm event as the water levels are sufficiently high to prevent the system to drain. Upstream of Corn Hill Road (top panel in both figures) the water levels return to normal lower tide levels with the optimized culverts draining approximately 0.5 days faster than with channel improvements alone. In both scenarios, removal of the bed aggradation in the lower marsh reach allows for increased drainage, and subsequently lower water levels at all times in the upper reaches of the system.

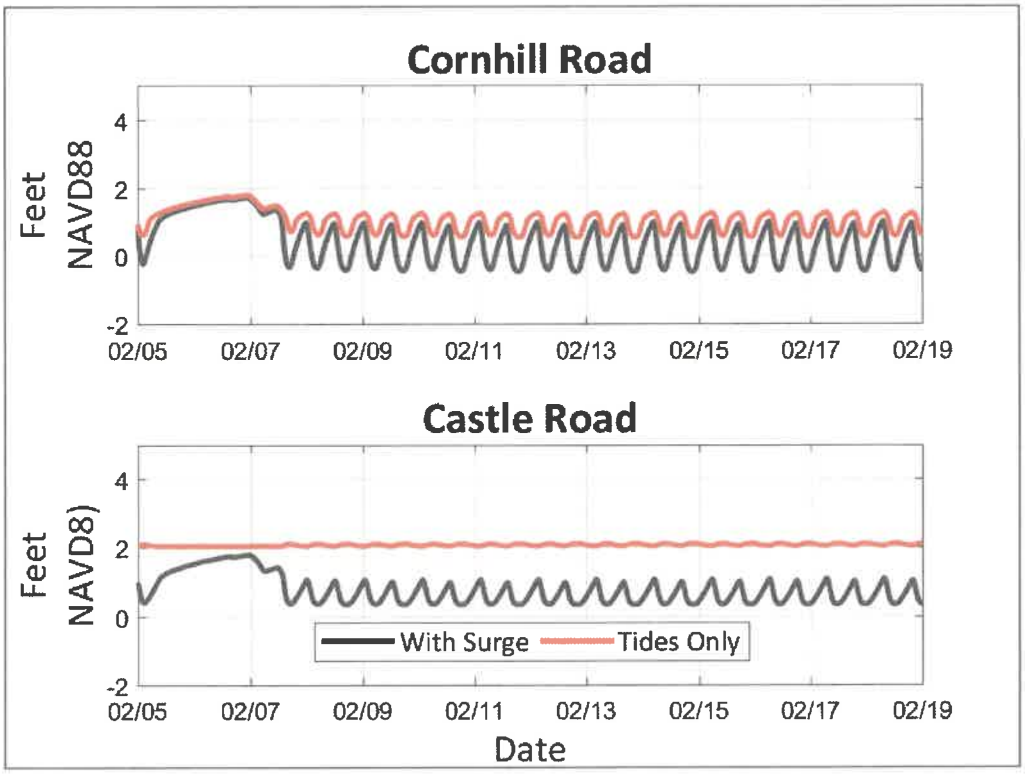

Figure 24. Effects of channel improvements in the Little Pamet River during a 100-year storm surge event.

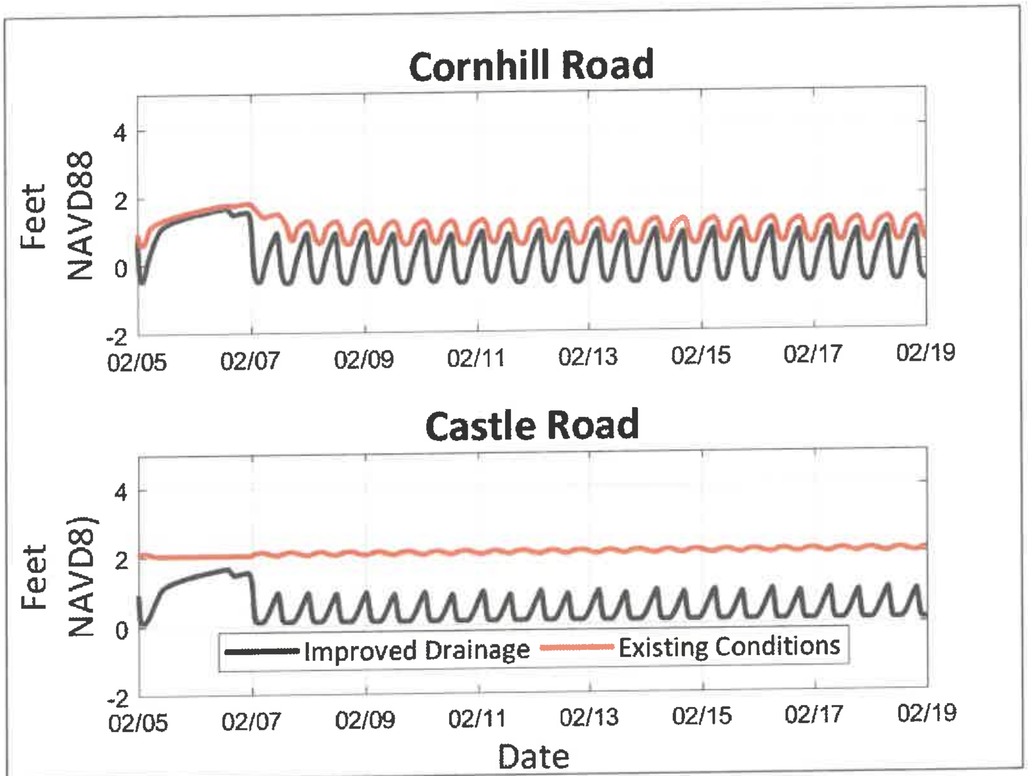

Figure 25. Effects of channel improvements and increased culvert size in the Little Pamet River during a 100-year storm surge event.

In addition to the 1%-annual-chance storm surge event, a simulation was conducted for the 100-year precipitation event for both proposed alternatives. The results from the extreme rainfall event simulation are shown in Figure 26 for the first alternative, with channel improvements only. During the rainfall event itself, and subsequent increased surficial flows, there is little benefit to the system with the channel improvements as peak water levels between the improved channel (black lines), and existing conditions (red lines) are essentially the same until water levels reach their typical, or pre-storm, condition after approximately 8 days. The enhanced channels provide for increased drainage throughout the system after the storm with tidal forcing only.

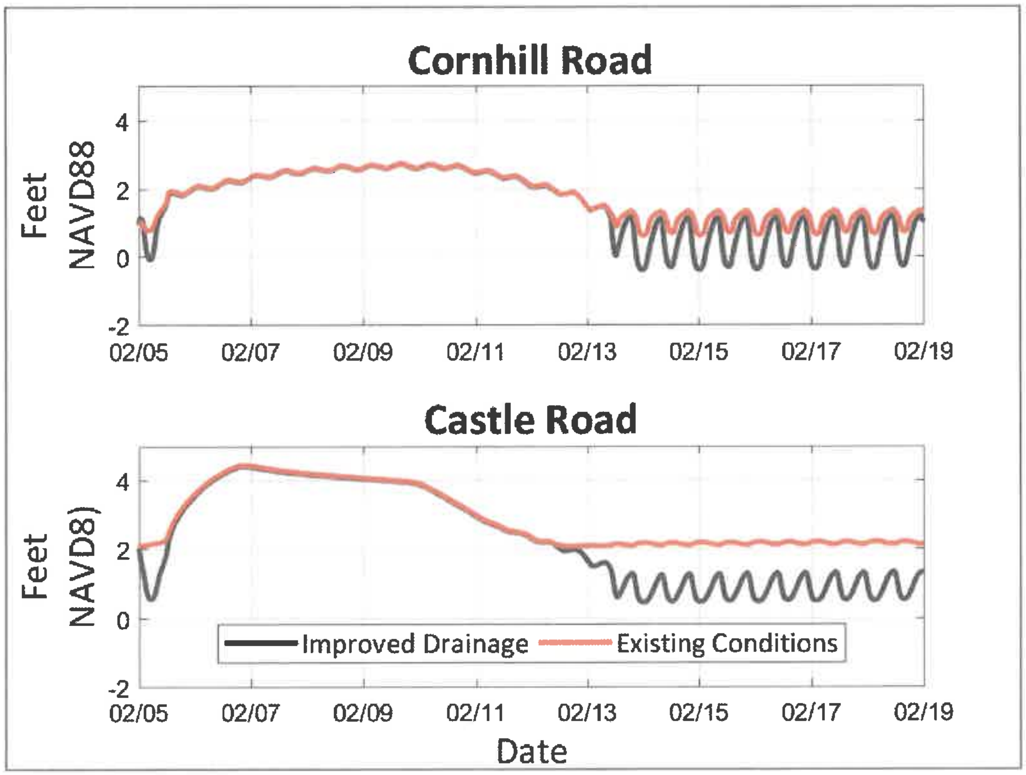

Figure 26. Effects of channel improvements in the Little Pamet River on drainage in the system during a 100-year rain event.

The results from the extreme rainfall event simulation are shown in Figure 27 for the second alternative which includes increasing the size of both culverts under Corn Hill Road and Castle Road. During the rainfall event itself, when peak flows in the lower marsh are seen almost instantaneously, there is a slight increase in water level. Water levels are then allowed to drain out of the system during the subsequent ebb tides, with the optimized culverts able to provide sufficient drainage to allow the increased flows from the 100-year precipitation event to flow under both roadways and discharge into the harbor. When compared to existing conditions, peak water levels in the upper marsh are reduced by over 2 feet and the drainage period is reduced by approximately 4 days.

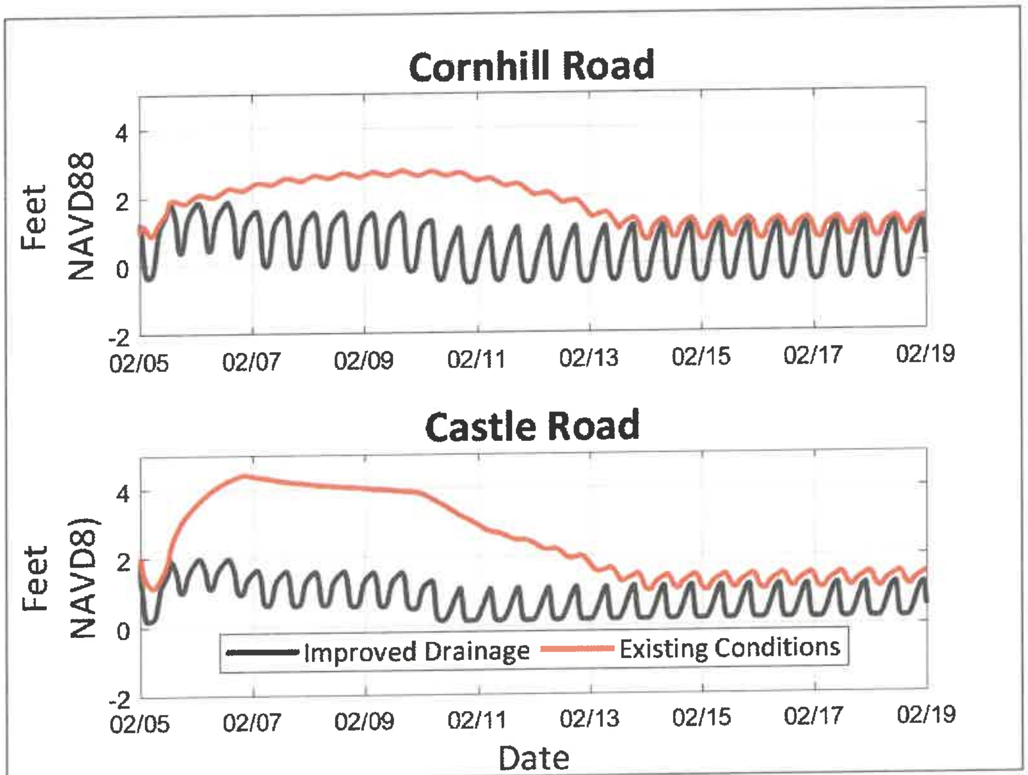

Figure 27. Effects of channel improvements and increased culvert size on drainage in the Little Pamet River during a 100-year rain event.

The 1%-annual-chance storm (100-year) precipitation event was also simulated with projected SLR in 2070 for the alternative with an improved channel and optimized culverts (4-foot pipes). The resulting water levels from the extreme rainfall event simulation are shown in Figure 28 for this alternative (black lines) and for existing conditions (red lines). With the occurrence of this type of event in 2070, the improved channel and culverts help to significantly increase drainage of the system when compared to existing conditions. With the existing configuration, peak water levels exceed 4.4 feet NAVD88 in the upstream marsh, and both marsh basins are not completely drained throughout the entire 14-day simulation. With the improvements, there is an increase in water levels at the start of the event with a peak of just over 2.4 feet NAVD88 in both the upper and lower marsh, and the drainage period is approximately 4 days after the peak.

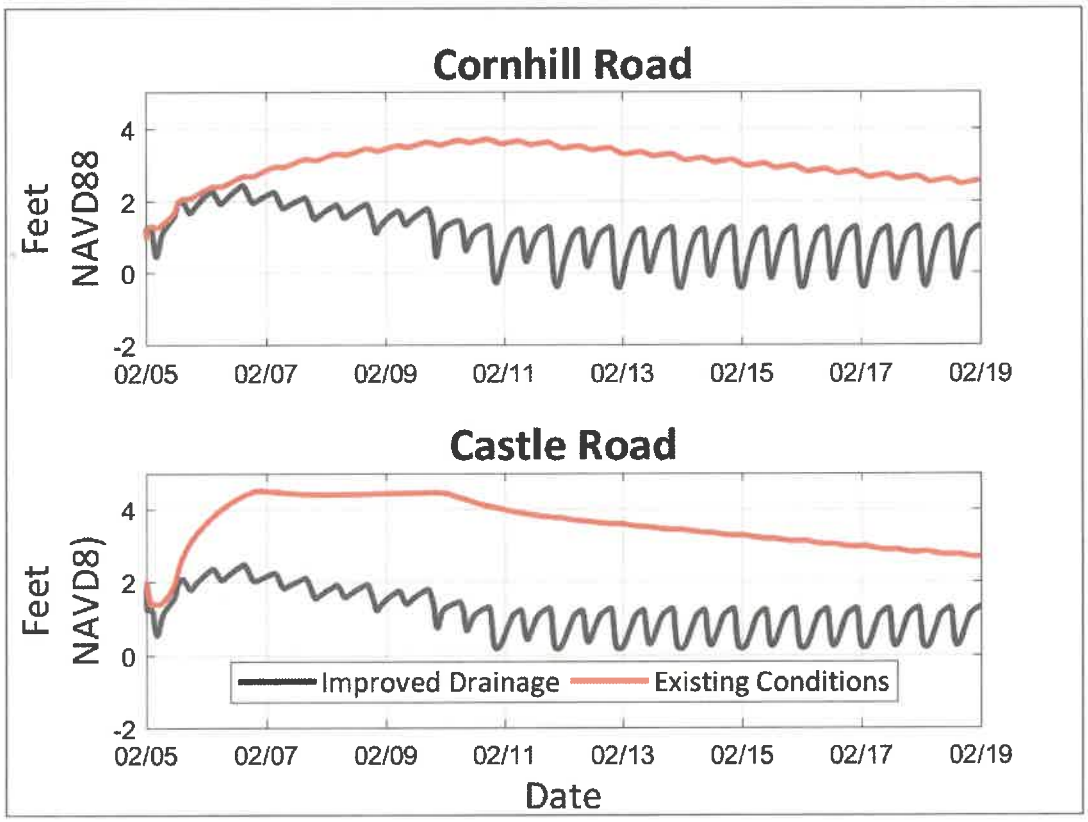

Figure 28. Effects of channel improvements and increased culvert size on drainage in the Little Pamet River during a 100-year rain event with sea level rise in 2070.

5. Summary of Findings and Recommendations

As currently configured, the Little Pamet River system is experiencing channel aggradation and reduced drainage capacity during rainfall events, likely due to reduced freshwater inputs emanating from the Pamet flow lens. Woods Hole Group conducted an H&H study to provide insight into the potential benefits, and effects of, channel/culvert improvements under typical tides, low frequency storm surge events, low frequency rainfall events, and with effects of increased sea level rise. Based upon the modeling results, increased drainage and, subsequently lower water levels in the two reaches of Little Pamet River can be achieved by improving the channel bed by dredging out aggraded material and removing any other obstructions to flow. While these channel improvements are likely to provide enhanced drainage during typical tides, it is also recommended that both the culvert under Corn Hill Road, and the culvert under Castle Road be increased in size from 2 feet in diameter to a diameter of 4 feet. The increased culvert size allows for sufficient drainage with the tide gate in place during the low frequency, high precipitation, storm events during the ebb portion of the tidal cycle. Additionally, increasing the diameters of both culverts would expedite marsh restoration efforts should the Town decide to restore tidal flow to the system. Specific findings/recommendations from the study include:

1. Aggradation of the channel between Corn Hill Road and Castle Road has limited flow conveyance creating a weir-like, perched effect on the upstream water levels, and is inhibiting drainage.
2. The tide gate/culvert combination at Corn Hill Road is not maximizing outflow from the riparian system during ebb tides.
3. Model simulations with channel improvements show that there is improved drainage during typical tides, reducing the mean water level in both the lower and upper reaches of the marsh.
4. Model simulations with channel improvements during a 100-year rainfall event does not show a significant improvement in drainage as the existing culverts are restricting flow.
5. Simulations conducted to assess the optimal culvert size at Corn Hill and Castle Road show 4-foot diameter pipes (or equivalent) would be required at both locations to limit peak water levels and provide sufficient drainage during both extreme coastal and rainfall events. Existing invert elevations can be maintained.

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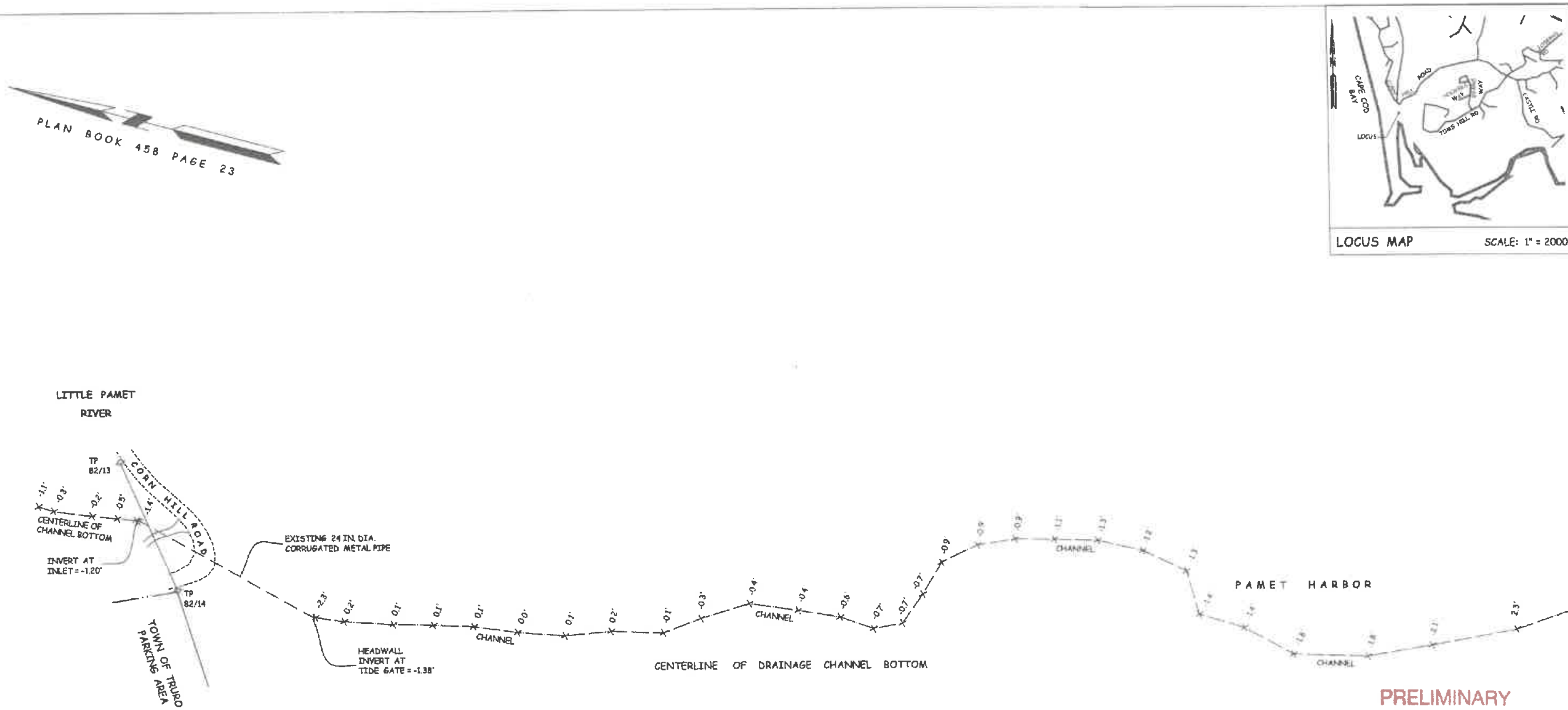


PRELIMINARY

DATUM: 1988 N.A.V.D.

NOTE: x 34.55' DENOTES SPOT ELEVATION.

SCALE OF FEET
0 50 100 200

PRELIMINARY

SITE PLAN OF LAND
IN
TRURO
DEPICTING THE
LITTLE PAMET RIVER
AS PREPARED FOR
TOWN OF TRURO
(OFF CORN HILL ROAD)

SCALE: 1 IN. = 100 FT. JULY, 2018

WILLIAM N. ROGERS
PROFESSIONAL
CIVIL ENGINEERS & LAND SURVEYORS
41 OFF CEMETERY ROAD, PROVINCETOWN, MASS.
508.487.1565 / 508.487.5809 FAX

T-18-2098

Health/Conservation Agent
Town of Truro
Phone: (508) 214-0202
Fax: (508) 349-5850

MEMO

To: Rae Ann Palmer, Town Manager
From: Patricia Pajaron
CC: Kelly Clark, Asst. Town Manager, Jarrod Cabral, DPW Director
Date: August 4, 2017
Re: **Little Pamet River Meeting**

Earlier this year, I contacted staff from the Association of Cape Cod (APCC) to assist the Town in evaluating the Little Pamet River system. As you know, the Town has received numerous calls from abutters to report a decline in marsh health (degraded habitat quality, narrowing of the river channel, spread of invasive species, loss in birds and wildlife, etc.). I scheduled a meeting for August 3rd with the APCC staff and also invited abutters to the Little Pamet to discuss any concerns or changes observed in the marsh in recent years. A site visit was conducted of the Little Pamet River from the Perry Farm by invitation from the Perrys as well as observation of the Corn Hill culvert.

The next step will be a field assessment of the site to include vegetation sampling, photo-documentation, culvert assessment and water quality monitoring. Project staff may need to access private property for the purposes of collecting the data. I have received written consent from 5 property owners allowing project staff to access their property to conduct the field work.

The field assessment is anticipated to begin the week of August 21st through September. I have attached a scope of work for this project.

Little Pamet River Project Assessment Plan

Project Name: Little Pamet River

Project Location: Little Pamet River and surrounding wetland areas north of Corn Hill Road and west of Castle Road in Truro, MA. This river and surrounding wetland area is hydrologically connected to Cape Cod Bay via a culvert beneath Corn Hill Road.

Problem

A long culvert under Corn Hill Road with a one-way clapper valve restricts flow from Pamet Harbor to the Little Pamet River salt marsh. Fresh river water is allowed to flow downstream into Pamet Harbor but incoming tidal salt water is blocked by the valve. The culvert is functional but the current health status of marsh is unknown. Nearby residents have been calling the town reporting decline in marsh health (degraded habitat quality, narrowing of the river channel, spread of invasive species, loss in birds and wildlife, etc.). Individuals have anecdotally noted that the marsh "looks sick."

Background

Bordering the northern spur of the marsh is actively farmed land owned by the Perry family. The Town voted at the 1925 Town Meeting to take over the culvert at Corn Hill Dyke used for draining Little Harbor meadows. Mark Robinson, Executive Director of the Compact of Cape Cod Conservation Trust has noted that a management plan/vegetation study was completed in 1985 (only available in hard copy) by the Center for Coastal Studies, but no further known assessment has been done. The town does provide occasional maintenance dredging to clear sand and sediment from areas downstream of the culvert, but current dynamics of downstream sand movement are not well known. The farmland, immediately adjacent to the marsh edge, would likely be impacted by tidal restoration. It is our understanding that this land is still currently farmed making feasibility of tidal restoration low at present. However, concerns over changes in the marsh warrant some initial assessment to better understand current conditions and characterize the status of the marsh.

Deborah McCutcheon, Chair of Community Preservation Committee may have further details about the status of the Perry family farm that could inform current status and background on the project prior to meeting with the Perry family. The site is likely most accessible from the old railroad bed that runs behind the cottages owned by the Rose family.

The Little Pamet River is located within an area categorized with a 4a TMDL and FEMA special flood hazards zone. The total area of the salt marsh is estimated at 67 acres based on initial GIS mapping by APCC. The adjacent waterbody prohibits shellfishing indicating poor water quality. The area contains multiple sensitive resources and has greater linkages with open space. According to APCC's initial mapping assessment of resilience to the impacts of climate change this site has moderate resilience to sea level rise and high resilience to erosion.

Goal

Complete initial GIS and field assessment of Little Pamet River marsh and culvert to characterize current conditions and recent changes as well as determine potential to improve the health of the system.

Plan

Task 1 – GIS Site Assessment (July)

Prior to field assessment APCC proposes to complete a GIS site assessment to map the area and extent of the marsh, determine elevation of area, identify low lying properties, delineate wetland areas, examine current and historical aerial maps of site, and draft a more detailed field assessment plan. LIDAR maps will be utilized for initial assessment of site elevation. Elevation of the marsh will be identified, likely direction of groundwater flow and any low-lying properties that may be impacted by flooding or tidal restoration. These elevations will be ground truthed with a few spot elevation measurements taken during the field assessment. APCC will also compile existing historical information about the site including maps, agreements, and previous studies from the town, Mark Robinson, and the Center for Coastal Studies. This information will inform the discussion with abutters and final plans for field assessment.

Task 2 – Input from the Public (Proposed August 3, 2017)
(Potential dates for AW/BH to meet with abutters of the Little Pamet River on Aug 3, 2017 at 10:30AM in Truro Town Hall.)

APCC will work with Pat Pajaron from the town of Truro to identify and contact all abutters and other neighbors who have noted changes in the marsh. APCC will send an introductory email or call these contacts to elicit input. APCC will then arrange to meet with the most relevant individuals in person for the initial site visit. At minimum APCC will seek to gather input from the abutters and the Community Preservation Committee Chair.

Task 3 – Field Assessment (late August – exact date TBD)

Based on the GIS information and input from abutters APCC will complete a field assessment of the site to characterize current conditions and recent changes in the marsh. Field assessment will include vegetation sampling, photo-documentation, culvert assessment, and water quality monitoring. A minimum of three vegetation transects will be run from creek edge to upland edge (near tide gauge, middle of marsh, and upstream). The line-transect methodology will be used to record transition zones from low marsh to high marsh and upland/freshwater species. Transect ends will be geolocated using a handheld Trimble GPS unit and photos will be taken looking up and down the transect line. If time and funding allows, additional survey work including: mapping of Phragmites or other select vegetation boundaries; sampling of vegetation in quadrats along the transects; and/or bird surveys could be completed. The culvert will be assessed to confirm current condition and function and measurements of length, depth and distance to harbor will be taken. Photos will be taken of the culvert as well as from the culvert looking upstream at the marsh and downstream towards the harbor. Water quality data (pH, temp, salinity, D.O.) would be collected using a YSI probe. Water level, salinity, and temperature data loggers could be installed to measure tidal change upstream versus downstream of the marsh if there are indications that the upstream area is tidally influenced.

Task 4 – Summary Report (Sept/Oct 2017)

APCC will compile the GIS, anecdotal, and field assessment information into a final report to be filed with the town of Truro.

Cost: Total estimated cost - $2,820.

Funding: APCC has submitted a request to the Friendship Fund for $1,043 to supplement existing funds provided by the Cape Cod Foundation and APCC membership donations to complete this scope of work.

Partners

APCC proposes to complete this scope of work on the behalf of the Town of Truro working with Pat Pajaron, Truro Health and Conservation Agent. Other partners include: Mark Robinson, Executive Director of The Compact of Cape Cod Conservation Trusts; Center for Coastal Studies; the Massachusetts Division of Ecological Restoration; Community Preservation Committee; and site abutters/neighbors.

marsh system. Project is downstream of TR-7 tidal restriction (weir and box culvert). Additional restrictions of East Harbor to Salt Meadow (owned by CCNS) might need to be considered with restoration.

- June 2016: Woods Hole Group completed a report of the evaluation of the East Harbor Culvert. Woods Hole Group worked with Fuss and O' Neill on the conceptual engineering alternatives analysis which is included in the report.

- April 2017: Voters at TM approved funding in the amount of $3.7 million to replace the East Harbor culvert pipe between Route 6 and Shore Road and the replacement of the two seaward sections of pipe and debris gate

- June 2017: Woods Hole Group Inc will be preparing a proposal for the design of the culvert and repair of the seaward end of this structure.

Little Pamet River/Culvert

Goal: Evaluate the Little Pamet River and culvert to characterize current conditions and recent changes to the river and marsh system as well as determine potential improvements to the health of the system.
Long Term: Possible replacement of the culvert.

- 2010: Coastal Engineering Company conducted an evaluation which included a recommendation to remove and replace the existing culvert.

- January 2012: DPW cleaned the culvert and recorded video. At that time there was no negative finding in regards to the structural integrity of the culvert, or blockage of any kind that could significantly restrict the flow of water during the outgoing tide.

- July 2017: Maintenance was performed by the DPW which consisted of clearing of any debris or sediment build up in front the inlets and Clapper valve on the seaward side. Prior to and, following the maintenance, the clapper valve was, and is functional, and water is draining at low tide.

- August 2017
  - Meeting scheduled with APCC staff and abutters to the Little Pamet to discuss any concerns or changes observed in the marsh in recent years. A site visit was conducted of the Little Pamet River and of the Corn Hill culvert.
  - An examination of the integrity of the 500' long culvert has been scheduled with Truax Corporation. This will also include cleaning and video recording of the interior of the culvert.
  - APCC will conduct a field assessment of the Little Pamet to include vegetation sampling, photo-documentation, culvert assessment and water quality monitoring. The field assessment is anticipated to begin in late August.

Ongoing monthly visual inspection and annual maintenance to include the cleaning (jetting) of the culvert, and recording of video be conducted.

Old County Culvert

- Development of request for qualifications and scope of work for engineering services to be accomplished by September, 2017.

- Bid announcement through Barnstable County procurement office to be implemented no later than October 2017.

- Engineering services to be awarded no later than December 2017.
Bid announcement for removal and replacement of Old County culvert to be implemented through Barnstable county procurement office no later than February 2018.

- Removal and replacement of Old County culvert to be awarded no later than May, 2018.

TOWN OF TRURO
P.O. Box 2030, Truro MA 02666
Tel: (508) 349-7004 Fax: (508) 349-5505
Office of the Town Administrator
Pamela T. Nolan

September 30, 2010

To: Board of Selectmen

From: Pam Nolan

Re: Engineering opinion on Culvert at Corn Hill.

On Monday, Paul Morris, Charleen Greenhalgh and I met with Roy Okurowski from Coastal Engineering. He provided us with his opinion on the work needed to improve drainage at the culvert at Corn Hill. The existing culvert (Photo #1) has been there since approximatley 1978. The existing pipe has a life expectancy of between 10 and 20 years, depending on circumstances. The culvert at this time is only working minimally and is in need of either repair or replacement. The existing corrugated metal pipe, 500' long running from the Little Pamet under Corn Hill Road to the Harbor, would be replaced with a 500' plastic ADS pipe, at his suggestion. Along with the the pipe replacement is a 5 foot manhole structure to serve as a weir which would adjust the levels of the Little Pamet for better controlled flow. The existing Headwall (Photo #2), located on the inward side (Harbor side) with its clapper valve, would also need to be replaced.

First and foremost, the watershed area that feeds into the culvert would need to be mapped. This will provide the necessary calculations to determine how much water will need to be drained at any given time. In addition, the property upstream of the culvert would need to develop a soils management plan to address and contain sediment which currently is depositing into the channel area which is contributing to the system failing. This is extremely important.

Grants may be available to assist with this project; however the initial engineering services would most likely be an upfront cost. The estimates for work are as follows:

- Manhole/weir structured - $5,000
- Road work - $5,000
- 30" plastic ADS pipe, 500' long - $20,000
- Headwall - $10,000
- Engineering Work - $11,500

The Town of Truro can expect to pay $50,000.00 to $55,000.00 on the repair at Corn Hill.

Phone: 508-349-7004, ext 11
Email: Townadm@truro-ma.gov
Web: www.truro-ma.gov

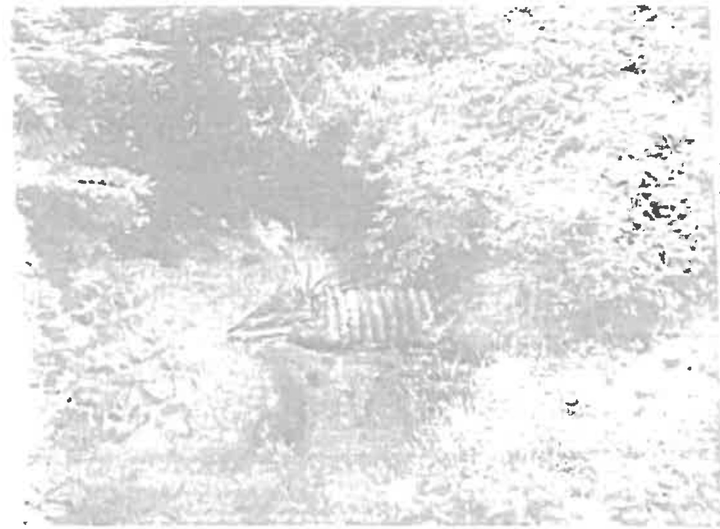


PHOTO #1

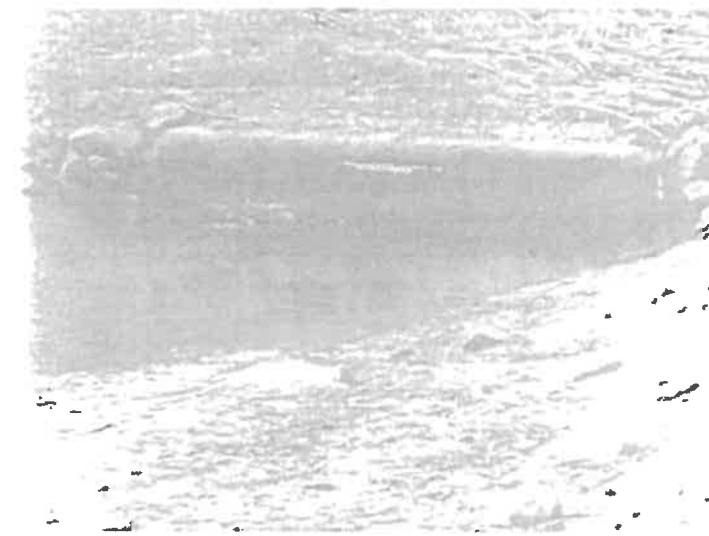


PHOTO #2

COASTAL
ENGINEERING
COMPANY, INC.

260 Cranberry Hwy., Orleans, MA 02653
508-255-6511 Fax: 508-255-6700 www.cecapecod.com

AUTHORIZATION FOR PROFESSIONAL SERVICES

To: Town of Truro
Attn.: Mr. Paul Morris, DPW Director
Ms. Pam Nolan, Town Administrator
P.O. Box 2030
Truro, MA 02666
VIA EMAIL: dpwdirector@truro-ma.gov
townadmin@truro-ma.gov
VIA FACSIMILE: 508-349-5508
T: 508-349-5160

Date: 08/31/2010 Project No. P100838.00
Project: Drainage and Flood Control Improvements

Location: Little Pamet River at Corn Hill Road, Truro, MA

Budget Estimate: See Attached Scope of Services.

As requested by you on 08/26/10, Coastal Engineering Company, Inc. (CEC) will perform the following professional services relating to the referenced project.

SCOPE OF SERVICES:

See Attached Scope of Services

REO/eok

SUBJECT TO TERMS AND CONDITIONS ON REVERSE SIDE

☐ We are proceeding with service(s) noted as per your direction. Immediate notification in writing is required if you wish to alter this authorization.

☒ Please execute this agreement authorizing us to proceed. No services will be performed until you return this agreement with authorization in writing.

☒ This document will become our original agreement.

Acceptance of this agreement by signature authorizes COASTAL ENGINEERING to proceed as described. This proposal expires in 90 days if not signed by both parties.

AUTHORIZED FOR COASTAL ENGINEERING:

By: [signature]
Roy E. Okurowski, P.E.
Marine Division Manager

Date: August 31, 2010

AUTHORIZED BY CLIENT:

Signature ____________ Date ____________

Printed Name and Title ____________

PLEASE SIGN AND RETURN ONE COPY

SCOPE OF SERVICES

Little Pamet River at Corn Hill Road, Truro, MA

Proposed drainage and flood control improvements at Little Pamet River at Corn Hill Road. Scope of work to include repairs and improvements to existing drainage culvert and installation of drainage control structures to prevent upland flooding during storm tidal events. Scope of services to include:

Phase 1 (Data Accumulation Plan) .... *Budget Estimate: $2,500*

- Determine resource area delineation within a 200' wide corridor using the flow path of the river as the project centerline.
- Fieldwork to establish horizontal and vertical survey control to locate existing site structures and resource area information. Gather topographic information sufficient to complete the design and permitting for this scope of the project.
- Acquire detailed information on the dimensions and condition of the existing structures and culverts.
- Prepare office computations and plotting of field data.
- Produce an existing conditions plan with pertinent site information.

Phase 2 (Design for Repair of Weir and Culverts) .... *Budget Estimate: $6,000*

- Perform hydraulic analysis of Perry Road watershed system to resize culvert.
- Design of new culvert/tide gate and weir water control system.
- Produce engineering plans and report with information necessary for this scope of the project.
- Meet with client to review plans and recommendations.

Phase 3 (Notice of Intent Permitting) .... *Budget Estimate: $3,000*

- Prepare and file a Notice of Intent or a Request for Determination of Applicability with the Truro Conservation Commission and the Massachusetts Department of Environmental Protection (including abutter notification).
- Rough-stake the proposed project for viewing by the Truro Conservation Commission.
- Provide engineering representation at the Truro Conservation Commission hearing (allowance for one meeting).

TOTAL BUDGET ESTIMATE: *$11,500*

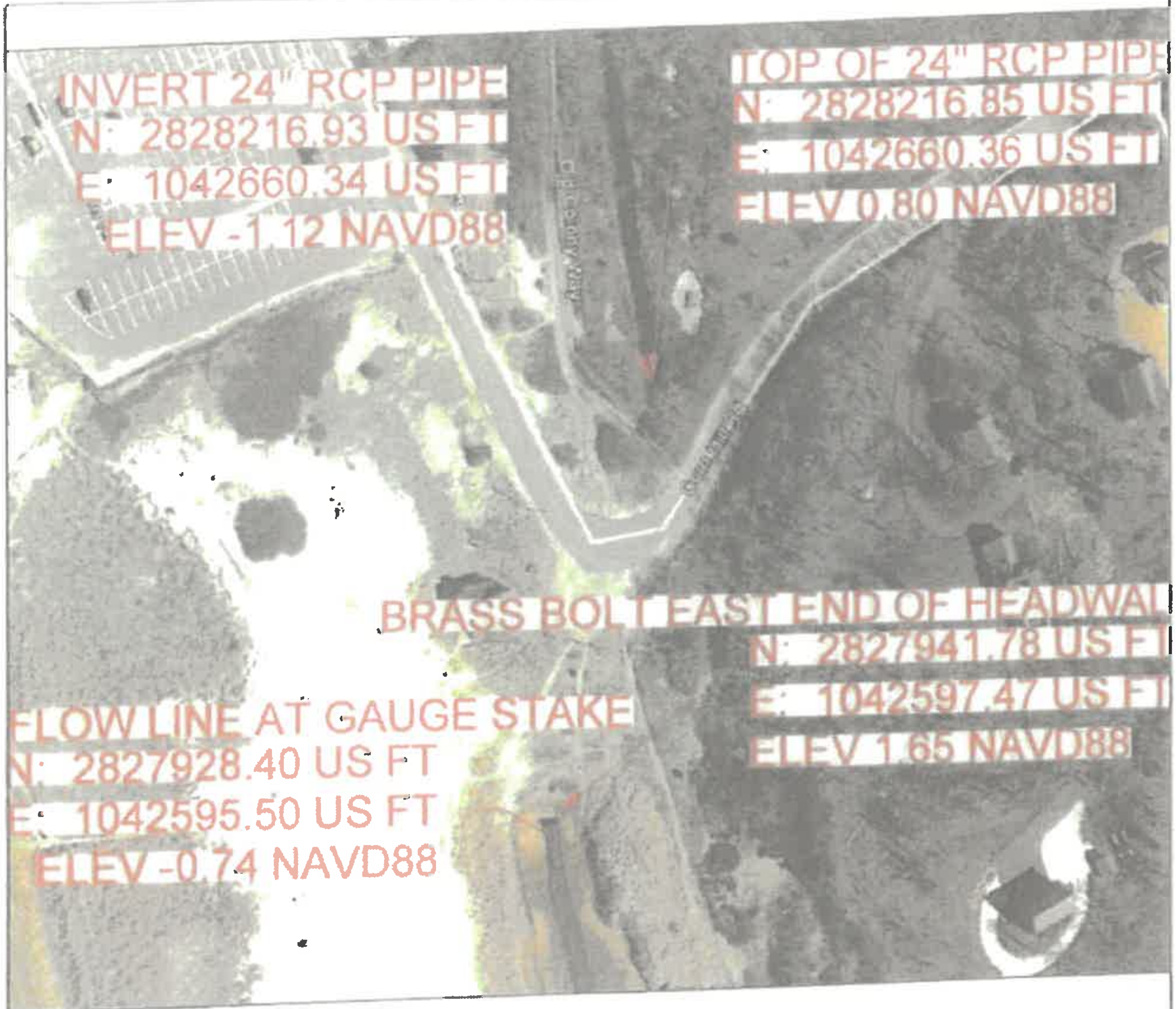
Please note that Coastal Engineering's services do not include the following:

- Department of Waterways Chapter 91 License
- Massachusetts Environmental Policy Act (MEPA) filing
- Army Corps of Engineers (ACOE) permit
- Wetland/marsh restoration
- Watershed analysis or relocated environmental studies
- Wildlife or resource area habitat studies

CEC would be pleased to provide any of the above, non-inclusive services for an additional fee if so desired.

PHOTO #1

PHOTO #2



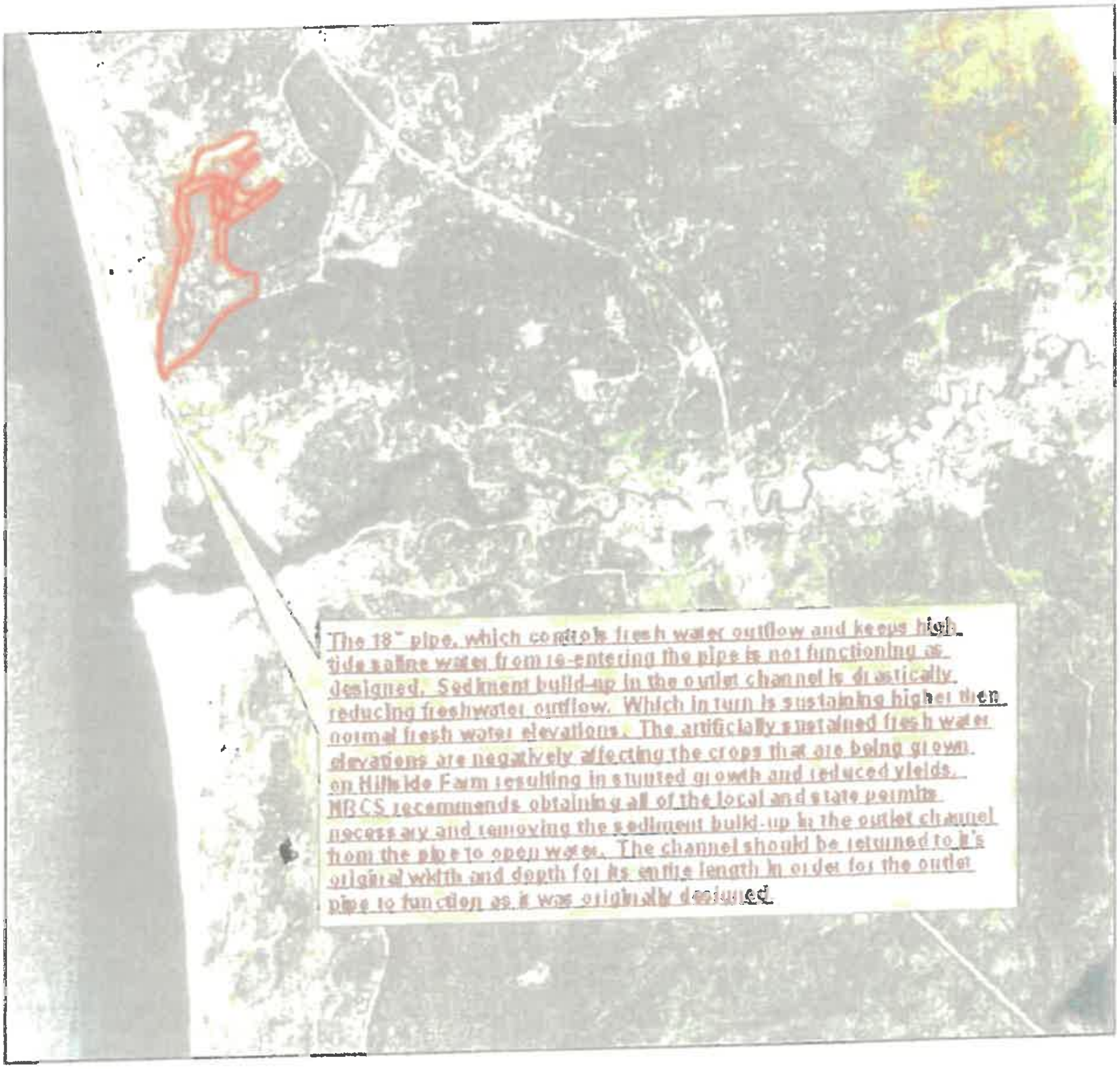
OUTERMOST LAND SURVEY, INC.
#46 Main Street
Brewster, MA
508-255-0477

Sketch Plan of Land
CORN HILL ROAD, TRURO MA
Scale 1"=100' Oct. 20, 2017
ols#654001

Obstruction Removal Plan Map

Field Office: HYANNIS SERVICE CENTER
Agency: USDA-NRCS
Assisted By: STEVEN BEAULIEU

Customer(s): HILLSIDE FARM



1:25,000

1,200 0 1,200 2,400 3,600 4,800 Feet

N W E S

Natural Resources Conservation Service
United States Department of Agriculture

Culvert Evaluation

prepared for

Locke

in

County, Truro, Ma

Designer: SPB
Date: 09/09/2010

Checker:
Date:

'n' value: 0.025
Length: 60 ft.
Diameter: 18 in.
Projecting - groove edge ; Ke = .25

Capacity = 4.4 cfs

Outlet Controls Flow

Elevation of Headwater: 100
Elevation of Inlet: 97
Elevation of Tailwater: 99.5
Elevation of Outlet: 96.8

Natural Resources Conservation Service
United States Department of Agriculture

Culvert Evaluation

prepared for

Locke

in

County, Truro, Ma

Designer: SPB
Date: 09/09/2010

Checker:
Date:

'n' value: 0.025
Length: 60 ft.
Diameter: 18 in.
Projecting - groove edge ; Ke = .25

Capacity = 6.2 cfs.

Outlet Controls Flow

Elevation of Headwater: 100
Elevation of Inlet: 97
Elevation of Tailwater: 99
Elevation of Outlet: 96.8

Natural Resources Conservation Service
United States Department of Agriculture

Culvert Evaluation

prepared for

Locke

in

County, Truro, Ma

Designer: SPB
Date: 09/09/2010

Checker:
Date:

'n' value: 0.025
Length: 60 ft.
Diameter: 18 in.
Projecting - square edge ; Ke = .46

Capacity = 8.5 cfs

Outlet Controls Flow

Elevation of Headwater: 100
Elevation of Inlet: 97
Elevation of Tailwater: 98
Elevation of Outlet: 96.8

Natural Resources Conservation Service
United States Department of Agriculture

Culvert Evaluation

prepared for

Locke

in

County, Truro, Ma

Designer: SPB
Date: 09/09/2010

Checker:
Date:

'n' value: 0.025
Length: 60 ft.
Diameter: 18 in.
Projecting - groove edge ; Ke = .25

Capacity 7.5 cfs

Outlet Controls Flow

Elevation of Headwater: 100
Elevation of Inlet: 97
Elevation of Tailwater: 98.5
Elevation of Outlet: 96.8

Preliminary Ecological Assessment of the Lower Little Pamet River Valley, Truro, Massachusetts

Prepared for the Town of Truro, Massachusetts

by

Bryan Horsley, Jo Ann Muramoto, Ph.D., Carl DePuy, and April Wobst
Association to Preserve Cape Cod

July 3, 2018

Table of Contents

List of Tables

List of Figures

List of Appendices

Preliminary Ecological Assessment of the Lower Little Pamet River Valley, Truro, Massachusetts

Prepared for the Town of Truro, Massachusetts

by

Bryan Horsley, Jo Ann Muramoto, Ph.D., Carl DePuy, and April Wobst
Association to Preserve Cape Cod

July 2, 2018

1. Introduction

On August 3, 2017, Association to Preserve Cape Cod (APCC) staff attended a meeting at the Truro town hall with Conservation Department staff and seasonal and year-round residents of the lower Little Pamet valley. The meeting was initiated by Conservation staff who invited APCC to attend the meeting to learn about the concerns of landowners regarding the health of the river and surrounding wetlands. Landowners living primarily along Resolution Road, which overlooks the river valley, expressed concern about the apparent rapid degradation of the Little Pamet River in the lower valley that has occurred over the past five to seven years. Landowners described the shallowing and disappearance of open water in the river channel, loss of ability to navigate the river by kayak, spread of invasive vegetation, loss of aesthetic value, increased mosquitos, and loss of avian and terrestrial wildlife throughout the valley. Owners of Hillside Farm, on Perry Road on the northern edge of the valley, voiced a different concern from their perspective as farmers, which focused on their desire to maintain downstream flow at the Corn Hill Road culvert for the purpose of farm drainage. The farm owners believe that restricted flow at the Corn Hill Road culvert has impeded drainage from the farm into the stream resulting in occasional flooding and loss of crops in areas planted at the edge of the marsh. The farm owners also noted recent observations of extreme low water in the valley as indicated by complete drying up of their farm pond in summer 2016, which they had never witnessed before.

In response to these concerns and at the invitation of Town staff, APCC conducted a preliminary ecological survey and assessment of the area to document existing conditions and to explore potential factors contributing to the apparent degradation of the river channel and surrounding wetlands. The lower Little Pamet valley project assessment area was defined as the lower section of the river flowing from a culvert beneath Castle Road to a culvert and tide gate beneath Corn Hill Road (**Figure 2**, site map). The survey entailed two site visits and in-office research with the goal being to collect information to inform recommendations for next steps in further assessment and potential restoration of healthy ecological function to the system.

2. Background Information

2.1. Historical conditions

Historically the Little Pamet River flowed from its source in the higher elevations of central Truro to its outlet at Cape Cod Bay. In colonial times it is likely that the wetlands of the lower valley were estuarine and were likely dominated by tidally influenced salt marsh habitat. A topographic map from 1890 depicts the Little Pamet River before Corn Hill Road was constructed, showing only a railroad crossing the valley (**Figure 3**). On this 1890 map the horizontal blue lines, which extend throughout the valley upstream and downstream of the railroad, indicate areas of wetland or open water. In the lower reaches of the Little Pamet River it is likely that these wetlands were estuarine and included significant areas of salt marsh habitat. The historical upstream extent of estuarine conditions cannot be determined at this point without further field investigations.

Later maps show a progression of increasing human alteration including the addition of roadways, buildings and homes, and finally the complete redirecting of the river through a culvert pipe by 1938. When the decision was made to install a tide gate to block inland tidal flow, it is likely that the previously saline wetland system began transitioning into a freshwater system. Earlier maps are provided in Appendix 1.

2.2. Current conditions

Wetlands, culvert and tide gate

The lower Little Pamet River valley is an area of approximately 46 acres of fresh and brackish wetland and stream habitat located in Truro, Massachusetts (**Figure 2**). The Little Pamet River originates east of Route 6 near the intersection of Long Nook Road and Atwood Road at Long Nook Meadows Farm and flows westward before joining with the saline tidal waters of Pamet Harbor and finally terminating in Cape Cod Bay. A 280-foot long, 24-inch diameter culvert pipe allows downstream discharge beneath Corn Hill Road but restricts upstream tidal flow with a hinged steel flapper valve on the downstream side. The culvert and hinged flapper valve function as a tide gate designed to allow freshwater to flow out into Cape Cod Bay while restricting or preventing seawater flow into the valley. Additional road crossing culverts allow downstream discharge beneath Castle Road, State Route 6, and two private driveways east of Route 6.

Land use

Surrounding land use is primarily seasonal residential with at least three active agricultural areas directly adjacent to the river and a significant automotive transportation corridor (State Route 6) crossing the river near its source.

Fish

The Massachusetts Division of Marine Fisheries (DMF) conducted a survey of anadromous fish runs on Cape Cod which indicated that the nearby Pamet River system contains alewife, blueback herring and trout (Reback et al., 2004). No information was available for the Little Pamet River system, however.

Rare species

The entire valley is identified as Priority Habitat for Rare Species by Mass Wildlife's Natural Heritage and Endangered Species Program (NHESP), which means that this area provides habitat for state listed rare species and that any habitat alteration is thus subject to regulatory review by NHESP (**Figure 4**).

Water quality

The Little Pamet River discharges into Pamet Harbor at the mouth of the greater Pamet River. The Pamet River is listed by the state as a Category 4A impaired water due to fecal coliform bacteria in the 2014 and 2016 Massachusetts List of Impaired Waters, signifying that water quality must be improved to comply with state and federal clean water standards (**Figure 5**). However the Little Pamet River is not listed as an impaired water ((MA DEP 2014, MA DEP 2016). It is not known whether this is due to lack of water quality data or whether water quality data exists that indicates good water quality. One question for potential future study is whether the Little Pamet River outflow contributes bacteria to the Pamet River estuary.

Groundwater

The headwaters of the Little Pamet River watershed are located above the highest portion of the Pamet groundwater lens of the Cape Cod aquifer as shown in **Figure 6** below from Masterson (2004). At its highest, the top of the water table in this area is at 6 feet above sea level beneath the surface of the ground (Masterson, 2004). Groundwater flows outward and downward from the highest point in the groundwater lens to lower altitude areas along the coast. Groundwater that wells up into a stream is called baseflow. It is likely that the Little Pamet River originates in groundwater flowing downgradient from this high point which provides baseflow to the stream.

3. Assessment Methods

To document existing conditions in the river and surrounding wetland area and to explore potential causes of degradation to the system, APCC staff conducted a field survey on August 16, 2017. APCC also conducted research involving historical and current maps and other information to further evaluate potential impacts to the system. The methods used to conduct the field survey and research are described below.

Satellite Imagery

APCC used the Massachusetts Ocean Resource Information System (MORIS) online mapping tool created by the Massachusetts Office of Coastal Zone Management (CZM) to collect historic satellite images of the lower Little Pamet River valley from 2005 to 2016 to assess visual changes in the river and surrounding wetland areas from an aerial perspective over time. Specific dates of images are not available so we do not know exactly when and at what time of year images were taken. We have included these images in chronological order in **Appendix 1**.

Data Logger Deployment

APCC deployed Solinst LTC Edge data loggers in the stream channel on either side of the Corn Hill Road culvert on August 16, 2017 to collect data for four weeks. The two loggers were set to collect information about water level, temperature, and conductivity every ten minutes throughout the deployment period. The downstream logger was deployed roughly ten feet south of the flapper valve on the southern end of the Corn Hill Road culvert in a deep pool and the upstream logger was deployed roughly 80 feet north of the northern end of the culvert. Six-foot long metal fence posts were driven into the river bed to a depth where they were secure. Data loggers were then secured to the fence posts at a depth near the stream bed where they would not breach the water surface at low tides. A third logger (Solinst Barologger) was deployed above water near the culvert to collect atmospheric pressure data, which was later used to correct water level data for variations in atmospheric pressure to produce the final output of water depth at each logger.

Stream Bed Substrate Survey

APCC staff conducted a qualitative assessment of stream bed material on both the upstream and downstream sides of the Corn Hill Road culvert at the same locations where water quality was sampled and data loggers were deployed (**Figure 2**). Walking in the stream channel with chest waders APCC staff used a tape measure and six-foot long metal fence post as a probe to measure depth of soft organic sediment upstream of the Corn Hill Road culvert. Walking in this area of the channel was very difficult due to the very mucky conditions, and at times staff felt that they would sink beyond the tops of their waders. On the downstream side staff observed that the stream bed was sandy and lacked any significant organic deposits.

Vegetation Survey

APCC staff conducted a walking and visual survey of vegetation in the lower Little Pamet River valley from surrounding roads, bordering residential properties, and by walking through the marsh wearing waders. The southwestern region of the lower river valley was dominated by a large area of non-native invasive common reed, *Phragmites australis*. To map the current extent of *Phragmites*, we used a handheld Trimble differential GPS unit to map the northeastern edge of this area, which was defined using the "50-percent method" (i.e., areas of 50 percent or greater density of *P. australis* defined the edge where the mapped line was drawn). The Trimble GPS unit is accurate to less than one meter. The GPS coordinates were then used to create a mapped polyline (continuous line composed of multiple segments) using GIS.

The purpose of mapping the edge of the Phragmites-dominated area is to create a baseline map that can be re-assessed during future surveys to document changes in location and area of the *Phragmites*-dominated area. This method also helps to omit outliers or sparse areas of the target plant species so the survey can effectively outline a continuous plot of the targeted vegetation. After uploading the polyline file from the GPS device to a PC desktop computer, we used

ArcGIS Desktop software to complete an enclosed polygon around the entire stand of *Phragmites* by estimating the remaining edges using changes in color and patterns visible on an aerial satellite photograph basemap as a guide. With this polygon, we were able to calculate the estimated area of the plot. In future surveys it will be possible to track changes in size and location over time. See site map **(Figure 3)**.

Water Quality Spot Sampling

Using a salinity refractometer and a handheld YSI Pro Plus water quality probe, we collected spot readings of water temperature, pH, and dissolved oxygen at four locations in the river channel: upstream and downstream of the Corn Hill Road culvert and upstream and downstream of the Castle Road culvert. See site map **(Figure 3)** for locations. Prior to taking readings both the refractometer and YSI instruments were calibrated according to manufacturer's recommendations.

GIS Mapping

A GIS map was created that includes the boundary of the lower valley, boundary of the Little Pamet river watershed, area of the largest continuous *Phragmites* patch, and locations of data logger deployment and water quality sampling sites **(Figure 3)**. The boundary of the lower valley was created in ArcGIS by tracing the estimated edge of the wetland area using the inner edges of Corn Hill Road and Castle Road and estimated edge of upland habitat as guides. This area was delineated for reference in this report and for comparison with the mapped *Phragmites* area. The entire Little Pamet river watershed area was delineated using the United States Geological Survey (USGS) Stream Stats web based mapping program*. Locations of the *Phragmites* patch, data logger deployment sites, and water quality sampling sites were collected using a handheld Trimble GPS and were uploaded to ArcGIS as shapefiles. On each side of Corn Hill Road the locations for data logger deployment, water quality sampling, and sediment assessment sites overlapped so only two point locations were provided to indicate all three activities on the site map **(Figure 3)**.

Groundwater levels

For a preliminary assessment of whether groundwater levels have changed recently, APCC downloaded the USGS groundwater monitoring data for the Truro monitoring well which is located on the Pamet groundwater lens **(Figure 7)**. Groundwater elevations for the past year are presented in the Results, below.

4. Results and Assessment

APCC staff evaluated the information collected above. The results and discussion are presented here.

* https://water.usgs.gov/osw/streamstats/

Satellite Imagery Results

During our review of satellite images we noted small changes in stream channel width and open water area that occurred between 2005 to 2011. More rapid and dramatic changes occurred from 2011 to 2013 and 2013 to 2016 as nearly all open water disappeared from the marsh area stretching from the northern lobe of the valley adjacent to Perry Road southward through the center of the valley to Corn Hill Road. Based on visual examination of the satellite images, previously open water areas are now filled in with either sediment or vegetation or both. To ground-truth these observations, we conducted a field survey and walked through some of these previously open water areas. These were found to be filled in with fine organic sediment and densely vegetated with *Phragmites*.

Data Logger Results

Data loggers were installed to collect data to document differences in hydrology (changes in tidal water elevation), conductivity and temperature on either side of the Corn Hill Road culvert to assess what impacts the culvert is having on the river system. Since this culvert is fitted with a tidegate consisting of a one-way flapper valve designed to limit inflow of tidal salt water we expected to see dramatic differences in all three parameters on opposite sides of the culvert, especially water level and conductivity. Graphs below summarize the data collected (**Figures 8 and 9**). The date range shown in these figures was abbreviated to focus in on the period from August 20th through 26th to provide a more detailed look at daily trends. Additional data are available for a longer period of time.

The graph of water level and temperature (**Figure 8**) clearly depicts a significant difference in tidal water elevations between the downstream and upstream loggers. The downstream logger recorded a large tidal range, averaging roughly five feet from low to high tide, while the upstream logger recorded a significantly restricted tidal range, averaging less than one foot each tidal cycle. Temperature data depicted in this figure shows less of a difference between the upstream and downstream loggers but does depict a warming and cooling trend that is well correlated with tidal cycles. During incoming tides both loggers recorded a warming trend as warmer saline water entered the system from Pamet Harbor and Cape Cod Bay. During outgoing tides loggers reported a cooling trend as cool groundwater-sourced fresh stream water filled in as the warmer saline water ebbed seaward. Groundwater on Cape Cod maintains a consistently cool temperature around 12.5 degrees Celsius (55 °F). These trends in water level and temperature fluctuation with tidal range suggests that there is tidal influence upstream of the Corn Hill Road culvert, despite the restrictive one-way flapper valve. This also suggests that the one-way flapper valve is not functioning as originally intended to keep seawater out; or, seawater may be bypassing the tidegate in some other manner.

The graph of conductivity (**Figure 9**) depicts large fluctuations in conductivity that correlate with the tidal water elevation fluctuations of Figure C. Conductivity is a measure of the electrical conductance of the water, driven by the concentration of charged ions that serve to conduct electricity through water, which is a good indicator of salinity. During incoming and high tides, both loggers recorded a large increase in conductivity from almost entirely fresh water at around 1,000 microSiemens per centimeter (µS/cm) up to roughly 48,000 µS/cm or nearly full conductivity of seawater. Freshwater is generally defined by conductivity of 50 to 800 μS/cm while seawater is around 50,000 μS/cm. This spike in conductivity during incoming and high tides further suggests that there is tidal influence upstream of the Corn Hill Road culvert.

While tidal fluctuations of water surface elevation and conductivity are currently occurring upstream of Corn Hill Road (at least to 80 feet upstream of the culvert), APCC did not conduct additional monitoring further upstream, which would be necessary to document how far upstream this tidal influence extends. Collection of additional upstream data would help to better understand the extent of tidal influence in the lower Little Pamet River valley, to draw connections to surrounding vegetation communities, to consider potential effects of altering the existing culvert-flapper valve system, and to define potential solutions for addressing concerns about marsh health and farm drainage.

Stream Bed Substrate Results

The stream bed substrate on the upstream side of the Corn Hill Road culvert consisted of very soft and deep organic black mud. Probing with a six-foot long metal fencepost we found four feet of organic sediment sitting atop denser sandy base material. On the downstream side of the culvert the stream bed was sandy with no visible organic material present. This significant difference between sediments upstream and downstream of Corn Hill Road suggests the following: 1) that much organic material is either being produced within or finding its way into the stream channel, and 2) that the culvert is restricting natural downstream sediment transport and is causing accumulation of organic sediment on the upstream side of the culvert.

It is worth noting that when downstream tidal water elevation (pressure on the flapper valve) is equal to or higher than that on the upstream side of the Corn Hill Road culvert, downstream flow is halted for a period of hours, which effectively allows suspended material that would otherwise be moving downstream toward Pamet Harbor to settle out just upstream of the culvert.

Sources of organic matter likely include decomposition of plants and algae (exacerbated by excessive nutrient inputs). The stream bed serves as a natural trap for accumulating organic debris that is carried downhill by stormwater runoff. Natural streamflow that could flush this material out of the system may be obstructed by the culvert at Corn Hill Road which appears to be interrupting natural downstream sediment transport processes.

Impacts may include degraded water quality due to the accumulation of nutrient-rich organic sediment upstream of the culvert. This is likely contributing to degraded water quality due to leaching of accumulated nutrients, bacteria, and other contaminants.

Potential strategies to address nutrient enrichment include: identification of potential sources of organic matter, nutrients, bacteria and other contaminants; controlling sources of pollution; mitigating pollution through ongoing management (recurrent intervention to maintain downstream flow through the culvert combined with dredging to remove sediment from the system); and/or restoration of natural stream flow and sediment regimes (remove or widen restriction at Corn Hill Road culvert) to enable two-way flow similar to the natural flow that once existed before the railroad bed and tidegate were installed.

Vegetation Survey Results

During our visual field survey of vegetation, the central area of the lower Little Pamet valley appeared to be dominated by native broad-leaved cattail (*Typha latifolia*). Extensive areas on the northern lobe of the marsh near Hillside Farm and adjacent to the Corn Hill Road culvert were covered with two invasive species, Common reed (*Phragmites australis*), and purple loosestrife (*Lythrum salicaria*). Using a handheld Trimble GPS unit and ArcGIS Desktop software to outline the largest continuous area of *Phragmites,* we estimate this plot covered an area of 82,617-square-feet (about 2 acres), which is about 4.4% of the entire 46-acre lower Little Pamet River valley.

Phragmites australis is a widely abundant invasive plant found throughout brackish and fresh marshes as well as disturbed areas. It tolerates salinities up to 18-25 ppt and when it is found in large stands it is often an indicator of brackish conditions. It spreads quickly to outcompete more beneficial native plants. Spread of *Phragmites* in marshes across Cape Cod has resulted in reduced cover of beneficial native plants and diminished habitat value for wildlife. It spreads underground via persistent rhizomes and is very difficult to eradicate once established. Restoration of saline tidal flow to restricted marshes, like the lower Little Pamet valley, has been shown to kill back and stunt growth and spread of *Phragmites* provided that the restored tidal flow reaches the elevation of *Phragmites* stands. Purple loosestrife, while often perceived as an attractive purple flowering plant, is also harmful to native wetland habitats and can be controlled in the same manner.

Additionally, each of these species, particularly *Phragmites*, produce extensive aboveground biomass each growing season. *Phragmites* growth can increase the amount of plant biomass by a much as two or three times the biomass of other plant communities, and the resulting accumulation of organic matter enhances the rate of accretion of the marsh surface (Rooth et al., 2003). In winter above ground foliage and stem material dies back and falls to the marsh surface and into stream channels where it decomposes and contributes significant organic material to form layers of peat on the marsh surface and accumulation of nutrient-rich organic sediments in the stream bed. In the case of the Little Pamet River, this accumulation of organic sediment in the stream bed combined with restricted flow and sediment transport at the Corn Hill Road culvert has likely contributed to shallowing and vegetation encroachment in the river channel.

To track ongoing changes in the marsh this area and other areas dominated by invasive plants should be remapped in future years and overlaid for comparison with this baseline map.

Water Quality Spot Sampling Results

Using a salinity refractometer and YSI Pro Plus water quality probe, water quality spot samples were taken between 8:00 AM and 9:00 AM on August 16, 2017 during an outgoing tide. High tide occurred at 6:45 AM the morning of the survey and low tide was forecast for 12:50 PM*. The following table contains the results of these spot samples.

* Tide data was for Wellfleet Harbor as this was the nearest tide data station. Actual tides at Little Pamet likely varied slightly.

Table 1. Water quality monitoring results for four stations, taken between 8 AM and 9 AM, 8/16/17.

	Downstream of Corn Hill Road	Upstream of Corn Hill Road	Downstream of Castle Road	Upstream of Castle Road
Temperature	23.33 °C (74.0 °F)	22.28 °C (72.1 °F)	19.89 °C (67.8 °F)	20.28 °C (68.5 °F)
DO (mg/L)	6.60	5.74	2.50	2.44
pH	7.88	7.68	5.87	5.64
Salinity (ppt)	30	25	2	2

Water temperatures, DO, pH, and salinities were lower at the Castle Road sampling sites compared with the Corn Hill Road sites. In addition to quantitative readings we also noted very turbid brown colored water on either side of the Castle Road culvert and no perceptible downstream flow. In summary, the Castle Road sites had cooler water, lower DO, lower pH, and were much fresher than the Corn Hill Road sites. The Corn Hill Road sites had warmer water, higher DO, higher pH, and higher salinities approaching seawater (32 ppt). Note these measurements were taken in the morning, when DO levels would normally be low due to plant respiration during the night that uses up DO. Followup monitoring should include monitoring a site throughout the day in order to account for diurnal changes.

There are several possible reasons for these observed differences between the Castle Road and Corn Hill Road sites:

1) Water in the Castle Road area may have a relatively higher amount of groundwater that would be cooler, fresher, lower in pH and lower in DO;
2) Water in the Castle Road area may be lower in pH and DO due to decomposition of the abundant organic matter built up in this area and the low flow of the stream in this area;
3) Water in the Corn Hill Road area may be experiencing more influx of seawater from Cape Cod Bay and hence has higher DO, pH, salinity and temperatures;
4) All of the above;
5) There are no differences between the Castle Road site and Corn Hill Road site; the numbers that we saw can be explained by normal daily fluctuations.

Whatever the causes of the differences in water quality, the low DO and pH of the upstream samples at Castle Road indicate poor water quality and degraded habitat for aquatic life. While different species have differing levels of tolerance for low DO, the concentrations recorded at Castle Road of less than 3 milligrams per liter (mg/L) are considered sub-oxic; that is, low in oxygen. High water temperatures (approaching 70 degrees Fahrenheit during our sampling) serve to reduce the aquatic oxygen saturation point and thus are also a contributing factor to degraded water quality in this system.

Anecdotal information from a resident suggests that the Little Pamet river may have once supported abundant fish populations, possibly including sea run brook trout. Sea run brook trout prefer good water quality with high DO and cold temperatures indicative of a healthy groundwater fed stream system; adult trout prefer DO of at least 6.5 mg/L and their eggs will die in conditions below 6 mg/L†. Current low flow, low pH, warm temperatures and low DO conditions would likely not support sea run brook trout.

Groundwater levels: results

Groundwater levels in the period from July 2017 to June 2018 are plotted in **Figure 10**, where the red dot represents the monthly measurement and the colored bars represent the range of values observed in past years. In this period groundwater levels were very high, above the median level. High groundwater levels will likely cause an increase in baseflow to the Little Pamet River, whereas low groundwater levels will likely cause baseflow to the river to decrease.

A detailed understanding of the freshwater and groundwater dynamics of this area would require a hydrological study to examine the importance of groundwater in maintaining the freshwater-seawater balance in the Little Pamet River. Monitoring of salinity of the stream at different depths during low tide could also provide information on freshwater baseflow into the stream. Changes in upstream water withdrawals from the Pamet groundwater lens could potentially affect the water table and stream baseflow. Truro and Provincetown are served by a municipal well drawing on the Pamet lens, and by private wells. In order to evaluate the potential effect of existing water withdrawals on groundwater and stream flow, the hydrological study would need to include an analysis of groundwater withdrawal rates. The USGS has been monitoring groundwater levels at the Truro monitoring well for many years and that information could be analyzed to determine whether there are any trends over time.

5. Conclusions and Recommendations

This preliminary assessment describes some of the existing conditions in the lower Little Pamet River. The lower portion of the stream valley appears to have changed significantly over time, experiencing filling in of open water areas, replacement of native wetland plant species with invasive Phragmites and purple loosestrife, and increasing salinity. The upper portion of the lower valley appears to be suffering from sluggish water flow, poor water quality, sediment accumulation, and widespread invasive plant growth. Both areas may be in a state of degraded ecological health relative to a healthy open-water system.

Our preliminary study suggests some possible causes of narrowing of the stream channel, overall loss of open water and changes in wetland vegetation. These possible causes are:

1) Filling in of the open water areas has occurred due to a combination of sedimentation from nearby elevated areas, organic matter from increased plant biomass (e.g., *Phragmites australis*) within the marsh area, and organic matter from surrounding land use practices;

2) The tidal restriction (tidegate, culvert) has acted as a dam to retain sediments and organic matter and reduce tidal flushing of the valley, hastening the filling in of the valley;

† http://www.fondriest.com/environmental-measurements/parameters/water-quality/dissolved-oxygen/

3) Nutrients from surrounding land uses (e.g., septic systems, farming) may be stimulating plant growth such as invasive *Phragmites australis*;

4) Changes in salinity due to incursion of seawater that may have fostered the spread of invasive *Phragmites* and discouraged the growth of freshwater plant species.

Other possible causes include sea level rise and changes in groundwater due to natural and manmade causes. This study did not examine these possible causes. More in-depth assessment is needed in order to identify the key factors responsible for the major changes that have occurred, and to identify appropriate strategies restore ecological health.

Recommendations are provided below for next steps. In most cases further information collection and research would be needed to confirm the causes of change and degradation. This would be useful as it could help to inform the selection of appropriate mitigation and restoration strategies.

Recommendations

1) Form a Little Pamet River working group to compile information on natural resources and historical practices, develop a watershed plan with recommendations for restoration, protection and long-term management, and provide outreach on findings and recommendations.

2) Until a decision is made concerning management and restoration, maintain the culvert and tidegate to ensure that water flow is not impeded;

3) Conduct a hydrological study to understand how groundwater affects streamflow, determine how seawater is entering, the upstream extent of tidal and saltwater influence on the Little Pamet River valley, what the current freshwater-seawater balance is, whether hydrology has changed over time, effects of vegetation growth, and possible causes of change (e.g., groundwater withdrawals for public water supply, sea level rise, septic systems, erosion and infilling with sediments and organic matter). The goal of this study would be to determine the major causes of the hydrological changes seen in the valley, i.e., loss of open water and increasing brackish conditions) and to help identify which factors may be feasible to address.

4) Evaluate potential sources of nutrients and bacteria (e.g., stormwater runoff, septic systems, waterfowl, land uses, etc.) and determine whether the Little Pamet River contributes pollutants to the larger Pamet River system which is a state-listed impaired water body.

5) Conduct more comprehensive mapping of vegetation and wetlands throughout the valley to serve as a baseline for future surveys and for permitting. Identify the rare species present in the valley and determine its habitat requirements. This will need to be taken into account in any restoration or management plan.

6) Coordinate with the Barnstable County mosquito control staff to establish an ongoing management plan for the valley that will include culvert clearing and may include other measures to improve and protect water quality and habitat.

7) In concert with the Town's coastal resilience planning, evaluate the long-term fate of this valley as sea level rises and what measures if any the Town will take to increase resilience. The role of *Phragmites* in increasing the accretion rate in the marsh plain is potentially of interest (Rooth et al., 2003).

8) If the Town decides to undertake restoration, the guiding principle should be a holistic watershed approach that restores the physical and chemical conditions that will lead to improved habitat for fish and wildlife and improved water quality.

6. References

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7. Acknowledgements

This project was made possible through support from the Friendship Foundation, the Massachusetts Bays National Estuary Program, and dues and donations from APCC members.

Figures

Figure 1. View facing southwest and looking downstream over the lower Little Pamet River valley from Castle Road toward Corn Hill Beach. Photo taken 8/3/17.

Lower Little Pamet River Valley Ecological Assessment

Truro, Massachusetts
May 2018

In response to concerns voiced by town staff and residents about the apparent decline of ecological health in the lower Little Pamet valley, the Association to Preserve Cape Cod offered to conduct a general ecological assessment of the area and to produce the *Lower Little Pamet River Valley Ecological Assessment Report, May 2018*, to describe findings and potential next steps to assess and restore health to the system.

This map was produced to serve as an attachment to the report to depict the focal area and locations of APCC's field assessment work.

For more information contact APCC's Restoration Coordination Center staff at: 508-619-3185.

Watershed Area
Lower Valley
Phragmites australis
Sample Points

Figure 2. Area of study in the lower Little Pamet River valley, Truro, Massachusetts.

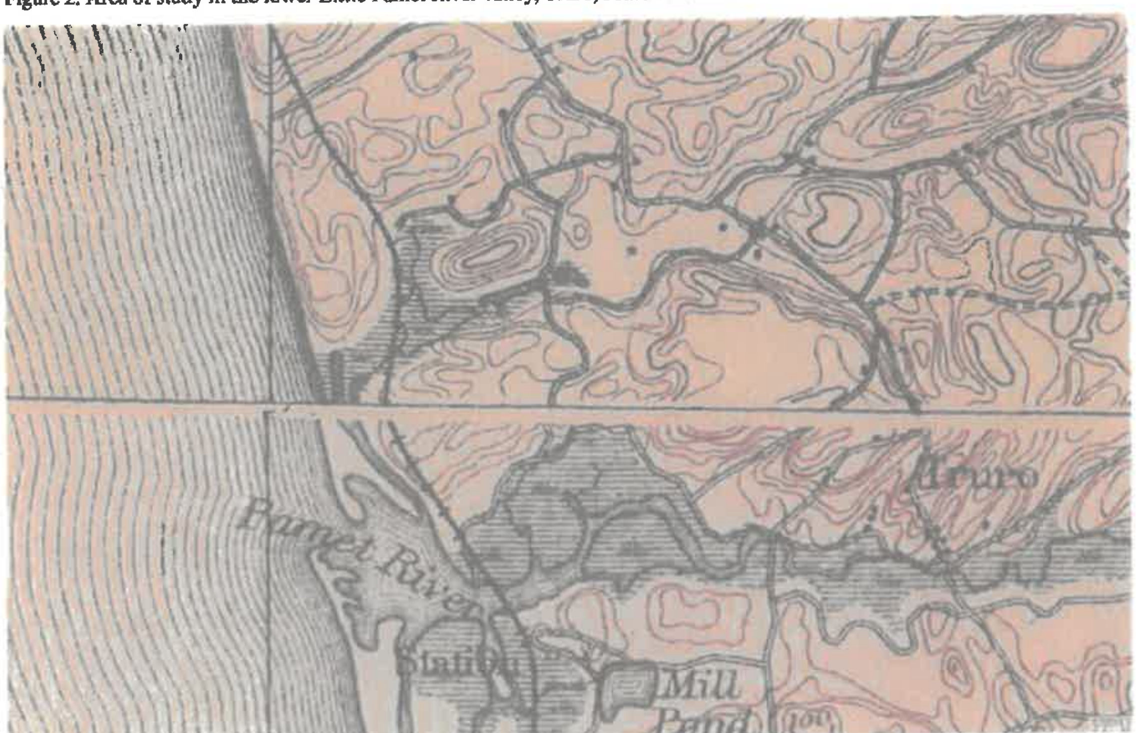

Figure 3. Topographic map of the Pamet River and Little Pamet River area, 1890.

Figure 4. Map of Priority Habitat for Rare Species. The yellow hatched area is Priority Habitat.

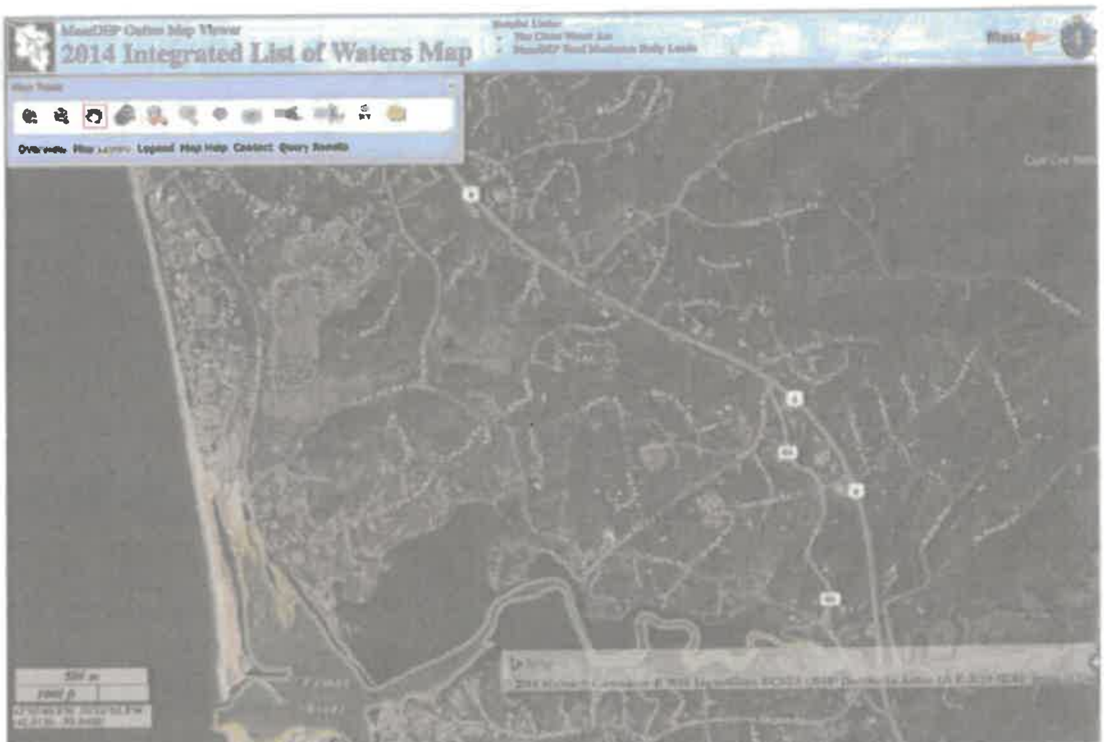

Figure 5. Water quality of the Pamet River and Little Pamet River. The yellow overlay indicates that this area of the Pamet River is listed as a "Category 4A Impaired-TMDL completed" in the Massachusetts 303(d) list of impaired waters. The impairment is due to fecal coliform bacteria. (MA DEP 2014, MA DEP 2016).

Introduction 3

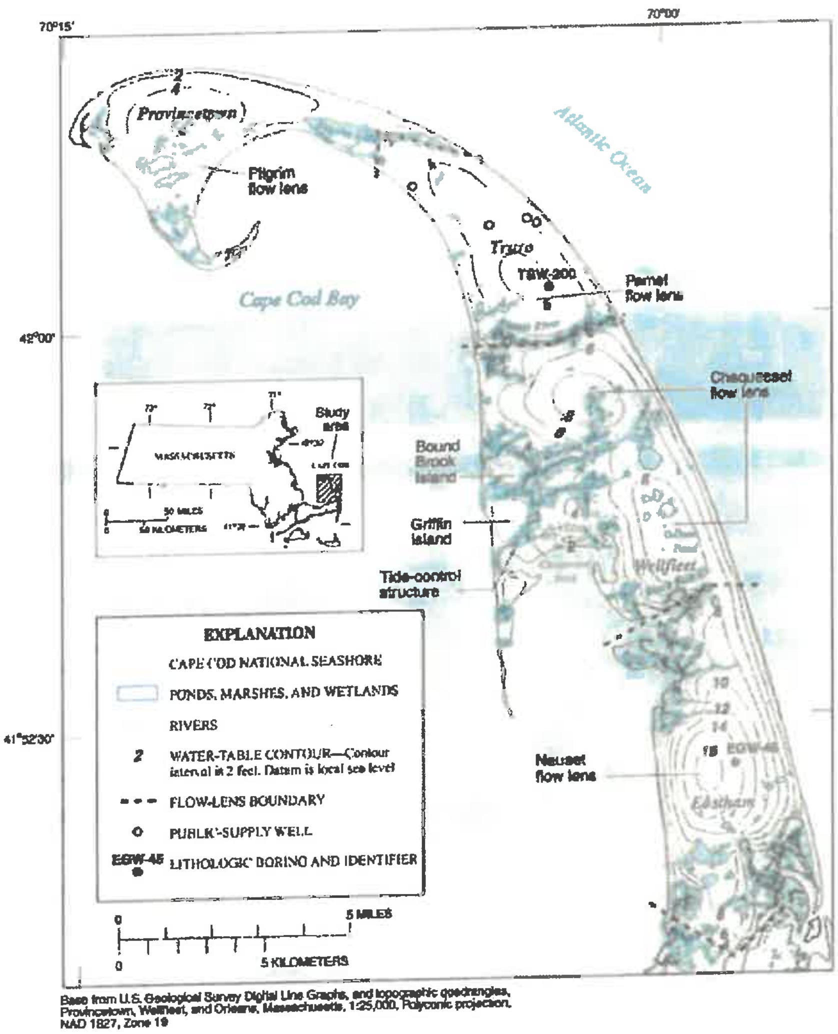

Figure 1. Location of the four flow lenses of the Lower Cape Cod aquifer system and model-calculated water-table contours, Cape Cod, Massachusetts.

Figure 6. Location of the Pamet groundwater lens in the Lower Cape Cod aquifer system. (Masterson, 2004). The highest point in the Pamet lens is located at the headwaters of the Little Pamet River.

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Site Number: 420051070024805 - MA-TSW 203 TRURO, MA

DESCRIPTION:

Latitude 42°00'51", Longitude 70°02'48" NAD27
Bernstable County, Massachusetts, Hydrologic Unit 01090002
Well depth: 35.4 feet
Hole depth: 37.0 feet
Land surface altitude: 26.32feet above NGVD29.
Well completed in "Sand and gravel aquifers (glaciated regions)" (N100GLCIAL) national aquifer.

AVAILABLE DATA:

Data Type	Begin Date	End Date	Count
Field groundwater-level measurements	1973-09-25	2018-05-23	330
Revisions	Loading...		

Additional Data Sources	Begin Date	End Date	Count
Groundwater Watch **offsite**	1973	2018	330

OPERATION:

Record for this site is maintained by the USGS Massachusetts Water Science Center
Email questions about this site toMassachusetts Water Science Center Water-Data Inquiries

Figure 7. Location of the USGS monitoring well in Truro. This figure describes the monitoring data collected.

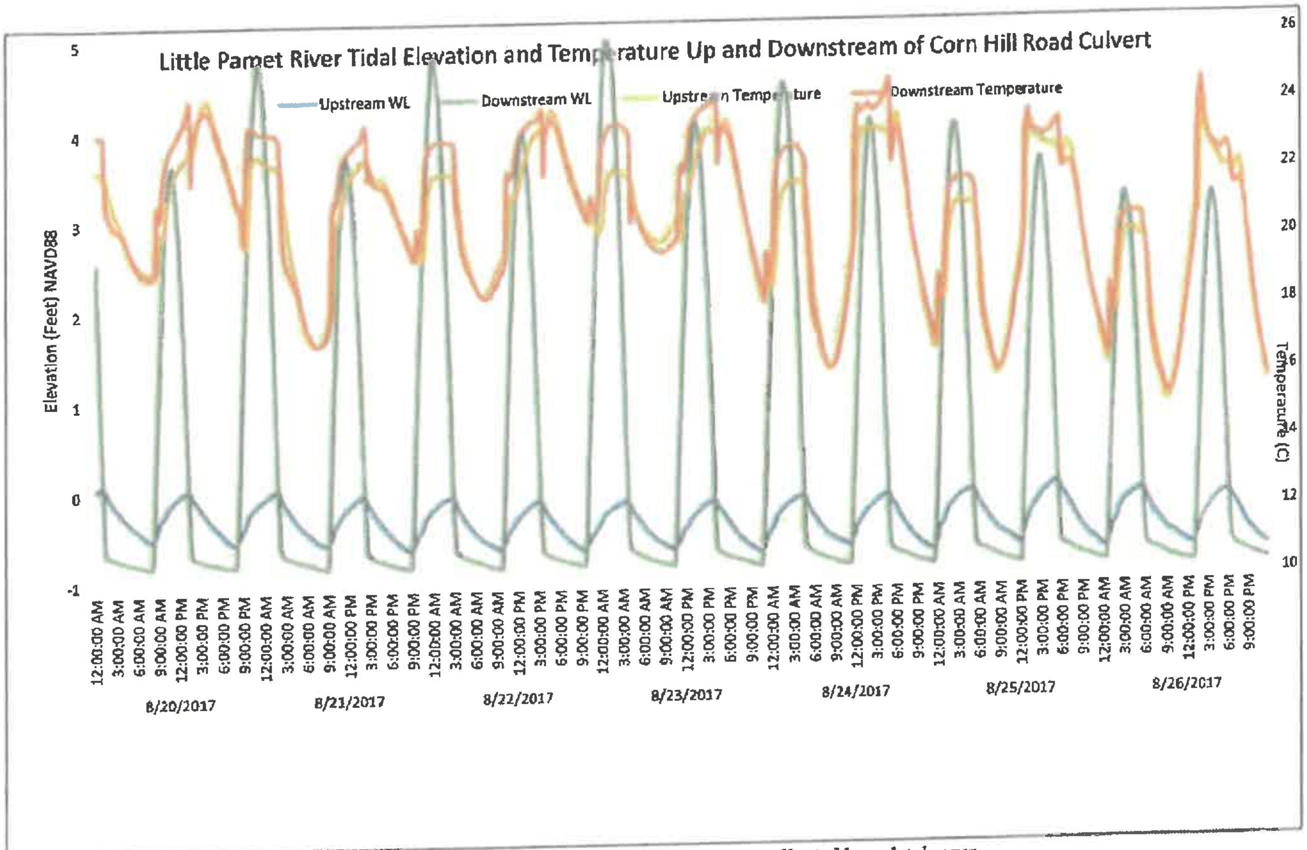


Figure 8. Plot of water level and temperature in the Little Pamet River. The data were collected by a datalogger.

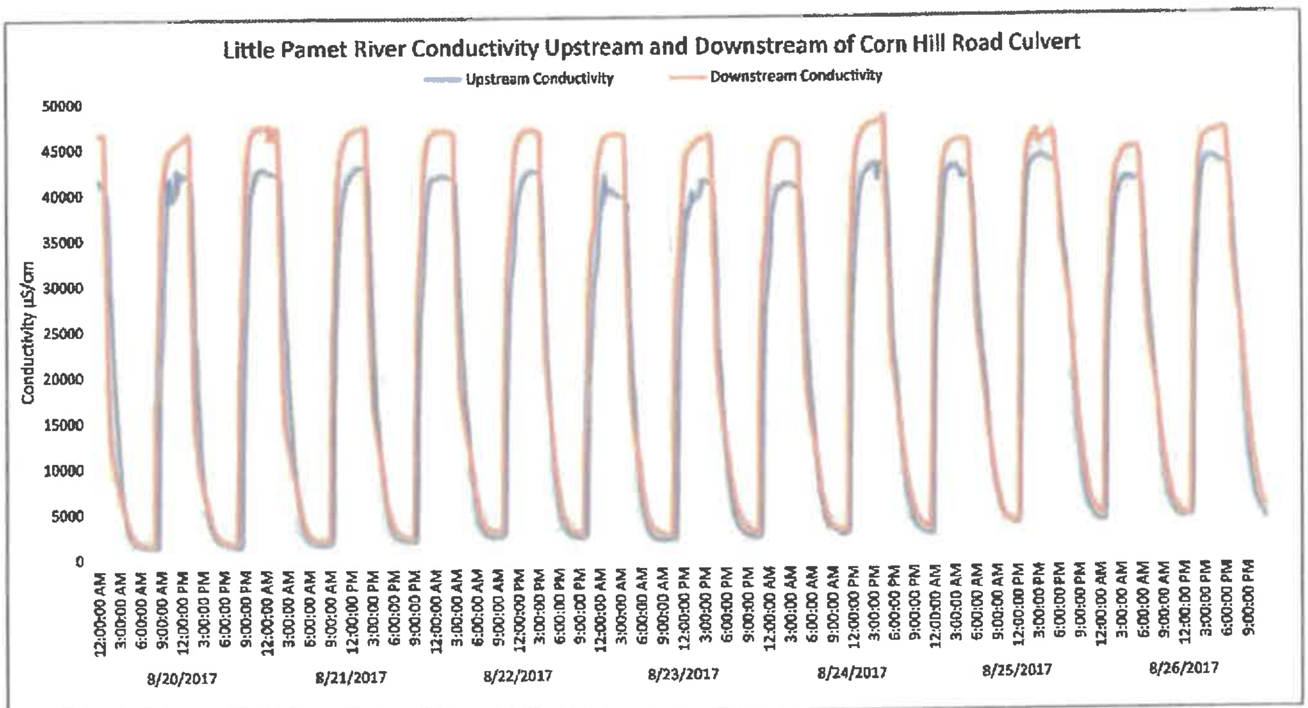
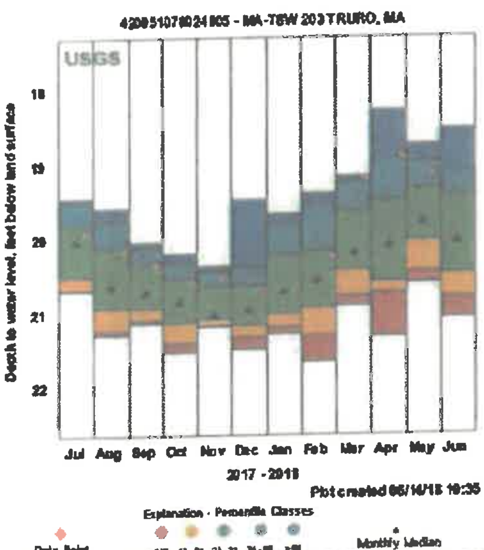


Figure 9. Plot of conductivity in the Little Pamet River.



Most recent data value: 19.13 on 5/23/2018
Period of Record Monthly Statistics for 420051070024805
Depth to water level, feet below land surface
All Approved Continuous & Periodic Data Used In Analysis
Note: highlighted values in the table indicate closest statistic to the most recent data value.

Month	Lowest Median	10th %ile	25th %ile	50th %ile	75th %ile	90th %ile	Highest Median	Number of Years
Jan	21.28	21.18	21.00	20.71	20.23	19.80	19.66	15
Feb	21.65	21.30	20.92	20.57	20.17	19.53	19.38	36
Mar	20.90	20.77	20.42	20.20	19.62	19.24	19.16	13
Apr	21.32	20.72	20.58	20.11	19.50	18.92	18.28	40
May	20.60	20.44	20.03	19.77	19.34	18.95	18.73	13
Jun	21.08	20.79	20.48	20.05	19.40	19.11	18.52	37
Jul	20.68	20.66	20.49	20.01	19.81	19.48	19.44	13
Aug	21.29	21.22	20.92	20.64	20.12	19.75	19.57	40
Sep	21.12	21.07	20.93	20.72	20.34	20.12	20.03	15
Oct	21.52	21.39	21.13	20.85	20.53	20.31	20.18	39
Nov	21.18	21.16	21.07	21.02	20.64	20.42	20.35	13
Dec	21.49	21.32	21.17	20.96	20.63	20.37	19.47	40

..as of 6/15/2018 13:39-2

View month/year statistics

Figure 10. Groundwater levels (red diamonds) at the Truro monitoring well, July 2017 – June 2018. Groundwater levels during this period were higher than the monthly median (where the monthly median is based on many years of monitoring).

Appendix 1. Aerial satellite photographs showing changes in stream channel and valley from 2005 to 2016.

Lower Little Pamet River Valley, 2005.

Lower Little Pamet River Valley, 2008.

Lower Little Pamet River Valley, 2011.

Lower Little Pamet River valley, 2013.

Lower Little Pamet River Valley, 2016.