June 30, 2021

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RE: Preliminary Field Investigation for Mill Pond Restoration Project, Truro, Massachusetts

Cristina:

The following technical memorandum (tech memo) provides a summary of the Preliminary Field Investigations Mill Pond Restoration Project completed to date by the Woods Hole Group and project partner Fuss & O'Neill for the Division of Ecological Restoration and Town of Truro (Town) under the Ecological Restoration Technical Services Master Agreement (RFR ID # DER 2019-01) executed May 17, 2021. The purpose of this field investigation was to establish baselines for topography, bathymetry, tides, coastal wetland resources, and subsurface geological conditions for this tidally restricted system that includes Mill Pond, the culvert structure, and the downstream channel including the former railroad berm. The results will be used to support the eventual engineering design and permitting of potential replacement alternative(s) (including potential railroad berm modifications) to allow for better storm flooding drainage and damage prevention while potentially providing ecological restoration. Previously, the Louis Berger Group (LBG) conducted a similar study entitled *Hydraulic Modeling Report for Mill Pond Restoration* (January 2013) that collected similar field data and modeled feasible culvert replacement alternatives; however, it was determined that supplemental and updated data and modeling were needed to pursue the eventual engineering design, permitting, and construction of the selected alternative. Therefore, this study will provide data and information necessary to establish baseline conditions and fulfill anticipated future data requirements.

Introduction

Mill Pond is a shallow coastal embayment in Truro, MA that is connected to the Pamet River Basin through a culvert underneath Mill Pond Road (Figure 1). The Pamet River Basin includes the Pamet River, Little Pamet River, and Eagle Neck Creek (another DER Priority Project), which are in various phases of restoration by the Town that the Woods Hole Group is also supporting (see relevant projects). The area of interest shown in Figure 1 for this Scope of Work includes Mill Pond upstream of the Mill Pond Road culvert (yellow outline), the shallow embayment downstream between Mill Pond Road and an abandoned railroad berm (red outline, referred to as "middle channel"), and the breach through the berm that connects the system with Pamet Harbor (purple outline). The Town and the Truro Conservation Trust own the land surrounding the Mill Pond culvert. The downstream side of the former railroad bed is owned by the Pamet Harbor Yacht Club and the upstream side is private property.

The project encompasses two potential tidal restrictions, one at the Mill Pond Road crossing and the second at the former railroad bed breach. Mill Pond Road crossing consists of a 33-inch diameter pipe underneath Mill Pond Road, which is undersized and has led to degradation of the salt marsh habitat upstream in Mill Pond. A second potential tidal restriction occurs at the breach through the former railroad berm that was shown to be a tidal restriction for Eagle Neck Creek restoration project to the south. This has resulted in Mill Pond being recognized as TR-2 in the Cape Cod Atlas of Tidally Restricted Salt Marshes, identified as TR-SM-2 on the Cape Cod Water Resources Restoration Project, and was approved as a DER Priority Project in 2011 (RFR DER 2011-01). Subsequently, the Mill Pond culvert structure was heavily flooded and damaged during the winter 2018 storm season and the Town of Truro is concerned that this culvert structure is at risk to future storm damage and even failure. The Town, with assistance from DER, now seeks to conduct a field investigation as a first step towards assessing potential culvert replacement or flow control alternatives to reduce storm flooding and drainage damage while also providing ecological restoration of salt marsh habitat.

Figure 1. ***Overview of the Pamet River Basin showing Mill Pond (yellow outline), the downstream middle channel (red), and Pamet Harbor junction (purple). Also shown are Pamet River, Little Pamet River, and Eagle Neck Creek.***

Worked completed to date for the Mill Pond Investigation included the following:

- A project kickoff meeting was held on May 14, 2021 with the project team and stakeholders to discuss the scope of work, the field investigation schedule and logistics, and deliverables as documented in Meeting Minutes (June 2, 2021) that is included electronically in Attachment E.
- A memorandum w documenting the existing data review, anticipated future data needs and recommendations was issued on June 29th, 2021. A copy can be found in Attachment D and electronically in Attachment E.
- A draft version of this Tech Memo was submitted to DER for review on June 25, 2021.
- A final project review meeting was held on June 28th to review the results of the investigation and address comments on the Tech Memo. Meeting minutes were issued on June 30th, 2021 and are included electronically in Attachment E.

The scope of for the field investigation included the following five (5) tasks:

1. **Site Survey and Plans** – Conduct a topographic site survey and locate features/structures and then develop an existing conditions base plan for Mill Pond.
2. **Wetlands Resource Delineation** – Locate and survey a baseline of wetland resource areas and salt-marsh extent for future permitting and monitoring needs.
3. **Tidal Study** – Deploy pressure, conductivity, and temperature sensors in each of the 3 basins to develop tide metrics and statistics.
4. **Bathymetric Survey** – Collection of tidal and sub-tidal elevation data within the pond, channel, and harbor.
5. **Subsurface Investigation** – Collected two (2) geotechnical borings to determine the subsurface geology to aid in future foundation design for a replacement structure (culvert or other).
6. **Reporting** – Document the findings in a technical memo.

Existing Conditions Site Survey

The existing conditions survey was performed by Joel Kubick, P.E., P.L.S. and a survey technician on May 18th and June 10th, 2021. Survey equipment included a Trimble® R8 Real Time Kinematic Global Positioning System (RTK GPS) receiver and Leica TS-13 robotic total station. The R8 receiver operates by receiving satellite position data while simultaneously receiving position corrections in real time over the cellular data network from the KeyNetGPS Virtual Reference Station (VRS) network. The rover processes the two sets of data to resolve the ambiguities and obtain an accurate position with horizontal and vertical precisions of ± 1cm and 2cm, respectively. The R8 receiver allows for fast and accurate collection of survey data across the site in reference to a chosen coordinate system. In areas with overhead interference that can cause multipathing errors such as trees, tall vegetation, buildings and other structures, a TS-13 total station, survey rod, and prism were used to make measurements based on the state plane horizontal coordinates and orthometric elevations established by the R8 on selected survey traverse control points. The survey included collecting ground elevation shots and locating existing structures, roadways, and drainage utilities as follows:

- Located edge and centerline of Mill Pond Road 300' north and 370' south of culvert plus centerline shots an additional 600' southerly
- Located culvert with invert and top elevations
- Recovered and located 3 existing property monuments
- Located guardrails, concrete posts, and catch basins adjacent to roadway
- Topographic shots around upper Mill Pond and flats adjacent to west side of roadway
- Topographic shots along old railroad
- Recovered and located 4 existing property monuments
- Additional topographic shots around flats adjacent to west side of roadway
- Located additional edge and centerline of Mill Pond Road northerly of culvert
- Located edge and centerline of portion of Depot Road north of upper pond

The collected survey data was processed in CAD and an existing conditions plan was created showing topographic contours and spot shots, property lines compiled from GIS data, tide gauge and boring locations, and the existing culvert were all overlaid on an aerial image for spatial reference. The GIS property boundaries are approximate based on MassGIS layers. Topographic survey data was supplemented with 2016 USGS CoNED Topobathymetric LIDAR data set to fill in areas within the wetland boundary as it is a large area with inconsistent terrain and dense stands of *Phragmites*. The horizontal datum for the project is the Massachusetts State Plane Coordinate System, Mainland Zone, in units of feet, that is based on the North American Datum of 1983 (NAD83) and the vertical datum is based on the North American Vertical Datum of 1988 (NAVD88) in units of feet. The coverage of the topographic survey data is shown in Figure 13 and a copy of the Existing Conditions Base Plan is shown in Attachment B. The raw point data is included in Attachment E.

Mill Pond Coastal Resource Area Delineation

On June 9th and 10th, 2021, a Woods Hole Group Professional Wetland Scientist (PWS) conducted a coastal resource area delineation along the causeway of Mill Pond Road and around the Mill Pond basin, Truro, MA. The resource area delineation extended approximately 500 linear feet (l.f.) north and south of the existing Mill Pond culvert and around the entirety of the terminal, upstream basin of the Pond. Survey points were collected in real-time during the delineation using a Trimble R8 RTK-GPS, indicating the extent of salt marsh and bordering vegetated wetland (BVW) resource areas. The approximate location of the toe of the coastal bank was delineated based on site topography and land subject to coastal storm flowage (LSCSF) was delineated relative to the extent of local FEMA-Firms (100-year flood elevation). The extent of salt marsh, coastal beach, coastal bank, BVW, and LSCSF are shown in Figure 2. Characteristics of each resource area are described in the following sections and a backup of the survey points for the delineation are found Attachment E. In general, comparing the delineated resources in Figure 2 to the Cover Type Map from the LBG Report (June 2012) indicated that the extent of salt marsh, BVW, coastal beach, and coastal bank appears to similar. The one difference is that *Phragmites*, while not mapped because it is not a separate resource, was noted to have expanded its footprint somewhat in areas where it was already present.

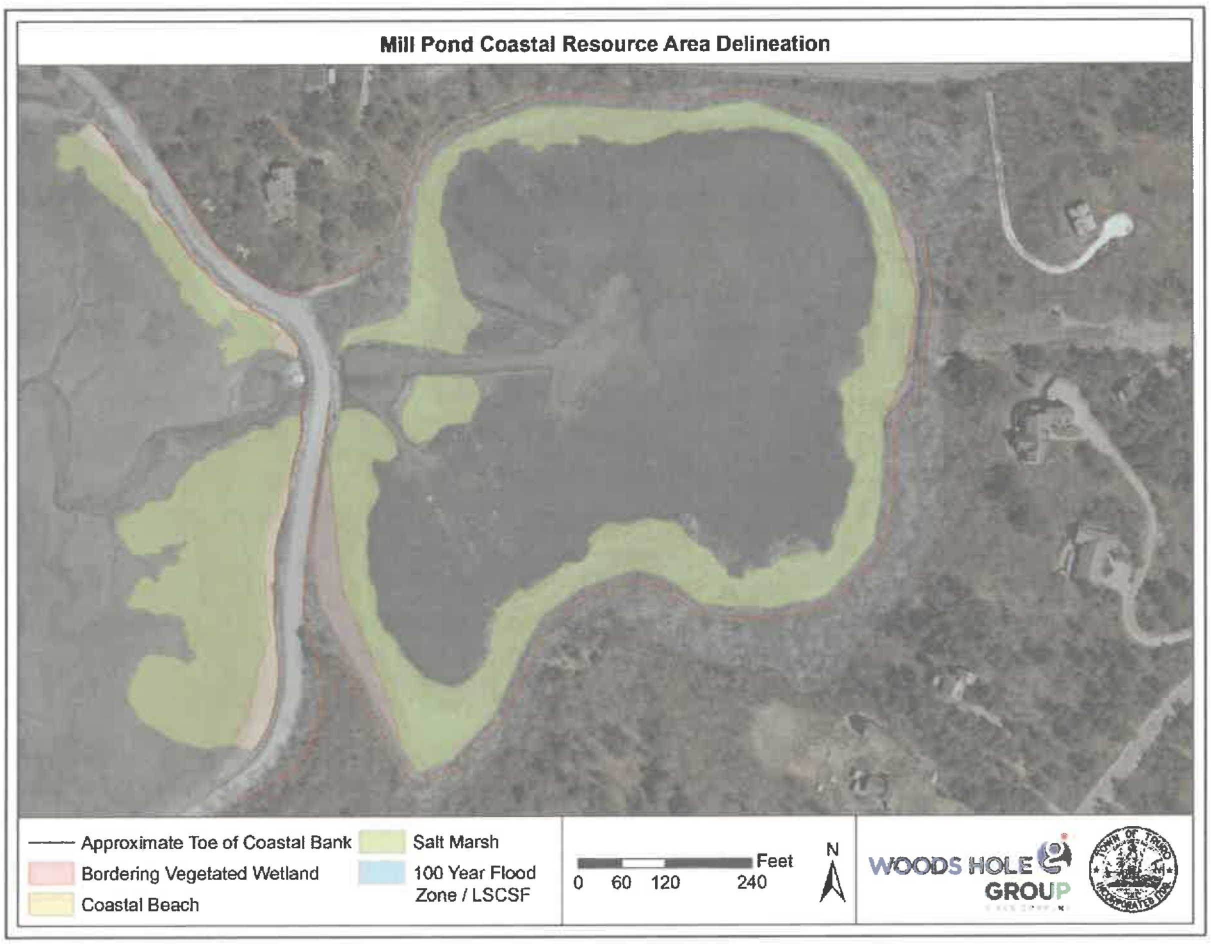

Figure 2. Coastal resource areas along Mill Pond Road and Mill Pond basin.

Salt Marsh

The salt marsh delineation was conducted on the upstream and downstream side of the existing culvert and roadway. Downstream of the culvert, the delineation extended approximately 500 linear feet (l.f.) north and south of the culvert opening. The salt marsh in this location was separated from the toe of the roadway embankment by a narrow, sandy coastal beach and extended seaward before transitioning to mudflat (Figure 3). Areas downstream of the culvert were vegetated with dense stands of vegetation characteristic of New England coastal salt marsh systems, including, salt marsh cord grass (*S. alterniflora*), salt marsh hay (*S. patens*), sea pickle (*Salicornia, spp.*), sea lavender (*Limonium, spp.*), and sea blight (*Suaeda, spp.*) (Figure 4).

Upstream of the culvert, in the Mill Pond basin, the salt marsh formed a narrow ring around the pond and was primarily vegetated with the low growth form of *S. alterniflora*. A distinct hedge row of high tide bush (*B. halimifolia*) was found at the landward edge of the salt marsh along the toe of the coastal bank (Figure 5). Often, the high tide bush was located landward of invasive common reed, (*Phragmites australis*), encroaching on the marsh plain. The seaward edge of the salt marsh in the Mill Pond basin showed signs of degradation and die-back of marsh vegetation, active erosion, and retention of marine algae (Figure 6).


Figures 3-4. ***Salt marsh separated from roadway embankment by narrow coastal beach (left). Vegetation characteristic of New England coastal salt marshes (right).***


Figures 5-6. ***Phragmities and high tide bush growing along landward edge of salt marsh in the Mill Pond basin (left). Salt marsh die-back evident along seaward edge of marsh in the Mill Pond basin (right).***

Coastal Beach

On the downstream side of the existing culvert, a narrow coastal beach separated the salt marsh from the toe of the armored roadway embankment (Figure 7). The beach was largely unvegetated and comprised of medium to coarse sand with some gravel and cobbles present. Immediately seaward of the beach, the roadway side slopes were armored with a sloping rock revetment (Figure 8). Coastal beach was not present along the toe of the roadway embankment on the upstream side of the existing culvert.

Figures 7-8. Narrow coastal beach located between the landward edge of the salt marsh and the toe of the roadway embankment.

Coastal Bank

A narrow, low-lying coastal bank was found along all sections of Mill Pond Road that abutted the salt marsh and coastal beach resource areas, which included long sections of armored roadway embankment (Figure 9). The coastal bank extended from the landward-most extent of the salt marsh and coastal beach up the roadway embankment(s) to a point along the roadway shoulder where the slope of the embankment had dissipated to less than (10:1). Significantly higher, naturally occurring coastal bank was located along the eastern side of Mill Pond Road and around the entirety of the Mill Pond basin (Figure 10). The height of the coastal bank (both naturally occurring bank and the roadway embankments) varied across the project area from less than 6' to more than 20'. In nearly all cases, the bank was vegetated with dense swaths of native and invasive coastal salt-tolerant vegetation, including native bayberry (*M. pennsylvanica*), beach plum (*P. maritima*), bear oak (*Q. ilicifolia*), bearberry (*A. uva-ursi*) black cherry (*P. serotina*), eastern red cedar (*J. virginiana*), *B. halimifolia*, and switchgrass *(P. vrigatum)* and invasive shrub honeysuckle (*Lonicera spp.*), common reed (*Phragmites australis*), and oriental bittersweet (*C. orbiculatus*).

Figures 9-10. Low-lying coastal bank along the roadway embankment (left). Naturally occurring coastal bank located east of Mill Pond Road and around the entire Mill Pond basin (right).

Bordering Vegetated Wetland

Bordering vegetated wetland (BVW) was found in locations upstream of the existing culvert around the Mill Pond basin where freshwater leaching from the upland was impounded between the landward extent of the salt marsh and the toe of the coastal bank. In these areas, small, freshwater drainages entered the marsh, supporting freshwater vegetation characteristic of BVW, rather than salt marsh. Cattail (*Typha, spp.*), high bush blueberry (*V. coryumbosum*), sweet pepperbush (*C. alnifolia*), and northern arrowwood (*V. dentatum*) were documented (Figure 11). It is worth noting that the freshwater drainage appeared to occupy areas below the annual high tide line, the regulatory boundary of salt marsh. However, the vegetation growing in the drainage was indicative of a freshwater wetland and the resource area was therefore delineated as BVW.

Figure 11. BVW occupying a freshwater drainage along the toe of the coastal bank in the upper Mill Pond basin.

Land Subject to Coastal Storm Flowage

Land subject to coastal storm flowage (LSCSF) extended well beyond the project area, occupying the FEMA-Firm VE and AE zones. As a result, LSCSF also encompasses all the resource areas that were observed on site, the roadway shoulders (where the slope of the roadway embankment became less than 10:1), the roadway itself, and all associated municipal infrastructure and assets.

Natural Heritage Priority and Estimated Habitat

Although Estimated and Priority Habitat for Rare and Endangered Species as identified by the Massachusetts Natural Heritage and Endangered Species Program (NHESP) does extend into the basin located between the downstream end of the existing culvert and the railroad berm, NHESP habitat does not intersect with nor occupy any of the resource areas described in this report (Figure 12).

Figure 12. ***NHESP Habitat does not intersect with nor occupy the proposed project site.***

Bathymetric Survey
On June 7th, 2021, a bathymetric survey was conducted to supplement past data collected to establish existing conditions for storage and tidal prism and to support hydrodynamic modeling efforts and eventual design of the replacement culvert structure. It was performed during high tide using a canoe outfitted with an RTK GPS and EchoLogger EUD24 dual-frequency echosounder and supplemented with wading shots where it was too shallow to navigate. Wading shots were necessary in Mill Pond, where maximum depth during high tide was insufficient to allow motorized operation of the canoe. The bathymetric survey covered the area from the Truro Harbor Yacht Club dock eastward to the Mill Pond Road culvert and Mill Pond, except where depth was too shallow for operation (Figure 13). The extent of the bathymetric data is shown in Figure 13 and the Mill Pond Existing Conditions Plan in Attachment B. The raw data is included in Attachment E.

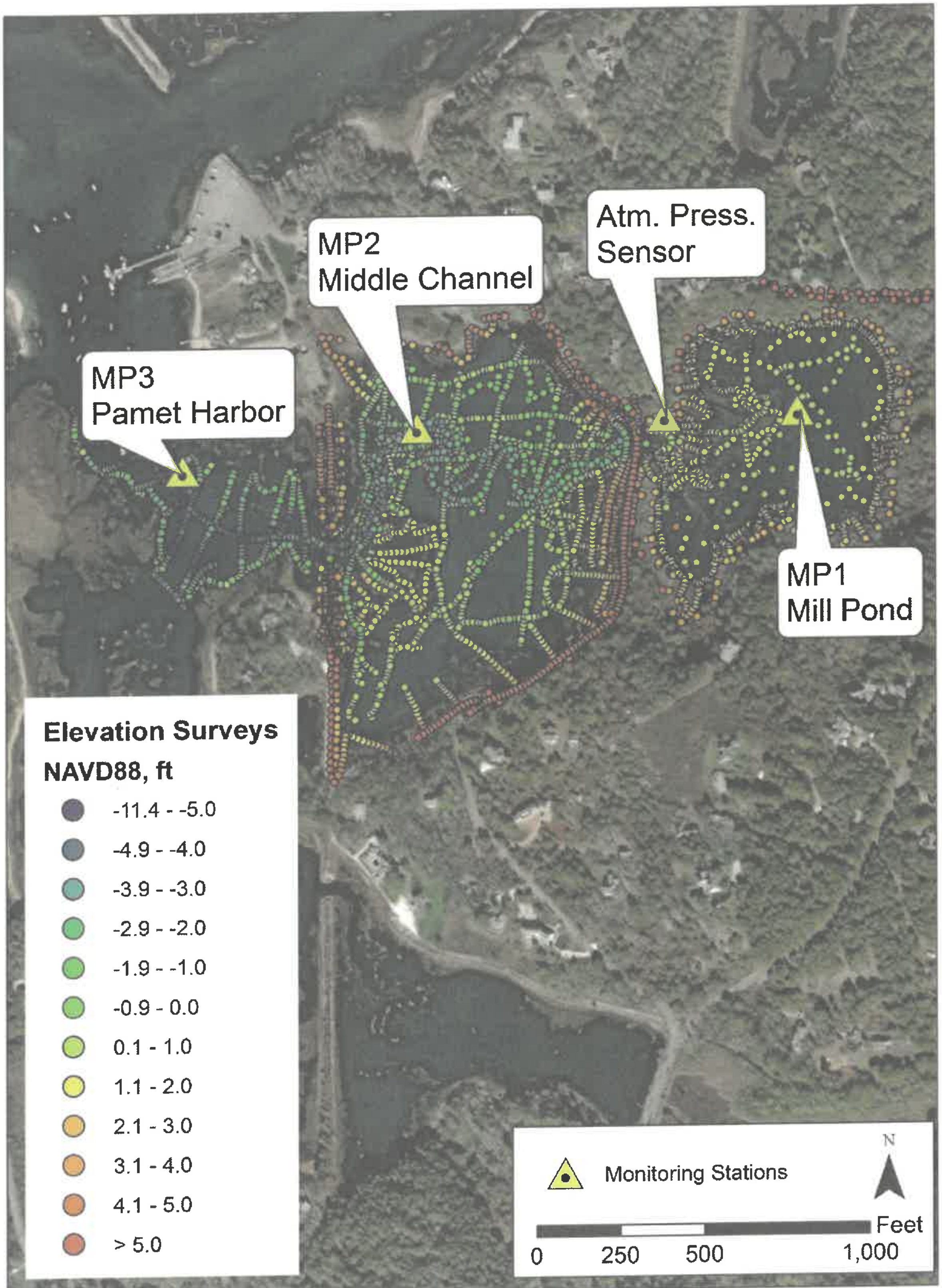

Figure 13. Coverage map for topographic and bathymetric survey data sets.

Tide Study

A tide study was conducted to evaluate attenuation of tide and salinity between Pamet Harbor and Mill Pond. Three (3) In-Situ AquaTroll 200 data loggers were deployed for 32 days between May 17th to June 17th, 2021 at the following station locations as shown in Table 1 and Figure 14:

1) MP-1 within Mill Pond
2) MP-2 within the central portion of the creek channel between the railroad berm and Mill Pond Road, and
3) MP-3 downstream of the railroad berm in Pamet Harbor, adjacent to the Yacht Club.

The instrument deployed in Pamet Harbor was secured to a weighted bottom platform. The gauges deployed in the middle channel salt marsh and in Mill Pond were attached to a metal pipe anchor and then pushed into the creek and pond beds, respectively (see Attachment C – Field Photolog). The instruments collected conductivity (salinity), temperature, and water pressure (water level) readings (0.02 ft accuracy) at 6-minute intervals over the 31-day deployment period, which captured an entire monthly lunar tidal cycle (approximately 29.5 days). The gauges were surveyed with RTK GPS to the North American Vertical Datum of 1988 (NAVD88) in units of feet immediately after deployment and before recovery. An atmospheric pressure sensor was deployed east of the culvert near Mill Pond to allow for the correction of the water pressure readings for atmospheric pressure. Precipitation data during the deployment period was retrieved from Provincetown Municipal Airport located approximately 10 miles northwest of the site.

Table 1. ***Tidal data logger locations and surveyed elevation.***

Station	Latitude	Longitude	Elevation (NAVD88, ft)
MP-1 (Mill Pond)	41.990074986	70.065351059	0.99
MP-2 (middle channel)	41.990021807	70.069539835	-5.00
MP-3 (Pamet Harbor)	41.989727170	70.072123632	-6.42

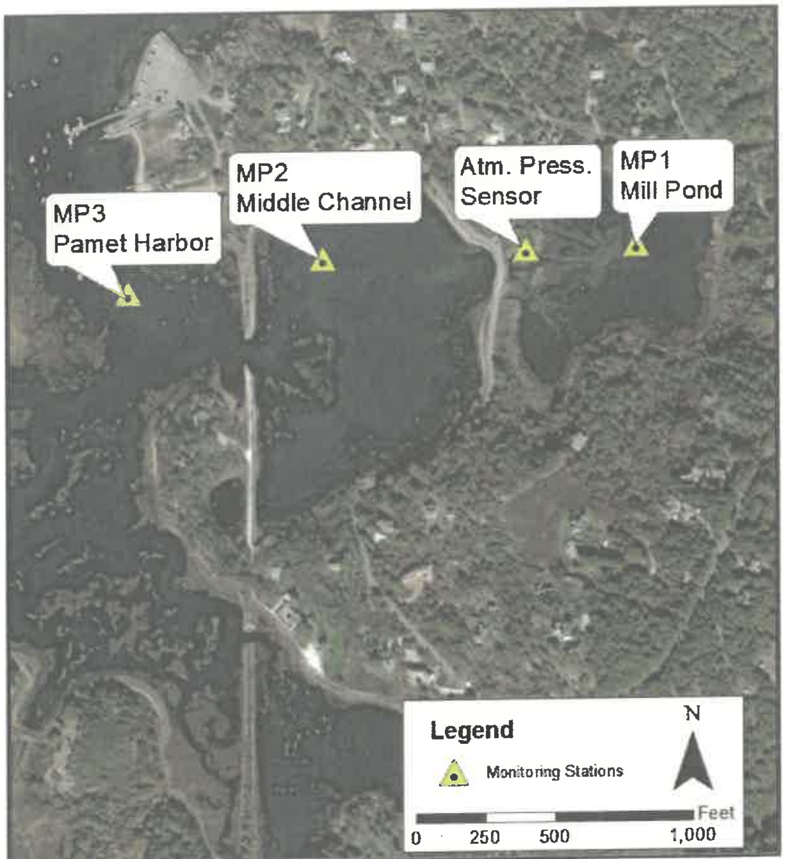

Figure 14. ***Locations of tidal data logger stations MP-1, MP-2, MP-3 and the atmospheric pressure sensor.***

Tidal data loggers recorded 60 complete tidal cycles (Figure 15). The water surface (tide) elevation recorded at all three (3) stations demonstrate a semi-diurnal (twice daily) tide signal that is typical for the east coast of the United States. During the first five days of deployment, salinity at station MP-1 reached a peak on every other high tide compared to the other stations which peaked at every high tide (Figure 16). This trend ended on approximately May 23 when salinity began to peak on every high tide. Water temperature ranged from 15 - 30°C for most of the deployment. The only time water temperature decreased below 15°C was during an extreme rainfall event between May 26 – 31, when all stations dropped to approximately 8°C (Figure 15, Table 2). This rainfall had no obvious effect on water surface elevation that also occurred during a spring tide but did temporarily reduce salinity at the Pamet Harbor station MP-3 from 32 PSU to 21 PSU, before returning to >30 PSU on June 2 (Figure 16). This temporary drop in salinity during the storm event is likely due to significant freshwater input to Pamet Harbor from the Pamet River, Little Pamet River, and Eagle Neck Creek systems. Salinity at upstream stations MP-2 and MP-1 were less affected by the rainfall, and it is possible that higher salinity water may have been trapped in Mill Pond by these higher tides.

Table 2. ***Measured temperature and salinity statistics for Stations MP-1, MP-2, and MP-3.***

	Pamet Harbor MP-3		Middle Channel MP-2		Mill Pond MP-1	
	Salinity (PSU)	Temp (°C)	Salinity	Temp	Salinity	Temp
Maximum	31.94	29.59	32.02	29.22	30.66	27.23
Mean	29.80	19.41	30.79	18.26	29.08	17.71
Minimum	20.59	8.78	24.83	8.02	24.93	7.76

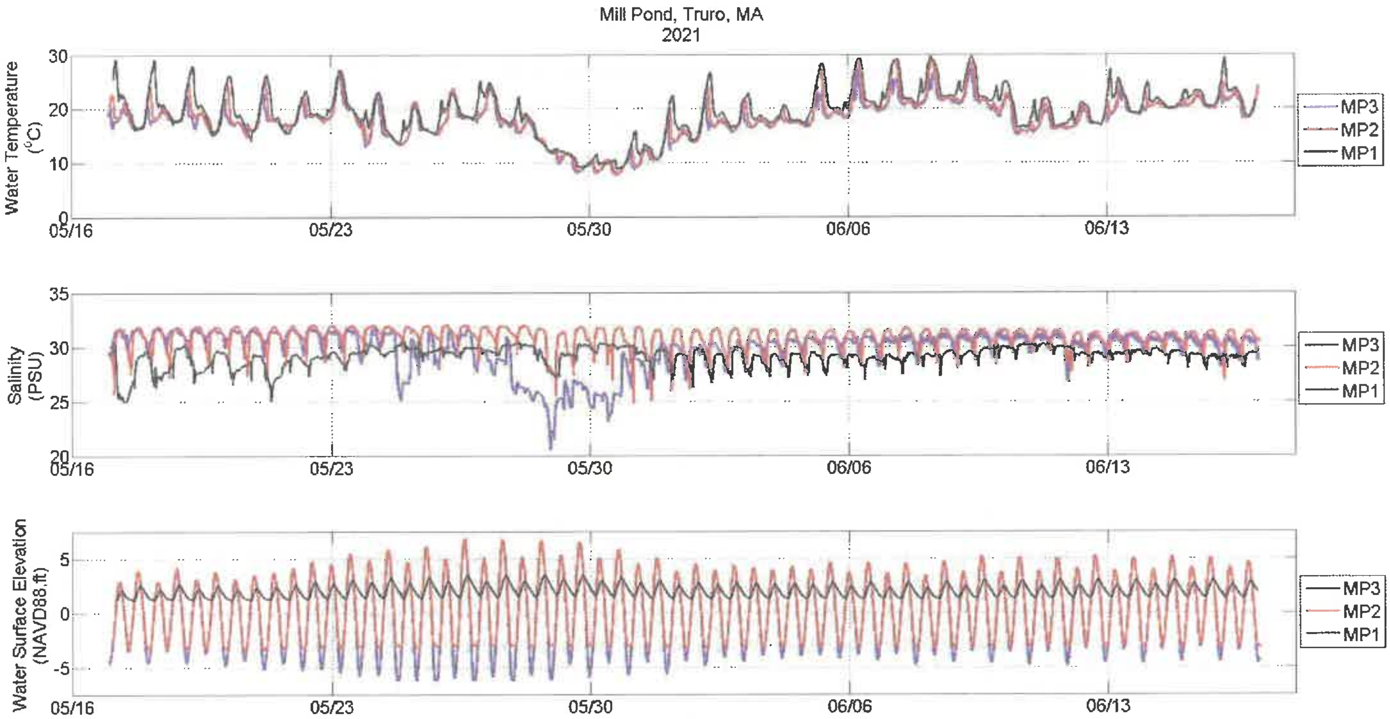

Figure 15. ***Time series of water temperature, salinity, and water surface elevation (tide) data for Stations MP-1, MP-2, and MP-3 over the 31-day deployment.***

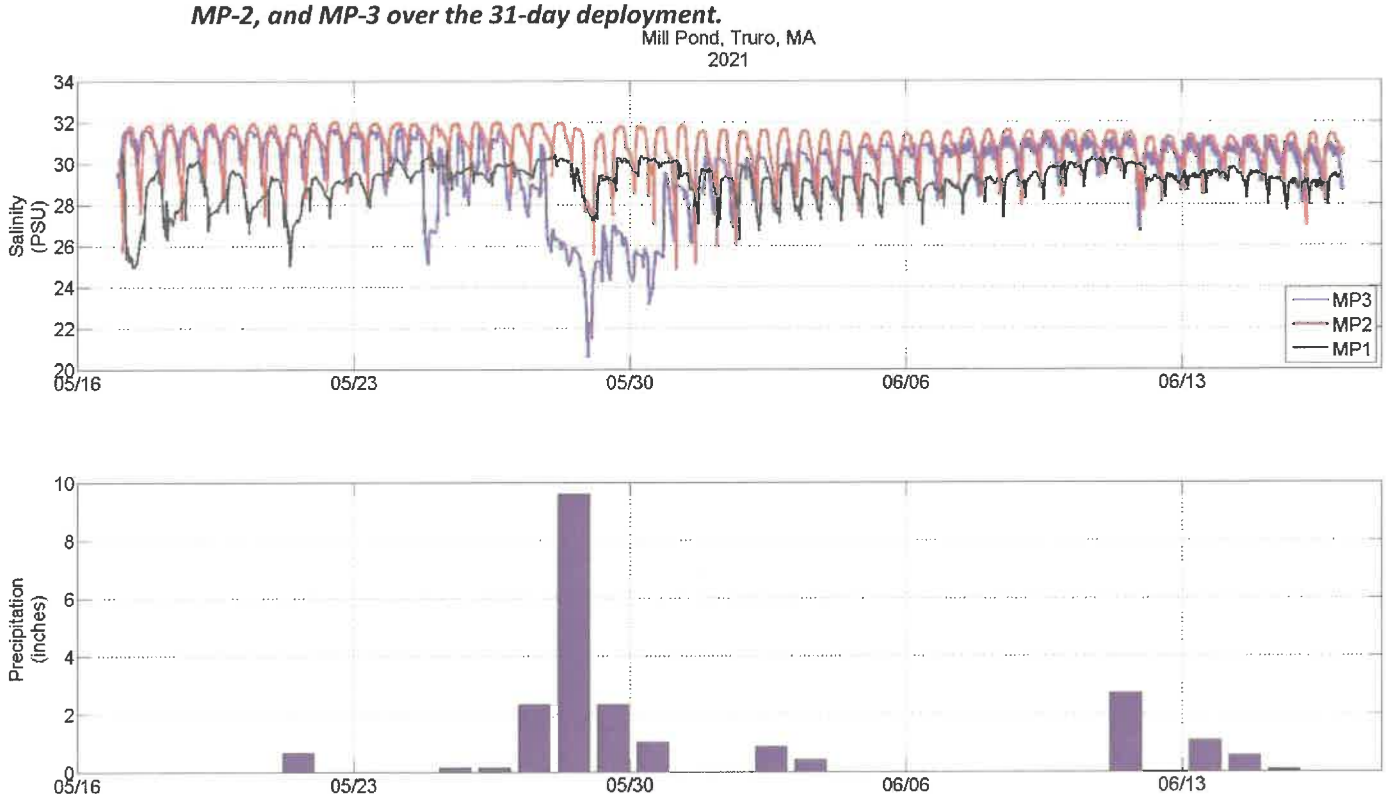

Figure 16. ***Time series of salinity and daily precipitation recorded at Provincetown Municipal Airport for stations MP-1, MP-2, and MP-3 over the 31-day deployment.***

Tide datums and metrics were calculated for each of the three (3) stations MP-1, MP-2, and MP-3 as shown in Table 3 with names and abbreviations. The tidal datums for MHW and MHHW were the same between stations MP-3 and MP-2 with no time lag that suggests unrestricted tidal exchange between Pamet Harbor junction and the middle channel downstream of Mill Pond. However, MLW and MLLW were higher at MP-2 than MP-3, likely because the elevation of the creek bed is higher than the low tide elevation in Pamet Harbor. The MLLW datum was not significantly lower than the MLW datum (0.03 feet), at both MP-1 and MP-2. At MP-1, this is in part due to the elevation of the deployed sensor, the small tidal range, and insufficient drainage in the pond. At MP-2, this is likely the artificial result of the sensor's deployment location within a scour in the channel thalweg, which ensured the sensor would remain submerged. MLLW in the middle channel is likely controlled by the channel bed elevation, as water depth in the channel falls to several inches at low tide. Tidal amplitudes for all metrics appear to be symmetrical: at each station, MHW and MLW are approximately the same amplitude from MTL regardless of tidal phase. Tidal range was 1.5 feet at station MP-1 in Mill Pond, and MHHW and MHW differed by only 0.1 feet. This is significant dampening as compared to the mean tidal range in the Middle Channel (7.7 ft) and Pamet Harbor (9.2 ft). While the low tide datums (MLW, MLLW) are not as low at the Middle Channel, this is a result to the pond bed being at a higher elevation than the downstream channel as the pond is only inches deep at low tide. Therefore, additional drainage is unlikely without dredging. However, MHW is dampened 1.7 through the culvert from the Middle Channel to Mill Pond indicating that there is the potential to increase the high tide elevation and flooding extent in Mill Pond.

Table 3. ***Tidal datums calculated for tide gauge stations (NAVD88 feet).***

Tide Metric	Abbreviation	Pamet Harbor	Middle Channel	Mill Pond
		MP-3	MP-2	MP-1
Mean Higher High Water	MHHW	5.0	5.0	2.9
Mean High Water	MHW	4.5	4.5	2.8
Mean Tide Level	MTL	-0.1	0.7	2.0
Mean Low Water	MLW	-4.7	-3.2	1.3
Mean Lower Low Water	MLLW	-5.1	-3.2	1.3
Mean Tide Range	MR	9.2	7.7	1.5
Mean Range Dampening	--	0	1.5	7.7
MHW dampening	--	0	0	1.7

Figure 17 and 18 show a zoomed in view for three (3) water level time series (tides) for a Neap and Spring tide, respectively, to understand whether there is any variation in the tide signal during periods of smaller or higher lunar tides. Overall, there is no significant variation or deviation of the tide signal when comparing these monthly minimums and maximums of the tide signal for Mill Pond. Salinity also did not appear to vary significantly based on Spring or Neap tides and was more affected by the large storm event instead.

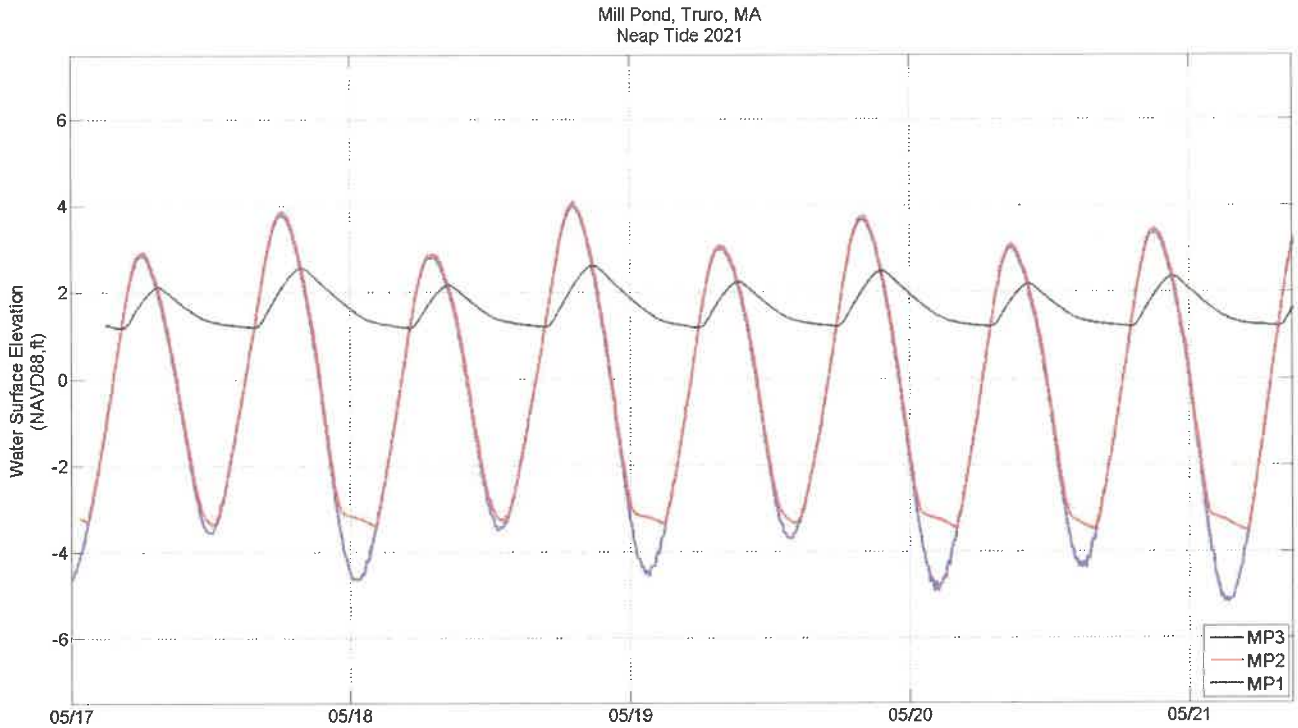

Figure 17. ***Time series of water levels (tides) during the Neap Tide for MP-1, MP-2, and MP-3.***

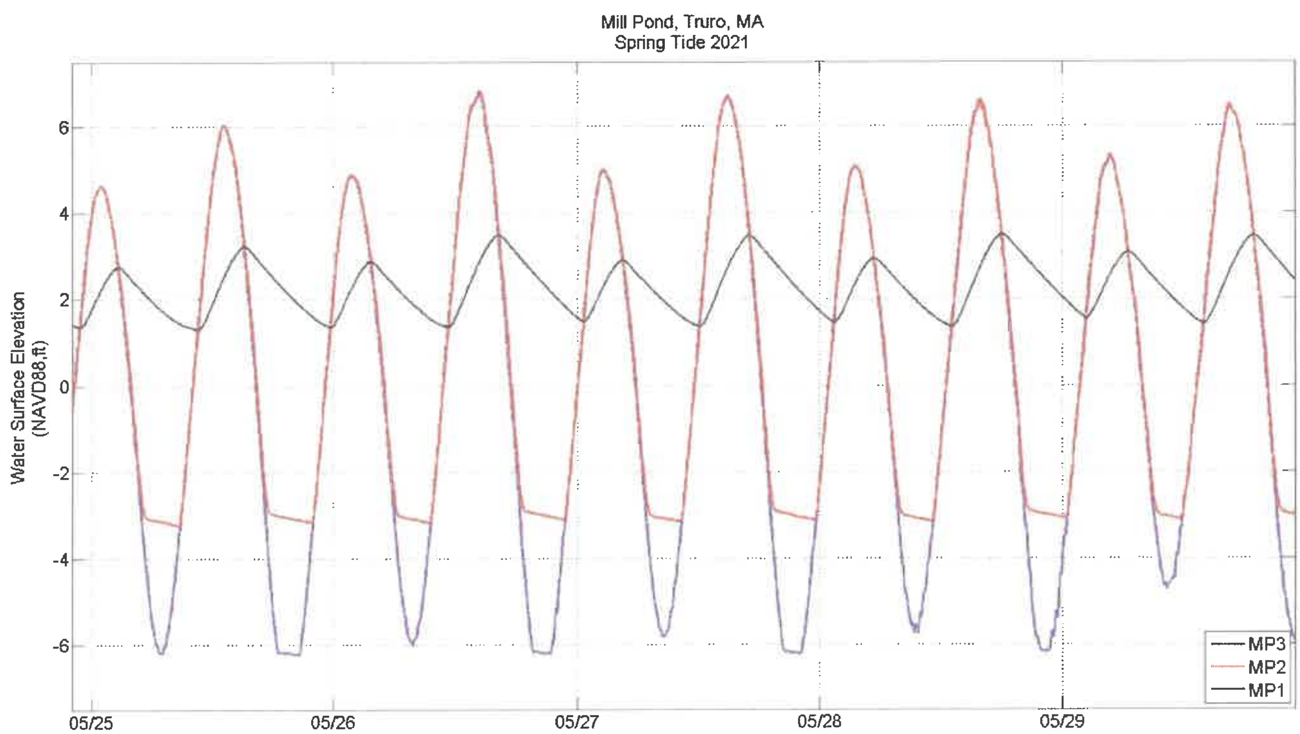

Figure 18. ***Time series of water levels (tides) during the Spring Tide for MP-1, MP-2, and MP-3.***

A tidal constituent analysis, or harmonic analysis, is a method to determine the relative importance of various components of the tide caused by the sun, moon, etc. Harmonic analysis was used to add physical meaning to what is causing the tide and enhances the development of the hydrodynamic model. A tidal constituent analysis was conducted using the tide gauge data using the Tidal Analysis Toolbox developed by R. Pawlowicz, R. Beardsley, and S. Lentz (December 1, 2001). Some common tidal constituents for the New England region are listed in Table 4.

Table 4. ***Common tidal constituents for New England***

Constituent Name	Symbol	Description
Principal lunar	M_2	Roughly twice daily, or semi-diurnal, tides caused by the moon
Principal solar	S_2	Semi-diurnal effect of the sun
Luni-solar diurnal	K_1	Combined with O_1 and P_1 causes one high tide to be higher each day in this area
Principal lunar diurnal	O_1	Daily effect of the moon, which causes one high tide to be higher each day in this area
Principal solar diurnal	P_1	Daily effect of the sun, which causes one high tide to be higher each day in this area
Luni-solar synodic fortnightly constituent	M_{sf}	Roughly two-week variability of the tide height caused by the relative alignment between the moon and the sun
Shallow water over tides of principal lunar constituent	M_4	First harmonic of semi-diurnal tide, which may be used in conjunction with M_2 to assess the nonlinearity in the tidal signal
Lunar monthly	M_m	Longer period (monthly) effect of the moon
Lunar eccentricity	N_2	Larger lunar elliptic semidiurnal component

The results of the tidal constituent analysis are shown in Table 5 that demonstrates that over 91% of the water level signal in Mill Pond was resolvable by the tidal constituents, which increased to 98% for the downstream basins. This indicates that the system is primarily driven by tidal forces and that non-tidal forces such as rainfall runoff, freshwater input, wind tides, etc. are not significant factors. The six largest resolved tidal constituents from the three tide gauge stations are shown in Table 5, which reveals, as expected, that the roughly twice-daily (semi-diurnal) influence of the moon (M_2) dominates since its amplitude is more than 3 times greater than the next largest constituent K1. The subsequent constituents contribute less to the overall signal.

The phase delay (minutes) was calculated between the Pamet Harbor and upstream stations to help quantitively assess the constriction that the railroad berm may have on the incoming tidal signal from Pamet Harbor. The results indicate that there is an approximate 116.2 minutes (1.94 hr) time delay between the dominant M2 high tide in Pamet Harbor and Mill Pond, which indicates that the tide signal to Mill Pond is primarily restricted by the culvert under Mill Pond Road. This is supported by the fact that there is essentially no time delay (0.04 minutes) in the tide signal through the Railroad Berm between the Middle Channel and Pamet Harbor, indicating that the railroad berm does not appear to significantly attenuate normal tides.

Table 5. ***Tidal constituent analysis results for the tide stations showing the results for the six largest constituents.***

Constituent		Frequency (Hz)	Mill Pond MP1 Amplitude (ft)	Mill Pond MP1 Phase Delay (minutes)	Middle Channel MP2 Amplitude (ft)	Middle Channel MP2 Phase Delay (minutes)	Harbor MP3 Amplitude (ft)
M2	Principal lunar semidiurnal	0.0805114	0.65	116.2	3.88	0.04	4.40
S2	Principal solar semidiurnal	0.0833333	0.07	-17.8	0.39	-0.22	0.50
N2	Larger lunar elliptic semidiurnal	0.0789992	0.15	563.0	0.92	0.01	1.19
K1	Lunar diurnal	0.0417807	0.16	493.0	0.46	0.00	0.57
M4	Shallow water overtides of principal lunar	0.1610228	0.14	-60.0	0.31	0.51	0.08
O1	Lunar diurnal	0.0387307	0.13	-771.9	0.31	0.00	0.38
M6	Shallow water overtides of principal lunar	0.2415342	0.02	184.3	0.10	0.18	0.12
Total Tidal Amplitude for 6 Constituents			**1.31**	--	**6.36**	--	**7.24**
Total Measured Mean Tide Amplitude (MR)			1.70	--	8.20	--	10.10
Resolved Tidal Signal			91.3%		98.1%		98.6%
Tidal Prism (cubic feet)			**725,395**		**4,489,718**		N/A

Tidal prism is the volume of water exchanged within a basin between low tide and high tide and is useful for understanding tidal dynamics within a system. Tide prism can be calculated by developing a relationship between water level (tide) data and topographic data using hypsometric curves. A hypsometric curve is a cumulative elevation frequency curve created by plotting cumulative basin area versus elevation. Hypsometric curves were created for Mill Pond and the Middle Channel using the combined topography, bathymetry, and LIDAR data within each basin as shown in Figure 19. Note that the tidal prism was not calculated for Pamet Harbor because the Harbor is so large that it well exceeds the study area limits. Then the tidal datums MLW and MHW were plotted on Figure 19 against the hypsometric curves to provide a visual aide of the relative mean tidal range versus cumulative basin area. The tidal prism for Mill Pond and the Middle Channel is determined by calculating the volume of water that the hypsometric curve could store for each basin between MLW and MHW. The tidal prism for Mill Pond is 725,395 cubic feet (cft), which is approximately 84% less than the Middle Channel at 4,489,718 cft due to a much smaller mean tide range as shown in Table 3.

A digital record of the tide, salinity, and temperature data and tide metrics in Microsoft Excel format is provided in Attachment E.

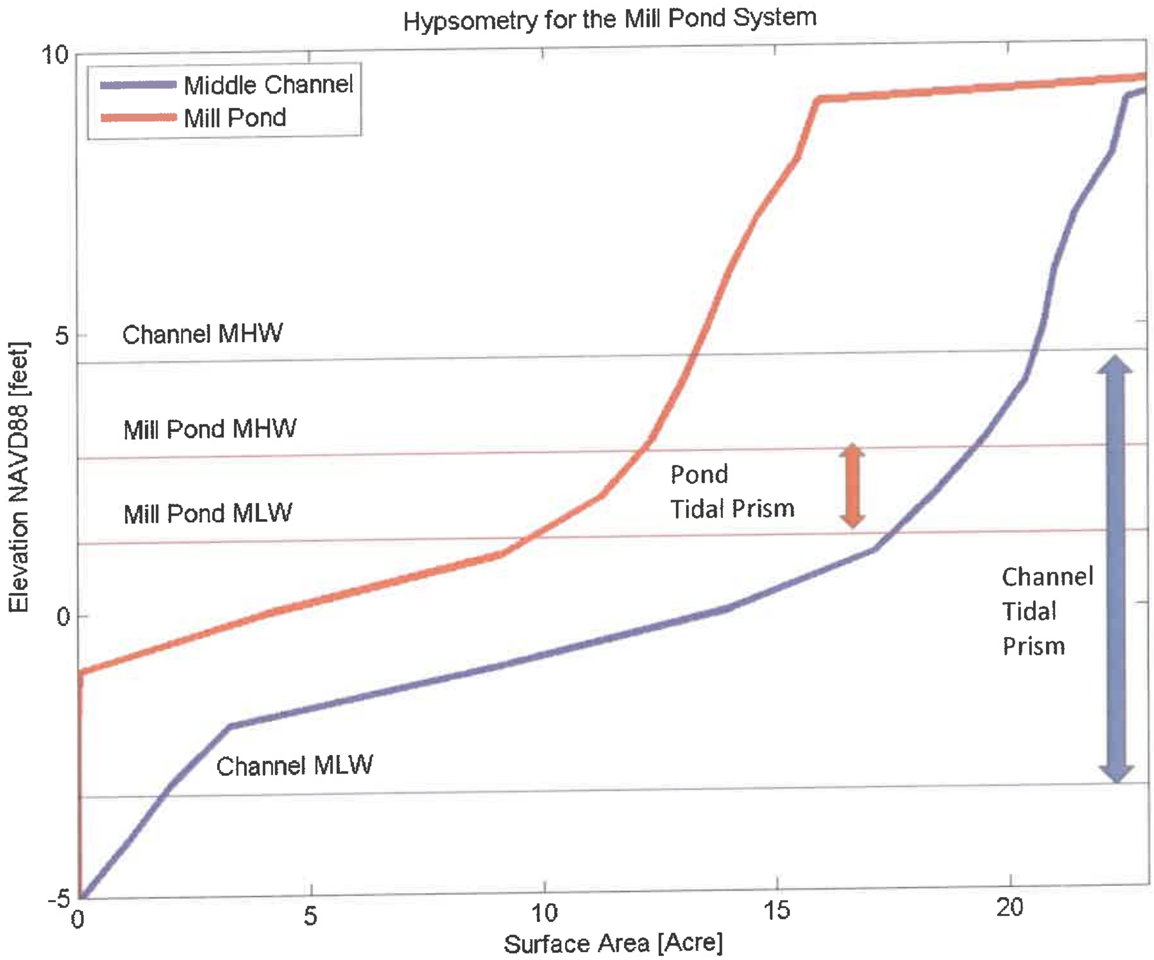

Figure 19. ***Hypsometric curves for Mill Pond and the downstream Middle Channel plotted with their respective MLW and MHW tidal datums to estimate tidal prism.***

Subsurface Investigation

A subsurface investigation was completed by Fuss & O'Neill that included two (2) geotechnical boreholes with representative samples undergoing gradation analyses at an approved laboratory. The borings were extended down to a depth needed for potential pile design, since physical properties at that depth would be required if upper horizons did not provide adequate bearing capacities. Both borings were ended without refusal and were ended by our discretion as a potential pile design would not rely on the properties of soil below this depth. The terminal boring depth was chosen so that drilling could be initiated for the second boring in order to have lateral coverage for the characterization and future analyses (i.e., if there's a pocket of different material in a different section of the future culvert).

The results indicated that a layer of brown sandy fill rests over a reddish-brown fine to medium grain native sand. Sample S-2 from Boring B-1 characterizes fill associated with the causeway, which has 2.3% passing a #200 sieve according to the sieve analysis. Since there is less than the 10% fines in this samples this does not trigger the threshold that necessitates the need for additional chemical analyses. There were no indications of contaminants (odor, staining etc.) from observation of soils. The results of the boring are not an unexpected and do not pose any major issues for structural design of a replacement structure. Please see Attachment A for the full report entitled *Mill Pond Road Subsurface Investigation* (Fuss & O'Neill, June 24, 2021).

Summary and Next Steps

Below is a summary of the scope completed for this preliminary field investigation:

- Topographic and bathymetric survey data was collected from Mill Pond through the downstream channel past the railroad berm and no major impediments were encountered. An existing conditions base plan was developed from this data and also showed the locations tide gauge locations, wetland resources, tidal datums, and subsurface boring locations.
- Jurisdictional wetland resource areas delineated within the project area included salt marsh, coastal beach, coastal bank, BVW, and LSCSF.
- *Phragmites* are still present within the same areas where they were mapped in the June 2012 LBG Report. It was noted that their footprint appears to have expanded somewhat since then, but not at a rate to cause significant concern yet.
- The tidy study demonstrated that the mean tide range in the Middle Channel (MP-2) is attenuated from 7.7 ft to only 1.5 ft in Mill Pond (MP-1) through the Mill Pond Road culvert with a ~2-hour lag time. While the elevation of the pond bed is likely to high to support further low tide drainage without dredging, the high tide to Mill Pond is dampened by 1.7 ft and could potentially be restored with a proper sized culvert or similar opening.
- The former railroad berm does not appear to significantly attenuate tidal exchange between Pamet Harbor (MP-3) and the middle channel (MP-2) since the MHW and MHHW tidal datums were the same. The differences in MLW and MLLW datums are due to the channel bed being at a higher elevation for MP-2 than the low tide datums at MP-3. However, confirmatory modeling should be conducted to ensure it does not influence storm flooding or drainage.
- Two geotechnical subsurface borings were completed at Mill Pond Road that revealed a sandy fill over native fine to coarse sand, which is not unexpected and poses no significant impediments to foundation design of a replacement structure.
- Unless further explorations or characterizations reveal soils with greater fines, or other indications of contamination, it is anticipated that this material could potentially be beneficially reused. However, it would most likely not meet a specification for structural fill to backfill the replacement structure. The results also do not indicate what the design of foundational for the replacement structure would consist of (piles, spread footing, etc.) since this would require a foundational design analyses to be completed for the replacement structure that has not been designed yet and is outside of this scope of work. Nevertheless, these results do not necsssarily rule anything out yet.

- Woods Hole Group made a number of recommendations for future data and project needs in a June 24, 2021 *Draft Mill Pond Project Review and Additional Study Needs Memorandum.* These recommendations are all still valid and please see that document for additional information in Attachment D.

We appreciate the opportunity to support the Town of Truro on the project and look forward to continuing to support this project. Please contact myself via phone (508-495-6210) or email (mbuck@woodsholegroup.com) with any questions, comments, or requirements for additional information.

Sincerely,

Mitchell Buck

Mitchell Buck, P.E
Coastal Engineer

Attachment A: Mill Pond Subsurface Investigation (Fuss & O'Neill, June 24, 2021).
Attachment B: Mill Pond Existing Conditions Plan
Attachment C: Field Photolog
Attachment D: Final Mill Pond Project Review and Additional Study Need Memorandum
Attachment E: Electronic Data Deliverables (EDD) including:

1. Existing conditions plan in CAD and PDF formats
2. Processed tide, salinity and temperature data in Excel format
3. Topographic survey data in Excel Format
4. Bathymetric survey data in Excel Format
5. Point data of wetland delineation
6. Field photolog
7. Report in Word and PDF format

Attachment A – Mill Pond Subsurface Investigation (Fuss & O'Neill, June 24, 2021)

Attachment B – Mill Pond Existing Conditions Plan

Attachment C – Field Photolog

Attachment D – Final Mill Pond Project Review and Additional Study Need Memorandum

Attachment E – Electronic Data Deliverables (digital download)

310 CMR 10.99

DEP File No. SE75-293
(To be provided by DEP)

Form 5

City/Town Truro

Applicant Town of Truro, DPW

Commonwealth of Massachusetts

Order of Conditions
Massachuetts Wetlands Protection Act
G.L. c. 131, §40

From Town of Truro Conservation Commission Issuing Authority

To Town of Truro, DPW (Name of Applicant) — Town of Truro - Selectmen (Name of property owner)

Address Town Hall Road ~~P.O. Box 2030, Truro, MA~~ — Address Town Hall Rd., P.O. Box 2030, Truro, MA 02666

This Order is issued and delivered as follows:

☒ by hand delivery to applicant or representative on June 11, 1993 (date)

☐ by certified mail, return receipt requested on ______ (date)

This project is located at Mill Pond Road, Truro

The property is recorded at the Registry of ______

Book ______ Page ______

Certificate (if registered) ______

The Notice of Intent for this project was filed on May 14, 1993 (date)

The public hearing was closed on June 7, 1993 (date)

Findings

The Commission has reviewed the above-referenced Notice of Intent and plans and has held a public hearing on the project. Based on the information available to the Commission at this time, the Commission has determined that the area on which the proposed work is to be done is significant to the following interests in accordance with the Presumptions of Significance set forth in the regulations for each Area Subject to Protection Under the Act (check as appropriate):

☐ Public water supply
☒ Private water supply
☒ Ground water supply
☒ Flood Control
☒ Storm damage prevention
☒ Prevention of pollution
☒ Land containing shellfish
☒ Fisheries
☐ Protection of Wildlife Habitat

Total Filing Fee Submitted none State Share ______ (1/2 fee in excess of $25)

Fee waived for municipality

City/Town Share ______

Total Refund Due $ ______ City/Town Portion $ ______ (1/2 total) State Portion $ ______ (1/2 total)

Paul J. [signature] 6/14/93

RECEIVED ORIGINAL ORDER OF CONDITIONS SE 75-293 (MILL POND ROAD)

FILE

Therefore, the Commission hereby finds that the following conditions are necessary, in accordance with the Performance Standards set forth in the regulations, to protect those interests checked above. The Commission orders that all work shall be performed in accordance with said conditions and with the Notice of Intent referenced above. To the extent that the following conditions modify or differ from the plans, specifications or other proposals submitted with the Notice of Intent, the conditions shall control.

General Conditions

1. Failure to comply with all conditions stated herein, and with all related statutes and other regulatory measures, shall be deemed cause to revoke or modify this Order.

2. The Order does not grant any property rights or any exclusive privileges; it does not authorize any injury to private property or invasion of private rights.

3. This Order does not relieve the permittee or any other person of the necessity of complying with all other applicable federal, state or local statutes, ordinances, by-laws or regulations.

4. The work authorized hereunder shall be completed within three years from the date of this Order unless either of the following apply:
   (a) the work is a maintenance dredging project as provided for in the Act; or
   (b) the time for completion has been extended to a specified date more than three years, but less than five years, from the date of issuance and both that date and the special circumstances warranting the extended time period are set forth in this Order.

5. This Order may be extended by the issuing authority for one or more periods of up to three years each upon application to the issuing authority at least 30 days prior to the expiration date of the Order.

6. Any fill used in connection with this project shall be clean fill, containing no trash, refuse, rubbish or debris, including but not limited to lumber, bricks, plaster, wire, lath, paper, cardboard, pipe, tires, ashes, refrigerators, motor vehicles or parts of any of the foregoing.

7. No work shall be undertaken until all administrative appeal periods from this Order have elapsed or, if such an appeal has been filed, until all proceedings before the Department have been completed.

8. No work shall be undertaken until the Final Order has been recorded in the Registry of Deeds or the Land Court for the district in which the land is located, within the chain of title of the affected property. In the case of recorded land, the Final Order shall also be noted in the Registry's Grantor Index under the name of the owner of the land upon which the proposed work is to be done. In the case of registered land, the Final Order shall also be noted on the Land Court Certificate of Title of the owner of the land upon which the proposed work is to be done. The recording informatin shall be submitted to the _______________ on the form at the end of this Order prior to commencement of the work.

9. A sign shall be displayed at the site not less than two square feet or more than three square feet in size bearing the words, "Massachusetts Department of Environmental Protection, File Number SE 75 - 293"

10. Where the Department of Environmental Protection is requested to make a determination and to issue a Superseding Order, the Conservation Commission shall be a party to all agency proceedings and hearings before the Department.

11. Upon completion of the work described herein, the applicant shall forthwith request in writing that a Certificate of Compliance be issued stating that the work has been satisfactorily completed.

12. The work shall conform to the following plans and special conditions:

Plans:

Title	Dated	Signed and Stamped by:	On File with:
EXHIBITS I,II,III,IV,V,& VI			
SKETCH, MILL POND RD CULVERT & ROADWAY RESTORATION PROJECT, PJG, 6/4/93			

Special Conditions (Use additional paper if necessary)

12a. The applicant shall give written notice to the Commission 48 HOURS IN ADVANCE that the work is to be done and all work shall be under supervision of the Commission.
12b. For any change made or intended in the plans or work, the applicant shall file a new Notice of Intent or inquire in writing to the Commission whether the change is significant enough for another Notice.
12c. Members of the Commission or its agent shall have the right to enter upon and inspect the site to ensure compliance with this Order.
12d. The Commission finds the site is a washed out culvert and roadway crossing tidal salt marsh.
12e. Failed 12 inch diameter culvert will be replaced with 36 inch diameter culvert by Cape Cod Mosquito Control Project.
12f. Applicant shall place no fill in the marsh in any place not previouly filled, or in a position where it can be washed into the marsh. Applicant shall stabilize slopes with riprap or other material approved by the Commission to prevent erosion of fill into the marsh. Applicant shall monitor the site for erosion of fill into marsh and

(Leave Space Blank)

Plans:

Title	Dated	Signed and Stamped by:	On File with:

Special Conditions (Use additional paper if necessary)

shall further stabilize the slopes if necessary to prevent erosion of fill into marsh. Planting vegetation is recommended for stabilizing. 12g. Parts of Mill Pond Road which have settled should be raised to prevent further flooding of the roadway and possible further erosion. 12h. The Commission questions whether the 36 inch diameter culvert is big enough to handle the amount of water without further failure. Applicant shall monitor the culvert and replace if necessary. 12i. Repair and replacement of the culvert and roadway are permitted by the Commission subject to the above conditions.

(Leave Space Blank)

310 CMR 10.99

Form 8

DEP File No. SE 75-293

(To be provided by DEP)

City/Town Truro

Applicant Town of Truro

Commonwealth of Massachusetts

Certificate of Compliance
Massachusetts Wetlands Protection Act, G.L. c. 131, §40

From Town of Truro Conservation Commission Issuing Authority

To Town of Truro (Name) Town Hall, Truro, Mass. 02666 (Address)

Date of Issuance November 8, 1993

This Certificate is issued for work regulated by an Order of Conditions issued

to Town of Truro dated June 11, 1993.

and issued by the Town of Truro Conservation Commission

1. ☒ It is hereby certified that the work regulated by the above-referenced Order of Conditions has been satisfactorily completed.

2. ☐ It is hereby certified that only the following portions of the work regulated by the above-referenced Order of Conditions have been satisfactorily completed: (If the Certificate of Compliance does not include the entire project, specify what portions are included.)

3. ☐ It is hereby certified that the work regulated by the above-referenced Order of Conditions was never commenced. The Order of Conditions has lapsed and is therefore no longer valid. No future work subject to regulation under the Act may be commenced without filing a new Notice of Intent and receiving a new Order of Conditions.

(Leave Space Blank)

RECEIVED: Paul J. [signature], TOWN ADMINISTRATOR
11/11/93

FILE

4. ☐ The certificate shall be recorded in the Registry of Deeds or the Land Court for the district in which the land is located. The Order was originally recorded on ______________________ (date) at the

Registry of ______________________, Book ________, Page ________.

5. ☐ The following conditions of the Order shall continue: (Set forth any conditions contained in the Final Order, such as maintenance or monitoring, which are to continue for a longer period.)

Issued by Town of Truro Conservation Commission

Signature(s) ______________________________

M. J. Viader · Carol Wheeler

Harry Towle · [illegible]

R. Hollander · Howard S. Irwin

When issued by the Conservation Commission this Certificate must be signed by a majority of is members.

On this 9th day of November, 19 93, before me personally appeared HOWARD S. IRWIN, to me known to be the person described in and who executed the foregoing instrument and acknowledged that he/she executed the same as his/her free act and deed.

Anne Q. Nickerson
Notary Public

October 28, 1999
My commission expires

Detach on dotted line and submit to the Truro Conservation Commission

....

To Truro Conservation Commission Issuing Authority

Please be advised that the Certificate of Compliance for the project at: Mill Pond Road

File Number SE 75-293 has been recorded at the Registry of ______________________

and has been noted in the chain of title of the affected property on ______________, 19______

If recorded land the instrument number which identifies this transaction is ______________________

If registered land the document number which identifies this transaction is ______________________

Signature ______________________________ Applicant

ORIG TO TOWN ADMIN, COPY TO FILE, SEC, BLDG INSP, DEP, BD HEALTH

NOV 11 '93

Issued By Town of Truro Conservation Commission

Signature(s)

This Order must be signed by a majority of the Conservation Commission.

On this 14th day of JUNE 19 93, before me personally appeared CHARLES S. DAVIDSON, to me known to be the person described in and who executed the foregoing instrument and acknowledged that he/~~she~~ executed the same as his/~~her~~ free act and deed.

Notary Public — My commission expires October 28, 1999

The applicant, the owner, any person agrrieved by this Order, any owner of land abutting the land upon which the proposed work is to be done, or any ten residents of the city or town in which such land is located, are hereby notified of their right to request the Department of Environmental Protection to issue a Superseding Order, providing the request is made by certified mail or hand delivery to the Department, with the appropriate filing fee and Fee Transmittal Form as provided in 310 CMR 10.03(7), within ten days from the date of issuance of this determination. A copy of the request shall at the same time be sent by certified mail or hand delivery to the Conservation Commission and the applicant.

Detach on dotted line and submit to the Conservation Commission prior to commencement of work.

....

To Truro Conservation Commission Issuing Authority

Please be advised that the Order of Conditions for the project at Mill Pond Road

File Number SE75-293 has been recorded at the Registry of __________ and has been noted in the chain of title of the affected property in accordance with General Condition 8 on __________, 19______.

If recorded land, the instrument number which identifies this transaction is __________

If registered land, the document number which identifies this transaction is __________

Signature ____________________ Applicant

RECEIVED
6/11/93

Commonwealth of Massachusetts
Executive Office of Environmental Affairs

Department of Environmental Protection

Southeast Regional Office

William F. Weld
Governor
Daniel S. Greenbaum
Commissioner

RE: NOTIFICATION OF FILE NUMBER
WETLANDS/ TRURO
(city/town)

DATE: June 4, 1993

The Department is in receipt of the following application filed in accordance with the Wetlands Protection Act (M.G.L. Ch. 131 s. 40):

APPLICANT: Town of Truro - DPW OWNER: Town of Truro - Seletmen

ADDRESS: P.O. Box 2030
Truro, MA 02666

ADDRESS: Same

PROJECT LOCATION: Mill Pond Road

This project has been assigned the following file #: SE 75-293

Although a file # is being issued, please note the following:
310 CMR 10.25, 10.30, 1032. Land Subject to Coastal Storm Flowage.

No file # will be assigned to this project until the following missing information is sent to this office to complete the filing in accordance with the Act:

( ) Notice of Intent ( ) Locus Map ( ) Fee transmittal form
( ) Title 5 Plans ( ) Appendix A Documentation ( ) Plans

PLEASE RETURN THIS FORM WITH REQUESTED INFORMATION.
COMMENTS:

( ) Application has been forwarded to Waterways Licensing Program to determine if a Chapter 91 License is required.

(X) Applicant is advised to forward a copy of the Notice of Intent to the Corps of Engineers for Sec. 404 review (Call 1-800-362-4367 for further information).

The project described in your Notice of Intent requires a 401 Water Quality Certification from the DEP. See flip side of page for further information:

20 Riverside Drive • Lakeville, Massachusetts 02347 • FAX (508) 947-6557 • Telephone (508) 946-2700

(X) Before the activity described in the Notice of Intent can commence, you must obtain a Water Quality Certification (WQC) from this Regional Office. Please complete and file the enclosed application form with this Regional Office for review.

( ) Your project involves dredging of greater than 100 cubic yards of material, or requires a permit from the Federal Energy Regulatory Commission for work in "waters of the Commonwealth". Therefore, your proposed project is subject to 314 CMR 9.00 and requires a Water Quality Certification. Please complete and file the enclosed application form with the DEP/ Division of Water Pollution Control, One Winter Street, Boston, MA 02108. You may contact the Division of Water Pollution Control at 617-292-5655 if you have any questions.

( ) The Department of Environmental Protection has reviewed the plans submitted by the applicant and finds that there is reasonable assurance that the project or activity will be conducted in a manner which will not violate Massachusetts water quality standards, provided that:

a) the applicant receives and complies with a Final Order of Conditions from the local conservation commission or the Department; and

b) the Order of Conditions does not cause the loss of more than 5,000 sq. ft. of bordering vegetated wetlands and land under water; and

c) the project: is subject to 310 CMR 10.00 (i.e., not exempt from the MA Wetlands Protection Act - c.131, § 40); is not part of a subdivision ; and does not cause the loss of any wetlands of Outstanding Resource Waters, or any salt marsh.
Therefore, provided that the above conditions are satisfied, this will serve as the Water Quality Certification for this project. This Certification does not relieve the applicant of the duty to comply with any other statutes or regulations.

ISSUANCE OF A FILE NUMBER INDICATES ONLY COMPLETENESS OF FILING SUBMITTED, NOT APPROVAL OF APPLICATION.

PMK/bh

cc: Conservation Commission
( ) U. S. Army Corps of Engineers, Reg Branch
( ) Coastal Zone Management
( ) Board of Health
( ) Building Inspector

FILE

Truro Conservation Commission

TRURO, MASSACHUSETTS 02666

MAINTENANCE PERMIT

NAME Paul J. Guida

TELEPHONE NO 349-3635

ADDRESS Town Hall, P.O.B. 2030

Truro, MA 02666

DATE OF APPLICATION June 3, 1993

TOWN Truro

WORK TO BE PERFORMED Resurfacing of Mill Pond Rd. 50± ft. south of the Mill Pond Dike & culvert to Old County Rd. Resurfacing with bituminous concrete 2" to 3". Road bed will be built up with processed stone from present grade to eighteen inches (18") on marsh side. Rip-rap will be installed along marsh.

RESOURCE AREA " " Mill Pond Swamp & Tidal Marsh.

Paul J. Guida

SIGNATURE OF APPLICANT

APPROVED BY CONSERVATION COMMISSION

DATE OF APPROVAL JUNE 7, 1993

Carol Whalen

Harry Towle

[illegible]

[illegible]

John Monahan

M. L. [illegible]

[illegible]

CONSERVATION COMMISSION SIGNATURE

3 REQUIRED

NOTE: FOR ADDITIONAL INFORMATION CONTACT:

Paul Morris
Truro Department of Public Works
Town Hall Road
Truro,MA 02666
508/349-2140

TRURO CONSERVATION COMMISSION

TRURO, MASSACHUSETTS 02666

May 14, 1993

Legal Advertisement:

TOWN OF TRURO
CONSERVATION COMMISSION

TO ALL INTERESTED PERSONS: The Truro Conservation Commission will hold a public hearing at 8:00PM Monday May 24, 1993 at Truro Town Hall pursuant to Massachusetts General Law 131 section 40 (Wetlands Protection Act) regarding a Notice of Intent by Town of Truro, DPW for repair of dike and road,and culvert installation in conjunction with Cape Cod Mosquito Control, to replace damaged road at Mill Pond Road, Truro.
Charles S. Davidson, Chairman, Truro Conservation Commission

The Cape Codder
P.O. Box 39
Orleans, MA 02653
one insertion May 18
bill to Truro Conservation Commission/Town Hall/Truro, MA 02666

copy to:
Truro town clerk
Truro board of health
Paul J. Guida/Truro town administrator
Truro bldg. commissioner
Town of Truro-DPW
Town of Truro - Selectmen
post at town hall May 14
Wetlands Div./ Dept. of Envir. Protection Southeast Region/Lakeville Hospital/Lakeville, MA 02347
abutter: Martha Ingrum/Box 532/Truro, MA 02666
abutter: Ruth Dunn Laidlaw/c/o Anne D. Harris/134 Autumn Ave,/Duxbury, MA 02332
abutter: Truro Conservation Trust/Box 327/N. Truro, MA 02652
abutter: Richard & Ann Marie Aubin/740 Boylston St. Apt. 31/Boston, MA 02199
John W. Doane/Cape Cod Mosquito Control Project/86 Willow St./Yarmouth Port, MA 02675

FLC

12. Is the project within estimated habitat which is indicated on the most recent Estimated Habitat Map of State-Listed Rare Wetlands Wildlife (if any) published by the Natural Heritage and Endangered Species Program?

YES [ ] NO [XX] Date printed on the Estimated Habitat Map
NO MAP AVAILABLE [ ] (if any) 1993 revised 4/14/93

If yes, have you sent a copy of the Notice of Intent to the Natural Heritage and Endangered Species Program via the U.S. Postal Service by certified or priority mail (or otherwise sent it in a manner that guarantees delivery within two days) no later than the date of the filing of this Notice of Intent with the conservation commission and the DEP regional office?

YES [ ] NO [ ]

If yes please attach evidence of timely mailing or other delivery to the Natural Heritage and Endangered Species Program.

Part II: Site Description

Indicate which of the following information has been provided (on a plan, in narrative description or calculations) to clearly, completely and accurately describe existing site conditions.

Identifying Number/Letter (of plan, narrative or calculations)	
	Natural Features
EXHIBIT II	Soils
EXHIBIT II	Vegetation
EXHIBIT II	Topography
EXHIBIT II	Open water bodies (including ponds and lakes)
EXHIBIT II	Flowing water bodies (including streams and rivers)
EXHIBIT II	Public and private surface water and ground water supplies on or within 100 feet of site
EXHIBIT II	Maximum annual ground water elevations with dates and location of test
EXHIBIT II	Boundaries of resource areas checked under Part 1, item 11 above
	Other
	Man-made Features:
EXHIBIT II	Structures (such as buildings, piers, towers and headwalls)
EXHIBIT II	Drainage and flood control facilities at the site and immediately off the site, including culverts and open channels (with inverts), dams and dikes
	Subsurface sewage disposal systems
	Underground utilities

12. Is the project within estimated habitat which is indicated on the most recent Estimated Habitat Map of State-Listed Rare Wetlands Wildlife (if any) published by the Natural Heritage and Endangered Species Program?

YES [ ] NO [XXX] Date printed on the Estimated Habitat Map
NO MAP AVAILABLE [ ] (if any) 1993 revised 4/14/93

If yes, have you sent a copy of the Notice of Intent to the Natural Heritage and Endangered Species Program via the U.S. Postal Service by certified or priority mail (or otherwise sent it in a manner that guarantees delivery within two days) no later than the date of the filing of this Notice of Intent with the conservation commission and the DEP regional office?

YES [ ] NO [ ]

If yes please attach evidence of timely mailing or other delivery to the Natural Heritage and Endangered Species Program.

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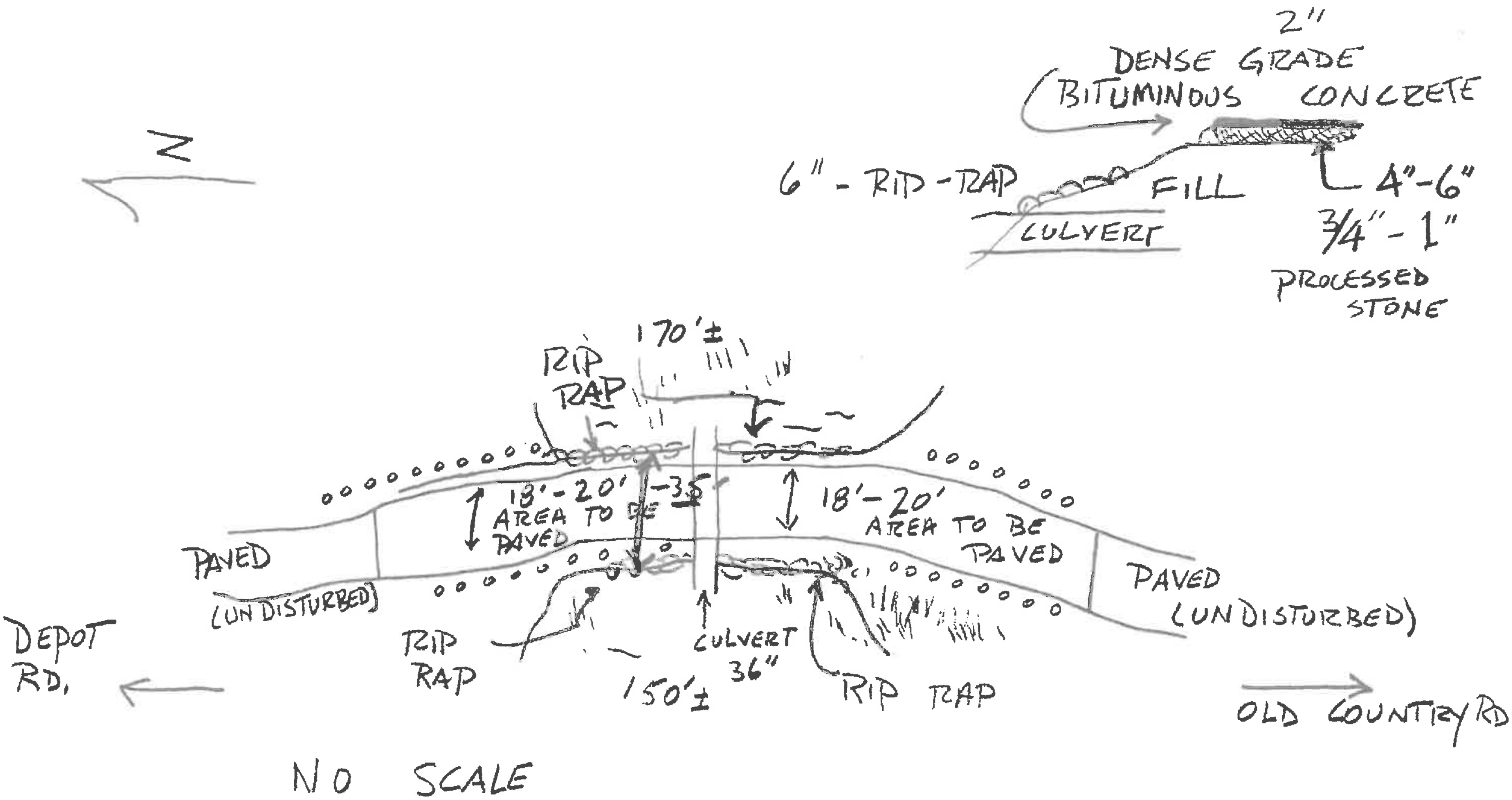
	Underground utilities



SKETCH

MILL POND RD CULVERT &
ROADWAY RECONSTRUCTION PROJECT

PIG ?/4/02

Hydraulic Modeling Report for *Mill Pond Restoration Project*

January 2013

Prepared for:

Cape Cod Conservation District

Prepared by:

THE Louis Berger Group INC

Table of Contents

Table of Figures

Table of Tables

1 INTRODUCTION

1.1 Background and Description

The Louis Berger Group, Inc. (LBG) was contracted by the Cape Cod Conservation District (CCCD) to provide several services as part of the Mill Pond Restoration Project located in Truro, Massachusetts (Figure 1). The site was identified by the Cape Cod Water Resources Restoration Project (CCWRRP) as a candidate site for restoration to address an existing tidal restriction. An existing 33-inch corrugated plastic pipe under Mill Pond Road restricts tidal flow into Mill Pond from Pamet Harbor and Cape Cod Bay. This site is referred to as Mill Pond Road, Truro (TR-SM-2) in the CCWRRP and is listed in the Cape Cod Atlas (Atlas) of Tidally-Restricted Salt Marshes as TR-2. The current assignment includes the development of a hydraulic model that analyzes the existing conditions of the intertidal habitat landward of Mill Pond Road and associated tidal creek system against several culvert replacement alternatives. This modeling effort will assist in selecting a preferred culvert replacement alternative that will minimize the existing tidal restriction.

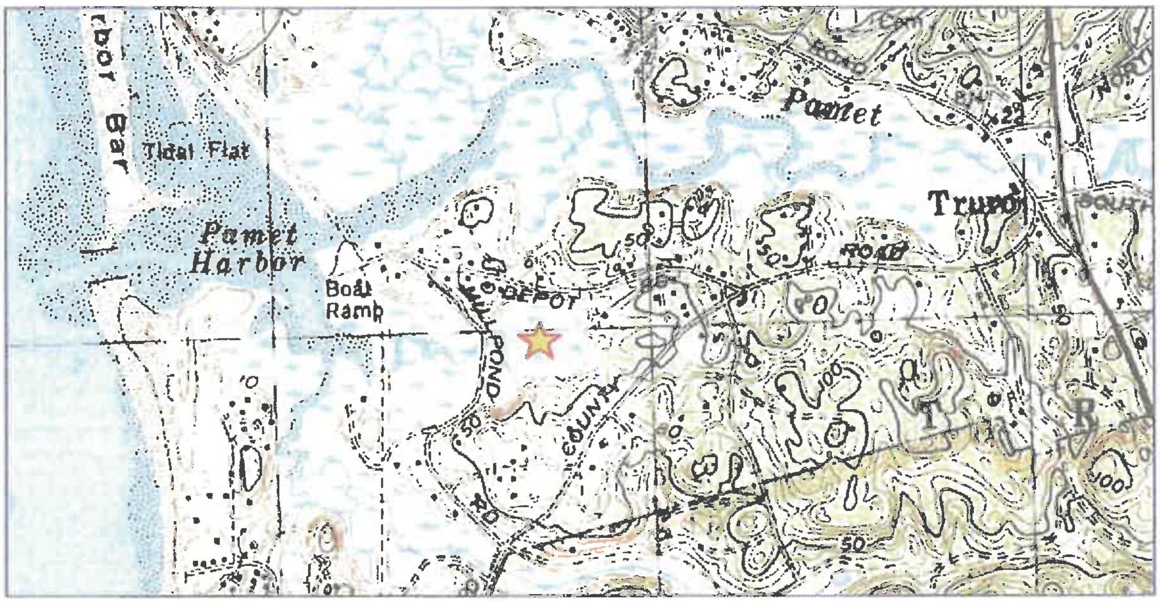


Figure 1. Mill Pond Restoration Project Locus Map. (United States Geological Service)

The Mill Pond channel seaward of Mill Pond Road is approximately 10 feet wide. Landward of Mill Pond Road, the channel is approximately 15 feet wide before flowing into the pond. Mill Pond has an extensive history of anthropogenic uses dating back to the colonial settlement. During the period of the Revolutionary War, the British blockaded the imports of salt resulting in Mill Pond being one of the largest saltworks, extending over several acres and continuing into the mid-nineteenth century (Whalen 2007[1]). Truro, along with other Cape Cod towns enjoyed success as major producers of salt due to the undiluted salinity of its shoreline waters.

Based on a review of available historical photographs and personal communications with Truro Historical Society staff, LBG learned Mill Pond was previously referred to as "Pie Meadow." This name came from the pie-like series of ditches within the former salt marsh to identify plots family members could farm (Figure 2). John Doan, Superintendent, of the Cape Mosquito Control, confirmed the ditches were dug to serve this

[1] Whalen, Richard F. 2007. Truro: The Story of a Cape Cod Town. The History Press. 255 pages.

purpose rather than as a mosquito control measure (pers. com. J. Doane, August, 27, 2012).

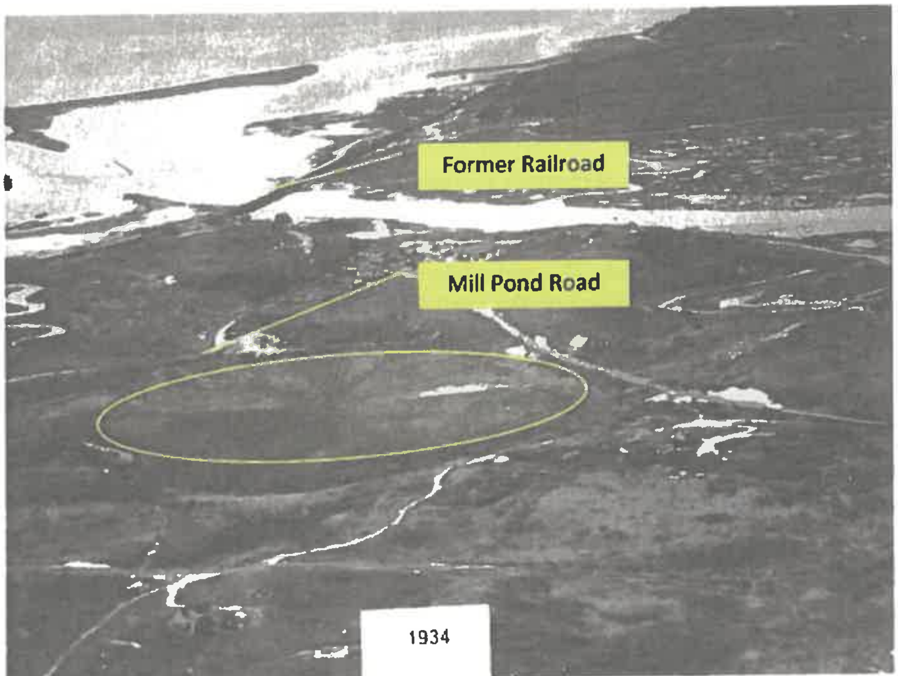


Figure 2. Oblique Aerial of Mill Pond (a.k.a. Pie Meadow) with Pie Shaped Farming Plots

An abandoned railroad bed runs through Pamet Harbor and its associated marshes seaward of Mill Pond Road. Available information indicates Mill Pond has long been impaired from a tidal restriction caused by construction of the railroad crossing in 1869. Reportedly, the railroad embankment near Pamet Harbor stopped tidal flows into Mill Pond, changing it into a freshwater marsh until a storm in 1978 broke through the dike (Whalen 2007). According to the Atlas, the railroad bed was completely breached by the no-name storm in 1991. According to the Cape Cod Mosquito Control Superintendent, the existing 33-inch pipe was installed following the storm as a temporary measure. The intent was to replace the temporary pipe with a timber bridge design from the U.S. Forest Service, Timber Bridge Initiative (TBI). Established by Congress, the TBI and the Intermodal Surface Transportation and Efficiency Act (ISTEA) provided a national emphasis on wood transportation structures in the early 1990's. However, the temporary pipe installed almost 20 years ago is still in place and is the impetus of this study.

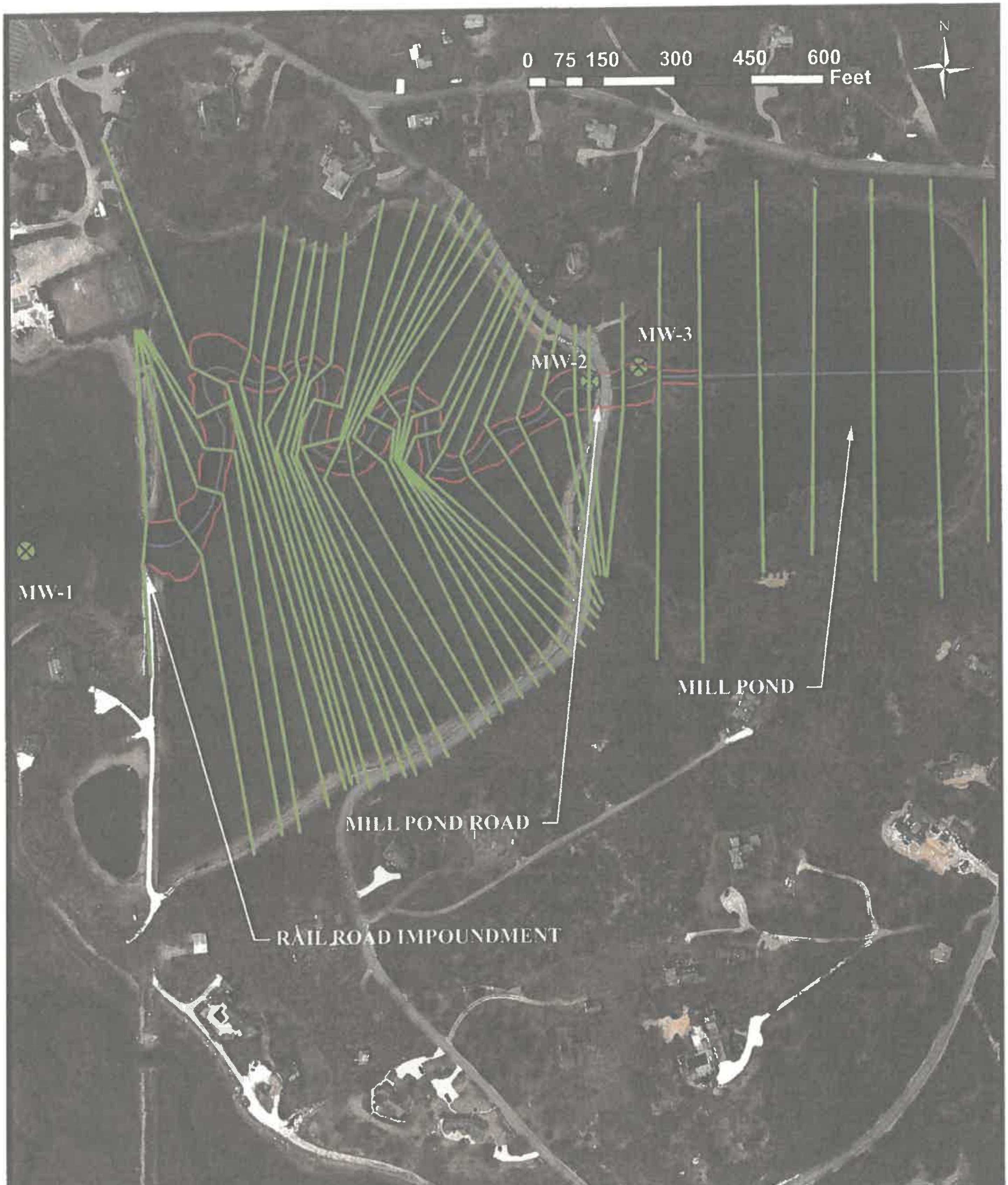
Some change in vegetation has occurred since the railroad breach, but the existing culvert under Mill Pond Road is undersized to promote salt marsh restoration landward. Indicators of a restriction include bed scouring, tidal lag, ponding, and minor bank erosion. A brief tidal study conducted in June 2011, as well as the tidal monitoring conducted as part of this project, documented the extent of the tidal restriction. The goal is to replace the undersized culvert under Mill Pond Road in an effort to restore a comparable tidal prism found seaward.

2 EXISTING DATA REVIEW

Several sources of data were obtained and reviewed prior to the development of the hydraulic model. Existing topography of the Mill Pond Restoration area included Light Detection and Ranging (LiDAR) data obtained by the CCCD and provided to LBG. This information included contour information and spot elevations of the tidal creek, marsh surfaces, and the immediate surrounding area, within the project area.

In addition, Bryant Associates (Bryant) performed a detailed field survey in the project area in May and June 2012. Cross sections of the creek were recorded approximately every 100 feet. All of the sections were collected over an approximately 1,600-foot reach seaward of Mill Pond Road. Elevation data were collected on the landward side of Mill Pond Road. The survey data utilized provided elevation information including, the left top of bank elevation, several points on the channel bottom including the centerline, and right top of bank elevation, as well the elevation of the Mill Pond Road and associated infrastructure.

The previous tide datA collected by LBG was reviewed to establish the stage elevations used in the model at the three monitoring stations (MW-1, MW-2, and MW-3, see Figure 3).



The Louis Berger Group, Inc.

MILL POND RESTORATION

MILL POND HYDRAULIC MODELING

EXTENT OF HYDRAULIC MODEL

Cape Cod Conservation District

FIGURE 3	*SCALE: AS SHOWN*	JANUARY 2013

3 HYDRAULIC MODEL DEVELOPMENT

To analyze the existing conditions and the proposed alternatives for the habitat restoration project, hydraulic models of both existing conditions and proposed conditions were developed.

3.1 Existing Conditions

The existing conditions of the intertidal habitat landward of Mill Pond Road and tidal creek were developed using the Hydrologic Engineer Center River Analysis System (HEC-RAS) unsteady state flow model. In addition, HEC-GeoRAS Version 10, a utility for processing geospatial data in ArcGIS, was used to develop the geometry of the system to be input into the model. The development of the existing conditions model included LiDAR elevation data provided by the CCCD and conventional supplemental survey information obtained by Bryant.

3.2 Geometry

In HEC-GeoRAS 10, the existing topography, spot elevations, and elevation information were used to create a triangulated irregular network (TIN) to represent the existing elevations of the tidal creek and intertidal habitat landward of Mill Pond Road. The model was then generated and cross sections were extracted. The model extends approximately 1,670 feet seaward and 775 feet on the landward side of Mill Pond Road. Cross sections for the HEC-RAS model were taken at approximately 100-foot intervals, in the general vicinity of the cross sections recorded in the June 2012 field survey. In addition, due to the sinuosity of the tidal creek, additional cross sections were provided to reduce the potential for model instability.

The hydraulic model cross sections extend to the limits of the floodplain (generally elevation 11 NAVD 88 or above). Model cross sections were also taken at locations immediately seaward and landward side of the Mill Pond Road to reflect accurately the geometry of the road and associated culvert. Bank stations were developed based on the spot elevations provided by Bryant and photographs taken at the site. Figure 3 provides the limits of analysis within the project area.

Once the creek centerline and cross sections were developed in HEC-GeoRAS, the data was imported into HEC-RAS 4.1 for further development and refinement. Once in HEC-RAS, left and right bank stations were assigned, Mannings "n" values were determined, and the geometry was refined to reflect the current condition of the creek. In addition, points along the cross section were filtered to remove unnecessary points, such as points that were within a tolerance of 0.05 horizontal and vertical feet. Ineffective flow areas were also added to the model in areas where water would not be actively conveyed.

3.3 Mannings "n" Values

Mannings "n" values were assigned using available aerial photography, as well as, field observations. Main channel Mannings "n" values were assigned a value of 0.045. These values are associated with main channels that are "clean, winding, some pools and shoals, but some weeds and stone" (HEC-RAS Hydraulic Reference Manual, 2010). Left and right overbanks contained several Mannings "n" values that reflect the land cover within the project area. Generally, roads and trails were assigned a value of 0.016 to reflect rough asphalt and other smooth surfaces. Vegetated areas of the marsh surface had Mannings "n" values ranging from 0.05-0.1. Those areas with less vegetative cover/roughness had lower values assigned in comparison to those areas with denser vegetation/roughness. Mannings "n" values were calibrated in the modeling process to reflect the existing conditions at the site for the tidal creek and associated marsh.

3.4 Road and Culvert

The Mill Pond Road and culvert were coded into the HEC-RAS model. Since contraction and expansion coefficients are not used in unsteady state modeling applications, the Manning's "n" values were increased to reflect typical transitions to the culvert. Data concerning the roadway surface and curbs from the Bryant survey was also used and entered into the model. The culvert was entered into the model using data gathered during the Bryant survey and included shape, seaward and landward side inverts, entrance and exit coefficients, and Manning's roughness coefficients. The diameter of the culvert was initially set to be 33 inches. The seaward invert of the culvert was set to be -1.8 and the landward invert was set to be -1.4.

3.5 Storage Areas

A storage area was included in the end of the model to account for the storage of the Mill Pond marsh. To determine the volume of the storage area, two methods were employed to ensure that accurate data was used in the model. In the first method, Geographic Information Systems (GIS) was used to outline the extents of the basin to elevation 8 NAVD 88 and from here, the program electronically derived the associated volume. Elevation 8 was selected as the upper limit because it is the approximate elevation in which the Mill Pond Road is overtopped with water and there is no additional storage associated with the pond. The second method involved calculating the volume for the same area using the average end area method. Comparing the digitally derived volume to the hand calculation, it was concluded that the volume calculated by GIS for the basin was accurate.

3.6 Boundary Conditions

Boundary conditions for the hydraulic model are a requirement in unsteady state modeling applications. As the model included a storage area at one end of the model, it is considered the boundary condition for this location. The opposite boundary condition was chosen as the stage hydrograph associated with the tidal data for MW-1.

3.7 Calibration

Once all of the necessary data were entered into the model, the model was run for the period between June 17, 2012 to June 21, 2012, and the results were analyzed for calibration purposes. Using the known water surface elevations at MW-2 and MW-3, the water surface elevations computed in the model were compared, and the model was calibrated such that the HEC-RAS model coincided with observed water surface elevations. To calibrate the marsh system seaward (MW-2), Mannings "n" values were adjusted within the expected range of values given for a respective land cover. Furthermore, incorrect or irrelevant elevation points that were entered in the model during development in HEC-GeoRAS were filtered and removed from all cross sections within the model. To calibrate the marsh system above Mill Pond Road (MW-3), the parameters associated with the existing culvert including Manning's roughness coefficients, entrance and exit losses, pipe size, and pipe invert were modified. These values were adjusted to until the observed and predicted water surface elevations were within reasonable tolerance.

3.8 Validation

Once the model had been calibrated, the model was simulated once again with a separate date range of tidal elevations to validate that the calibration effort was successful. For the validation run, the period between June 22, 2012 and June 25, 2012 was utilized. The observed elevation data associated with MW-2 were compared to the elevation data at this location in the HEC-RAS model. In addition, the observed elevation data at MW-3 were compared to the elevation data at this location in the HEC-RAS model.

3.9 Proposed Culvert Alternatives

Once the existing conditions model was calibrated and validated, the alternatives developed for the project area, as described below, were modeled in HEC-RAS to determine the extent to which the existing tidal restriction was reduced. In each of the alternatives, the existing conditions culvert parameters were altered in the HEC-RAS model to reflect the proposed conditions. The following is a description of each of the alternatives and how each of the components were modified.

One modeling scenario consisted of a single 54-inch corrugated aluminum pipe culvert. The invert for the culvert was established at -2.0 feet (NAVD 88). It was assumed that the culvert would project from the slope and therefore, the entrance loss coefficient was modified to be 0.9. In addition, the Manning's roughness coefficient was modified to be 0.024 to correspond to corrugated metal pipe. A second modeling scenario included a single 72-inch diameter corrugated aluminum pipe culvert. In this scenario, the parameters used to model the 54-inch pipe diameter were retained in the model, however, the diameter of the pipe was increased to 72 inches. A third alternative was based on a clear span of 30 feet. This dimension is the approximate width of the tidal creek below Mill Pond Road. For this alternative, a span of 30 feet with a height of 8 feet was coded into the model. The model was adjusted to count for both pressure and weir flow should either occur in the course of the calculations. Three additional alternatives were selected by the project partners to be modeled. A 10-foot span and 7-foot rise concrete box culvert, 9-foot span and 7-foot rise concrete box culvert, and 6-foot span and 7-foot rise concrete box culvert. Each model scenario described above was adjusted to account for these dimensions. The model was adjusted to count for both pressure and weir flow should either occur in the course of the calculations. The invert of all alternatives was set at elevation -2.0 feet (NAVD 88), slightly lower than the existing culvert invert of between -1.8 to -1.4 feet (NAVD 88). Several model iterations were run to determine the preferred alternative based on the project partners' criteria. The 10-foot span and 7 foot rise concrete box culvert was selected by the project partners as the preferred alternative.

4 HYDRAULIC MODELING RESULTS

The HEC-RAS model results for both the existing conditions and alternatives are presented below.

4.1 Calibration Modeling Results

Following the coding of the necessary data in the HEC-RAS model, the calibration model was run for the period of June 17 to June 21, 2012. The observed water surface elevation at MW-2 (seaward of Mill Pond Road) versus the HEC-RAS model predicted water surface elevation at this location were graphed (Figure 4).

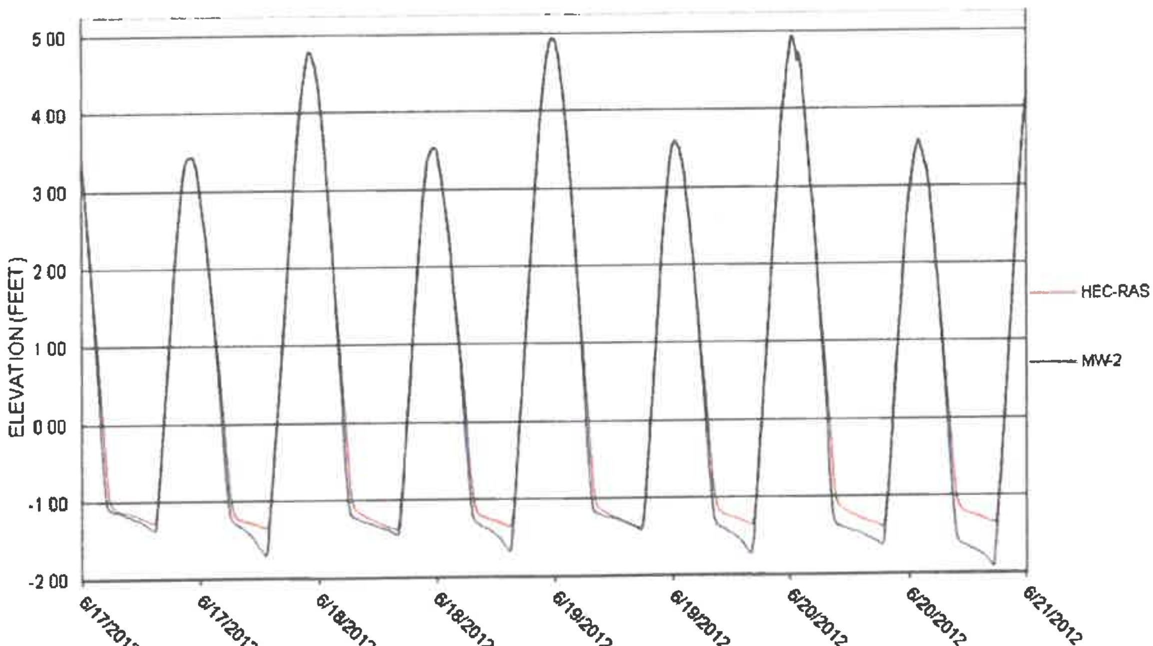


Figure 4. MW-2 versus HEC-RAS Water Surface Elevation

The observed water surface elevation at MW-3 (landward of Mill Pond Road) versus the HEC-RAS model predicted water surface elevation at this location was graphed (Figure 5).

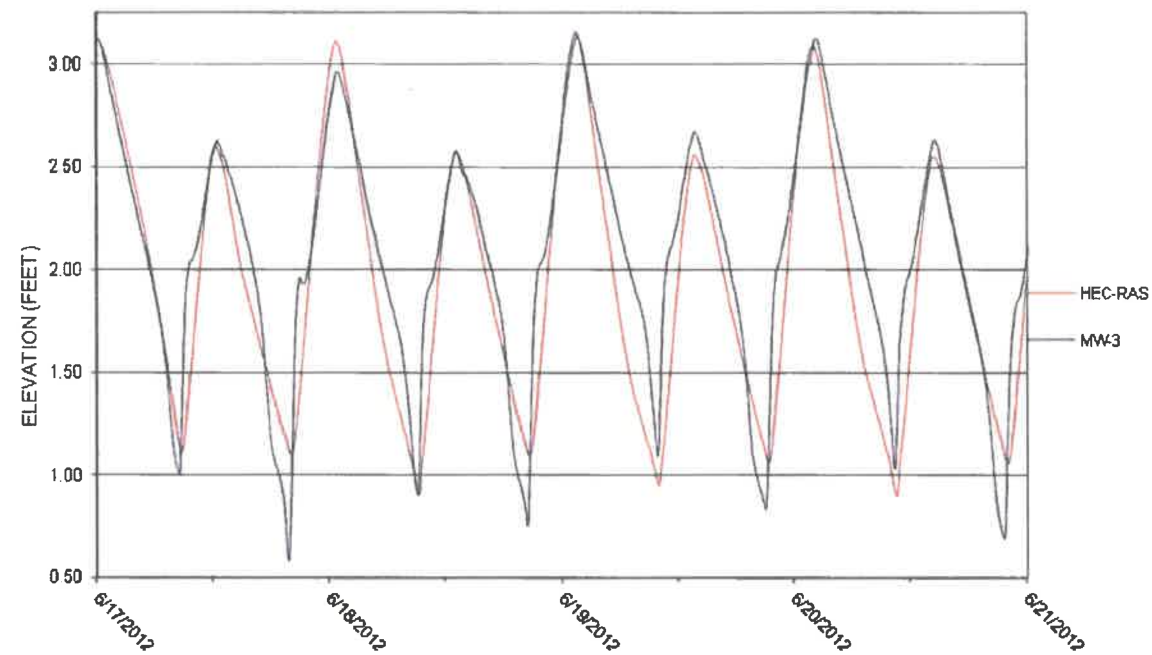


Figure 5. MW-3 versus HEC-RAS Water Surface Elevation

4.2 Validation Modeling Results

The calibrated geometry was utilized in running the validation scenario between June 22, 2012 and June 25, 2012. The observed MW-2 and MW-3 water surface elevation versus the modeled water surface elevations at these locations were compared (Figure 6 and Figure 7).

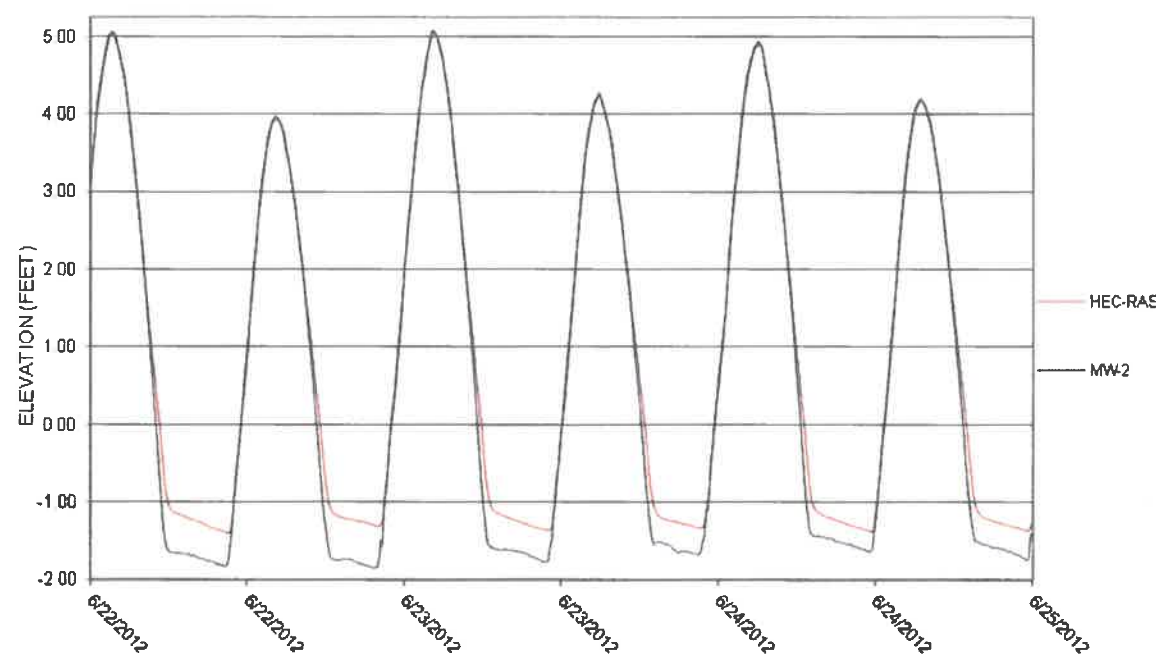


Figure 6. MW-2 versus HEC-RAS Water Surface Elevation

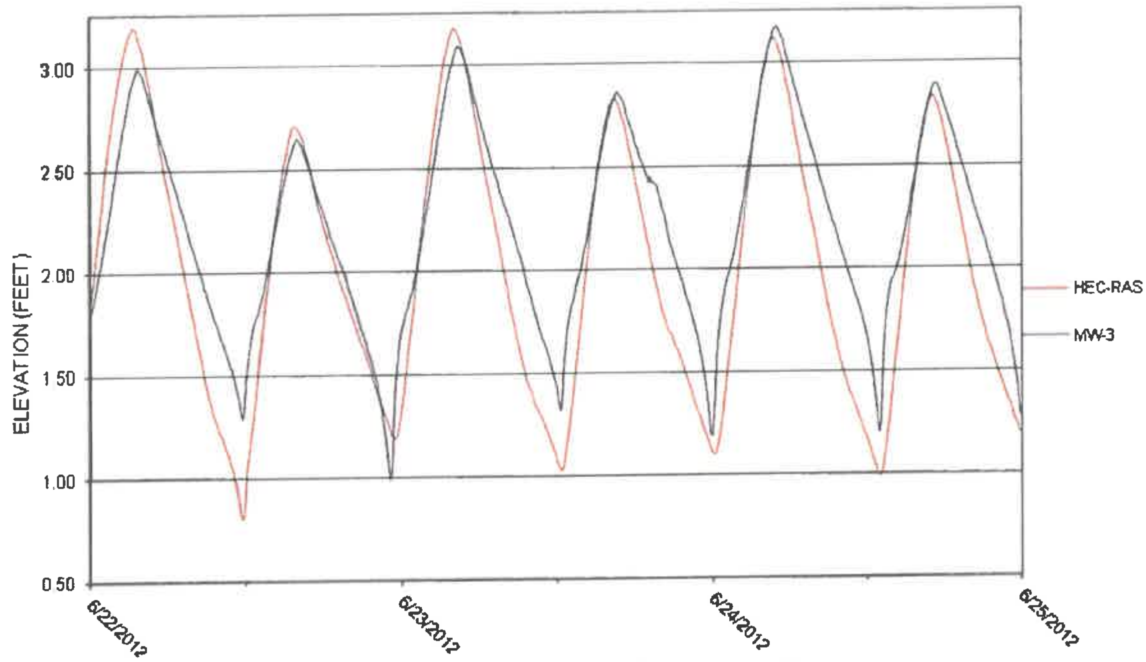


Figure 7. MW-3 versus HEC-RAS Water Surface Elevation

4.3 Alternative Modeling Results

Following the coding of the necessary data in the HEC-RAS model for each of the initial alternative scenarios (72-inch culvert, 54-inch culvert, and 30-clear span opening) the model was run for a spring tide event, which occurred on June 22, 2012. The spring tide data was entered into the model, the model was run, and the water surface elevations seaward and landward of the alternative culverts during this tide scenario were graphed (Figure 10).

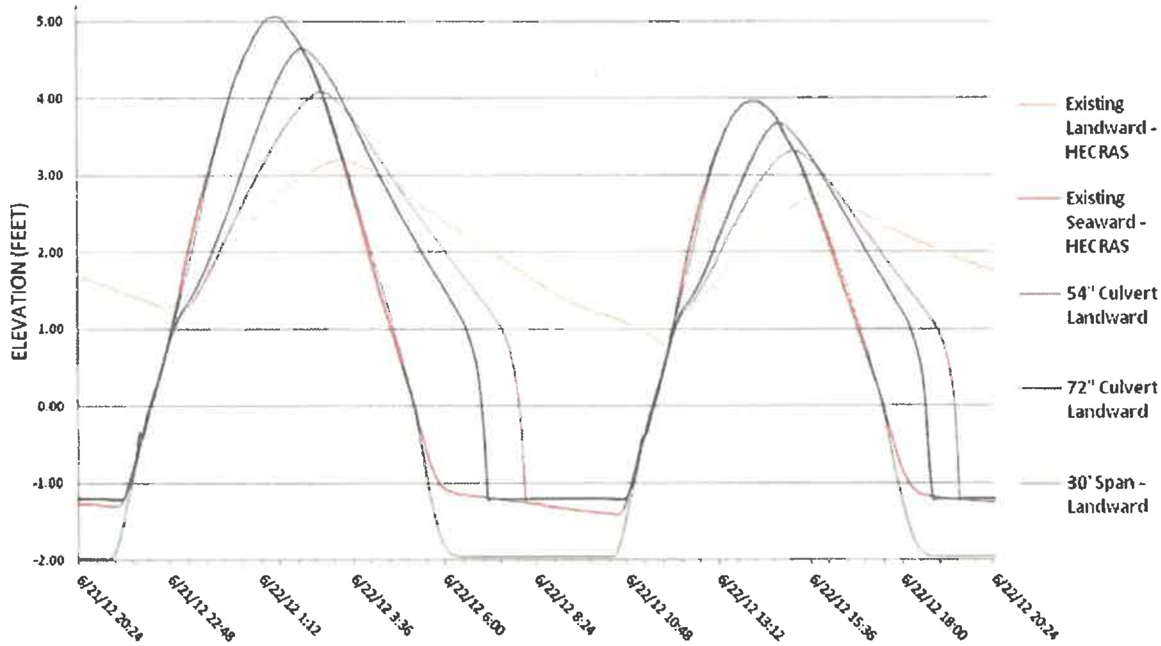


Figure 8. Existing Conditions versus Proposed Alternatives Model Data

Under existing conditions, the 33-inch culvert under Mill Pond Road results in a tidal dampening of approximately 1.9 feet and a phase delay of 102 minutes. The 54-inch pipe scenario reduced the existing restriction by 47 percent to approximately 1.0 feet and reduced the phase delay by 29 percent to 72 minutes. The 72-inch pipe scenario reduced the existing restriction by 79 percent to approximately 0.4 feet and reduced the phase delay by 59 percent to 42 minutes. The clear span scenario eliminated both the existing restriction and phase delay. These values are displayed in Table 1. As with most tidal restoration projects, a substantial increase in the effective opening of a replacement structure is required to entirely eliminate a tidal restriction with an associated increase in cost.

Table 1. Tidal Dampening and Phase Delay Comparison for Initial Alternatives

Model Scenario	Tidal Dampening (Feet)	Phase Delay (Minutes)
Existing Conditions	1.9	102
54-Inch Pipe	1.0	72
72-Inch Pipe	0.4	42
Clear Span	0	0

Following the analysis each of the initial alternative scenarios by the project partners, additional modeling alternative scenarios were run for a spring tide event (6-foot by 7-foot culvert, 9-foot by 7-foot culvert, and 10-foot by 7-foot culvert), which occurred on June 22, 2012. A summary of the tidal dampening and phase delay data for this tide regime are presented in Table 2.

Under existing conditions, the 33-inch culvert under Mill Pond Road results in a tidal dampening of approximately 1.9 feet and a phase delay of 102 minutes. The 6-foot span by 7-foot rise precast concrete culvert scenario reduced the existing restriction by 76 percent to approximately 0.46 feet and reduced the phase delay by 76 percent to 24 minutes. The 9-foot span by 7-foot rise precast concrete culvert scenario reduced the existing restriction by 99 percent to approximately 0.02 feet and reduced the phase delay completely. The 10-foot span by 7-foot rise precast concrete culvert scenario eliminated the existing restriction and phase delay.

Table 2. Tidal Dampening and Phase Delay Comparison for Spring Tide

Model Scenario	Tidal Dampening (Feet)	Phase Delay (Minutes)
Existing Conditions	1.9	102
6 by 7-foot Culvert	0.46	24
9 by 7-foot Culvert	0.02	0
10 by 7-foot Culvert	0	0

The 10-foot span by 7-foot rise precast concrete culvert was selected as the preferred alternative by the Project Partners. Further modeling scenarios were completed for the alternatives (6-foot by 7-foot culvert, 9-foot by 7-foot culvert, and 10-foot by 7-foot culvert) to determine the effects of the culverts during several additional tidal scenarios. These modeling scenarios included:

- Spring Tide
- Spring Tide with Sea Level Rise
- Mean High Water Tide,
- Mean High Water Tide with Sea Level Rise
- Annual High Tide (June 5, 2012),
- Annual High Tide with Sea Level Rise, and
- 100-Year Flood.

To establish the mean high and annual high tide water surface elevations at the project site, the U.S. Army Corps of Engineers in the New England Coastline Tidal Flood Survey (1988)[2] was reviewed. Based upon this data source, mean high water at the site is approximately 5.3 feet (NGVD 1929) or 4.4 feet (NAVD 88). The recorded tide occurring on June 13, 2012 had a maximum water surface elevation of 4.44 feet (NAVD 88). The hydrograph for this tide was selected for the mean high water model run. Based upon this data source, the one-year frequency tidal flood is approximately 7.9 feet (NGVD 1929) or 7.0 feet (NAVD 88). A similar elevation of 7.54 feet (NAVD 88) was recorded at instrument MW-1 during a major coastal storm event in June 2012. Therefore, the tide cycle occurring during this timeframe was selected for the annual high tide model run.

The table below presents tidal dampening and phase delay comparisons for the three alternatives analyzed during the modeling scenarios. It should be noted that values were not calculated for annual high tide with sea level rise as the results were not as accurate in comparison to other modeling scenarios due to limitation of the modeling program and errors generated as a result.

[2] Department of the Army, New England Division, Corp of Engineers. September 1988. New England Coastline Tidal Flood Survey, Tidal Flood Profile No. 10, Chatham, Mass. to Cohasset, Mass.

Table 3. Tidal Dampening and Phase Delay Comparison

Model Scenario	Tidal Dampening (Feet)	Phase Delay (Minutes)
Spring Tide		
6 by 7 foot Culvert	0.46	24
9 by 7 foot Culvert	0.02	0
10 by 7 foot Culvert	0	0
Spring Tide with Sea Level Rise		
6 by 7 foot Culvert	0.41	30
9 by 7 foot Culvert	0.09	12
10 by 7 foot Culvert	0	0
Mean High Water Tide		
6 by 7 foot Culvert	0.22	18
9 by 7 foot Culvert	0	0
10 by 7 foot Culvert	0	0
Mean High Water Tide with Sea Level Rise		
6 by 7 foot Culvert	0.47	30
9 by 7 foot Culvert	0	0
10 by 7 foot Culvert	0	0
Annual High Water Tide		
6 by 7 foot Culvert	0.51	18
9 by 7 foot Culvert	0	0
10 by 7 foot Culvert	0	0

4.3.1 Determination of Sea Level Rise

To determine the impact of sea level rise, the report entitled *Sea-Level Change Considerations for Civil Works Programs*[3] was utilized. Using guidance from this document and data obtained from National Oceanic and Atmospheric Administration (NOAA) Mean Sea Level Trends for U.S. Tide Stations, it was calculated that there would be an approximate rise of 1.7 feet over the typical (50 year) life cycle of the proposed concrete culvert. It was assumed that construction of the culvert would be completed in the year 2015.

Therefore, the tide data obtained at the site was increased by 1.7 feet for the Spring, Mean High Water, and Annual High Tides. In reviewing the data, it was determined that increasing the annual high tide data by 1.7 feet (elevation 8.7 NAVD 88) would overtop Mill Pond Road by approximately 1.3 feet. Therefore, the proposed culvert would not increase the potential for flooding surrounding Mill Pond. The existing location of the low point of the road is approximately 100 feet south of the existing culvert and has an approximate elevation of 7.4 (NAVD 88). According to the Army Corp of Engineer data, the road is presently expected to be overtopped with a frequency between a 1- and 10-year tidal flood. There are no design elements in the proposed culvert that would alleviate this flooding, current or future, as the location of the low point of the road has been previously identified to be south of the project area.

4.3.2 Modeling Results of Spring Tide for 6-Foot by 7-Foot Culvert

The spring tide data was entered into the model, the model was run and the water surface elevations seaward and landward of the culvert during this tide scenario were graphed (Figure 9).

It can be seen that a 6-foot by 7-foot culvert would result in a tidal dampening of approximately 0.46 feet and

[3] Department of the Army, Corps of Engineers. 2011 Sea-Level Change Considerations for Civil Works Programs. 32 pages.

a phase delay of 24 minutes during a spring tide.

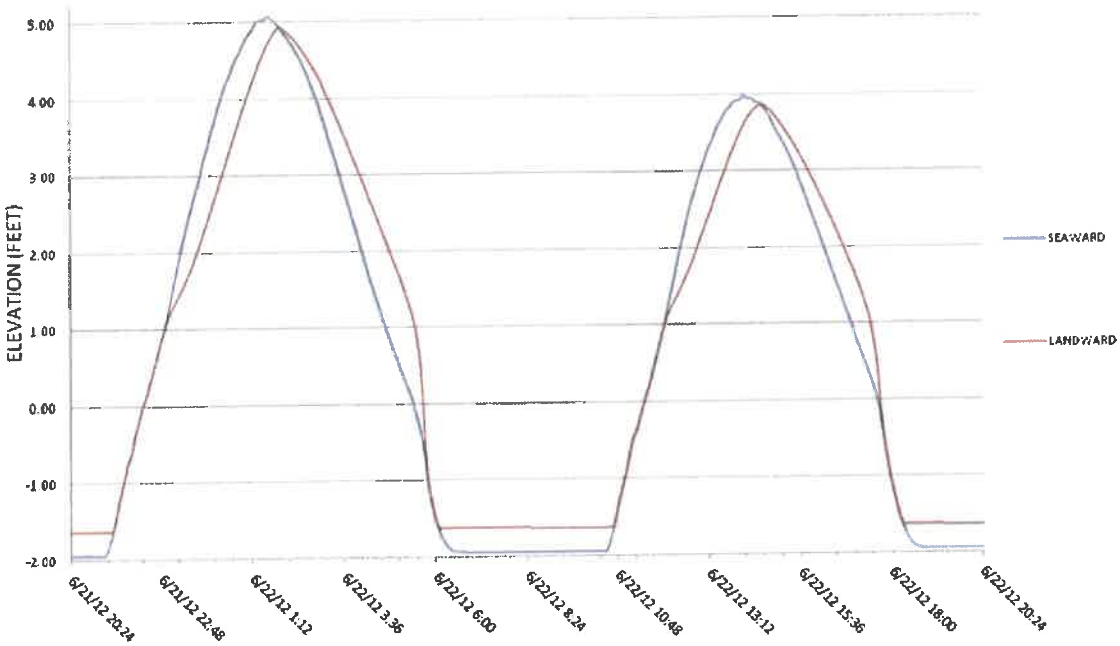


Figure 9. Proposed 6-foot span by 7-foot rise culvert during Typical Spring Tide Event

4.3.3 Modeling Results of Spring Tide for 9-Foot by 7-Foot Culvert

The spring tide data was entered into the model, the model was run, and the water surface elevations seaward and landward of the culvert during this tide scenario were graphed (Figure 10).

A 9-foot by 7-foot culvert would result in a tidal dampening of approximately 0.02 feet and removed the phase delay during a spring tide.

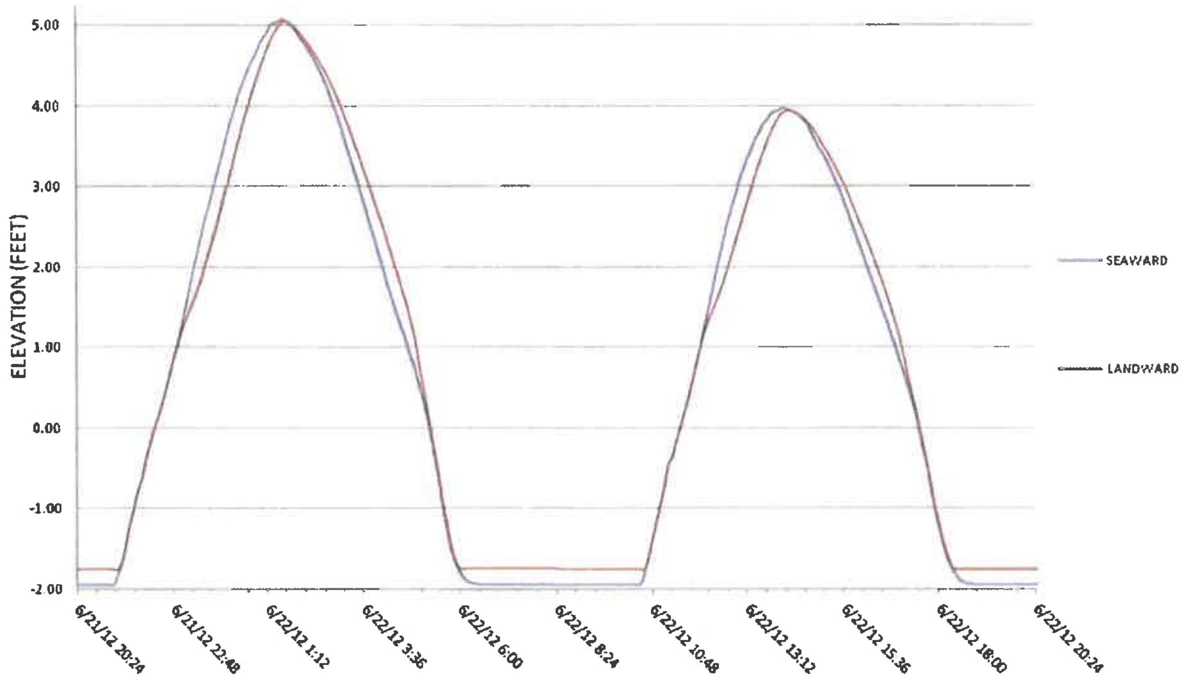


Figure 10. Proposed 9-foot span by 7-foot rise culvert during Typical Spring Tide Event

4.3.4 Modeling Results of Spring Tide for 10-Foot by 7-Foot Culvert

The spring tide data was entered into the model, the model was run, and the water surface elevations seaward and landward of the culvert during this tide scenario were graphed (Figure 11).

The proposed 10-foot by 7-foot culvert would result in elimination of tidal dampening phase delay.

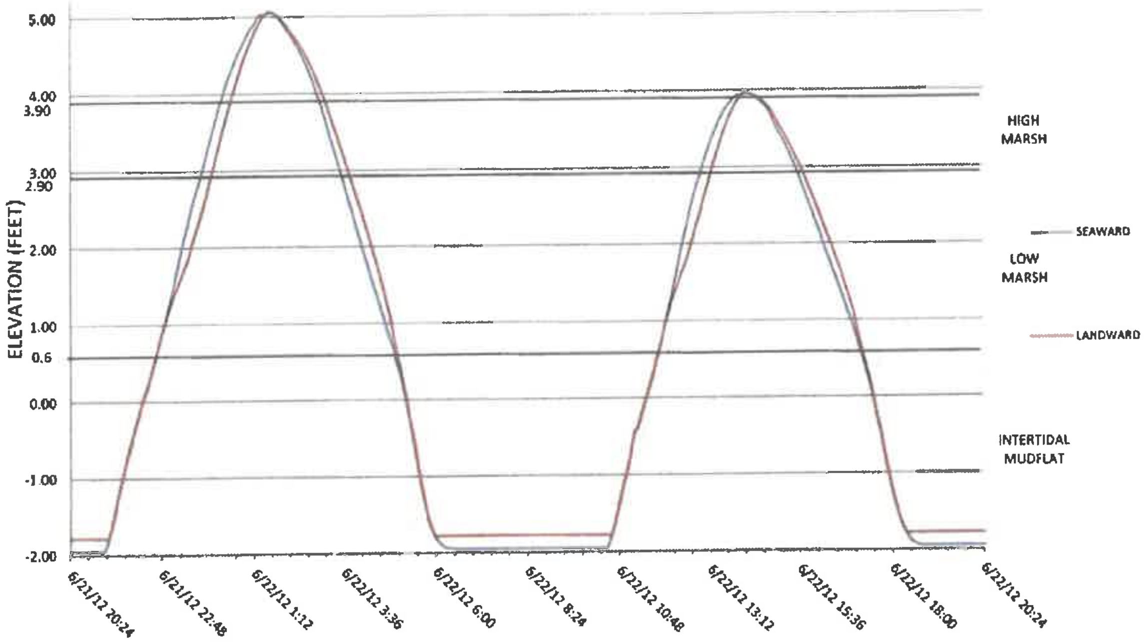


Figure 11. Proposed 10-foot span by 7-foot rise culvert during Typical Spring Tide Event

4.3.5 Modeling Results of Spring Tide with Sea Level Rise for 6-Foot by 7-Foot Culvert

The spring tide data with sea level rise was entered into the model, the model was run, and the water surface elevations seaward and landward of the culvert during this tide scenario was graphed (Figure 12).

The 6-foot by 7-foot culvert would provide similar reduction in tidal restriction as the modeling scenario with the spring tide data which did not account for sea level rise. It can be seen that a 6-foot by 7-foot culvert would result in a tidal dampening of approximately 0.41 feet and a phase delay of 30 minutes during a spring tide modified to account for sea level rise.

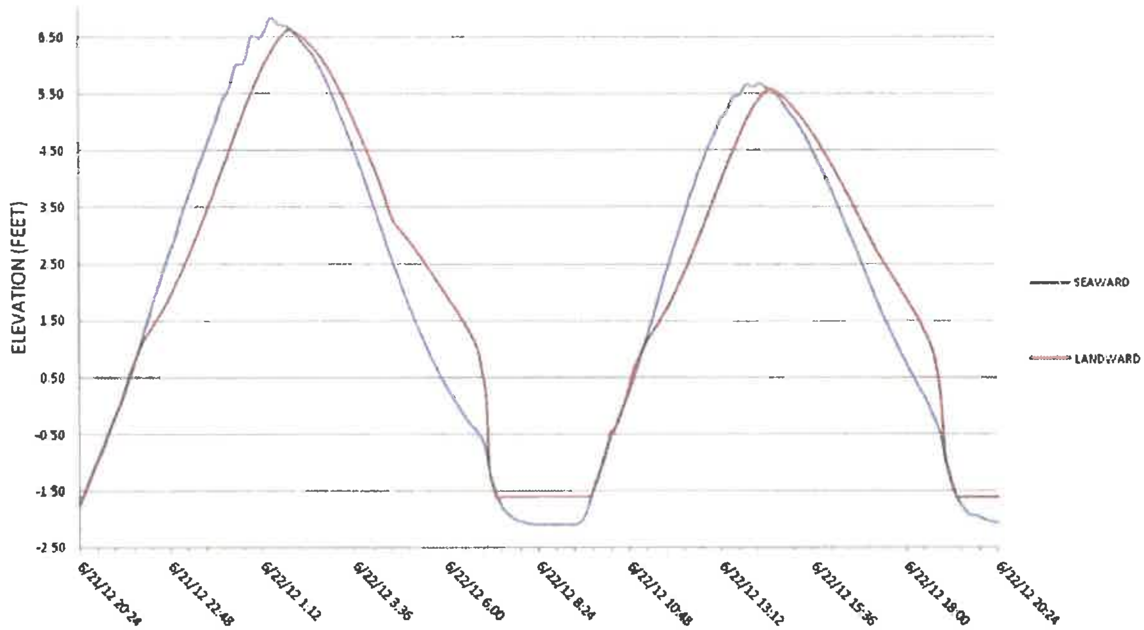


Figure 12. Proposed 6-foot span by 7-foot rise culvert during Typical Spring Tide Event with Sea Level Rise

4.3.6 Modeling Results of Spring Tide with Sea Level Rise for 9-Foot by 7-Foot Culvert

The modified spring tide data with sea level rise was entered into the model, the model was run, and the water surface elevations seaward and landward of the culvert during this tide scenario was graphed (Figure 13).

The proposed culvert would provide a similar reduction in tidal restriction as the modeling scenario with the unmodified spring tide data. It can be seen that a 9-foot by 7-foot culvert would result in a tidal dampening of approximately 0.09 feet and a phase delay of 12 minutes during a spring tide modified to account for sea level rise.

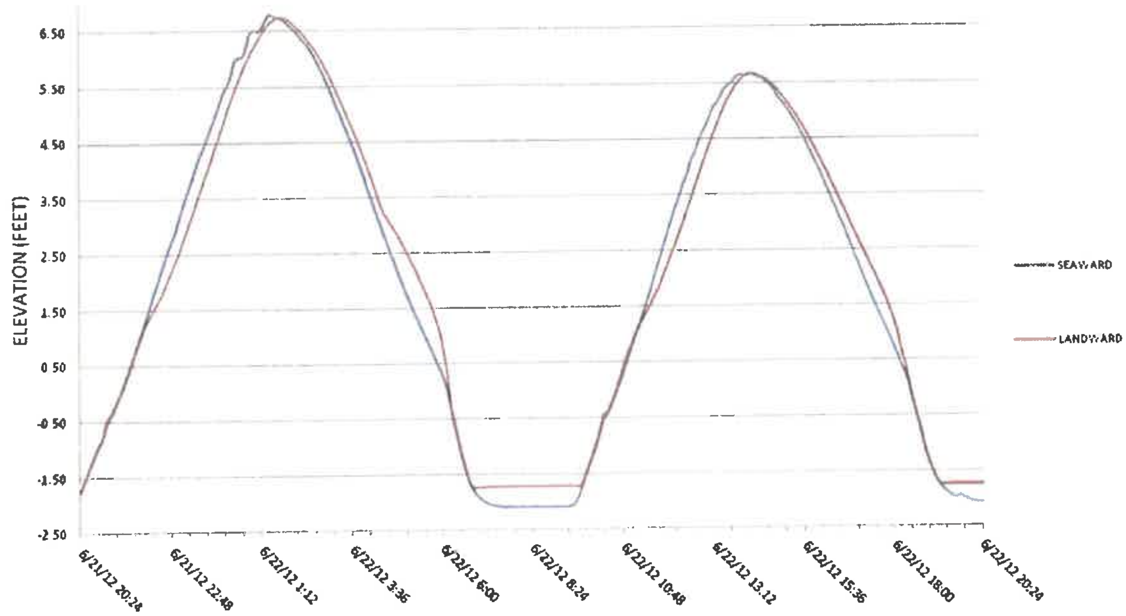


Figure 13. Proposed 9-foot span by 7-foot rise culvert during Typical Spring Tide Event with Sea Level Rise

4.3.7 Modeling Results of Spring Tide with Sea Level Rise for 10-Foot by 7-Foot Culvert

The modified spring tide data with sea level rise was entered into the model, the model was run, and the water surface elevations seaward and landward of the culvert during this tide scenario were graphed (Figure 14).

The proposed 10-foot by 7-foot culvert would provide a similar reduction in tidal restriction as the modeling scenario with the unmodified spring tide data. It can be seen that a 10-foot by 7-foot culvert would result in an elimination of tidal dampening and phase delay during a spring tide modified to account for sea level rise.

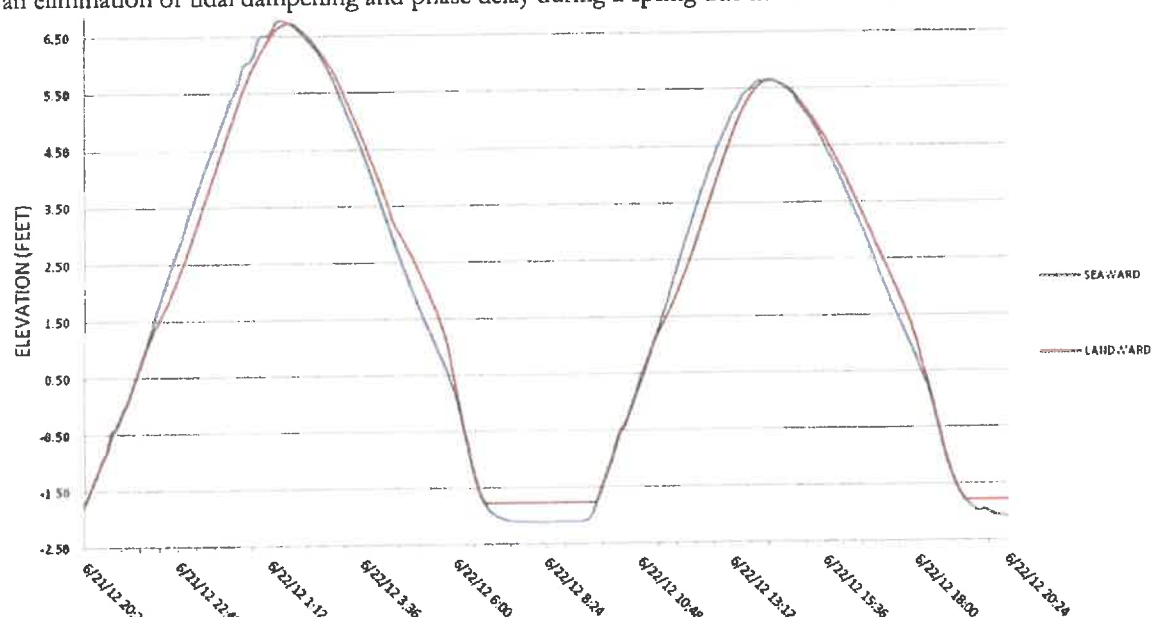


Figure 14. Proposed 10-foot span by 7-foot rise culvert during Typical Spring Tide Event with Sea Level Rise

4.3.8 Modeling Results of Mean High Water Tide for 6-Foot by 7-Foot Culvert

The mean high water tide data was entered into the model, the model was run, and the water surface elevations seaward and landward of the culvert during this tide scenario were graphed (Figure 15).

According to the model, a 6-foot by 7-foot culvert under would result in a tidal dampening of approximately 0.22 feet and a phase delay of 18 minutes during a mean high water tide.

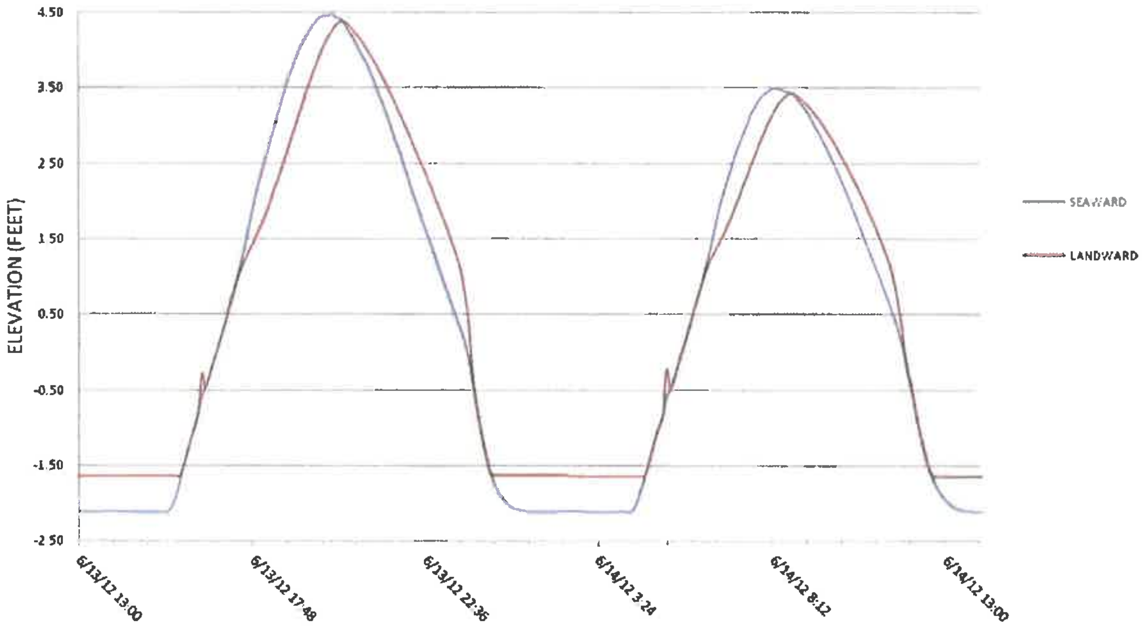


Figure 15. Proposed 9-foot span by 7-foot rise culvert during Mean High Water Tide Event

4.3.9 Modeling Results of Mean High Water Tide for 9-Foot by 7-Foot Culvert

The mean high water tide data was entered into the model, the model was run, and the water surface elevations seaward and landward of the culvert during this tide scenario were graphed (Figure 16).

A 9-foot by 7-foot culvert would result in an elimination of tidal dampening and phase during a mean high water tide.

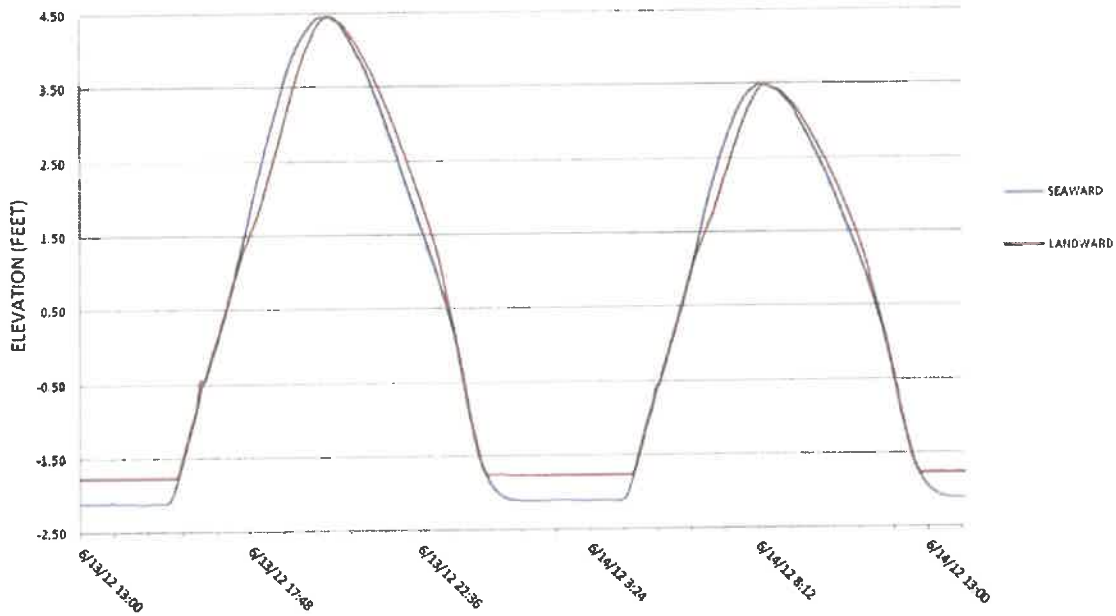


Figure 16. Proposed 9-foot span by 7-foot rise culvert during Mean High Water Tide Event

4.3.10 Modeling Results of Mean High Water Tide for 10-Foot by 7-Foot Culvert

The mean high water tide data was entered into the model, the model was run, and the water surface elevations seaward and landward of the culvert during this tide scenario were graphed (Figure 17).

During this tidal cycle, the culvert eliminates the tidal dampening and phase delay in a similar manner to that during the Spring Tide Event. It can be seen that a 10-foot by 7-foot culvert would result in an elimination of tidal dampening and phase delay.

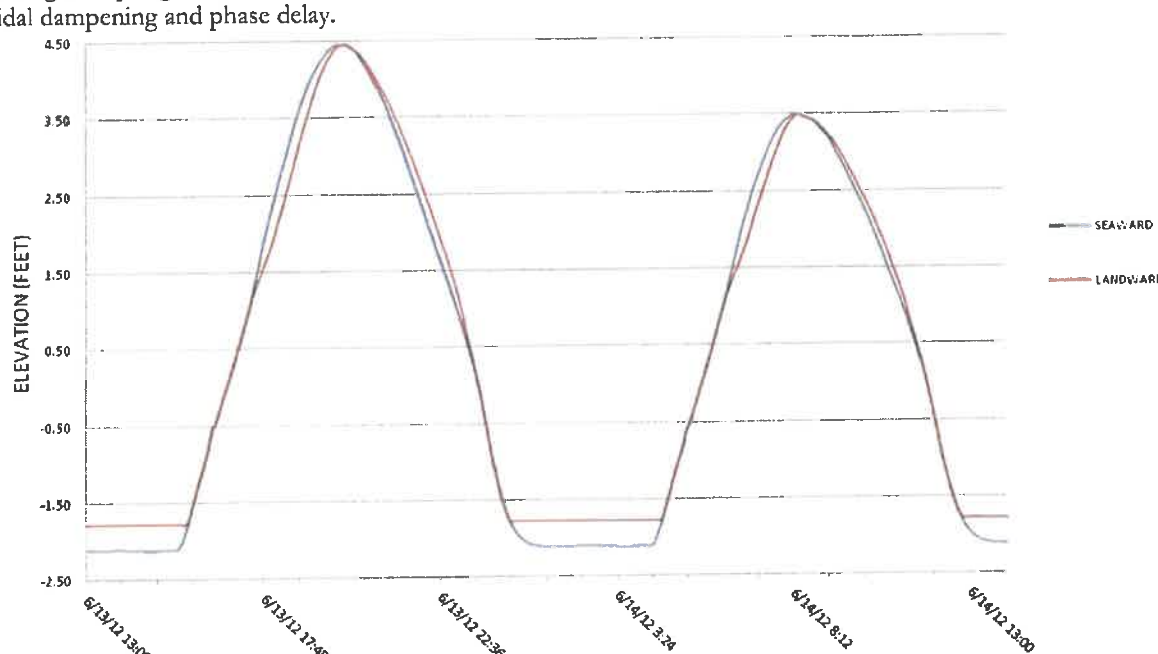


Figure 17. Proposed 10-foot span by 7-foot rise culvert during Mean High Water Tide Event

4.3.11 Modeling Results of Mean High Water Tide with Sea Level Rise for 6-Foot by 7-Foot Culvert

The mean high water tide data with sea level rise was entered into the model, the model was run, and the water surface elevations seaward and landward of the culvert during this tide scenario were graphed (Figure 18).

According to the model, a 6-foot by 7-foot culvert under Mill Pond Road would result in a tidal dampening of approximately 0.47 feet and a phase delay of 30 minutes during a mean high water tide modified to account for sea level rise.

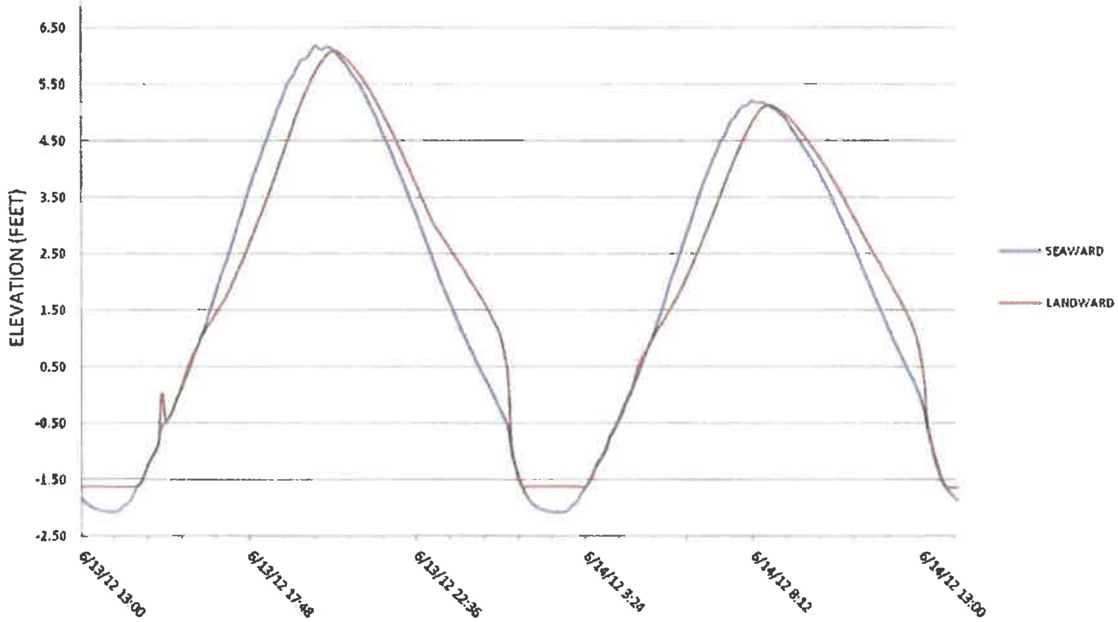


Figure 18. Proposed 6-foot span by 7-foot rise culvert during Mean High Water Tide Event with Sea Level Rise

4.3.12 Modeling Results of Mean High Water Tide with Sea Level Rise for 9-Foot by 7-Foot Culvert

The mean high water tide data with sea level rise was entered into the model, the model was run, and the water surface elevations seaward and landward of the culvert during this tide scenario were graphed (Figure 19).

A 9-foot by 7-foot culvert would result in an elimination of tidal dampening and phase delay during a mean high water tide modified to account for sea level rise.

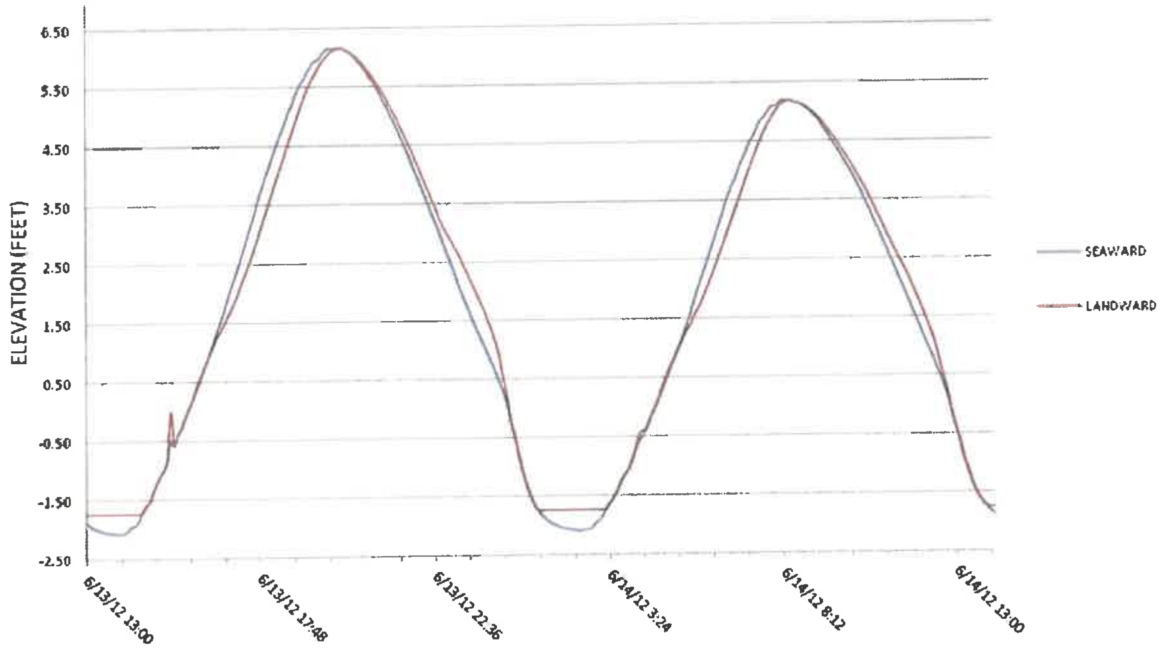


Figure 19. Proposed 9-foot span by 7-foot rise culvert during Mean High Water Tide Event with Sea Level Rise

4.3.13 Modeling Results of Mean High Water Tide with Sea Level Rise for 10-Foot by 7-Foot Culvert

The mean high water tide data with sea level rise was entered into the model, the model was run, and the water surface elevations seaward and landward of the culvert during this tide scenario were graphed (Figure 20).

The resultant data demonstreates a 10-foot by 7-foot culvert would provide similar reduction in tidal restriction as the modeling scenario with the mean high water tide data which did not account for seal level rise. Therefore, a 10-foot by 7-foot culvert would result in an elimination tidal dampening and phase mean high water tide modified to account for sea level rise.

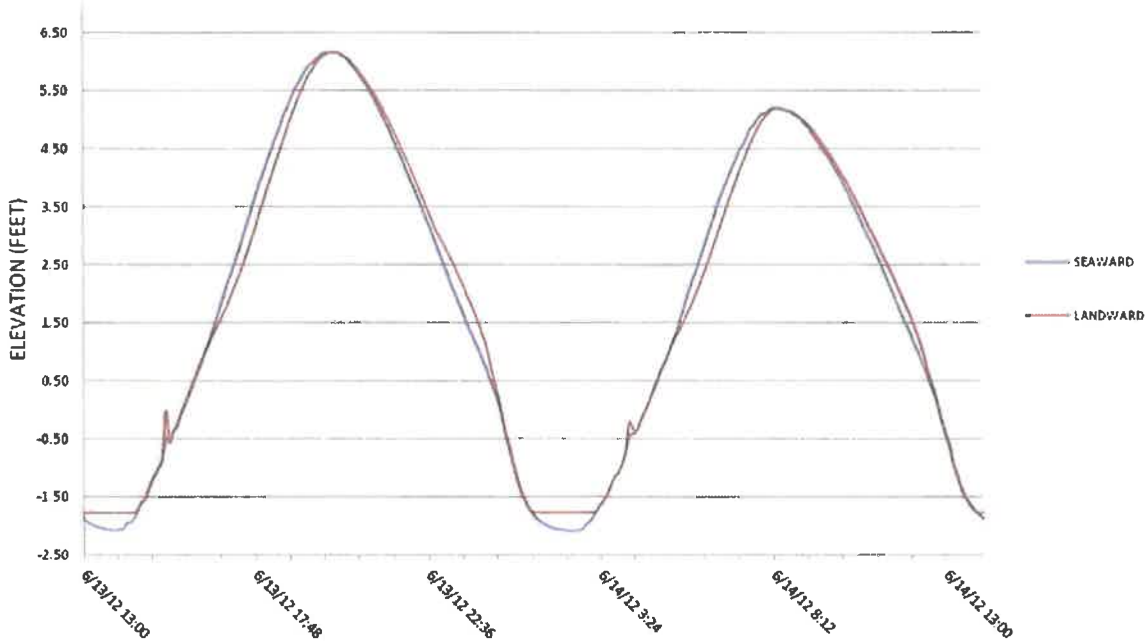


Figure 20. Proposed 10-foot span by 7-foot rise culvert during Mean High Water Tide Event with Sea Level Rise

4.3.14 Modeling Results of Annual High Tide for 6-Foot by 7-Foot Culvert

The annual high tide data of June 5, 2012 was entered into the model,the model was run, the water surface elevations seaward and landward of the culvert during this tide scenario were graphed (Figure 21).

A 6-foot by 7-foot culvert would result in a tidal dampening of approximately 0.51 feet and a phase delay of 18 minutes during an annual high tide event.

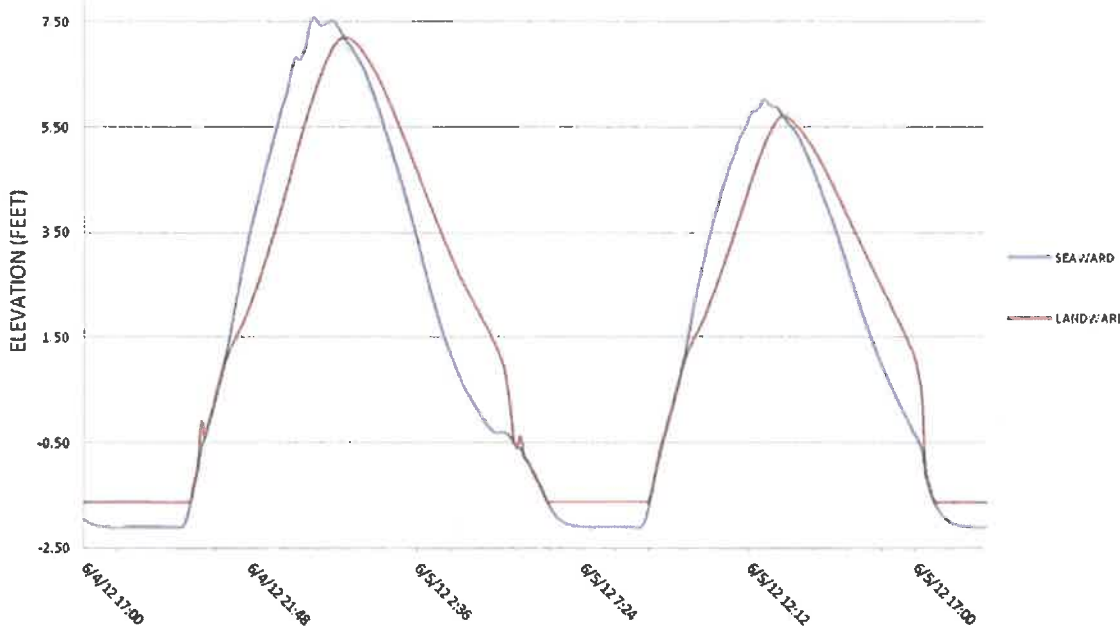


Figure 21. Proposed 6-foot span by 7-foot rise culvert during Annual High Tide Event

4.3.15 Modeling Results of Annual High Tide for 9-Foot by 7-Foot Culvert

The annual high tide data of June 5, 2012 was entered into the model, the model was run, and the water surface elevations seaward and landward of the culvert during this tide scenario were graphed (Figure 22).

A 9-foot by 7-foot culvert would result in an elimination of tidal dampening and phase delay during an annual high tide event

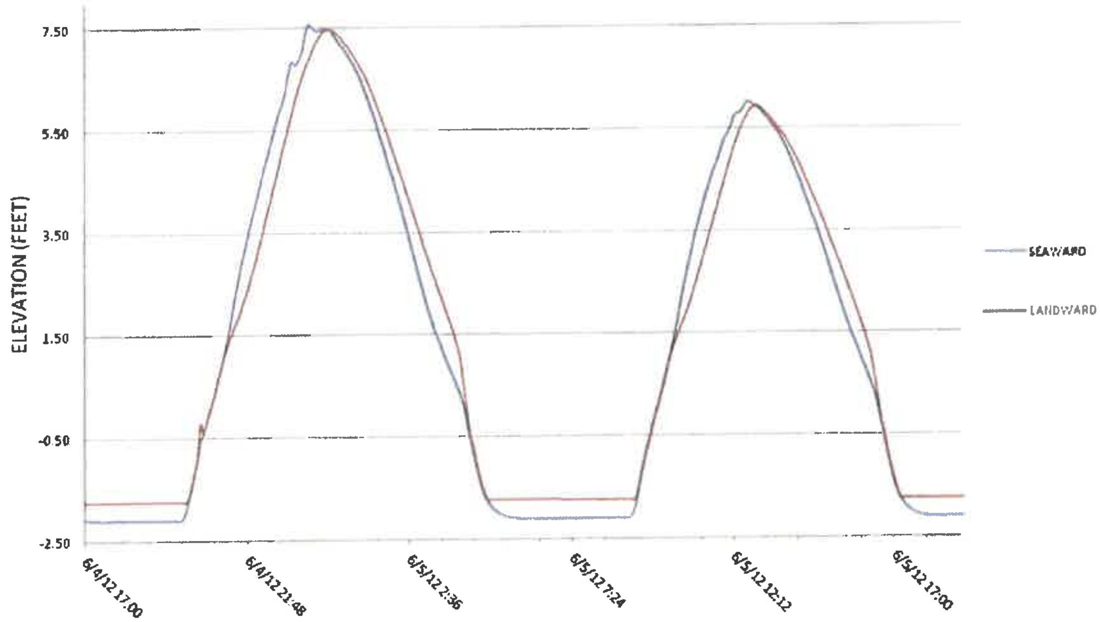


Figure 22. Proposed 9-foot span by 7-foot rise culvert during Annual High Tide Event

4.3.16 Modeling Results of Annual High Tide for 10-Foot by 7-Foot Culvert

The annual high tide data of June 5, 2012 was entered into the model the model was run, the water surface elevations seaward and landward of the culvert during this tide scenario were graphed (Figure 23).

The water surface elevation seaward of the proposed culvert exceeds the low point of the Mill Pond Road of approximately 7.4 NAVD 88, south of the culvert. According to the resultant model data, the proposed 10-foot by 7-foot culvert would result in an elimination of tidal dampening and phase delay during a annual high tide event up to elevation 7.4 NAVD 88 where the road would be overtopped.

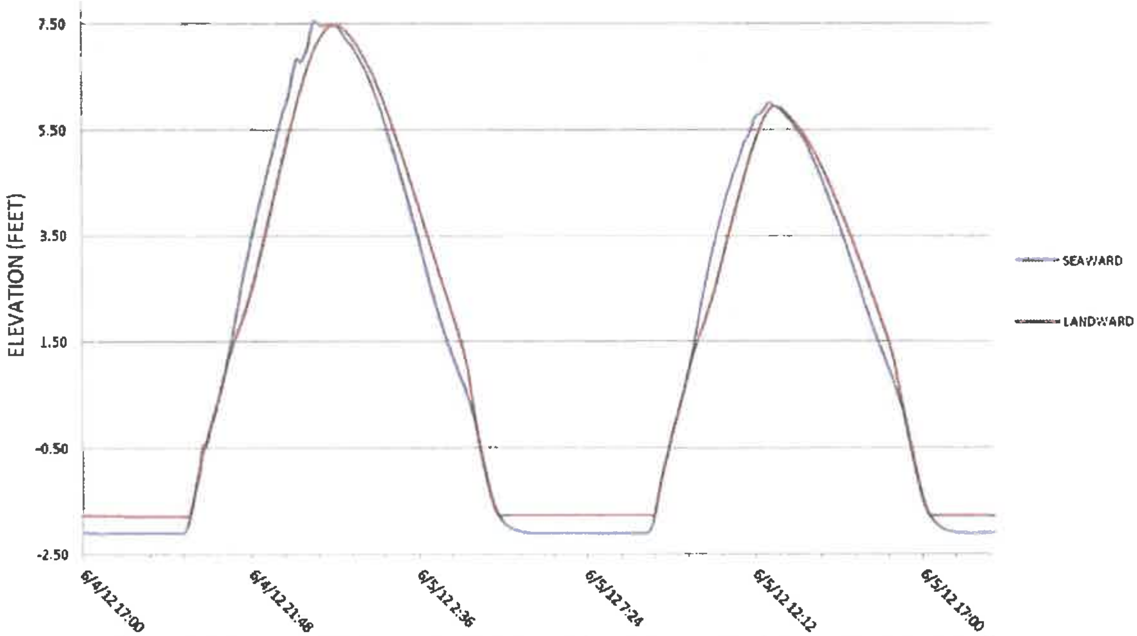


Figure 23. Proposed 10-foot span by 7-foot rise culvert during Annual High Tide Event

4.3.17 Modeling Results of Annual High Tide with sea Level Rise for 6-Foot by 7-Foot Culvert

The modified annual high tide data of June 5, 2012 was entered into the model, the model was run, and the water surface elevations seaward and landward of the culvert during this tide scenario were graphed (Figure 24).

There are instabilities in the model resulting from the high rate of increase in water elevation at the Mill Pond Road. It can be seen that the water is completely inundating the road, accounting for the oscillations seen in the graph provided. The oscillations are shown in the graph

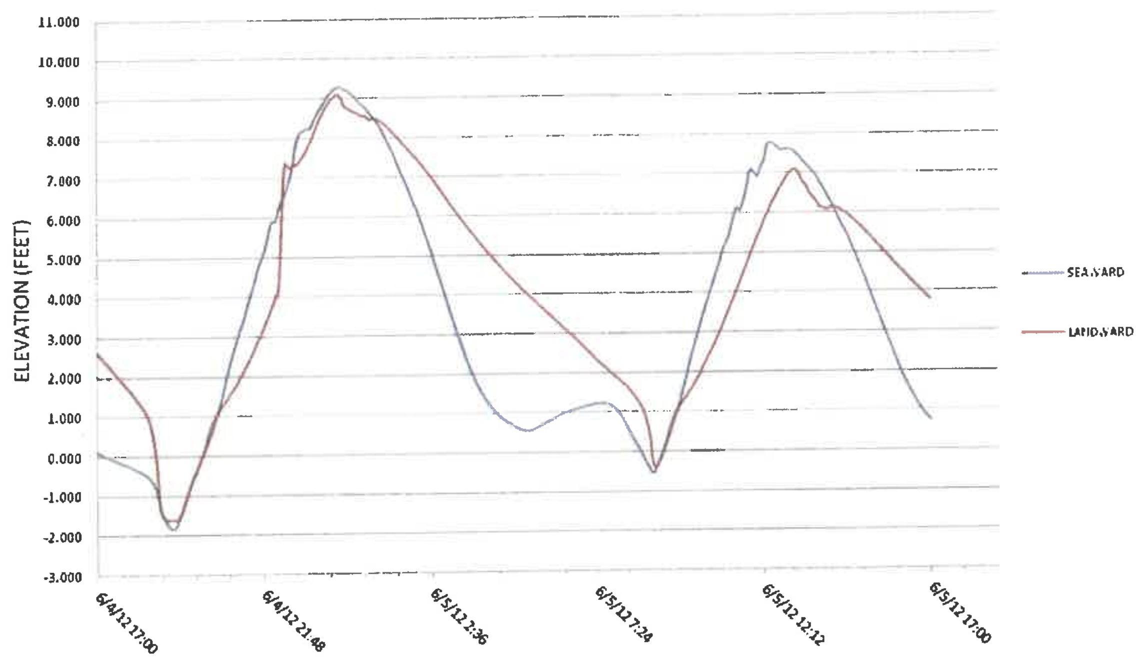


Figure 24. Proposed 6-foot span by 7-foot rise culvert during Annual High Tide Event with Sea Level Rise

4.3.18 Modeling Results of Annual High Tide with Sea Level Rise for 9-Foot by 7-Foot Culvert

The modified annual high tide data of June 5, 2012 was entered into the model, the model was run, and the water surface elevations seaward and landward of the culvert during this tide scenario were graphed (Figure 25).

There are instabilities in the model resulting from the high rate of increase in water elevation at the Mill Pond Road. It can be seen that the water is completely inundating the road, accounting from the oscillations seen in the graph provided.

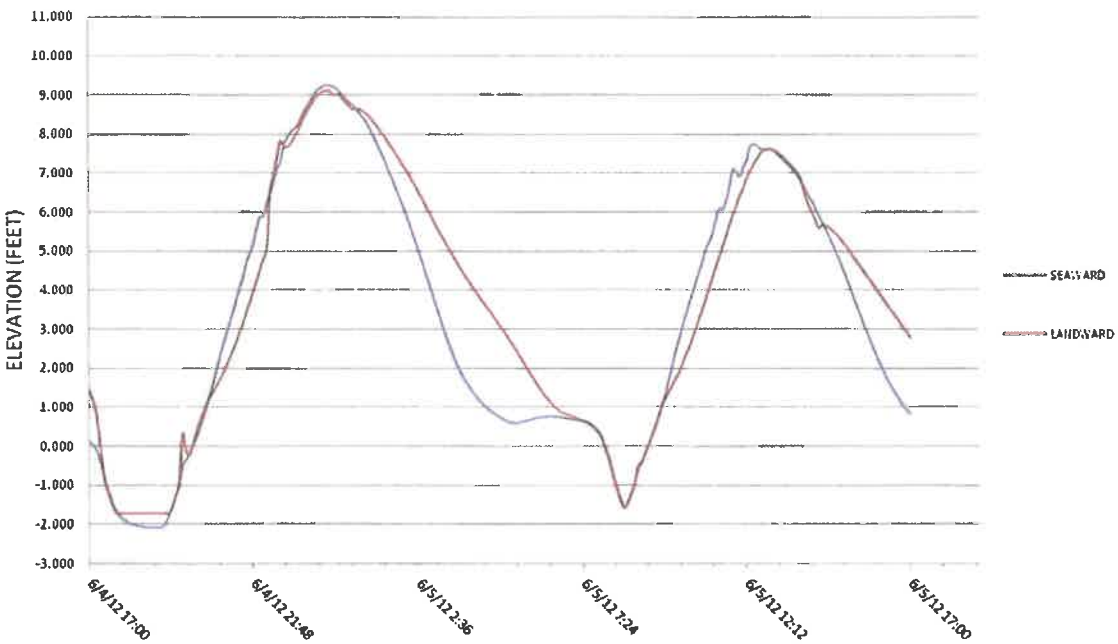


Figure 25. Proposed 9-foot span by 7-foot rise culvert during Annual High Tide Event with Sea Level Rise

4.3.19 Modeling Results of Annual High Tide with Sea Level Rise for 10-Foot by 7-Foot Culvert

The modified annual high tide data of June 5, 2012 was entered into the model, the model was run, and the water surface elevations seaward and landward of the culvert during this tide scenario were graphed (Figure 26).

There are instabilities in the model resulting from the high rate of increase in water elevation at the Mill Pond Road. It can be seen that the water is completely inundating the road, accounting from the oscillations seen in the graph provided.

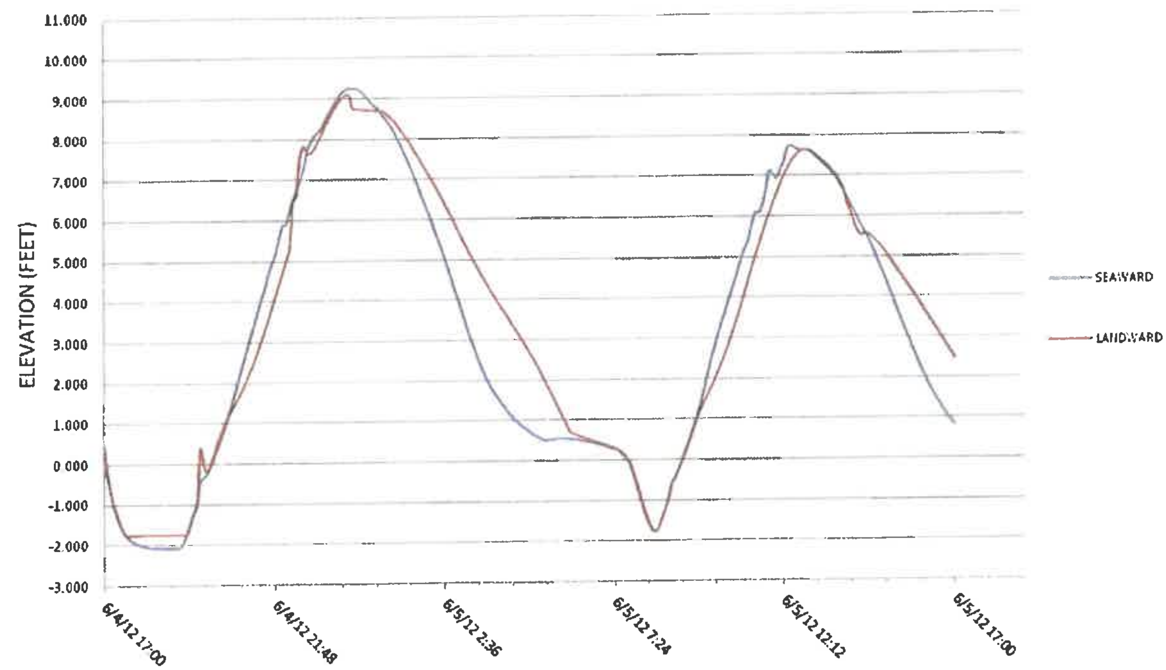


Figure 26. Proposed 10-foot span by 7-foot rise culvert during Annual High Tide Event with Sea Level Rise

4.3.20 Modeling Results of 100-Year Flood for 10-Foot by 7-Foot Culvert

To model the anticipated 100-year flood for the 10-foot by 7-foot culvert, the U.S. Army Corps of Engineers in the New England Coastline Tidal Flood Survey (1988)[4] was reviewed. Based upon this data source, the 100-year flood at the site is approximately 10.1 feet (NGVD 1929) or 9.2 feet (NAVD 88). Using the annual high tide hydrograph, the values were simultaneously increased by a value of 1.7 for the peak tide elevation to equal 9.2, the peak 100-year flood. This peak water surface elevation is higher than the low point of the road.

Figure 27 graphs the water surface elevations seaward and landward of the culvert during this tide scenario.

It can be seen that limitations of the hydraulic model are creating errors in the results, as shown in the oscillations in the graph. It can be seen that the water overtops the road and this event it causing instabilities in the results. The water surface elevations are higher than the road elevations and as a result, the culvert does not hydraulically control the system.

[4] Department of the Army, New England Division, Corp of Engineers. 1988. New England Coastline Tidal Flood Survey.

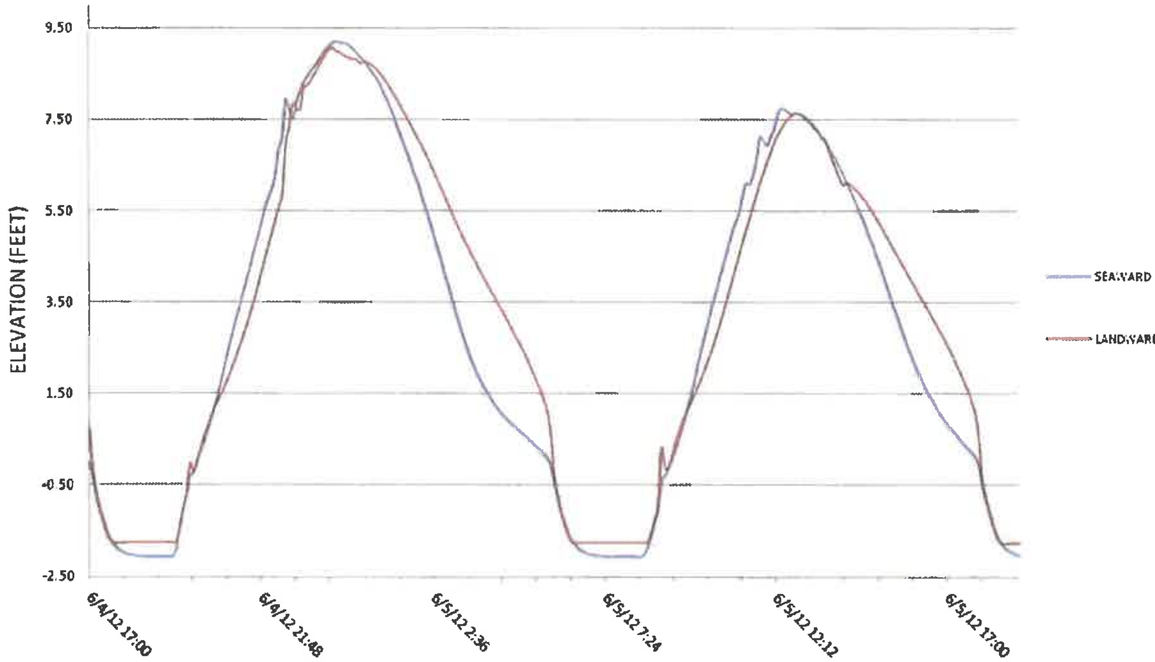


Figure 27. Proposed 10-foot span by 7-foot rise culvert during 100-Year Flood Event

4.3.21 Modeling Results of 100-Year Flood for 9-Foot by 7-Foot Culvert

The 9-foot by 7-foot culvert was modeled in the same fashion as described above. However, the opening of the proposed culvert is too small and creates too large of an error in the calculations of the water surface during the time period. Based on the limitations of the model in its ability to calculate a result within acceptable error limits, and that the culvert does not hydraulically control the system, the model is not able to produce a valid result and has not been presented.

4.4 Channel Velocities

Main channel velocities expected to occur were examined for the preferred alternative of the 10-foot by 7-foot box culvert. The table below presents the peak main channel velocities immediately seaward and immediately landside of the culvert during the modeling scenarios presented above.

Table 4: Channel Velocities

Model Scenario	10-Foot by 7-Foot Culvert Velocities (Feet per Second)	
	Seaward	***Landside***
Spring Tide	5.00	5.05
Mean High Water Tide	4.65	4.68
Annual High Water Tide	6.64	6.73
Spring Tide with Sea Level Rise	6.98	6.8
Mean High Water Tide with Sea Level Rise	6.47	6.33
Annual High Water Tide with Sea Level Rise	12.76	12.76

4.5 Identification of Low Lying Properties

Using the existing survey base maps, a review of any potential low-lying properties and infrastructure surrounding Mill Pond were examined for potential flood impacts as a result of any proposed culvert replacement. There are no properties adjacent to Mill Pond that will be affected by the proposed culvert replacement. The lowest residential building adjacent to the pond has an approximate elevation of 30 NAVD 88.

The Mill Pond Road was the only infrastructure identified to be affected by flood waters, and it is anticipated that the road is currently inundated during existing conditions. Therefore, the installation of a new culvert will not provide new flooding onto the road that would not happen during present conditions.

4.6 Vegetation Community Analysis

In 2012, under a separate contract with the Massachusetts Department of Ecological Restoration, LBG conducted a vegetation baseline survey east and west of Mill Pond Road. A total of six vegetation transects; two downstream and eight upstream were established. Along each transect which extended from the edge of open water to the wetland/upland interface, a range of elevations within distinct plant communities (i.e. low marsh, high marsh, Phragmites, shrub wetland) including the break between low and high marsh was measured. This effort resulted in over 200 distinct survey elevations within the plant communities surrounding Mill Pond and the vegetated area immediately west of Mill Pond Road. A total of five plant communities were identified which include: low marsh, high marsh, *Phragmites australis* (common reed), *Typha angustifolia* (narrow-leaved cattail), and shrub wetland. West of Mill Pond Road, low marsh was found growing between elevations 0.6 and 2.9 while high marsh(2.9 to 3.9 feet) was found growing up to elevation 3.9 feet.

LBG analyzed the hydroperiod for low and high marsh ranges over a 24 hour period during a typical spring tide event (Figure 11). The hydroperiod for the low marsh zone (0.6 to 2.9 feet) ranged between a low of 5.1 hours (21.25% of the 24 hour period) to a high of 12.5 hours (52.25% of the 24 hour period). The hydroperiod for the high marsh zone (2.9 to 3.9 feet) ranged between a low of 3.9 hours (16.25% of the 24 hour period) to a high of 5.1 hours (21.25% of the 24 hour period). The hydroperiod for the interdial mudflat zone (below 0.6 feet) was calculated to be equal to 12.5 hours (52% of the 24 hour period) or greater.

5 CONCLUSIONS

A hydraulic model was developed as part of the Mill Pond Restoration Project. Both existing conditions and several proposed alternatives were initially analyzed using the hydraulic model HEC-RAS. The results show the substantial benefits gained with a modest increase in the size of the existing culvert (i.e., 6-foot by 7-foot culvert) as well as the upper end of possible alternatives based upon the width of the existing tidal creek below the restriction. The preferred alternative, selected by the Project Partners (i.e. the 10-foot by 7-foot pre-cast concrete culvert) practically eliminates the tidal restriction and phase delay.