Final Technical Memorandum
Muddy Creek Wetland Restoration
Chatham and Harwich, Massachusetts

Cape Cod Conservation District

Barnstable, MA

February 2012

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Executive Summary

Pleasant Bay is a rich estuarine ecosystem with several tributaries and coves providing exceptional habitat for numerous shellfish and migratory fish species. Flushing in Muddy Creek, a tidal river and sub-embayment of the Pleasant Bay estuarine system, has been severely restricted by construction of an earthen embankment with stone culverts at Muddy Creek's discharge to Pleasant Bay where Route 28 crosses this waterbody.

The culvert-induced tidal restriction has been determined by previous studies under the Massachusetts Estuaries Project to have exacerbated water quality problems associated with nitrogen loading in Muddy Creek from surrounding land uses. These studies have also determined that 100% of current watershed nitrogen load would need to be removed from lower Muddy Creek and 75% from upper Muddy Creek in order to achieve state-mandated nitrogen thresholds for healthy water quality. In addition to water quality impacts, this tidal restriction has caused vegetative communities within Muddy Creek to evolve toward species inclined to freshwater systems, including coastal invasive species *Phragmites* and *Typha.* The two culverts also inhibit passage of migratory fisheries to varying degrees and affect the health and viability of upstream shellfish beds for harvesting due to water quality concerns.

Background

The four towns that share the watershed of Pleasant Bay (Orleans, Chatham, Harwich and Brewster) formed the Pleasant Bay Alliance (PBA) to develop and implement a Resource Management Plan for the Pleasant Bay Area of Critical Environmental Concern and watershed, which recently has focused on assessing alternatives to improve water quality, the health of vegetative communities, fish passage and shellfish communities in Muddy Creek as part of its overall goal of improving the natural environment and the public's use and enjoyment of Pleasant Bay. Muddy Creek has been chosen as a priority project under the Cape Cod Water Resources Restoration Project (CCWRRP) to conduct additional feasibility studies associated with the potential widening of the opening under Route 28, with a goal of improving water quality and restoring the natural health and vitality of Muddy Creek's coastal resources.

Previous hydrodynamic modeling studies have determined that a 24-foot wide opening would provide the optimal amount of tidal flushing to the Muddy Creek sub-estuary to achieve the desired restoration benefits while avoiding flooding impacts or excessive scouring/sedimentation at the ends of the replacement structure. This current study has been undertaken to gather additional data, complete additional evaluations and develop design alternatives to determine a recommended configuration for future design and permitting.

Field Data Collection and Investigations

As part of this study, previous topographic mapping of Muddy Creek was updated through a detailed survey of the embankment and culverts, including bathymetric cross-sections immediately adjacent to the culverts and the documentation of existing underground utilities along Route 28. A geotechnical investigation of embankment soils was completed, which included two borings on Route 28 flanking the existing culverts.

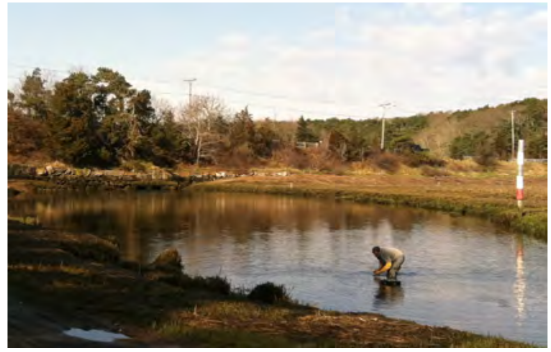
Wetland flags were placed/surveyed and a field study involving detailed assessments of herbaceous community compositions at 20 transects within respective Muddy Creek communities was completed. Research and field assessments of migratory fisheries and shellfish communities were also completed, including four transects on either side of the existing culvert to document existing shellfish populations. A letter report issued by Massachusetts Division of Fisheries and Wildlife (MassDFW) identified state-listed rare species in the vicinity of Muddy Creek, and the field study identified habitat for a state-listed threatened animal, which was reported to MassDFW.

Anticipated Impacts/Benefits to Water Quality and Natural Resources

Based on the anticipated increase in tidal range and volume from future construction of a 24-ft. wide channel opening below Route 28, evaluations were completed to assess the expected impacts/benefits to respective vegetative communities, shellfish areas and migratory fisheries. In downstream portions of the Muddy Creek estuary, low marsh communities will likely see the greatest immediate expansion, with sub-tidal areas expected to become mudflats and areas that are high marsh expected to become low marsh.

It is also expected that low marsh vegetation (i.e. *Spartina alterniflora*) will colonize areas of mudflats and out-compete areas of high marsh species through landward expansion. As flooding and salinity levels increase, existing stands of *Typha* and *Phragmites* are expected to contract and woody vegetation along the toe of slope retreat landward, helping to improve the downstream wetland system's overall biodiversity. In the upstream portion of the Muddy Creek estuary, the extent of mudflat areas exposed during low tide is expected to increase, where these areas will be colonized first by low marsh species while more landward areas, where freshwater inputs are greater, will be vegetated by brackish marsh or high marsh assemblages.

Increasing the size of the culvert will improve opportunities for herring passage by increased light and space provided by the larger opening, in addition to more favorable water depths resulting from the increased tidal range. Additionally, the enlarged opening is expected to improve water quality within the upper system by increased tidal exchange and flushing, which would decrease nutrient concentrations, diminishing algal blooms, increasing dissolved oxygen, and restoring other natural functions, all of which will improve conditions for American eel. Other migratory species such as White Perch (*Morone americana*) and Blue Crab (*Callinectes sapidus*) are expected to benefit from water quality improvements resulting from the proposed replacement structure.



Shellfish habitat areas near the culverts are expected to be enhanced by improving environmental conditions associated with the setting of shellfish larvae. Improved flushing through the enlarged opening is expected to reduce organic sediment amounts near the culverts, which should lower organic content and alleviate any existing hypoxia and anoxia inhibiting the vitality of shellfish beds. While the increase in tidal flushing and resulting reduction in water residence time may have a small effect on shellfish setting, larger factors governing shellfish recruitment including larval health, abundance, predatory, and environmental conditions will have more dominant long-term influences on restoration of shellfish populations in Muddy Creek. The enlarged opening will provide adequate flushing to sustain to the natural transport of sediment into the Muddy Creek system, which is critical to salt marsh health.

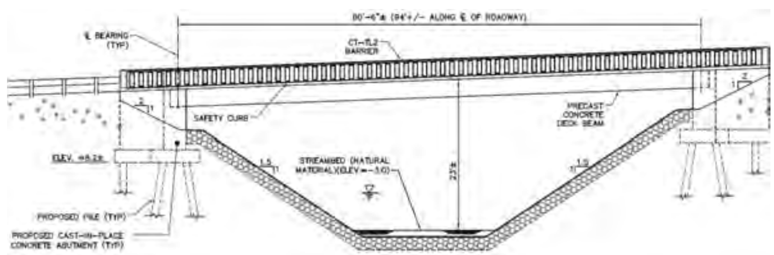
A modeling evaluation was completed to assess the potential effects of culvert replacement on bacteria concentrations in Muddy Creek and the nearby portion of Pleasant Bay. A one-dimensional, steady-state transport model was created using a finite difference approach at a level of complexity that matches the limited data that is currently available. The modeling results indicate that enlarging the structure will improve water quality in Muddy Creek, but will have no significant impact on water quality at the nearby beaches in Pleasant Bay. The enlarged opening is anticipated to reduce the difference between existing bacteria concentrations and the Total Maximum Daily Load (TMDL) target concentration, but additional bacteria reductions would still be required to reach the TMDL fecal coliform concentration established for Muddy Creek. Based on both the modeling results and a review of the historic water quality data and modeling, recommendations were provided for future water quality monitoring within Muddy Creek and the nearby portion of Pleasant Bay.

As part of the Massachusetts Estuaries Project (MEP), a linked watershed-embayment model was developed in 2006 to determine critical nitrogen loading thresholds for the Pleasant Bay system, including Muddy Creek. The potential influence of the increased tidal flushing from a 24-foot wide opening at the outlet of Muddy Creek was evaluated under the MEP through updated hydrodynamic-water quality modeling in 2010. The modeling analysis revealed that installation of the wider opening would reduce nitrogen concentrations significantly toward the goal of meeting the regulatory threshold values, assuming full build-out conditions within the watershed, and would not result in any significant changes in Pleasant Bay's water quality. However, further mitigation of watershed-derived nitrogen will still be necessary to meet the threshold values. In addition, the analysis further notes that all Pleasant Bay water quality and sentinel stations exceed their nitrogen thresholds under build-out conditions with or without the proposed widened opening, and additional nitrogen sources added to the watershed through build-out (new) development would need to be offset.

Technical Evaluation of Structural Alternatives

A geotechnical evaluation of embankment soils was completed, which included two borings on Route 28 flanking the existing culverts. Soils recovered from the borings were documented and assessed through laboratory testing, indicating subsurface soils comprising the embankment as generally loose fine to medium sand, with coarse sand and gravels encountered in some horizons. Small amounts of silt and clay were documented in native soil horizons below the embankment soils. An engineering analysis was completed to provide design recommendations and geotechnical parameters affecting the selection and future design of structural improvements.

While a number of potential alternative configurations exist to replace the existing Route 28 culverts, any replacement structure will need to comply with the current MassDOT Bridge Manual. Previous modeling determined that a 24-foot wide rectangular box culvert replacement structure would achieve the desired tidal flux into the Muddy Creek system. Three alternative culvert designs were initially evaluated based on the results this modeling. Upon reviewing the alternatives with project partners and MassDOT in September 2011, it was agreed that other bridge configurations with a modified geometric channel section (i.e., armored slopes forming an open channel) would be acceptable provided hydrodynamic modeling confirmed scour/channel configuration requirements could be met under this configuration.



Upon completion of this additional modeling evaluation in December 2011, a revised recommended approach was developed, reflecting a single-span bridge over an open channel below the Route 28 roadway. This updated modeling determined that the open channel bridge alternative would provide an equivalent increase in tidal range and flushing volume into Muddy Creek as the previously-modeled 24-foot wide rectangular culvert alternatives, and would, therefore, provide equivalent wetland resource benefits following construction. Further evaluation of this alternative determined that it would provide these benefits at a lower construction cost, while also providing improved recreational passage for canoes or kayaks. As a result, this alternative was determined to best meet the project's primary design criteria at the lowest cost and is the recommended configuration for future design, permitting and construction phases of this restoration project.

1 Wetland Community Resource Assessments

1.1 Overview and Background

1.1.1 Historical Review

Pleasant Bay is a rich estuarine ecosystem with several tributaries and coves providing exceptional habitat for numerous shellfish and migratory fish species. Over the course of several decades, watershed nitrogen loading has intensified, resulting in compromised estuarine water quality and degraded health and vitality of coastal habitats and resources in many of these waterbodies. In addition to impacts by nutrient levels causing trophic changes in some impoundments and tributaries, elevated bacteria concentrations in Muddy Creek have been documented, causing closure of certain former commercial shellfishing beds.

Flushing in Muddy Creek has been severely restricted due to construction of an earthen embankment with stone culverts at Muddy Creek's discharge to Pleasant Bay where Route 28 crosses this waterbody. In additional, a restriction formerly existed decades ago when an earthen "dike" across the channel existed at a location further upgradient to create a freshwater impounded waterbody for local use. Field observations along the channel profile in the area of this former dike have confirmed that water depths are shallower in the area of the former dike, in addition to a reduction in the channel width.

The two box culverts below Route 28 are each approximately 30 inches high and 45 inches wide and restrict tidal ranges and flushing volumes experienced in Muddy Creek, causing salinity levels to lower in both water and inundated soils. This has caused the vegetative communities to evolve toward species inclined to freshwater systems, including coastal invasive species *Phragmites* and *Typha*. The two culverts also inhibit passage of migratory fisheries to varying degrees and affect the health and viability of upstream shellfish beds for harvesting due to reduced flushing and water quality concerns.

Muddy Creek is a tidal river and sub-embayment of the Pleasant Bay estuarine system. The municipal boundary between the Towns of Chatham and Harwich runs along the center of the majority of the Creek. As shown in *Figure 1* below, Muddy Creek is bounded by the earthen embankment supporting Route 28 at its downstream limit, sparse residential development and protected undeveloped properties to the north in Harwich, and relatively sparse residential development to the west in Chatham, and moderately dense residential development to the south in Chatham.

Figure 1 - Aerial of Project Study Site (MA GIS)

Pleasant Bay is a state designated Area of Critical Environmental Concern (ACEC), and Muddy Creek is located within the ACEC boundary (see *Figure 2* below). The four towns that share the watershed of Pleasant Bay (Orleans, Chatham, Harwich and Brewster) formed the Pleasant Bay Alliance (PBA) to implement the locally and state-approved resource management plan for the ACEC and the Pleasant Bay watershed. Over the past two years the PBA has been exploring alternatives to improve water quality, the health of vegetative communities, and fish passage and shellfish communities in Muddy Creek as part of its overall goal of improving the natural environment and the public's use and enjoyment of Pleasant Bay in general.

Figure 2 – Areas of Critical Environmental Concern (MA GIS)

Muddy Creek has been chosen as a priority project under the Cape Cod Water Resources Restoration Project (CCWRRP) to conduct additional feasibility studies associated with the potential widening of the culvert under Route 28. The Cape Cod Conservation District (CCCD) is working in partnership with the PBA, the Towns of Chatham and Harwich, Massachusetts Division of Ecological Restoration (MassDER), the USDA Natural Resources Conservation Service (NRCS) and other state agencies and interested parties (collectively referred to as the Partnership) to undertake this study in support of its objective to improve water quality and restore the natural health and vitality of Muddy Creek's coastal resources, including resources within the near-shore zone at its discharge to Pleasant Bay and connectivity to upstream waterbodies.

Through this study, it is envisioned that human health and enjoyment of these resources will be addressed to ensure public recreation and safety interests are fully evaluated in consideration of culvert alternatives. The project's study of alternative culvert configurations is currently conceptual and is to be reviewed by local boards and commissions, state highway and environmental officials, federal permitting agencies as well as concerned citizens, prior to further pursuit of a preferred alternative. This study is intended to support the Partnership's understanding of historic and existing natural resource communities, water quality concerns, and how alternative culvert configurations will support attainment of project goals, with due consideration of permitting and construction timeline and cost constraints.

1.1.2 Previous Studies

A number of technical studies of water quality and other resource conditions in Muddy Creek have been undertaken in recent decades, including studies leading to the establishment of TMDLs for bacteria and Total Nitrogen. Following a number of previous studies, the PBA petitioned the Massachusetts Wetlands Restoration Program in 2008 to identify the Muddy Creek culvert study as a priority wetland restoration project. Subsequently, the PBA has worked with the MassDER to conduct feasibility studies and evaluations to assess natural resources at the site and assess alternative culvert configurations. In 2009, MassDER commissioned hydrodynamic modeling to identify the optimal size for a replacement culvert based on tidal monitoring data previously obtained in Pleasant Bay. The modeling recommended a 24-foot wide culvert opening to most effectively achieve increased tidal exchange while maintaining adequate discharge velocities to prevent sediment accretion at the culvert openings. Subsequently, the PBA commissioned the School for Marine Science and Technology (SMAST) to model changes in water column nitrogen concentrations inside and outside of Muddy Creek under a 24-foot wide inlet scenario.

In support of this current study, the following resources were provided and reviewed:

- August 30, 2010 technical memorandum regarding MEP Scenarios modeled by SMAST to evaluate water quality impacts of the addition of a 24 ft culvert in Muddy Creek inlet (Eichner et al., 2010)
- December 10, 2010 technical memorandum regarding Muddy Creek Culvert Scenarios (Kelley, 2010)
- December 2008 final report entitled *Resource Assessment to Evaluate Ecological & Hydrodynamic Responses to Reinstalling a Water Control Structure in the Muddy Creek Dike* (White et al., 2008)
- TMDL Reports entitled "Massachusetts Estuaries Project Bacterial TMDL for Muddy Creek, Report # MA 96-51-2004-01" and "Final Nitrogen Total Nitrogen TMDL for Pleasant Bay, Report # 96-TMDL-12"
- Massachusetts Department of Public Health, Bureau of Environmental Health bacterial sampling results at Jacknife Harbor near the project site from 2003 to September 2010
- Various maps, drawings and photographs of the areas immediately adjacent to Muddy Creek and Pleasant Bay, including press articles and anecdotal accounts by local biologists and historians (February 2005 correspondence from Bob Zaremba, PhD)

1.2 Historic Hydrologic Modifications

Muddy Creek has undergone significant hydrologic changes due to anthropogenic influences over the last 200 years. Side by side topographic maps in *Figure 3* below illustrate those changes. From this figure, roadways bordering Muddy Creek can be seen as they currently exist and historically existed, however a number of additional branching roads have been constructed encroaching on the forested upland areas surrounding this waterbody.

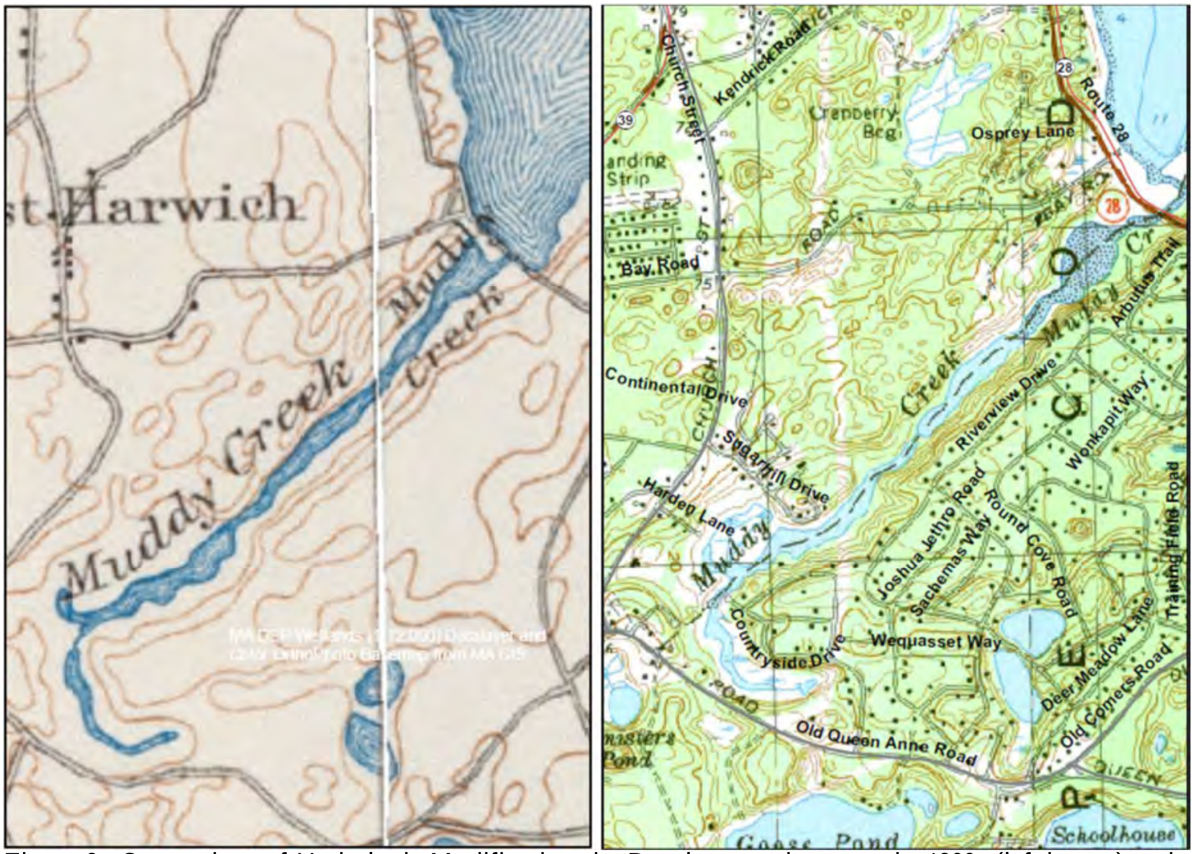


Figure 3 - Comparison of Hydrologic Modifications by Development between the 1890s (left image) and 1960s (right image).

As shown in *Figure 4* below, in the late 1800's, a pile supported timber bridge was constructed at the mouth of Muddy Creek which according to photos taken during this time period spanned the majority of the marsh system.

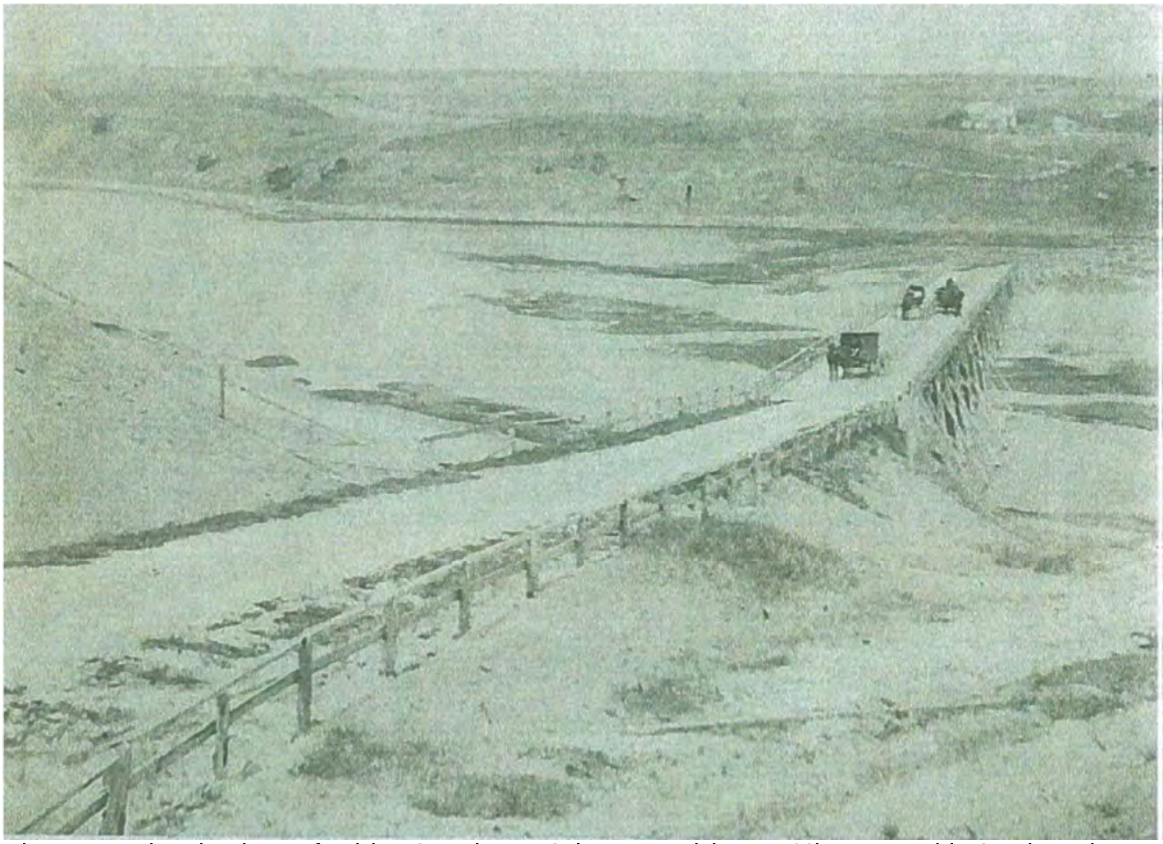


Figure 4 – Historic Photo of Bridge Crossing at Orleans Road (Route 28) over Muddy Creek Facing North Toward Harwich, circa 1871.

The bridge was eventually replaced in the 1900's with an earthen dike and single culvert which reportedly failed to provide adequate flushing into the upstream cove (see *Figure 5* below).

Figure 5 – Historic Photo of Earthen Fill Placement at Orleans Road (Route 28) over Muddy Creek Facing South Toward Chatham, circa 1900

The single culvert was replaced in the 1930s with the current double stone culverts, each equipped with manually controlled tide gates. Anecdotal accounts recall that the gates were typically blocked and for a number of years were only partially open (Buckley, 2011), after which the gates were eventually removed. A current photograph of the embankment and culverts is provided as *Figure 6* below.

Figure 6 – Photo of Earthen Embankment and Culverts at Orleans Road / Route 28 Crossing over Muddy Creek Facing West Toward Harwich (April 15, 2011).

Additional hydrologic modifications to the system reportedly occurred in the upper basin in the 1890s with the construction of an earthen dike with a 3 - 4 foot wide adjustable sluiceway near the midpoint of the Creek, just north of the Round Cove at Riverview Drive intersection (Buckley, 2011). The dike and sluiceway reportedly allowed for the flooding of cranberry bogs originally located along the Upper Pond of Muddy Creek and across Queen Anne Road (Buckley, 2011). A previous study report in 2008 noted that the dike was reportedly breached during the hurricane of 1938 and not subsequently repaired, allowing limited tidal brackish conditions to return in Muddy Creek's upper basin (White, et al, 2008). A current photograph of Muddy Creek's lower basin is provided as *Figure 7* below.

Figure 7 – Photo of Muddy Creek's Lower Basin, Facing Southwest From Orleans Road / Route 28 (March 5, 2011).

It is noted that a culvert conveying freshwater flow to Muddy Creek from Minister's Pond below Old Queen Anne Road currently remains in existence and has reportedly been modified by Massachusetts Department of Marine Fisheries staff in an effort to facilitate passage of elvers to this upstream waterbody. A photograph of this culvert is provided below as *Figure 8,* where the fish passage structure is inundated below the water level. At low tide conditions, the passage structure provides a substrate for elvers to swim upon and enter the culvert, where they are reportedly able to continue swimming upstream to Minister's Pond. This culvert and a nearby manhole were surveyed, as reflected on Sheet RC-*107 in Attachment A.*

Figure 8 – Culvert Discharging Flow from Minister's Pond to Muddy Creek (18" CMP) with Eel Passage Ramp Substrate (submerged)

1.3 Existing Conditions Assessment

1.3.1 Topographic Survey

Aerial contour mapping of the immediate area surrounding the culvert and wetland resources within and adjacent to Muddy Creek was previously prepared in support of studies in 2008 and 2009 of vegetative communities and hydrodynamic modeling of alternative culvert configurations under consideration. This topographic mapping of the project site, including a narrow zone around the pond's perimeter, was provided by CCCD for this current study. This mapping has been augmented by Baxter Nye Engineering & Surveying of Hyannis, MA under this current study through a ground level survey in the land and channel areas along and immediately adjacent to Route 28 where the culvert(s) will potentially be constructed.

Updated topographic mapping is included with this report as *Attachment A*. A version of this mapping overlain on 2009 Massachusetts GIS aerial image background is included as *Attachment B.* This mapping reflects the following elements added to the original mapping provided by CCCD in support of this current study. Mapping was prepared to Massachusetts State Plane horizontal datum (NAD83, feet) and NAVD88 vertical datum.

- Topographic contouring along Route 28 within the immediate area of the culvert, including bathymetric elevations in the immediate upstream and downstream channels.
- Locations of aboveground features along Route 28 including edge of pavement, guardrails, overhead utilities, signs and monuments.

- Locations of belowground utilities along Route 28 as marked by Dig Safe prior to subsurface borings conducted as part of this study; a buried communications conduit and gas line were identified and surveyed.
- Digital assessor's parcel mapping in Harwich and Chatham.
- State highway right-of-way bounds associated with Route 28.
- Locations of delineated wetland flagging immediately adjacent to the Route 28 culvert and at a former upstream dike location.
- Locations of 19 vegetative community study transects established in support of the current wetland assessment study, including elevations of transitional boundaries between community types along the transects.
- Visually identified structures along Muddy Creek below EL. 10; two culverts were identified and surveyed and former drainage structures were located at the end of a cul-de-sac in Chatham.
- Locations of tributaries and other stormwater channels discharging to Muddy Creek.
- Elevation benchmark adjacent to culverts for potential future surveys and construction.

1.4 Hydrology Assessment

1.4.1 Tidal Flushing and Freshwater Sources

Salinity data was obtained from the White et al (2008). This report was the result of a study undertaken by the PBA through a grant from the Cape Cod Water Protection Collaborative (CCWPC) *Shared Watershed, Shared Responsibilities* grant program. The report provided baseline information on the extent of wetlands and related resources in the vicinity of the shoreline of Muddy Creek and documented anticipated changes to wetland resources and upland areas bordering Muddy Creek.

Salinity data was obtained in both sediment and water within Muddy Creek as part of the 2008 study. Water samples were collected at one upstream location (i.e., in freshwater), PBA5A, and at one downstream location (i.e., in brackish water near the culvert under Route 28), PBA5, on seven different days between June and September 2008. Sediment samples were collected at five upstream locations (i.e., in freshwater) and five downstream locations (i.e., in brackish water). Depth-specific salinities within the sediment were obtained from 0-5 centimeters, 5-10 centimeters, and 10-15 centimeters depth intervals. Readings taken at respective locations are summarized below in *Table 1.* Sample locations are depicted in *Figure 9* and *Figure 10* below.

Table 1
Salinity Values Measured in Muddy Creek Water and Sediment

Sample Location	Depth Averaged Salinity (in parts per thousand (ppt))*
Approx. Reference Range within Pleasant Bay	29 (inner bay) – 35 (mouth at Chatham Harbor)*[a]
Muddy Creek Water	
Downstream - Brackish	
PBA5	25.3
Upstream - Freshwater	
PBA5A	13.5
Muddy Creek Sediment	
Downstream - Brackish	
MC1	25.8
MC2	6.4
MC3	9.0
MC4	22.2
MC5	16.4
Upstream - Freshwater	
MC6	13.1
MC7	9.8
MC8	0.5
MC9	0.6
MC10	1.0

* - White et al, 2008.
** - Pleasant Bay Resource Management Alliance, 2008; Pleasant Bay Citizen Water Quality Monitoring Program Quality Assurance Protection Plan, 2001.

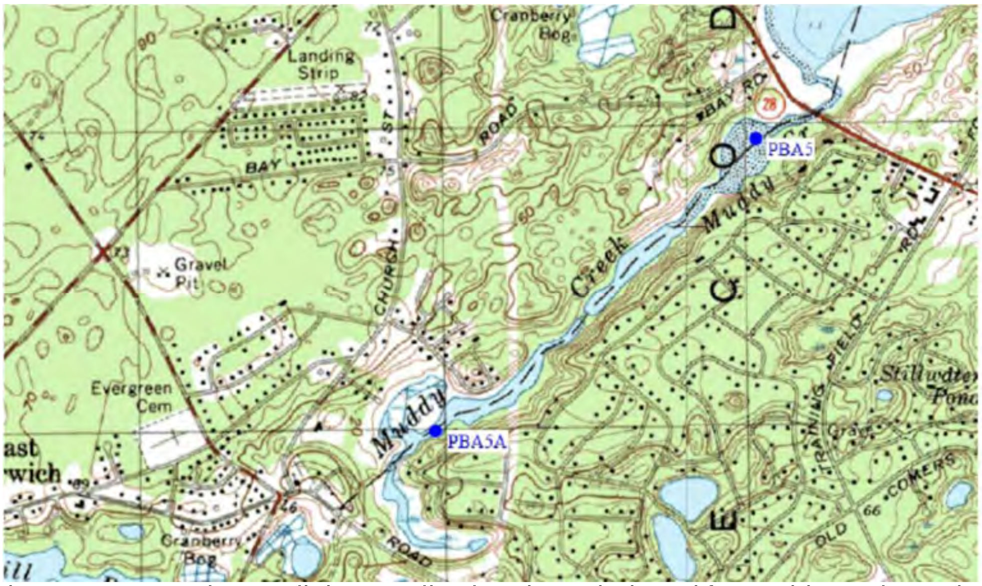


Figure 9 - Water column salinity sampling locations. (Adopted from White et al., 2008).

Figure 10 – Sediment porewater salinity measurement locations.
(Adopted from White et al., 2008).

Vegetative communities observed at respective sampling locations in the 2008 study generally reflected the presence of freshwater invasive *Phragmites* and *Typha* communities at locations where salinities were below 10 ppt, principally at MC2 and MC3 in the lower reach (below the former dike location, at locations immediately adjacent the Route 28 culvert) and at MC7, MC8, MC9 and MC10 in the upper reach (above the former dike location). Vegetative communities at locations MC8, MC9 and MC10 were noted as mixed assemblages of freshwater and salt-water tolerant species, reflecting limited mixing occurring in the upper reaches due to the dampened tidal range and freshwater inputs.

Two paved runoff channels were identified discharging from Route 28 to Muddy Creek immediately adjacent to the culvert location. In addition, a review of topographic mapping and field observations identified a number of tributaries and stormwater channels that discharge flow from both adjacent undeveloped areas and residential neighborhoods. A 12-inch diameter road storm drain culvert was surveyed adjacent to Sugar Hill Drive in Harwich, and an 18-inch diameter culvert was surveyed adjacent to Old Queen Anne Road in Chatham, which discharges roadway runoff from this road as well as outflow from Minister's Pond. Non-functional drainage infrastructure was also observed at the end of Countryside Drive in Chatham, where a slope collapse caused erosion of the end of this road and severe damage to the drainage structures that has not since been repaired.

1.4.2 Observed Tidal Range and Hydrodynamic Modeling

Tidal monitoring and hydrodynamic modeling ranges were reported by White et al. (2008), and Kelley (2009) evaluating alternative culvert configurations. A surface model of channel bathymetry within the Muddy Creek estuary was prepared in support of that study, which was presented as a colorized depth chart in this report with bottom elevations referenced to the NGVD29 vertical datum. This chart is included below as *Figure 11*, with reported elevations converted to the current project vertical datum (NAVD88).

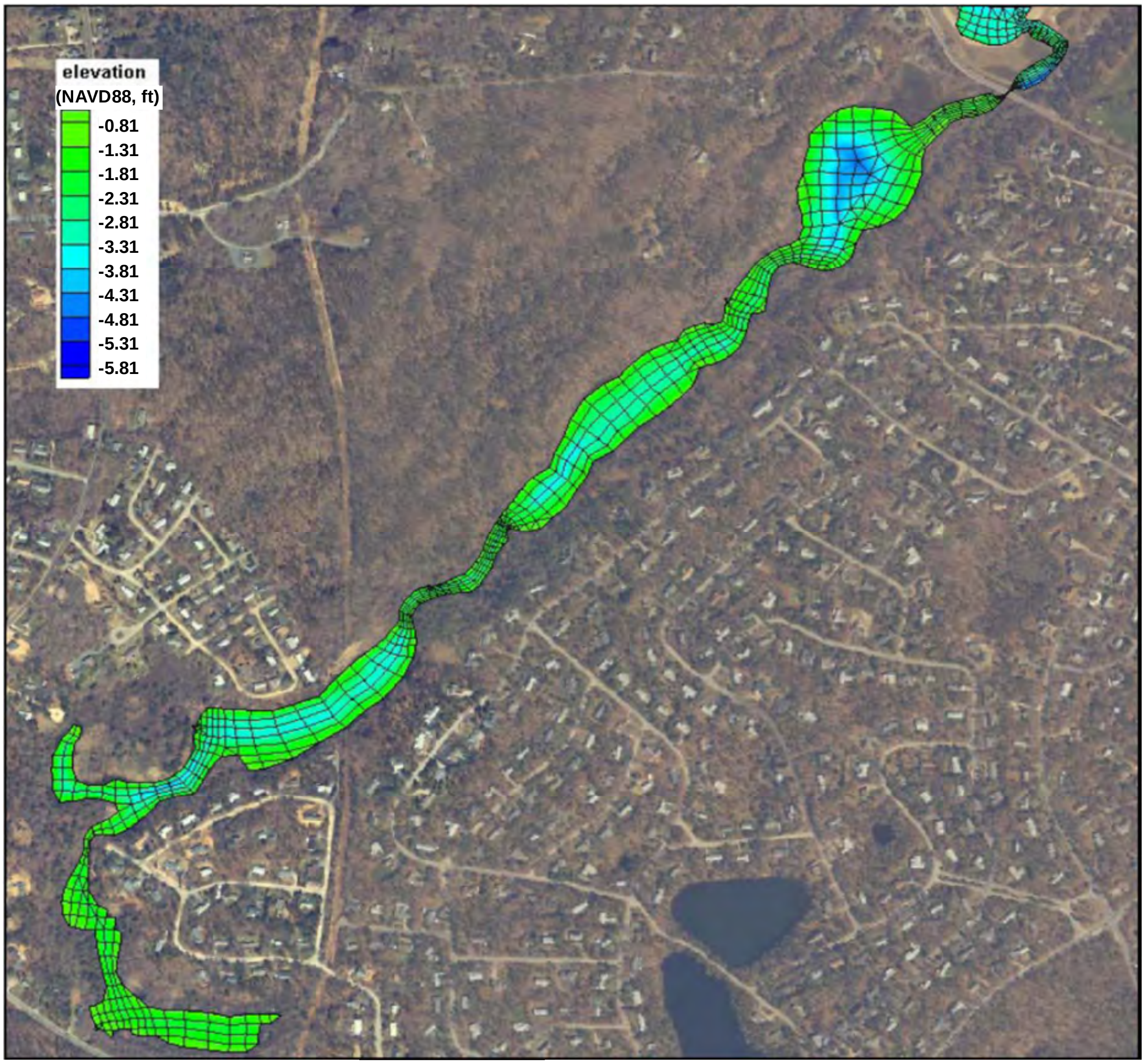


Figure 11 – Bathymetric model grid of Muddy Creek bottom elevations referenced to NAVD88. (Adopted from White et al. 2008)

This study presented tidal ranges in Muddy Creek under existing conditions both prior-to and subsequent to the breach of the north inlet to Pleasant Bay in 2007, and under a number of alternative culvert configurations. Upon review of tidal ranges modeled by respective culvert sizes, the study identified a 24-foot wide culvert as providing optimal velocities to prevent siltation within and adjacent to the culvert while avoiding channel scour erosion on either side of the inlet. Elevations reported in this study corresponding to the respective pre- and post-construction tidal ranges are provided below in *Table 2*, with reported elevations converted to the current project datum (NAVD88).

Table 2
Reported Tidal Elevations in Muddy Creek for
Evaluated Pre- and Post-Construction Conditions (Feet NAVD88)

Tidal Condition	West Pleasant Bay	Pre-Breach (2004)	Present (2009)	Proposed 24-ft. Single Culvert
Maximum Tide	4.02	1.89	2.02	3.92
MHHW	3.32	1.52	1.62	3.12
MHW	3.02	1.42	1.52	2.72
MTL	.92	1.22	1.32	1.12
MLW	-1.18	1.02	1.02	-0.48
MLLW	-1.38	0.92	1.02	-0.48
Minimum Tide	-1.48	0.72	0.72	-0.58

1.5 Vegetative Community Assessments

General assessments of vegetative communities observed along Muddy Creek are provided in the following sections. Wetland delineations and vegetative assessment transects described herein were completed by Baxter Nye Engineering and Surveying of Hyannis, MA between April and June 2011.

Wetland vegetation communities were classified using "Classification of the Natural Communities of Massachusetts" (Swain & Kearsley, 2001). Four wetland vegetation communities are located within the project limits along Muddy Creek: Estuarine/Intertidal Salt Marsh, Estuarine/Intertidal Freshwater/Brackish Tidal Marsh, Palustrine Shrub Swamp and Palustrine Red Maple Swamp.

Estuarine/Intertidal Salt Marsh (SM) is defined as a graminoid dominated, tidally flooded coastal community consisting of halophytes. For this report, this vegetation community was divided into two subclasses according to breaks in vegetation communities: Low Salt Marsh (LM) and High Salt Marsh (HM) with the upper most limits of *Spartina alterniflora* (Salt marsh cordgrass) forming that zonation change.

The Estuarine/Intertidal, Freshwater/Brackish Tidal Marsh (BM) communities represents wetlands dominated by erect, rooted, herbaceous hydrophytes located along coastal rivers. This classification defined in this report actually combines two community classes covered in the "Classification of Natural Communities of Massachusetts" (2004): Brackish Tidal Marshes which have an average annual salinity ranging from 0.5 to 18 ppt and Freshwater Tidal Marshes which have an average annual salinity of less than 0.5. Given that many of the hydrophytes in this report can occur in either freshwater or brackish conditions, the absence of salinity readings at each Transect and the tendency for Freshwater Tidal Marshes to occur immediately upland and adjacent to Brackish Tidal Marshes, these two classifications have been combined for this report to form the Freshwater/Brackish Tidal Marsh Community. Additional salinity readings would be necessary to further brake out these communities. However, given the salinity readings reported to date, in general the marsh communities within the Upper Basin downstream from Transect 8 (MCUB T-8)/Transect 7 (MCUB T-7) are predominantly Brackish Tidal Marshes while the marsh communities upstream of Transect 8 (MCUB T-8)/Transect 7 (MCUB T-7) are predominantly Freshwater Tidal Marshes.

The Palustrine Shrub Swamp (SS) community is a non-forested wetland community that is dominated with greater than 50% shrubs and contains less than 50% tree canopy. The wetlands occur on soils that are seasonally or temporarily flooded. These wetlands exist above the influence of tides along Muddy Creek and generally consist of a high water table associated with groundwater seeps and overland flow associated with the adjacent steeply sloping upland forested communities. Scattered red maples and pitch pines exist as a sub-canopy along some areas of the creek.

The Palustrine Red Maple Swamp (SW) community is a forested wetland community that is dominated with greater than 20% mature trees in the canopy. The wetlands occur on soils that are seasonally or temporarily flooded. These wetlands exist above the influence of tides along Muddy Creek and generally consist of a high water table associated with groundwater seeps and overland flow associated with the adjacent steeply sloping upland forested communities. Red Maples are generally dominant within this mapping with Pitch Pine on hummocks as co-dominant or sub-dominant species. However, areas dominated with Pitch Pine on hummocks are also often mapped within this community. These areas generally have pit and mound topography and are heavily vegetated in the understory with a dense shrub layer and an abundance of ferns.

Freshwater Forested Wetland (FW): To accommodate the town definition of wetland resource areas, a vegetation community classification specific to the site was defined and used to differentiate between the wetlands identified in the Massachusetts Classification System and the local definition of wetland resources. This wetland classification has been defined as Freshwater/Forested Wetland and tends to occur as a fringe wetland at an elevation above the upper most wetland system.

The upland vegetation community along the Muddy Creek corridor consists of mainly a Pitch Pine – Oak Forest Woodland community. Found on moraines, till, outwash, southerly exposures, and rocky slopes, this community is the matrix forest of southeastern Massachusetts. The canopy can range from predominantly pine with scattered oaks to predominantly oak with scattered pines. The structure can either be an open canopy with a thick understory or a closed canopy with scattered clumps of shrubs. Species consist of a mix of pitch pine and oaks such as black oak, *(Quercus velutina),* scarlet *(Q. coccinea),* and white *(Q. alba)*, with blueberries (*Vaccinium angustifolium* and *V. pallidum*), black huckleberry (*Gaylussacia baccata*) and other ericaceous shrubs forming an often continuous low shrub layer. Scattered patches of Scrub oak (*Quercus ilicifolia*) and bear oak (*Q. prinoides*) can be dense. Green briar *(Smilax rotundifolia)* and Catbriar *(Smilax glauca)* often form dense barriers around low, damp openings. The herbacous layer is generally sparse, with bracken fern (*Pteridium aquilinum*), wild sarsaparilla (*Aralia nudicaulis*), wintergreen (*Gaultheria procumbens*), Pennsylvania sedge (*Carex pensylvanica*), and, less commonly, pink lady's slipper (*Cypripedium acaule*). Occasional white pine (*Pinus strobus*) and red maple (*Acer rubrum*) contribute to the canopy.

1.5.1 Lower Muddy Creek

Wetland vegetation in Muddy Creek's lower basin consists of a mix of tidal and brackish saltmarsh communities. Typical vegetative communities are established along the hydrologic and haline gradient. Elevations of the saltmarsh (or "low marsh") subject to daily inundation by tidal waters are dominated by saltmarsh cordgrass. Higher saltmarsh elevations (or "high marsh") subject to tidal inundation only during spring high tides and storm events are dominated by saltmarsh hay (*Spartina patens*), but also support other common species such as glasswort (*Salicornia* sp.), saltgrass (*Distichlis spicata*) and blackgrass (*Juncus gerardii*).

Forested and shrub wetlands have also developed along the upper hydrologic boundary of the salt marshes. Dominant species in these areas include pitch pine (*Pinus rigida*), oak (*Quercus* sp.), highbush blueberry (*Vaccinium corymbosum*), wild raisin (*Viburnum cassinoides*) and shadbush (*Amelanchier* sp.). Some of the upper saltmarsh areas have also been colonized by common reed *(Phragmites australis*) and narrow leaved cattails *(Typha angustifolia.)*. Expansive monotypic communities of common reed have outcompeted native communities at several locations along the lower reaches of Muddy Creek.

Wetland soils are mapped as a mix of Ipswich, Pawcatuck and Matunuck peats with a slope of 0 to 1 percent. Ipswich soils are very poorly drained soils formed in thick organic deposits. Pawcatuck soils are very poorly drained soils formed in organic deposits over sandy mineral material. Matunuck soils are very poorly drained soils formed in shallow (grassy) organic mucky peat underlain by sandy marine or glaciofluvial deposits.

The wetland is abutted by a Pitch Pine – Oak Forest Woodland community supported on Carver coarse sands at 8 to 15 percent slope (Barnstable County Soil Survey, 2011). A palustrine shrub swamp forms the upper limits of wetland resources immediately south of the culvert where the floodplain widens. Dead and stressed stands of Eastern red cedar *(Juniper virginiana)* and pitch pine are located intermittently throughout the salt marsh on both the east and west sides of the channel.

To the west of the Route 28 culvert, it appears that the low marsh is gradually eroding. Over time, a combination of erosion and channelization has created a cove within the interior of the salt marsh system. The saltmarsh cordgrass along the interior of the cove appears to be continuing to erode, creating tidal flats. In addition the salt marsh system appears to be unable to keep up with rising sea levels due to an insufficient sediment source created by Route 28 and the associated tidal restriction.

Hummock and hollow microtopography is extensive within the low marsh system which is noticeably different from the intact, more stable low marsh located north and west of the culvert. New pannes and channels are currently forming within the remaining high marsh. It is anticipated that any continued erosion and channelization within the salt marsh will result in further salt marsh loss as high marsh transitions to low marsh and eventually tidal flats.

In comparison to the salt marsh along the western channel bank, the salt marsh along the eastern bank is stable with a typical transition from mean low water (MLW) to low marsh, to high marsh, to palustrine shrub swamp to a Pitch Pine – Oak Forest Woodland community. The upper limits of the salt marsh are fringed with narrow leaved cattails and common reed in some locations.

1.5.2 Upper Muddy Creek

Wetland resources north of the former dike generally represent a mix of freshwater and brackish communities. In general, vegetation communities along open water areas transition from brackish marsh to palustrine shrub swamp. Wetland soils located are mapped as predominantly Freetown coarse sand on a 0 to 1 percent slope and Freetown and Swansea mucks at a 0 to 1 percent slope.

A highly diverse complex of assemblage of vegetation is present throughout the Upper Muddy Creek marsh that is a mixture of salt tolerant and freshwater species. Common species in this reach include red maple, bayberry (*Morella pensylvanica*), common winterberry (*Ilex verticillata*), highbush blueberry, sweet pepperbush (*Clethra alnifolia*) wild raisin, sensitive fern (*Oneclea sensibilis*), *Sphagnum spp*., and saltmarsh cordgrass.

Common reed and narrow leaved cattails have invaded many of the brackish marsh communities located along the Creek banks. Large expanses of common reed are located along the western banks of the river east of Harden Lane and south of Sugar Hill Drive. As observed in lower sections of Muddy Creek, the upland consists of a Pitch Pine – Oak Forest Woodland community supported on Carver coarse sands at 8 to 15 percent slope (Barnstable County Soil Survey, 2011).

1.5.3 State-Listed Rare Species

Previous studies have been completed in Muddy Creek to identify state-listed rare species, including accounts by Bob Zaremba, PhD. The Massachusetts Division of Fisheries and Wildlife (MassDFW), Natural Heritage and Endangered Species Program (NHESP), was contacted to identify state-listed rare species in the vicinity of Muddy Creek. A letter report issued by MassDFW (included as *Attachment C*) identified the following state-listed rare species in the vicinity of Muddy Creek.

- Common Tern (*Sterna hirundo*)
- Eastern Box Turtle (*Terrapene carolina*)

Common Terns or Eastern Box Turtles were not observed along the creek during the vegetation and survey analysis stage of the project.

Individuals of *Decodon verticillatus (*Water Willow*)*, habitat for the State Listed, Threatened, Water *Papaipema sulphurata* (Water Willow Stem Borer), were observed along the edge of Muddy Creek in the upper basin, adjacent to wetland Transect 8 during the vegetation analysis stage of the project. No actual animals were observed at the time of the analysis. A Rare Species Observation Form was prepared and submitted to MNHESP on August 10, 2011 to report the presence of potential moth habitat.

1.5.4 Wetland Delineations

In accordance with Federal, State and Local definitions, the upper limits of wetland resource areas were delineated in the field within 200 feet of the proposed culvert and site of the former dike that previously separated Upper Muddy Creek from Lower Muddy Creek.

Vegetation, soils and hydrology were analyzed in the field to identify wetland resources located within the defined project limits and then the upper boundaries of wetland resources were flagged in the field. Where there was a significant horizontal deviation from the local, state and federal wetland resource lines (i.e. greater than 5 feet), the limits of Town of Chatham Vegetated wetlands were flagged in the field separately.

1.5.4.1 Wetland Resources Adjacent to Route 28 Culvert

Delineated wetland communities surveyed adjacent to the existing Muddy Creek culvert below Route 28 are reflected on *Sheet RC-101* in *Attachment A*. Identified communities are described in further detail below.

- Wetland ‘A’ represents the upper limits of coastal resources located north and east of the existing culvert.
    - The wetland flagging is numbered A-1 to A-9 in the field and starts at the edge of the channel bank at the retaining wall and extends north/northeast for a distance of approximately 200 feet.
    - The flagging represents the upper limits of salt marsh and is dominated by saltmarsh cordgrass and salt marsh hay.
    - The salt marsh is abutted by a steeply sloping upland forest community including a mix of black oak, white oak, pitch pine, low bush blueberries, and huckleberry.
    - The access road for the Pleasant Bay recreation area directly borders and encroaches on the salt marsh starting at wetland flag A-7. The access road is below the spring high tide elevation and is frequently flooded during high tide events.
    - The limits of the Spring High Tide Line were flagged in the field where the line crosses the access road and is represented by surveyed wetland flags A1-1 to A1-3.

- Wetland ‘B’ represents the upper limits of coastal resources located north and west of the existing culvert.

- The wetland flagging is numbered B-1 to B-11 in the field and extends along the upper limits of salt marsh starting at the western bank of the channel and extending west along the toe of the roadway slope.
- The wetland line represents the Spring High Tide Line and includes areas of low marsh, high marsh, brackish marsh, barrier beach and dune.
- In this area, the low marsh is a monotypic plant community consisting of saltmarsh cordgrass while the high marsh zones include salt marsh hay and glasswort *(Salicornia europaea).*
- The salt marsh is separated from the open water to the north by a narrow low forming dune and is subject to dune migration in a north to south direction.
- Overwash fans, which are areas along the back side of the dune where waves have washed over the dune leaving a fan of sediment on the upland or salt marsh side of the dune, were observed in the field. The salt marsh is also subject to a backwater effect caused by the culvert restriction.

- Wetland 'C' defines the upper limits of a palustrine shrub swamp bordering on salt marsh.
  - The wetland starts at the southeastern bank of the channel along the toe of the retaining wall and extends east along the wall for approximately 50 feet until it turns south.
  - The wetland flagging is numbered in the field C-1 to C-12 and represents the upper limits of state Bordering Vegetated Wetland and federal vegetated wetland.
  - The wetland is dominated with highbush blueberry and other species with Morrow's honey suckle *(Lonicera morrowii)* invading the upper limits of the wetland.
  - Dead and stressed stands of Eastern red cedar and pitch pine are located intermittently throughout the salt marsh providing evidence of historic hydrologic changes.
  - The line also represents the upper limits of the Town of Chatham Vegetated Wetland through wetland flag C-7 where the Chatham wetland line (C2-1 to C2-10) turns east/ northeast for approximately 50 feet and then south.
  - The town resource consists of 40% wetland vegetation with a wetland dominant shrub layer of northern bayberry, highbush blueberry, arrowwood, Morrow's honeysuckle and wild raisin, common greenbriar in the vine layer and an upland dominated tree layer consisting of black oak, white oak and pitch pine.
  - The wetland is abutted by a steeply sloping Pitch Pine – Oak Forest Woodland community including of a mix of black oak, white oak, pitch pine, low bush blueberry and huckleberry.

- Wetland 'D' represents the upper limits of salt marsh located south of Route 28 and west of the Creek.
  - The wetland line starts to the west of the culvert and extends westward along the toe of the roadway slope for approximately 140 feet until it turns south and then west/northwest around an elevated area dominated with Morrow's honeysuckle.

- The salt marsh consists of a mix of low and high salt marsh communities.
- Dead and stressed stands of mature Eastern red cedar and pitch pine are located intermittently throughout the salt marsh providing evidence of historic hydrologic changes in the system.
- Low marsh located south of the crossing, particularly within the cove, appears to be unable to keep up with rising sea levels due to the lack of sufficient sediment sources. In addition, evidence of erosion and slumping vegetation along the marsh edges has also been recorded.

1.5.4.2 Wetland Resources at the Former Dike Across Muddy Creek

Delineated wetland communities surveyed adjacent to the former dike location separating Upper Muddy Creek from Lower Muddy Creek are reflected on *Sheet RC-103* in *Attachment A*. Identified communities are described in further detail below.

- Wetland resources were delineated in the field 200 feet north and south of the former dike which is located northwest of the Riverview Drive and Chipping Stone Road intersection.
- A palustrine shrub swamp borders the east and west banks of Muddy Creek.
- The wetland is hydrologically connected to Muddy Creek but also receives overland flow from the adjacent, steeply sloping Pitch Pine – Oak Forest woodland community. Small isolated patches of *Saltmarsh cordgrass* were identified within the delineation limits at the edge of the channel.
- The upgradient limit of this wetland resource was delineated in the field and was observed to consist of a mix of wetland shrubs including highbush blueberry, male berry (*Lyonia ligustrina*), wild raisin, nanny berry *(Viburnum lentago),* and arrowwood.
- Wetland 'E' is located on the east bank in Chatham and the wetland is flagged in the field from north to south, E-1 to E-22.
- Wetland 'F' is located on the west bank in Harwich just north of the dike and is numbered in the field from north to south, F-1 to F-10. A thick colony of Morrow honeysuckle has invaded the wetland along the western bank just north of the abandoned dike.
- Wetland 'G' is located on the west bank in Harwich just south of the dike and is defined in the field with flags numbered G-1 to G-10.

1.5.4.3 Wetland Vegetative Community Quantitative Analyses

In order to monitor potential changes in vegetation community composition along the Muddy Creek corridor resulting from a potential widened culvert installation at the Route 28 crossing, permanent transects were installed at select locations north of the Route 28 crossing (Pleasant Bay Transects), between the Route 28 crossing and abandoned dike (Lower Basin Transects), and north of the abandoned dike (Upper Basin Transects). Within each transect, wooden stakes were installed at edges of the channel, where changes in vegetative dominance were noted within all communities, and at randomly selected points within the lower and upper salt marsh communities.

The stakes were then field located using a Leica RTK GS900 submeter GPS. Stands of invasive species within the general area of each transect were also evaluated in order to establish these communities' current spatial limits. Locations of surveyed transects completed are reflected on *Sheets* RC-*101* through *RC-107* in *Attachment A.*

- Three transects were established downstream of the culverts (PBT1-PBT3)
- Six transects have were established immediately upstream of the culverts in the Muddy Creek Lower Basin (LBT1-LBT6)
- Eleven transects were established in the Muddy Creek Upper Basin (UBT1-UBT11)

Vegetation communities along each transect were surveyed in the field after full leaf out of vegetation; as of the date of this work-in-progress memorandum in early July 2011, grass communities in the lower system are being evaluated and the results will be recorded in the final version of this memorandum (transects PBT-1, -2 and -3, LBT-1, -2, -3 and -4).

Salt marsh vegetation communities are to be analyzed in the field by placing a one square meter wooden sampling quadrat at each transect point, with the center point of one of the quadrat's sides placed immediately adjacent to the upland side of the stake. The percent cover of each plant species identified within the quadrat will be determined and the species' range midpoint recorded.

Percent cover within freshwater and brackish communities were assessed as outlined below.

- Herbaceous vegetation was assessed within a one square meter quadrat.
- Saplings and shrubs were analyzed within a 15-foot radius plot.
- Trees and woody vines were analyzed within a 30-foot radius plot.

Each community was assessed using the percent species dominance test per stratum. The following midpoints associated with a modified Braun-Blanquet cover scale were used under this evaluation.

Cover Ranges	Range Midpoint
1-5%	3.0
6-15%	10.5
16-25%	20.5
26-50%	38.0
51-75%	63.0
76-95%	85.5
96-100%	98.0

Wetland vegetation communities were classified using "Classification of the Natural Communities of Massachusetts" (Swain & Kearsley, 2001). The National Wetlands Research

Center of the U.S. Geological Survey (NWRC 2007) was referenced in identifying respective marsh communities by previous salinity data, with a saltwater marsh having a salinity range of 15-18 parts per thousand (ppt) or greater, a brackish marsh having a range from 3-15 ppt, an intermediate marsh having a salinity of about three ppt, and a freshwater marshes characterized by salinity ranges below 0.5 ppt.

1.5.4.4 Pleasant Bay Transects

Vegetative transects established downstream of the Route 28 culvert are described below. These transects are shown on *Sheet RC-101*. The transects were installed and surveyed on May 4, 2011 and the vegetation analysis was complete on July 12, 2011. Saltmarsh cordgrass and salt grass were not in flower at the time of the vegetation analysis and saltmarsh hay was just starting to flower. In order to distinguish between the two species, re-evaluation of the High Salt Marsh plots occurred in July and August 2011 when salt grass is in flower. Soils were observed in select location to obtain some general information concerning the depth of salt marsh peat. Soil information was gathered using an open 6" bucket Eidelman Auger.

<u>Pleasant Bay Transect 1 (PBT-1)</u>

Pleasant Bay Transect 1 is located just north of the Route 28 culverts and along the east bank of Muddy Creek. The transect starts at the edge of water and crosses through a narrow strip of Low Salt Marsh, to sparsely vegetated High Salt Marsh prior to ending at a disturbed forested upland.

The salt marsh system is narrow along this section due to the natural topography and the historic filling associated with the adjacent parking facilities and access road to the Pleasant Bay recreational area. The lower marsh at the channel edge appears to be eroding as a result of eddies and increased velocities associated with the restricted culverts. Sections of saltmarsh cordgrass are breaking away from the salt marsh system. The High Salt Marsh is sparsely vegetated due to a combination of foot traffic and the accumulation of wrack. The upland bank at the Spring High Tide Line is undercut by 6" with exposed roots.

Table 3
PBT-1 Vegetative Assessment

SALT MARSH		
Low Salt Marsh (T1-1 to T1-3)		
T1-1 (EOW/LM Transition) (1m2 Quadrat on upland side of stake)		
Spartina alterniflora	Salt Marsh Cordgrass	63%
T1-2 (LM) (1m2 Quadrat on upland side of stake)		
Spartina alterniflora	Salt Marsh Cordgrass	38%
Spartina patens	Salt Marsh Hay	10.5%
Salicornia europea	Common Glasswort	3%
Suaeda linearis	Sea Blite	3%
Soils: 0-4" Mucky Peat with *Spartina* roots		

SALT MARSH		
Low Salt Marsh (T1-1 to T1-3)		
4"–16" Sandy Muck 16-32" Coarse Sand		
High Salt Marsh (T1-3 to T1-5)		
T1-3 (LM/HM Transition) (1m2 Quadrat on upland side of stake)		
Spartina patens	Salt Marsh Hay	38%
Spartina alterniflora	Salt Marsh Cordgrass	10.5%
Salicornia europea	Common Glasswort	3%
Limonium nashii	Sea Lavender	3%
Suaeda linearis	Sea Blite	3%
Note: Wrack made up 38% of the plot.		
T1-4 (HM) No Vegetation Analysis		
T1-5 (HM/UP Transition) No Vegetation Analysis		

Pleasant Bay Transect 2 (PBT-2)

Pleasant Bay Transect 2 is located just north of the Route 28 culvert and along the west bank of Muddy Creek. The transect starts at the edge of the creek, transitions from Low Salt Marsh to High Salt Marsh, through a barrier beach and ends at the Spring High Tide Line at WF B-11. The low marsh along the edge of Muddy Creek appears to be eroding due to the velocities during tidal exchanges. Tufts of saltmarsh cordgrass are slumping at the edge of the creek. In addition, a secondary channel is located along the interior of the Low Marsh. The culvert restriction creates a backwater effect during tidal exchanges. Incoming tides pond up into the salt marsh adjacent to Route 28 prior to the tides reaching a state of equilibrium with the Lower Basin side of the system.

This Salt Marsh is a part of a barrier beach system. Immediately north of the transect is a dynamic beach/dune with evidence of tidal overwash fans observed on the Salt Marsh side of the dune. Historic tidal overwash is evident where sand were recorded within the soil profiles after augering to a depth of approximately 30".

It should also be noted that the Low Salt Marsh in this area is at a higher elevation with less micro-topography than the Low Salt Marsh located south of the culverts. It is speculated that the low salt marsh along the Pleasant Bay transect is better able to respond to hydrologic changes and sea level rise due to a more consistent supply of sediment from the adjacent barrier beach/dune.

Table 4
PBT-2 Vegetative Assessment

SALT MARSH		
Low Salt Marsh (T2-1 to T2-3)		
T2-1 (EOW/LM Transition) (1m2 Quadrat on upland side of stake)		
Spartina alterniflora	Salt Marsh Cordgrass	85.5%
Soils: 0-16" Mucky Peat with *Spartina* roots		

SALT MARSH		
Low Salt Marsh (T2-1 to T2-3)		
16"-24" Coarse Sand mixed with Muck 24"-30" Coarse Sand with Stone		
T2-2 (LM) (1m2 Quadrat on upland side of stake)		
Spartina alterniflora	Salt Marsh Cordgrass	63%
Note: Wrack as a result of backwater effect is extensive resulting in a decrease in *S. alterniflora* cover. Soils: 0-12" Mucky Peat with *Spartina* roots 12"-30" Coarse Sand with Stone		
High Salt Marsh (T2-3 to T2-7)		
T2-3 (LM/HM Transition) (1m2 Quadrat on upland side of stake)		
Spartina alterniflora	Salt Marsh Cordgrass	20.5%
Spartina patens	Salt Marsh Hay	20.5%
Note: Wrack as a result of backwater effect is extensive resulting in a decrease in *S. alterniflora* cover. Wrack covered 63% of the plot area. Soils: 0-6" Mucky Peat with *Spartina* roots 6"-24" Loamy Sand 24"-30" Coarse Sand with Stone		
T2-4 (HM) (1m2 Quadrat on upland side of stake)		
Salicornia europea	Common Glasswort	63%
Spartina patens	Salt Marsh Hay	38%
Spartina alterniflora	Salt Marsh Cordgrass	3%
Soils: 0-3" Loamy Muck with *Spartina* roots 3"-25" Loamy Sand 25"-28" Coarse Sand with Stone		
T2-5 (HM/BB Transition) (1m2 Quadrat on upland side of stake)		
Agropyron pungens	Stiff-leaved Quackgrass	20.5%
Spartina patens	Salt Marsh Hay	20.5%
T2-6 (BB) (1m2 Quadrat on upland side of stake)		
Agropyron pungens	Stiff-leaved Quackgrass	38%
Spartina patens	Salt Marsh Hay	20.5%
T2-7 at WW B-11 (BB/SHTL) No Vegetation Analysis		

Pleasant Bay Transect 3 (PBT-3)

Pleasant Bay Transect 3 is located north of the Route 28 culverts at the downstream bend in the Muddy Creek where the channel makes a sharp turn to the west. The lower marsh appears to be eroding at the channel bend. Sections of saltmarsh cordgrass are breaking away from the salt marsh system creating newly formed mud flats. A secondary channel is forming within the interior of the marsh which contributes to the erosion at channel's edge. The salt marsh transitions from low marsh, to high marsh to a newly forming dune/barrier beach. The Salt

Marsh is a part of a barrier beach system. Immediately north of the transect is a dynamic barrier beach/dune with tidal overwash occurring on the Salt Marsh side of the dune.

Table 5
PBT-3 Vegetative Assessment

SALT MARSH		
Low Salt Marsh (T3-1 to T3-3)		
T3-1 (EOW/LM Transition) (1m2 Quadrat on upland side of stake)		
Spartina alterniflora	Salt Marsh Cordgrass	85.5%
Soils: 0-9" Mucky Peat w/Spartina roots 9"-25" Coarse Sand 25"-30" Silty Coarse Sand with root fibers		
T3-2 (LM) (1m2 Quadrat on upland side of stake)		
Spartina alterniflora	Salt Marsh Cordgrass	85.5%
Soils: 0-20" Mucky Peat with Spartina roots 20"+ Coarse Sand		
High Salt Marsh (T3-3 to T3-4)		
T3-3 (LM/HM Transition) (1m2 Quadrat on Low Marsh side of stake)		
Spartina alterniflora	Salt Marsh Cordgrass	63%
Spartina patens	Salt Marsh Hay	10.5%
Salicornia europea	Common Glasswort	3%
Note: The High Marsh is narrow and disturbed with a foot path located at the High Marsh side of the stake. Therefore, the vegetation analysis was completed on the low marsh side of the stake. Soils: 0-6" Mucky Peat with *Spartina* roots 6-30" Coarse Sand		
T3-4 (HM/Dune Transition) (1m2 Quadrat on High Marsh side of stake)		
Spartina patens	Salt Marsh Hay	63%
Suaeda linearis	Sea Blite	3%
T3-4 (HM/Dune Transition) (1m2 Quadrat on Dune side of stake)		
Spartina patens	Salt Marsh Hay	10.5%
Suaeda linearis	Sea Blite	3%

1.5.4.5 Muddy Creek Lower Basin Transects

Muddy Creek and its adjacent Salt Marsh system immediately upstream of the Route 28 culvert are currently in transition. The Low Salt Marsh immediately upstream of the Route 28 Culverts is at a lower elevation than the Low Salt Marsh located on the Pleasant Bay side of Route 28 with a higher percentage of hollows and salt marsh pannes. The upper limit of the Salt Marsh has been invaded by common reed and narrow leaved cattails due to insufficient tidal flushing of the marsh and nutrient-rich freshwater runoff from upgradient areas.

Remains of still standing dead, mature Eastern red cedar and pitch pine and associated woody debris are located within the Salt Marsh communities indicating a historic change in hydrology which is potentially associated with the removal of the Route 28 tide gates and the resultant shift from a dryer vegetative community with more freshwater influence to that of a Salt Marsh community. In addition, salt burned vegetation is present along the upper forested and shrub edges of the salt marsh which appear to be representative of the recent breach in Chatham.

In the embayment area west/southwest of Route 28, Low Salt Marsh transitions directly to common reed and narrow leaved cattails along the much of the marsh length with a small percentage of High Salt Marsh. After reviewing available MA GIS orthophotos dating from the 1990's to the present, there appears to be little to no measurable change in the horizontal extent of the Salt Marsh. However, there may be a historic elevation change of the salt marsh not represented in the mapping.

Vegetative transects established immediately upstream of the Route 28 culvert are described below and shown on Sheet *CS-101* and *CS-102.* The transects were set at various time and vegetation analysis was completed over the project period as described below. Saltmarsh cordgrass and salt grass were not in flower at the time of the vegetation analysis. Salt marsh hay was just starting to flower. Given the similarities between salt marsh hay and salt grass, re-evaluation of the High Marsh plots should occur between August and October when salt grass is in flower. Soils were observed in select location to obtain some general information concerning the depth of salt marsh peat. Soil information was gathered using an open 6" bucket Eidelman Auger.

<u>Lower Basin Transect 1 (LBT-1)</u>

Lower Basin Transect 1 is located on the western bank of Muddy Creek just south of the Route 28 culvert. The transect was installed, surveyed and analyzed for vegetative composition in June 2011. The transect starts at the edge of the channel and traverses through low and high Salt Marsh communities ending at a Coastal Forested/Woodland community. Evidence of low marsh slumping was observed at the edge of the channel.

Salt marsh pannes are located within the immediate area of this transect and standing deadwood of mature Eastern red cedar are located within the Salt Marsh in the general area of the transect. The upland community consists of oaks, Eastern red cedar, Morrow's honeysuckle, oriental bittersweet, common greenbriar and poison ivy. Dead mature highbush blueberry shrubs are located within the upland community indicating a recent hydrologic change most likely associated with the rise in the tide elevations associated with the 2004 breach.

Table 6
LBT-1 Vegetative Assessment

SALT MARSH		
Low Salt Marsh (T1-1 to T1-3)		
T1-1 (EOW/LM Transition) (1m2 Quadrat on upland side of stake)		
Spartina alterniflora	Salt Marsh Cordgrass	63%
Soils: 0-30" Fibric Peat 30"+ Sand		
T1-2 (LM) (1m2 Quadrat on upland side of stake)		
Spartina alterniflora	Salt Marsh Cordgrass	63%
Soils: 0-6" Peat 6"-22" Sand		
T1-3 (LM/HM Transition) (1m2 Quadrat on High Salt Marsh side of stake)		
Spartina patens	Salt Marsh Hay	63%
Spartina alterniflora	Salt Marsh Cordgrass	20.5%
Salicornia europea	Common Glasswort	10.5%
Soils: 0-6" Peat 6"-12" Sand 12"-18" Peat 18"-30" Sand 30"-36" Peat		
T1-4 (HM) (1m2 Quadrat on upland side of stake)		
Spartina patens	Salt Marsh Hay	38%
Juncus gerardii	Black Grass	38%
Spartina alterniflora	Salt Marsh Cordgrass	10.5%
Salicornia europea	Common Glasswort	10.5%
Soils: 0-36" Alternating layers of Peat and Sand		
T1-5 (HM) (1m2 Quadrat on upland side of stake)		
Juncus gerardii	Black Grass	63%
Spartina patens	Salt Marsh Hay	20.5%
Solidago sempervirens	Seaside Goldenrod	20.5%
Salicornia europea	Common Glasswort	3%
Low Salt Marsh (T1-6 to T1-8)		
T1-6 (HM/LM Transition) (1m2 Quadrat on upland side of stake)		
Spartina alterniflora	Salt Marsh Cordgrass	38%
Spartina patens	Salt Marsh Hay	10.5%
T1-7 (LM) (1m2 Quadrat on upland side of stake)		
Spartina alterniflora	Salt Marsh Cordgrass	10.5%
T1-8 (LM/UP Transition) No Vegetation Analysis		

Lower Basin Transect 2 (LBT-2)

Lower Basin Transect 2 is located south of the Route 28 culvert along the upper reaches of the western salt marsh. The transect was installed and surveyed on May 4, 2011 and the vegetative analysis was completed in June 2011. The transect starts at the edge of the channel within a newly formed tidal flat and transitions directly from low salt marsh to a community of narrow leaved cattails and then to a community of common reed prior to ending at an upland stand of *Polygonum cuspidatum* (Japanese Knotweed). An area of ponding was observed just to the north of this stand of common reed and south of Route 28. The overall area of common reed contains felled and partially erect dead, mature pitch pine and small areas of open water. A secondary channel drains one of the areas of ponding adjacent to the transect.

Table 7
LBT-2 Vegetative Assessment

SALT MARSH		
Salt Marsh Flat (T2-1 to T2-2)		
T2-1 (EOW/Flats Transition) (No Vegetation Analysis)		
Low Salt Marsh (T2-2 to T2-3)		
T2-2 (Flats/LM Transition) (1m2 Quadrat on upland side of stake)		
Spartina alterniflora	Salt Marsh Cordgrass	85.5%
Note: 0-32" Mucky peat with strong sulfur odor and roots. 32"+ Medium sand with muck/silt.		
High Salt Marsh (T2-3 to T2-5)		
T2-3 (LM/Typha Transition) (1m2 Quadrat on upland side of stake)		
Typha angustifolia	Narrowleaved Cattail	85.5%
Spartina alterniflora	Salt Marsh Cordgrass	3%
Note: 0-30" Fibric Peat with abundant roots. 30-40" Medium sand with silt.		
T2-4 (Typha/Phrag Transition) (Estimate of Cover along transect between T2-4 to T2-5)		
Phragmites australis	Common Reed	85.5%
Toxicodendron radicans	Poison Ivy	3%
Note: Access is an issue in this area. The area is dense and difficult to traverse with open water areas. Percent cover should be verified.		
T2-5 (Phrag/UP Transition) No Vegetation Analysis		

Lower Basin Transect 3 (LBT-3)

Muddy Creek Lower Basin Transect 3 is also located south of the Route 28 culverts along the upper reaches of the western Salt Marsh. The transect was installed and surveyed on May 4, 2011. Vegetation analysis was complete on May 4, 2011. The transect starts at the EOW and transitions through Low Salt Marsh to High Salt Marsh to a stand of common reed and then to a narrow strip of Freshwater Forested Wetland prior to meeting a Pitch Pine – Oak Forest

Woodland community. The Low Salt Marsh is fragmented within this area with hummock-hollow microtopography.

Table 8
LBT-3 Vegetative Assessment

SALT MARSH		
Low Salt Marsh (T3-1 to T3-4)		
T3-1 (EOW/LM) (1m2 Quadrat on upland side of stake)		
Spartina alterniflora	Salt Marsh Cordgrass	85.5%
Note: Unable to verify percent cover in Summer. This area has significant microtopography and fragmentation. Access to the transect is dangerous.		
T3-2 (LM) (1m2 Quadrat on upland side of stake)		
Spartina alterniflora	Salt Marsh Cordgrass	85.5%
Note: Unable to verify percent cover in Summer. This area has significant microtopography and fragmentation. Access to the transect is dangerous.		
T3-3 (LM w/Phragmites Invasion) No Vegetation Analysis.		
High Salt Marsh (T3-4 to T3-5)		
T3-4 (LM/HM w/Phrag Transition) (1m2 Quadrat on upland side of stake)		
Phragmites australis	Common Reed	85.5%
***FRESHWATER FORESTED WETLAND* (T3-5 to T3-6)**		
T3-5 (HM w/Phrag/FW Transition) (No Vegetative Analysis)		
T3-5 to T3-6 (FW) Completed Midway (5, 15, 15 & 19 Foot Radius VP Plots)		
Tree Layer *(Modified radius to 19 feet to accommodate the width of wetland)*		
Pinus rigida	Pitch Pine	38%
Quercus sp.	Oak	38%
Shrub Layer		
Vaccinium corymbosum	Highbush Blueberry	63%
Amelanchier sp.	Shadbush	38%
Viburnum cassinoides	Wild Raisin	10.5%
Herbaceous Layer *(Ground cover not developed)*		
Vine Layer *(Modified radius to 19 feet to accommodate the width of wetland)*		
Smilax rotundifolia	Common Greenbriar	3%
T3-6 (FW/UP Transition) (No Vegetative Analysis)		

Lower Basin Transect 4 (LBT-4)

Muddy Creek Lower Basin Transect 4 is located along the eastern bank of Muddy Creek south of the Route 28 culvert. The transect was installed and surveyed on May 4, 2011. Vegetation analysis in the shrub community was complete on May 4, 2011 and in the salt marsh community on June 12, 2011. This transect extends from the seaward limit of Low Salt Marsh, through a narrow band of High Salt Marsh, to a band of common reed intrusion, to a Palustrine Shrub Swamp, to a Town of Chatham Freshwater Forested Wetland and ends at a mature Pitch Pine – Oak Forest Woodland community. Dead and salt stressed highbush blueberry and pitch pine was identified within the Shrub Swamp Community.

Table 9
LBT-4 Vegetative Assessment

SALT MARSH		
Low Salt Marsh (T4-1 to T4-3)		
T4-1 (EOW/LM Transition) (1m2 Quadrat on upland side of stake)		
Spartina alterniflora	Salt Marsh Cordgrass	38%
Note: Wrack covered 38% of the plot. Soils: 0-16" Fibric Peat (Roots Abundant with strong sulfur odor.) 16"-30" Coarse Sand intermixed with Mucky Peat		
T4-2 (LM) (1m2 Quadrat on upland side of stake)		
Spartina alterniflora	Salt Marsh Cordgrass	38%
Distichlis spicata	Salt Grass	20.5%
Soils: 0-12" Fibric peat with roots 12"-40" Sandy muck mixed with remaining root fibers		
High Salt Marsh (T4-3 to T4-5)		
T4-3 (HM) (1m2 Quadrat on upland side of stake)		
Spartina alterniflora	Salt Marsh Cordgrass	38%
Spartina patens	Salt Marsh Hay	10.5%
Juncus geradii	Black Grass	10.5%
Salicornia europea	Common Glasswort	3%
Atriplex patula	Marsh Orach	trace
Soils: 0-6" Fibric Peat 6"-40" Mucky sand with masses of silt and root fibers.		
T4-4* (HM w/*Phrag* Invasion*) (1m2 Quadrat on upland side of stake)		
Spartina patens	Salt Marsh Hay	63%
Juncus geradii	Black Grass	38%
Solidago sempervirens	Seaside Golden Rod	20.5%
Phragmites australis	Common Reed	3%
T4-5 (Phragmites) (5, 15, 30 Foot VP)		
Tree Layer		
Pinus rigida (dead)	Pitch Pine	3%
Shrub Layer - *None*		

SALT MARSH		
Low Salt Marsh (T4-1 to T4-3)		
Herbaceous Layer		
Phragmites australis	Common Reed	85.5%
Juncus geradii	Black Grass	3%
Solidago sempervirens	Seaside Golden Rod	3%
Carex sp.	Sedge sp.	3%
Vine Layer		
Toxicodendron radicans	Poison Ivy	3%
***SHRUB SWAMP** (T4-6 to T4-7)*		
Vegetation Analysis Completed along Transect Between T4-6 to T4-7		
Tree Layer		
Pinus rigida	Pitch Pine	
Quercus sp.	Oak	
Shrub Layer		
Vaccinium corymbosum	Highbush Blueberry	85.5%
Viburnum cassinoides	Wild Raisin	20.5%
Amelanchier arborea	Common Shadbush	10.5%
Aronia sp.	Chokecherry	10.5%
Morella pensylvanica	Bayberry	3%
Herbaceous Layer		
Ground cover not developed		
Vine Layer		
Toxicodendron radicans	Poison Ivy	38%
FRESHWATER FORESTED WETLAND (T4-7 to T4-8)		
No Vegetation Analysis		

Lower Basin Transect 5 (LBT-5)

Transect 5 is located approximately 1,200 feet upstream from the Route 28 culverts on the western bank of the creek in Harwich. The transect was installed at the apex of the salt marsh spit on May 19, 2011. The field survey and vegetation analysis was completed on the same day. Vegetation was reviewed on July 13 2011 to identify sedges and rushes located along the transect. Evidence of Salt Marsh accretion and the rafting of saltmarsh cordgrass was identified within the lower marsh in the area. Rafting saltmarsh cordgrass involves the dislodging of live mats of vegetation during high wave action and the transporting of that live vegetation to other areas along a salt marsh or creek system. Rafting often contributes to the colonization of otherwise unvegetated mudflats along a waterway.

Over washed sands in the lower Salt Marsh and the development of sand bars at the edge of water were noted along the spit. The transect transitions from the edge of the creek through low Salt Marsh and a mix of low and high salt marsh grasses intermixed with dead and felled pitch pine. A stand of narrow leaved cattails is located along the upper limits of the Salt Marsh outside the transect and to the northeast. The transect then continues inland through a narrow Palustrine Shrub Swamp Community with historic ditching at its upper limits. The Shrub Swamp Community ends at a Pitch Pine – Oak Forest Woodland community.

Table 10
LBT-5 Vegetative Assessment

SALT MARSH		
T5-1 (EOW/LM) (1m2 Quadrat on upland side of stake)		
Spartina alterniflora	Salt Marsh Cordgrass	38%
T5-2 (LM/HM Transition) (1m2 Quadrat on upland side of stake)		
Spartina patens	Salt Marsh Hay	68%
Spartina alterniflora	Salt Marsh Cordgrass	10.5%
Scirpus robustus	Salt Marsh Bulrush	10.5%
Solidago sempervirens	Seaside Golden Rod	3%
T5-3 (HM) (1m2 Quadrat on upland side of stake)		
Toxicodendron radicans	Poison Ivy	20.5%
Spartina patens	Salt Marsh Hay	10.5%
Scirpus robustus	Salt Marsh Bulrush	10.5%
Scirpus pungens	Common Three Square Rush	3%
PALUSTRINE SHRUB SWAMP (T5-4 to T5-6)		
Vegetation Analysis Completed at T5-5 (5, 10 & 10 Foot VP)		
Tree Layer – None *(Modified radius to 10 feet to accommodate the width of wetland)*		
Sapling Layer *(Modified radius to 10 feet to accommodate the width of wetland)*		
Quercus coccinea	Scarlet Oak	10.5%
Shrub Layer *(Modified radius to 10 feet to accommodate the width of wetland)*		
Viburnum dentatum	Arrowwood	10.5%
Morella pensylvanica	Northern Bayberry	10.5%
Viburnum cassinoides	Wild Raisin	3%
Vaccinium corymbosum	Highbush Blueberry	3%
Herbaceous Layer		
Scirpus pungens	Common Three Square Rush	10.5%
Thelypteris simulata	Massachusetts Fern	10.5%
Carex hormathodes	Marsh Straw Sedge	3%
Juncus balticus	Baltic Rush	3%
Rhubus sp.	Dewberry	3%
Panicum virgatum	Switchgrass	3%
Solidago sempervirens	Seaside Goldendrod	3%

	Grass sp.	3%
Vine Layer *(Modified radius to 10 feet to accommodate the width of wetland)*		
Toxicodendron radicans	Poison Ivy	63%
Calystegia sepium	Hedge Bindweed	10.5%

Lower Basin Transect 6 (LBT-6)

Transect 6 is located approximately 1,300 feet upstream from the Route 28 culverts on the eastern bank of the creek in Chatham, diagonally across the creek from Transect 5. The transect was installed at the apex of the salt marsh spit on May 19, 2011. The field survey and vegetation analysis was completed on the same day. The transect transitions perpendicular from the edge of the creek through low salt marsh and a mix of low salt marsh grasses intermixed with narrow leaved cattails prior to crossing a well developed, thick Palustrine Shrub Swamp with pit and mound micro-topography and a narrow Town of Chatham regulated Forested Wetland. The transect ends at the upland limits of the wetland at a Pitch Pine – Oak Forest Woodland community. An approximately 18 foot wide stand of narrow leaved cattails is located along the upper limits of the salt marsh and continues to the west and east of the transect.

Table 11
LBT-6 Vegetative Assessment

SALT MARSH (T6-1 to T6-4)		
Low Salt Marsh (T6-1 to T6-3)		
T6-1 (EOW/LM) (1m2 Quadrat on upland side of stake)		
Spartina alterniflora	Salt Marsh Cordgrass	63%
Typha angustifolia	Narrowleaved Cattail	3%
T6-2 (LM) (1m2 Quadrat on upland side of stake)		
Spartina alterniflora	Salt Marsh Cordgrass	85.5%
High Salt Marsh w/Typha Intrusion (T6-3 to T6-5)		
T6-3 (LM/Typha) (1m2 Quadrat on upland side of stake)		
Typha angustifolia	Narrowleaved Cattail	38%
Spartina alterniflora	Salt Marsh Cordgrass	3%
T6-4 (Typha) (1m2 Quadrat on upland side of stake)		
Typha angustifolia	Narrowleaved Cattail	38%
PALUSTRINE SHRUB SWAMP (T6-5 to T6-7)		
Vegetation Analysis Completed at T6-6		
Tree Layer – None *(Modified radius to 10 feet to accommodate the width of wetland)*		
Sapling Layer *(Modified radius to 10 feet to accommodate the width of wetland)*		
Prunus serotina	Black Cherry	3%
Shrub Layer *(Modified radius to 10 feet to accommodate the width of*		

wetland)		
Vaccinium corymbosum	Highbush Blueberry	38%
Viburnum dentatum	Arrowwood	10.5%
Viburnum cassinoides	Wild Raisin	3%
Herbaceous Layer		
Osmunda cinnamomea	Cinnamon Fern	10.5%
Rumex orbiculatus	Greater Water Dock	3%
Vine Layer *(Modified radius to 10 feet to accommodate the width of wetland)*		
Toxicodendron radicans	Poison Ivy	20.5%
Calystegia sepium	Hedge Bindweed	10.5%
Smilax rotundifolia	Common Greenbriar	3%
FRESHWATER FORESTED WETLAND (T6-7 to T6-9)		
Vegetation Analysis Completed at T6-8		
Tree Layer – None *(Modified radius to 10 feet to accommodate the width of wetland)*		
Quercus coccinea	Scarlet Oak	38%
Sapling Layer *(Modified radius to 10 feet to accommodate the width of wetland)*		
Prunus serotina	Black Cherry	3%
Quercus coccinea	Scarlet Oak	3%
Shrub Layer		
Gaylussacia baccata	Black Huckleberry	63%
Aronia floribunda	Purple Chokecherry	20.5%
Morella pensylvanica	Northern Bayberry	10.5%
Viburnum dentatum	Arrowwood	10.5%
Vaccinium corymbosum	Highbush Blueberry	3%
Ilex verticillata	Common Winterberry	3%
Viburnum cassinoides	Wild Raisin	3%
Rosa nitida	Shining Rose	3%
Herbaceous Layer - None		
Vine Layer *(Modified radius to feet to accommodate the width of wetland)*		
Toxicodendron radicans	Poison Ivy	3%
Smilax rotundifolia	Common Greenbriar	3%

1.5.5 Muddy Creek Upper Basin Transects

Vegetative transects established in the upper limits of the Muddy Creek estuary are described below and shown on *Sheets RC-104 – RC-107.*

Upper Basin Transect 1 (UBT-1)

Transect 1 is located on the Harwich side of Muddy Creek, south of the abandoned dike and just north of , under the power lines. According to the Harwich Geologic Quadrangle map the wetland is located in an area of Harwich outwash plain deposits and is listed in the DEP Wetland Mapping datalayer as a shrub swamp.

The transect was installed and field located on June 1, 2011. The vegetation analysis was completed on the same day. The vegetation community is an Estuarine Intertidal, Brackish Tidal Marsh (BM) dominated by common reed. The transect starts at the edge of the water and ends at a steeply sloping upland consisting of filled/disturbed slopes associated with the powerlines. Patches of saltmarsh cordgrass are located along the edge of the creek. No shrub or tree communities were present along the transect. A Palustrine Shrub Swamp is located to the north/northeast of the transect within an area mapped as abandoned cranberry bog according to the Harwich Geologic Quadrangle.

Table 12
UBT-1 Vegetative Assessment

BRACKISH TIDAL MARSH (T1-1 to T1-4)		
T1-1 (EOW/BM) (1m2 Quadrat on upland side of stake)		
Spartina alterniflora	Salt Marsh Cordgrass	63%
T1-2 (BM w/Phragmites) (5, 15, 15, 30 Foot Radius VP Plots)		
Phragmites australis	Common Reed	38%
Spartina alterniflora	Salt Marsh Cordgrass	3%
No Shrubs, Saplings, or Vines.		
T1-3 (BM w/Phragmites) (5, 15, 15, 30 Foot Radius VP Plots)		
Phragmites australis	Common Reed	38%
No Shrubs, Saplings, or Vines.		
T1-4 (BM w/Phragmites/Upland) (No VP)		

Upper Basin Transect 2 (UBT-2)

Transect 2 is located on the Chatham side of Muddy Creek, upstream of the abandoned dike and north of Country Side Drive. According to the Harwich Geologic Quadrangle map, the wetland is located in an area of swamp and marsh deposits and is listed in the DEP Wetland Mapping datalayer as a shallow marsh, meadow or fen.

The transect was installed and field located on June 1, 2011. The vegetation analysis was completed on the same day. The wetland community transitions from a Brackish Tidal Marsh to a Brackish Tidal Marsh/Palustrine Shrub Swamp mix to a Palustrine Shrub Swamp prior to ending at a steeply sloping Pitch Pine – Oak Forest Woodland community. Man made irrigation ditches exist throughout the wetland communities. Although not within any of the vegetation plots, patches of black grass are located within the lower hollows of the Brackish Tidal Marsh (BM) community immediately east of the transect on the east side of a parallel man made drainage channel. Vegetation assemblages located east of the adjacent channel are similar to the upper elevations of an Estuarine Intertidal Salt Marsh community. The vegetation densities increase within the Shrub Swamp community as the transect transitions from the edge of water to the upland. Hummock and hollow micro-topography is present within the Shrub Swamp.

Table 13
UBT-2 Vegetative Assessment

BRACKISH TIDAL MARSH		
T2-1 (EOW/BM-SS) (No VP)		
T2-2 (BM) (5, 15, 30 Foot Radius VP)		
Tree Layer - None		
Sapling Layer – None		
Shrub Layer		
Morella pensylvanica	Northern Bayberry	20.5%
Spirea tomentosa	Steeplebush	10.5%
Herbaceous Layer		
Grass sp.		38%
Solidago sempervirens	Seaside Goldenrod	20.5%
Vine Layer		
Toxicodendron radicans	Poison Ivy	63%
Calystegia sepium	Hedge Bindweed	
PALUSTRINE SHRUB SWAMP		
T2-3 (BM-SS/SS Transition) (5, 15, 15, 30 Foot Radius VP)		
Tree Layer – None		
Sapling Layer		
Pinus rigida	Pitch Pine	10.5%
Quercus coccinea	Scarlet Oak	3%
Shrub Layer		
Viburnum dentatum	Arrowwood	38%
Vaccinium corymbosum	Highbush Blueberry	20.5%
Morella pensylvanica	Northern Bayberry	20.5%
Lyonia ligustrina	Maleberry	20.5%
Ilex laevigata	Smooth Winterberry	20.5%
Viburnum cassinoides	Wild Raisin	10.5%
Herbaceous Layer		
Thelypteris palustris	Marsh Fern	10.5%
Panicum virgatum	Switchgrass	10.5%
Solidago sp.	Goldenrod	3%
Maianthemum canadense	Canada Mayflower	3%
Osmunda cinnamomea	Cinnamon Fern	3%
Trientalis borealis	Star Flower	3%

Sphagnum sp.	Sphagnum Moss	3%
Vine Layer		
Toxicodendron radicans	Poison Ivy	10.5%
Vitis sp.	Grape	3%
Smilax sp.	Greenbiar	3%
T2-4 (SS/UP) (No VP)		

Upper Basin Transect 3 (UBT-3)

Transect 3 is located on the Harwich side of Muddy Creek, upstream of the abandoned dike and southwest of Sugar Hill Drive. According to the Harwich Geologic Quadrangle map, the transect crosses an abandoned cranberry bog. Discussions with adjacent residents confirmed the presence of a historic bog in the area. Man made irrigation ditches are located within the systems. The area is listed in the DEP Wetland Mapping datalayer as a shrub swamp bordering on a shallow marsh, meadow or fen.

The transect was installed and the stakes were field located on June 1, 2011. The vegetation analysis was completed on the same day. The wetland communities along the transect transition from an Freshwater/Brackish Tidal Marsh located at the edge of the creek to an Palustrine Shrub Swamp back to an Freshwater/Brackish Tidal Marsh associated with bog ditching and then to an Palustrine Red Maple Swamp with hummock and hollow micro-topography prior to ending at a Pitch Pine – Oak Forest Woodland community.

Table 14
UBT-3 Vegetative Assessment

FRESHWATER/BRACKISH TIDAL MARSH (T3-1 to T3-3)		
T3-1 (EOW/BM) (1m2 Quadrat on upland side of stake)		
Spartina alterniflora	Salt Marsh Cordgrass	63%
T3-2 (BM) (1m2 Quadrat on upland side of stake)		
Spartina alterniflora	Salt Marsh Cordgrass	63%
Juncus gerardii	Black Grass	10.5%
Solidago sempervirens	Seaside Goldenrod	10.5%
T3-3 (BM/SS) (No VP)		
PALUSTRINE SHRUB SWAMP (T3-3 to T3-5)		
T3-4 (SS) (5, 15, 30 Foot Radius VP)		
Tree Layer - None		
Sapling Layer		
Quercus coccinea	Scarlet Oak	3%
Robinia pseudoacacia	Black Locust	3%
Crataegus sp.	Hawthorn	3%
Shrub Layer		
Lyonia ligustrina	Maleberry	20.5%

Viburnum dentatum	Arrowwood	20.5%
Vaccinium corymbosum	Highbush Blueberry	10.5%
Morella pensylvanica	Northern Bayberry	10.5%
Amelanchier arborea	Common Shadbush	3%
Herbaceous Layer		
Panicum virgatum	Switchgrass	38%
Thelypteris palustris	Marsh Fern	10.5%
Vine Layer		
Toxicodendron radicans	Poison Ivy	63%
Smilax sp.	Greenbriar	10.5%
T3-5 (SS/BM) (No VP)		
FRESHWATER/BRACKISH TIDAL MARSH (T3-5 to T3-7)		
T3-6 (BM) (5, 15, 30 Foot Radius VP)		
Tree Layer - None		
Sapling Layer - None		
Shrub Layer		
Morella pensylvanica	Northern Bayberry	10.5%
Aronia prunifolia	Purple Chokecherry	3%
Lonicera morrowii	Morrow's honeysuckle	3%
Herbaceous Layer		
Phragmites australis	Common Reed	10.5%
Typha angustifolia	Narrowleaved Cattail	10.5%
Thelypteris palustris	Marsh Fern	3%
Vine Layer		
Toxicodendron radicans	Poison Ivy	63%
T3-7 (BM/SW) (No VP)		
PALUSTRINE RED MAPLE SWAMP (T3-7 to T3-9)		
T3-8 (SW) (5, 15, 30 Foot Radius VP)		
Tree Layer – None		
Sapling Layer		
Pinus rigida	Pitch Pine	10.5%
Quercus coccinea	Scarlet Oak	3%
Shrub Layer		
Lyonia ligustrina	Maleberry	38%
Viburnum dentatum	Arrowwood	20.5%
Vaccinium corymbosum	Highbush Blueberry	20.5%
Amelanchier arborea	Common Shadbush	10.5%
Lonicera morrowii	Morrow's Honeysuckle	10.5%
Ilex laevigata	Smooth Winterberry	3%
Aronia prunifolia	Purple Chokeberry	3%
Viburnum cassinoides	Wild Raisin	3%
Herbaceous Layer		
Osmunda cinnamomea	Cinnamon Fern	20.5%

Sphagnum sp.	Sphagnum Moss	20.5%
Onoclea sensibilis	Sensitive Fern	10.5%
Solidago sp.	Goldenrod 1	3%
Solidago sp.	Goldenrod 2	3%
Vine Layer		
Toxicodendron radicans	Poison Ivy	20.5%
Calystegia sepium	Hedge Bindweed	3%
T3-9 (SW/UP) (No VP)		

Upper Basin Transect 4 (UBT-4)

Transect 4 is located on the Harwich side of Muddy Creek just to the west/southwest of Transect 3. According to the Harwich Geologic Quadrangle map, the transect crosses an abandoned cranberry bog. Discussions with adjacent residents confirmed the historic existence of a cranberry bog in the area. Man made irrigation ditches are located throughout the wetland communities. The area is listed in the DEP Wetland Mapping datalayer as a shrub swamp bordering on a shallow marsh, meadow or fen.

The transect was installed and the vegetation was analyzed on June 2, 2011 with the field location of the stakes completed on June 3, 2011. The wetland communities along the transect transition from an Estuarine Intertidal, Brackish Tidal Marsh - Palustrine Shrub Swamp (BM-SS) located at the edge of the creek to a Palustrine Red Maple Swamp (SW) with significant hummock and hollow micro-topography. The transect ends at an old cranberry bog drainage channel prior to transitioning to a Pitch Pine – Oak Forest Woodland community invaded with Oriental Bittersweet and Morrow's honeysuckle.

Vegetation within the Brackish Tidal Marsh/Palustrine Shrub Swamp community is in a state of transition with evidence of salt stress in the shrub layers including dead Arrowwood biomass and live highbush blueberry with evidence of "salt burn." *Calamagrostis Canadensis* (Reed bentgrass) is located on hummocks within the Brackish Tidal Marsh – Shrub Swamp community.

Table 15
UBT-4 Vegetative Assessment

TIDAL MARSH – SHRUB SWAMP (T4-1 to T4-4)		
T4-1 (EOW/BM-SS) (No VP)		
T4-2 (BM-SS) (5, 15, 30 Foot Radius VP)		
Tree Layer - None		
Sapling Layer - None		
Shrub Layer		
Viburnum dentatum	Arrowwood	3%
Ilex laevigata	Smooth Winterberry	3%
Morella pensylvanica	Northern Bayberry	3%
Herbaceous Layer		

Thelypteris palustris	Marsh Fern	38%
Calamagrostis canadensis	Reed Bentgrass	38%
Note: C. canadensis on hummocks		
Solidago sempervirens	Seaside Goldenrod	3%
Solidago sp.	Goldenrod	3%
Vine Layer		
Toxicodendron radicans	Poison Ivy	63%
Calystegia sepium	Hedge Bindweed	10.5%
T4-3 (BM-SS) (5, 15, 30 Foot Radius VP)		
Tree Layer - None		
Sapling Layer - None		
Shrub Layer - None		
Viburnum dentatum (dead)	Arrowwood	3%
Herbaceous Layer		
Phragmites australis	Common Reed	63%
Vine Layer		
Toxicodendron radicans	Poison Ivy	63%
Calystegia sepium	Hedge Bindweed	10.5%
T4-4 (BM-SS/SW) (No VP)		
PALUSTRINE RED MAPLE SWAMP (T4-4 to T4-7)		
T4-5 (SW) (5, 15, 30 Foot Radius VP)		
Tree Layer - None		
Sapling Layer - None		
Pinus rigida	Pitch Pine	3%
Shrub Layer		
Viburnum dentatum	Arrowwood	38%
Vaccinium corymbosum	Highbush Blueberry	38%
Lyonia ligustrina	Maleberry	20.5%
Morella pensylvanica	Northern Bayberry	3%
Spirea tomentosa	Steeplebush	3%
Herbaceous Layer		
Calamagrostis canadensis	Reed Bentgrass	38%
Note: *C. Canadensis* not on hummocks.		
Typha angustifolia	Narrowleaf Catail	10.5%
Osmunda cinnamomea	Cinnamon Fern	3%
Thelypteris palustris	Marsh Fern	3%
Phragmites australis	Common Reed	3%
Solidago sp.	Goldenrod	3%

Vine Layer		
Toxicodendron radicans	Poison Ivy	63%
T4-6 (SW) (5, 15, 30 Foot Radius VP)		
Tree Layer		
Pinus rigida	Pitch Pine	38%
Sapling Layer		
Quercus alba	White Oak	3%
Quercus sp.	Oak	3%
Note: *Quercus* seedlings present within vegetation plot.		
Shrub Layer		
Morella pensylvanica	Northern Bayberry	20.5%
Viburnum dentatum	Arrowwood	20.5%
Vaccinium corymbosum	Highbush Blueberry	3%
Ilex laevigata	Smooth Winterberry	3%
Kalmia angustifolia	Sheep Laurel	3%
Viburnum cassinoides	Wild Raisin	3%
Herbaceous Layer		
Thelypteris palustris	Marsh Fern	20.5%
	Grass sp.	20.5%
Typha angustifolia	Narrowleaf Catail	10.5%
Vaccinium macrocarpon	Cranberry	10.5%
Rubus hisbidus	Swamp Dewberry	3%
Phragmites australis	Common Reed	3%
Panicum virgatum	Switchgrass	3%
Solidago sp.	Goldenrod	3%
Vine Layer		
Toxicodendron radicans	Poison Ivy	38%
Smilax rotundifolia	Common Greenbriar	3%
T4-7 (SW) (5, 15, 30 Foot Radius VP)		
Tree Layer		
Pinus rigida	Pitch Pine	38%
Sapling Layer		
Toxicodendron vernix	Poison Sumac	10.5%
Juniperus virginiana	Cedar	3%
Shrub Layer		
Viburnum dentatum	Arrowwood	63%
Vaccinium corymbosum	Highbush Blueberry	63%
Aronia prunifolia	Purple Chokeberry	10.5%
Ilex laevigata	Smooth Winterberry	10.5%
Kalmia angustifolia	Sheep Laurel	3%
Morella pensylvanica	Northern Bayberry	3%
Lyonia ligustrina	Maleberry	3%
Herbaceous Layer		

Sphagnum sp.	Sphagnum	38%
Thelypteris palustris	Marsh Fern	20.5%
Rumex orbiculatus	Great Water Dock	10.5%
Solidago sp.	Goldenrod	3%
Trientalis borealis	Star Flower	3%
Rubus hisbidus	Swamp Dewberry	3%
Vine Layer		
Toxicodendron radicans	Poison Ivy	20.5%
Smilax rotundifolia	Common Greenbriar	10.5%
T4-8 (SW/UP) (No VP)		

Upper Basin Transect 5 (UBT-5)

Transect 5 is located on the Harwich side of Muddy Creek just to the west/southwest of Transect 4. According to the Harwich Geologic Quadrangle map, the transect crosses an abandoned cranberry bog. Discussions with adjacent residents confirmed the presence of a historic cranberry bog in the area. Man made irrigation ditches exist throughout the wetland communities. The area is listed in the DEP Wetland Mapping datalayer as a shrub swamp bordering on a shallow marsh, meadow or fen.

The transect was installed and the stakes were field located on June 3, 2011. The vegetation analysis was completed on the same day. The wetland communities along the transect transition from an Freshwater/Brackish Tidal Marsh located at the edge of the creek to a Palustrine Shrub Swamp with hummock and hollow micro-topography prior to ending at a Pitch Pine – Oak Forest Woodland community. Isolated and fragmented communities of saltmarsh cordgrass are located along the edge of the water adjacent to the abandoned cranberry bog.

Table 16
UBT-5 Vegetative Assessment

FRESHWATER/BRACKISH TIDAL MARSH (T5-1 to T5-5)		
T5-1 (EOW/BM) (1m2 Quadrat VP on upland side of stake)		
Spartina angustifolia	Salt Marsh Cordgrass	38%
T5-2 (BM) (5, 15, 30 Foot Radius VP)		
Tree Layer – None		
Sapling Layer – None		
Shrub Layer – None		
Herbaceous Layer		
Phragmites australis	Common Reed	63%
Juncus gerradii	Black Grass	10.5%
Solidago sempervirens	Seaside Goldenrod	3%
Vine Layer - None		
T5-3 (BM) (5, 15, 30 Foot Radius VP)		

Tree Layer – Dead *Pinus rigida* (Trace)		
Sapling Layer – None		
Shrub Layer – Dead shrubs (Trace)		
Herbaceous Layer		
Juncus gerradii	Black Grass	63%
Phragmites australis	Common Reed	38%
Solidago sempervirens	Seaside Goldenrod	20.5%
Vine Layer		
Toxicodendron radicans	Poison Ivy	3%
T5-4 (BM) (5, 15, 30 Foot Radius VP)		
Tree Layer – None		
Juniperus virginiana	Cedar	3%
Sapling Layer – None		
Shrub Layer – Dead *Ilex sp.* (Trace)		
Herbaceous Layer		
Phragmites australis	Common Reed	83%
Vine Layer		
Toxicodendron radicans	Poison Ivy	38%
T5-5 (BM/SS) (No VP)		
PALUSTRINE SHRUB SWAMP (T5-5 to T5-7)		
T5-6 (SS) (5, 15, 30 Foot Radius VP)		
Tree Layer - None		
Sapling Layer - None		
Shrub Layer		
Ilex laevigata	Smooth Winterberry	38%
Viburnum dentatum	Arrowwood	38%
Lyonia ligustrina	Maleberry	38%
Vaccinium corymbosum	Highbush Blueberry	20.5%
Morella pensylvanica	Northern Bayberry	3%
Spirea tomentosa	Steeplebush	3%
Viburnum cassinoides	Wild Raisin	3%
Aronia prunifolia	Purple Chokeberry	3%
Amelanchier arborea	Common Shadbush	3%
Toxicodendron vernix	Poison Sumac	3%
Herbaceous Layer		
Osmunda cinnamomea	Cinnamon Fern	20.5%
Sphagnum sp.	Sphagnum Moss	20.5%
Thelypteris palustris	Marsh Fern	10.5%
Trientalis borealis	Star Flower	3%
Rubus hisbidus	Swamp Dewberry	3%
	Sedge sp.	3%

Solidago sp.	Goldenrod	3%
Solidago sp.	Goldenrod	3%
Vine Layer		
Toxicodendron radicans	Poison Ivy	10.5%
T5-7 (SS/UP) (No VP)		

Upper Basin Transect 6 (UBT-6)

Transect 6 is located on the Harwich side of Muddy Creek just to the west/southwest of Transect 5. Although according to the Harwich Geologic Quadrangle map, the transect crosses an area of Harwich outwash plain deposits, manmade irrigation ditches were identified within the wetland communities in particular the Shrub Swamp community. The area is listed in the DEP Wetland Mapping datalayer as a shrub swamp.

The transect was installed and field located on June 3, 2011. The vegetation analysis was completed on the same day. The wetland communities along the transect transition from an Freshwater/Brackish Tidal Marsh (BM) dominated with common reed to a Palustrine Shrub Swamp with some hummock and hollow micro-topography prior to ending at a Pitch Pine – Oak Forest Woodland community with *Rosa multiflora* (Multiflora rose) invasion along the upland margins. A male Black Crowned Night Heron was observed north of the transect within the narrows on two separate visits.

Table 17
UBT-6 Vegetative Assessment

FRESHWATER/BRACKISH TIDAL MARSH (T6-1 to T6-3)		
T6-1 (EOW/BM) (1m2 Quadrat VP on inland side of stake)		
Spartina angustifolia	Salt Marsh Cordgrass	38%
Phragmities australis	Common Reed	20.5%
T6-2 (BM) (5, 15, 30 Radius VP)		
Tree Layer – None		
Sapling Layer – None		
Shrub Layer – None		
Herbaceous Layer (Phragmities australis Thatch - 83%)		
Phragmites australis	Common Reed	10.5%
Vine Layer		
Toxicodendron radicans	Poison Ivy	10.5%
T6-3 (BM/SS)		
PALUSTRINE SHRUB SWAMP (T6-3 to T6-5)		
T6-4 (SS) (5, 15, 30 Radius VP)		
Tree Layer		
Pinus rigida	Pitch Pine	3%
Sapling Layer – None		
Shrub Layer		

Ilex laevigata	Smooth Winterberry	63%
Viburnum dentatum	Arrowwood	38%
Viburnum cassinoides	Wild Raisin	10.5%
Clethra alnifolia	Sweet Pepperbush	3%
Herbaceous Layer		
Sphagnum sp.	Clubmoss	63%
	Grass sp.	10.5%
Solidago sp.	Goldenrod	10.5%
Thelypteris palustris	Marsh Fern	3%
Trientalis borealis	Star Flower	3%
Maienthemum canadense	Canada Mayflower	3%
Solidago sp.	Goldenrod	3%
Vine Layer		
Toxicodendron radicans	Poison Ivy	10.5%
T6-5 (SS/UP) (No VP)		

Upper Basin Transect 7 (UBT-7)

Transect 7 is located along the east bank of Muddy Creek in Chatham just south of the narrows. The transect traverses an old abandoned cranberry bog as reported by the adjacent land owner (May 19, 2011) and according to the Harwich Geologic Quadrangle. The area is listed in the DEP Wetland Mapping datalayer as a shrub swamp.

The transect was installed and field surveyed on April 22, 2011. The vegetation analysis was complete on May 19, 2011. A stand of common reed dominates the lower limits of the wetland between T7-1 to T7-2. The Fresh/Brackish Tidal Marsh Community gradually transitions to a heavily vegetated Palustrine Shrub Swamp Community with remnants of ditching and hummock-hollow micro-topography. The transect ends at a maintained lawn located at the upper limits of the wetland. Common reed was starting to emerge at the time of the vegetation analysis with sparse new growth in comparison to the remaining thatch. Percent cover of common reed described below is likely low as a result. A visible tree layer was absent from the transect. Redwing blackbirds were nesting in the marsh community at the time of the vegetation analysis.

Table 18
UBT-7 Vegetative Assessment

FRESH/BRACKISH TIDAL MARSH (T7-1 to T7-3)		
T7-1 (EOW/BM) (1m2 Quadrat on upland side of stake)		
Phragmites australis	Common Reed	10.5%
Scirpus acutus	Hardstem Bullrush	3%
T7-2 (BM/SS) (5 radius for herbaceous layer & 15ft radius for shrub, tree & vine layer)		
Tree Layer – None		

Sapling Layer - None		
Shrub Layer		
Aronia floribunda	Purple Chokecherry	10.5%
Morella pensylvanica	Northern Bayberry	10.5%
Vaccinium corymbosum	Highbush Blueberry	3%
Viburnum cassinoides	Wild Raisin	3%
Ilex verticillata	Common Winterberry	3%
Rosa nitada	Shining Rose	3%
Spiraea tomentosa	Steeplebush	3%
Herbaceous Layer		
Onoclea sensibilis	Sensitive Fern	10.5%
Thelypteris palustris	Marsh Fern	3%
Note: no new Phragmites australis shoots (just remaining thatch)		
Vine Layer		
Toxicodendron radicans	Poison Ivy	20.5%
PALUSTRINE SHRUB SWAMP (T7-2 to T7-4)		
T7-3 (SS) (5 ft radius for herbaceous layer & 15ft radius for shrubs, trees & vine layer)		
Tree Layer – None		
Sapling Layer		
Quercus coccinea	Scarlet Oak	3%
Shrub Layer		
Viburnum dentatum	Arrowwood	38%
Viburnum cassinoides	Wild Raisin	38%
Vaccinium corymbosum	Highbush Blueberry	20.5%
Lyonia ligustrina	Maleberry	3%
Aronia floribunda	Purple Chokecherry	3%
Amelanchier arborea	Common Serviceberry	3%
Herbaceous Layer		
Sphagnum sp.	Sphagnum Moss	10.5%
Phragmites australis	Common Reed	3%
Thelypteris palustris	Marsh Fern	3%
Onoclea sensibilis	Sensitive Fern	3%
Vine Layer - none		
T7-4 (SS/UP) (No VP)		

Upper Basin Transect 8 (UBT-8)

Transect 8 is located past the narrows on the west bank of the creek upstream of the narrows in Chatham. According to the Harwich Geologic Quadrangle map, the transect crosses an abandoned cranberry bog. Man-made irrigation ditches exist throughout the wetland communities. The area is listed in the DEP Wetland Mapping datalayer as a shrub swamp and wooded swamp coniferous.

The transect was installed and the stakes were field surveyed on April 22, 2011. The vegetation analysis was complete on June 8, 2011. The transect starts at the edge of water and transitions through a Fresh/Brackish Tidal Swamp prior to ending at a steeply sloping Pitch Pine / Oak Forest Woodland community. Remains of cranberry bog drainage ditches are located throughout the wetland with hummock-hollow micro-topography. Stressed pitch pine is located along the transect. Stress appears to be associated with salt burn.

Adjacent to T8-1, east and west of the transect along the waters edge, there are two communities of water willow. Water willow is habitat for Water Willow Stem Borer a species of moth listed as Threatened by the MA NHESP. The area was revisited on July 12, 2011 to identify the plant, however, the plant was not in full bloom. The buds were just starting to flower. The transect was revisited again on August 4, 2011 and the presence of water willow was confirmed. Approximately three multi-stemmed individuals were identified adjacent to the T8-1 stake, along the creek bank. Approximately four multi-stemmed individuals were identified approximately 10 feet east of T8-1, also on the western creek bank. No actual sign of Water Willow Stem Borer was observed at the site. The potential habitat should be reviewed by an entomologist to determine the presence of any eggs, pupae, larvae or live adults. A Rare Species Observation Form was prepared and submitted to MNHESP on August 10, 2011 to document the presence of potential habitat.

Table 19
UBT-8 Vegetative Assessment

PALUSTRINE RED MAPLE SWAMP (T8-1 to T8-5)		
T8-1 (EOW/SW) (1m2 Quadrat VP upland side of stake)		
Osmunda cinnamomea	Cinnamon Fern	38%
Thelypteris palustris	Marsh Fern	38%
Toxicodendron radicans	Poison Ivy	20.5%
Sphagnum sp.	Sphagnum Moss	20.5%
	Sedge sp.	20.5%
Impatiens capensis	Jewelweed	10.5%
Onoclea sensibilis	Sensitive Fern	10.5%
Juncus effusus	Soft Rush	3%
Agrostis gigantea	Red Top	3%
T8-2 (SW) (5, 15, 30 foot radius VP)		
Tree Layer - None		
Pinus rigida (Stressed)	Pitch Pine	3%
Sapling Layer - None		
Pinus rigida (Stressed)	Pitch Pine	3%
Shrub Layer		
Vaccinium corymbosum (Stressed)	Highbush Blueberry	38%
Viburnun dentatum	Arrowwood	10.5%
Viburnum cassinoides	Wild Raisin	3%
Ilex laevigata	Smooth Winterberry	3%

Morella pensylvanica	Northern Bayberry	3%
Herbaceous Layer		
Carex atlantica	Prickly Bog Sedge	63%
Osmunda cinnamomea	Cinnamon Fern	20.5%
Thelypteris palustris	Marsh Fern	3%
Solidago sp.	Goldenrod	3%
Sphagnum sp.	Sphagnum Moss	
Vine Layer		
Toxicodendron radicans	Poison Ivy	10.5%
Parthenocissus quinquefolia	Virginia Creeper	3%
T8-3 (SW) (No VP)		
T8-4 (SW) (5, 15, 30 foot radius VP)		
Tree Layer		
Pinus rigida (On hummocks)	Pitch Pine	20.5%
Sapling Layer - None		
Shrub Layer		
Vaccinium corymbosum	Highbush Blueberry	38%
Ilex verticullatta	Common Winterberry	38%
Viburnun dentatum	Arrowwood	20.5%
Ilex laevigata	Smooth Winterberry	10.5%
Kalmia angustifolia	Lambs Kill	3%
Lonicera morrowii	Morrow's Honeysuckle	3%
Herbaceous Layer		
Sphagnum sp.	Sphagnum Moss	38%
Osmunda cinnamomea	Cinnamon Fern	20.5%
Impatiens capensis	Jewelweed	3%
Vine Layer		
Toxicodendron radicans	Poison Ivy	20.5%
Smilax rotundifolia	Common Greenbriar	3%
T8-5 (SW/UP) (No VP)		

Upper Basin Transect 9 (UBT-9)

Transect 9 is located past the narrows on the east bank of the creek upstream of the narrows in Chatham. According to the Harwich Geologic Quadrangle map, the transect crosses an abandoned cranberry bog. Man made irrigation ditches exist throughout the wetland communities. The area is listed in the DEP Wetland Mapping datalayer as a shrub swamp.

The transect was installed and the stakes were field surveyed on April 22, 2011. The vegetation analysis was complete on June 8, 2011. The transect starts at the edge of water and transitions through a Freshwater/Brackish Tidal Marsh to a Palustrine Shrub Swamp to a narrow

Freshwater Forested Wetland prior to ending at a steeply sloping Pitch Pine / Oak Forest Woodland community. Remains of cranberry bog drainage ditches are located throughout the wetland with hummock-hollow micro-topography. A stand of red maple saplings is located to the north/northwest of the transect with red maple seedlings identified along the transect in the Shrub Swamp community. The Shrub Swamp is in the process of transitioning to a Palustrine Red Maple Swamp community.

Narrow leaved cattail has invaded the upper elevations of the Tidal Marsh and lower elevations of the Shrub Swamp. Redwing blackbirds were nesting in the Tidal Marsh community at the time of the vegetation analysis. Dislodged (floating) stands of hardstem bulrush were observed in the channel adjacent to the transect. The upper limits of Muddy Creek, upstream of approximately UBT-9, is mapped as a Emergent Marsh according to the MA GIS, DEP Wetland Mapping datalayer. It is possible that the extent of Emergent Marsh in the upper limits of Muddy Creek has diminished over time since the Chatham breach, an impact which is continuing to be realized, as observed with the present dislodging of vegetation.

Table 20
UBT-9 Vegetative Assessment

FRESH/BRACKISH TIDAL MARSH (T9-1 to T9-2)		
T9-1 (EOW/BM) (1m2 Quadrat VP)		
Scirpus acutus	Hardstem Bulrush	83%
T9-2 (BM/SS) (1m2 Quadrat VP)		
Scirpus acutus	Hardstem Bulrush	38%
Typha angustifolia	Narrowleaved Cattail	10.5%
PALUSTRINE SHRUB SWAMP (T9-2 to T9-4)		
T9-3 (SS w/ Typha) (5, 15, 30 foot radius VP)		
Tree Layer		
Acer rubrum	Red Maple	3%
Sapling Layer		
Acer rubrum	Red Maple	3%
Shrub Layer		
Viburnum cassinoides	Wild Raisin	10.5%
Vaccinium corymbosum	Highbush Blueberry	10.5%
Ilex laevigata	Common Winterberry	10.5%
Morella pensylvanica	Bayberry	10.5%
Viburnum dentatum	Arrowwood	10.5%
Rosa nitida	Shining Rose	3%
Lyonia ligustrina	Maleberry	3%
Amelanchier arborea	Common Shadbush	3%
Spirea tomentosa	Steeplebush	3%
Herbaceous Layer		
Typha angustifolia	Narrowleaved Cattail	10.5%
Thelypteris palustris	Marsh Fern	10.5%

Woodwardia virginica	Virginia Chainfern	10.5%
Eupatoriadelphus maculatus	Joepye Weed	3%
Vine Layer		
Toxicodendron radicans	Poison Ivy	20.5%
T9-4 (SS/FW) (No VP)		
FRESHWATER FORESTED WETLAND (T9-4 to T9-5)		
T9-5 (FW/UP) (No VP)		

Upper Basin Transect 10 (UBT-10)

Transect 10 is located past the narrows on the west bank of the creek upstream of the abandoned fish ladder in Chatham. According to the Harwich Geologic Quadrangle map, the transect crosses an abandoned cranberry bog. Man-made irrigation ditches exist throughout the wetland communities. The area is listed in the DEP Wetland Mapping datalayer as a shrub swamp.

The transect was installed and the stakes were field surveyed on April 22, 2011. The vegetation analysis was complete on May 19, 2011. The transect starts at the edge of water and transitions through a Fresh/Brackish Tidal Marsh to a Palustrine Red Maple Swamp to a narrow Freshwater Forested Wetland prior to ending at a steeply sloping Pitch Pine / Oak Forest Woodland community. Remains of cranberry bog drainage ditches are located throughout the wetland with hummock-hollow micro-topography. Red maple throws and tip up mounds are located within the Swamp community.

Table 21
UBT-10 Vegetative Assessment

FRESH/BRACKISH TIDAL MARSH (T10-1 to T10-3)		
T10-1 (BM) (1m2 Quadrat on inland side of stake)		
Typha angustifolia	Narrowleaved Cattail	20.5%
T10-2 (BM w/Shrub Swamp at upper limits) (5ft for Herb, 15 for SH,S,T&Vine Layers)		
Trees - None		
Saplings		
Acer rubrum	Red Maple	20.5%
Shrubs		
Aronia floribunda	Purple Chokecherry	10.5%
Viburnum dentatum	Arrowwood	10.5%
Clethra alnifolia	Sweet Pepperbush	3%
Vaccinium corymbosum	Highbush Blueberry	3%
Morella pensylvanica	Northern Bayberry	3%
Rosa nitida	Shining rose	3%

Ilex laevigata	Smooth Winterberry	3%
<u>Herbaceous Layer</u> - None		
Typha angustifolia	Narrowleaved Cattail	20.5%
<u>Vine Layer</u>		
Toxicodendron radicans	Poison Ivy	20.5%
<u>PALUSTRINE RED MAPLE SWAMP</u> (T10-3 to T10-5)		
T10-4 (SW) (5, 15, 30 foot VP)		
<u>Tree Layer</u>		
Acer rubrum	Red Maple	20.5%
<u>Sapling Layer</u>		
Acer rubrum	Red Maple	38%
<u>Shrub Layer</u>		
Rhododendron viscosum	Swamp Azalea	38%
Ilex laevigata	Smooth Winterberry	38%
Clethra alnifolia	Sweet Pepperbush	20.5%
Vaccinium corymbosum	Highbush Blueberry	3%
Morella pensylvanica	Bayberry	3%
<u>Herbaceous Layer</u>		
Onoclea sensibilis	Sensitive Fern	38%
Sphagnum sp.	Sphagnum moss	38%
Thelypteris palustris	Marsh Fern	3%
Impatiens capensis	Jewelweed	3%
Viola sp.	Violet	3%
T10-5 (SW/FW) (No VP)		
<u>FRESHWATER FORESTED WETLAND</u> (T10-5 to T10-6)		
T10-6 (FW/UP) (No VP)		

<u>Upper Basin Transect 11 (UBT-11)</u>

Transect 11 is located upstream of the abandoned fish passage on the east bank of the creek in Chatham. According to the Harwich Geologic Quadrangle map, the transect crosses an abandoned cranberry bog. The area is listed in the DEP Wetland Mapping datalayer as a shrub swamp.

The transect was installed and the stakes were field surveyed on April 22, 2011. The vegetation analysis was complete on May 19, 2011. The transect starts at the edge of water and transitions through a Fresh/Brackish Tidal Marsh to a Fresh/Brackish Tidal Swamp to a narrow Freshwater Forested Wetland/Floodplain Wetland prior to ending at a steeply sloping Pitch Pine / Oak Forest Woodland community. Remains of cranberry bog drainage ditches are located throughout the wetland with hummock-hollow micro-topography.

Table 22
UBT-11 Vegetative Assessment

FRESH/BRACKISH TIDAL MARSH (T11-1 to T11-3)		
T11-1 (EOW/BM) (1m2 Quadrat on upland side of stake)		
Scirpus acutus	Hardstem Bulrush	10.5%
T11-2 **(BM)** (1m2 Quadrat inland side of stake)		
Scirpus acutus	Hardstem Bulrush	20.5%
Typha angustifolia	Narrowleaved Cattail	10.5%
T11-3 (BM/SW) (No VP)		
PALUSTRINE SHRUB SWAMP (T11-3 to T11-5)		
T11-4 (5, 15, 30 foot Radius VP)		
Tree Layer		
Pinus rigida	Pitch Pine	3%
Sapling Layer - None		
Shrub Layer		
Ilex verticillata	Common Winterberry	38%
Clethra alnifolia	Sweet Pepperbush	20.5%
Viburnum dentatum	Arrowwood	20.5%
Morella pensylvanica	Bayberry	20.5%
Vaccinium corymbosum	Highbush Blueberry	3%
Rosa multiflora	Multiflora rose	3%
Herbaceous Layer		
Sphagnum sp.	Sphagnum moss	38%
Onoclea sensibilis	Sensitive Fern	10.5%
	Grass species	3%
Vines		
Toxicodendron radicans	Poison Ivy	3%
Smilax rotundifolia	Common Greenbriar	3%
T11-5 (SW/FW) (No VP)		
FRESHWATER FORESTED WETLAND (T11-5 to T11-7)		
T11-6 (FW) (5, 15, 15, 20 foot Radius VP)		
Tree Layer (Modified radius to 20 feet to accommodate the width of wetland)		
Pinus rigida	Pitch Pine	10.5%
Sapling Layer		
Sassafras albidum	Sassafras	3%
Shrub Layer		
Vaccinium corymbosum	Highbush Blueberry	38%
Viburnum cassinoides	Wild Raisin	20.5%
Viburnum dentatum	Arrowwood	20.5%
Ilex verticillata	Common Winterberry	10.5%
Herbaceous Layer		
Sphagnum sp.	Sphagnum moss	10.5%

Rhubus sp.	Dewberry	3%
<u>*Vine Layer*</u> (*Modified* radius *to 20 feet wide* to accommodate the *width of wetland*)		
Smilax rotundifolia	Common Greenbriar	20.5%
T11-7 (FW/UP) (No VP)		

1.5.6 Wetland Vegetative Community Mapping

Wetland vegetation communities along Muddy Creek were mapped using data from vegetative monitoring transects established to date, field evaluations and surveys and interpretation of aerial photographs. Vegetative communities were classified using the U.S. Fish and Wildlife Wetlands and Deepwater Habitats Classification system, specifically the estuarine classification system where estuarine communities can be classified as intertidal and subtidal.

An initial delineation of wetland vegetation communities surrounding Muddy Creek was conducted through photograph interpretation of 2009 United States Geological Survey (USGS) color orthophotography imagery obtained from MassGIS having a resolution of 30 centimeter (approximately 1-foot). Distinctive aerial ground cover signatures were used to draw initial community boundaries, which were subsequently correlated to communities documented through established transects and field assessments and surveys. Each community's vegetative characteristics were evaluated in the field and community transitional boundaries were verified and adjusted using sub-meter GPS survey data. Mapped wetland communities are reflected on *Sheets RC-101* through *RC-107* in *Attachment A*.

1.6 Fisheries and Shellfish Assessments

A desktop review of existing information, interviews with relevant officials, and a site visit were completed by Saquish Scientific LLC (Sasquish) of Duxbury, MA to provide an assessment of fisheries and shellfish communities currently and historically utilizing Muddy Creek. Information was collected from existing studies, reports, literature and anecdotal reports. Additional information was gathered through interviews with local Shellfish Constables (Thomas Leach of Harwich and Stuart Moore of Chatham) and MA Division of Marine Fisheries (DMF) staff. On May 20, 2011 field surveys were conducted to assess existing shell fish resources and diadromous fish habitats. Potential impacts and benefits to these communities resulting from potential culvert widening are discussed in *Sections 1.7.3* and *1.7.4*.

1.6.1 Fisheries Assessment

The Partners have identified the protection and enhancement of diadromous fish habitat as a priority for the overall restoration project. On May 20, 2011 a qualitative visual survey of the entire Muddy Creek system was conducted to assess habitat conditions for diadromous fish species. The results of this survey are incorporated into a historic review of the extent to which

Muddy Creek serves as a migratory passageway for American eel and other diadromous fish species.

1.6.1.1 Target Species

The primary fish species of concern in the Muddy Creek culvert improvement and restoration project are American eel (*Anguilla rostrata*) and alewife (*Alosa pseudoharengus).* As described in previous sections, a number of tidal restrictions occur throughout the Muddy Creek system. The existing restrictions at Route 28 and Old Queen Anne Road impact both habitat quality and passage. Remnant features from the former dike and agricultural operations also continue to influence many of the habitat features. For example, there is a substantial change in water depth at the former dike location. During significant low water conditions, remnants of the dike make Muddy Creek barely passable while immediately downstream water depths are 3 to 4 feet.

Tidal restrictions, obstructions, water quality impairments, and water diversions have likely had a negative impact on diadromous species. Other fish migratory species such as White Perch (*Morone americana*) are well known to utilize Muddy Creek. However, White Perch have limited recreational or commercial value, and as a result little research has been completed to assess their abundance in tidal waters. Inland freshwater introduction of White Perch has been the primary area of concern for this species. In addition to the finfish discussed above, Blue Crab (*Callinectes sapidus*) are known to utilize Muddy Creek during summer months.

1.6.1.1.1 American eel (*Anguilla rostrata*)

American eel is a catadromous fish that live the majority of their lives in freshwater, waiting as long as twenty-five years before returning to the Sargasso Sea to spawn. While tolerant to a range of salinities the preferred habitat for eels (particularly larger females) is freshwater in the upper reaches of watersheds. Following spawning in the Sargasso Sea in the late winter, eel larvae (*Leptocephali*) drift on ocean currents for approximately one year and are dispersed along western and eastern Atlantic shores. Once in near coastal waters, the larvae metamorphose into a juvenile swimming stage, known as 'glass eels' for their lack of pigmentation, and seek out estuaries.

As eels continue to grow they are referred to as 'yellow eels' where they finally take on unique sexual characteristics. Yellow eels may continue to work their way upstream and inland over the course of several years, taking advantage of preferred flows and temperatures during various seasons. In general, females tend to migrate further into freshwater habitats while males may spend the majority of their life in brackish or estuarine environments.

In an estuarine environment, eels gain pigmentation at the 'elver' stage (2-5 inches) and swim up tidal rivers. In Muddy Creek the Route 28 culvert is the first obstacle that eels face in their upstream migration. Juvenile eels are relatively weak swimmers and increased water velocities have the potential to prevent passage. However, elvers use a strategy of swimming upstream with the flood tides then resting on the bottom during the ebb tides. In Muddy Creek it is likely that this swimming strategy allows elvers to overcome the challenges of the existing culvert.

Upstream of Route 28 the velocities are generally low, allowing for relatively easy upstream passage. Water depths at the site of the old dike and at the entrance to the east branch of the creek (i.e. Upper Pond) although shallow are sufficient for eel passage. The attractant from the Upper Pond likely encourages the majority of eels towards the east branch of the creek. The west branch appears to have generally low habitat potential. Water depths are generally shallow and even in mid-May benthic and surface algal mats covered the majority of the area.

The Upper Pond of Muddy Creek is former cranberry bog. The entrance to Upper Pond is a shallow winding channel before dropping back into the slightly deeper waters of the pond. Although previous water quality studies did not address micro-scale features of the upper reaches, this shallow entrance likely further restricts water exchange and leads to even longer residence times and greater water quality impairments in the Upper Pond. The Upper Pond has a generally poor habitat, with bottom sediments composed primarily of very fine muck. The field assessment was conducted in mid-May, in the very early growing season, yet dense aquatic weeds were already present and surface algal mats covered large portions of the pond. Several elvers were observed swimming amongst the aquatic growth.

Freshwater flows into the Upper Pond portion of Muddy Creek from Minister's Pond on the south side of Old Queen Anne Road through an 18" corrugated metal culvert (see *Figure 8*). DMF has reportedly observed large numbers of juvenile eels congregating at this location and has installed a passive-flow eel ramp to this outflow pipe in 2008. While the addition of the eel ramp improves the potential for eel passage it is unlikely that significant numbers of eels are successful in reaching Minister's Pond.

It is unknown how well the pipe serves as a conduit to outmigrating 'silver eels' on their way to spawn. The pipe travels approximately 800-ft underground through a number of catch basin/manhole structures with unknown invert elevations, and is subject to variable flows. There is potential that in addition to migrating elvers some larger, stronger swimming female yellow eels may make passage through the culvert under certain conditions. DMF has stated a continued interest in optimizing the eel ladder, water quality, and other conditions that would improve the eel population in Muddy Creek.

Although some eels may pass the ramp/ladder, it is believed that a majority of the Muddy Creek eel population remains below Old Queen Anne Road. Both Brad Chase (DMF) and Tom Leach (Town of Harwich) anecdotally reported adult eels throughout Muddy Creek. Depending on size and life stage American eel can serve as either important prey or key predators in system. Larger eels prey on small fish, benthic invertebrates, and are cannibalistic on smaller eels.

While eels are tolerant to a range of salinity conditions they are sensitive to water quality. The 2007 MADEP TMDL report listed upper Muddy Creek as 'significantly impaired' to 'severely degraded' with dissolved oxygen concentration at <6 mg/L up to 88% of the time and <4 mg/L up to 76% of the time. It is likely that eels move throughout the Muddy Creek system throughout the year seeking the best available water quality and food supply. Resident eel populations under the current condition are likely stressed by limited suitable habitat at many times of year.

1.6.1.1.2 Alewife (*Alosa pseudoharengus*)

Alewife runs occur throughout eastern coastal streams. Adults average 10 to 14 inches in length and weigh less than a pound. The alewife is an important forage species on which striped bass, bluefish, and other economically important fish prey. Alewives were traditionally an important commercial fish species, however large-scale population declines have lead to restrictions on the take of alewife in many Atlantic states including Massachusetts. Alewife have been impacted both inshore (habitat loss, obstructions, overfishing, etc) and offshore (bycatch). Efforts to reduce fishing pressures and improve inshore spawning potential are underway through the eastern US.

Muddy Creek was historically known as an alewife run. The 1990 Cape Cod Critical Habitats Atlas shows Muddy Creek as a significant or critical habitat based on the fish run. It is also anecdotally referenced in a number of local books including William Sargent's "Shallow Waters, a Year on Pleasant Bay." More recently, local property owners have reported seeing alewife at the mouth of the outflow pipe below Old Queen Anne Road. Both DMF and the local Shellfish Constables suggested that it is presently a small run at best. Alewife face a number of challenges in the existing conditions of Muddy Creek and it is unlikely that spawning is successful to any great degree. Alewives move inshore and travel up Cape Cod streams by early April.

Alewives are often deterred by long, narrow, dark culverts such as the ones at the Route 28 crossing. However, the reports of their upstream presence suggest that some do in fact make it past this first obstacle, and once upstream of Route 28 further passage is relatively unimpeded to the upper system. Although low points at the former dike location and the entrance to Upper Pond may be challenging on some lower tides, alewife require only about 6" of water for travel. It is likely that they pass these areas without trouble at most times or wait for opportune tides before moving upstream.

Alewives prefer to spawn above the head of tide in freshwater ponds, lakes, and slow-flowing segments of rivers and streams (Bigelow and Schroeder 1953, Scott and Scott 1988). In Muddy Creek, access to this preferred habitat is mostly denied, and whether alewife presently spawn within Muddy Creek at all is unknown. While herring tend to return to their natal grounds as adults, some mixing of stocks does occur (Ross, 1991) so their presence is not a guaranteed indicator of previous reproductive success in the system. The lack of suitable benthic substrate for eggs suggests that spawning success in the upper reaches of Muddy Creek is limited at best. Poor water quality (esp. low dissolved oxygen) and high predation in the relative tight confines of the Creek will likely have further impacts on any fry that do hatch.

While alewives have been observed schooling at the attractant freshwater flow from the outflow pipe from Minister's Pond, it is highly unlikely that any alewife swim up through this culvert. As previously noted, the configuration of catch basins/manholes currently in place along this culvert are not currently known. In particular pipe invert elevations within these connecting structures are not known, and it is possible that either perched culvert outlets exist or restrictive flow conditions (e.g., excessive velocities or turbulence) exist that impede or preclude successful upstream migration during some or all flow conditions. Even if conditions through the culvert and connecting structures were suitable according to known criteria for passage (e.g., depth, velocities), herring are not generally known to swim great lengths through dark, enclosed conduits. The pipe from Minister's Pond to Muddy Creek exceeds 800-ft of underground travel and would present a significant obstacle to successful passage. Given the above considerations, reproductive success of alewives in Muddy Creek is assessed to be low under present conditions.

1.6.2 Shellfish Assessment

The PBA has identified the protection and enhancement of shellfish as a priority for the overall restoration project. On May 20, 2011 Saquish Scientific conducted a shellfish survey in association with the proposed culvert replacement under Route 28 on the Harwich/Chatham line, Massachusetts. The shellfish survey was conducted using standard sampling methodologies for shellfish surveys. The purpose of the shellfish survey was to gather data pertaining to the existing density of shellfish and benthic habitat characteristics encompassing the area adjacent to the Route 28 culvert.

In addition to conducting the shellfish survey, Saquish also reviewed the Shellfish Suitability Area Maps and Shellfish Growing Area Maps produced by the DMF, for the above referenced site. Saquish also consulted with the shellfish constables in Harwich and Chatham and previewed the methods of shellfish sampling that were conducted in this study. The results of the shellfish survey and historic review are reported below. Additionally, anticipated changes in the condition shellfish habitat resulting from the installation of an enlarged culvert have been estimated and are reported in *Section 1.7.4*.

1.6.2.1 Background

The site upstream of the culvert is a partially mixed, low energy estuarine environment that runs northwest several kilometers where it transitions into a freshwater system. The area downstream of the Route 28 culvert is a relatively high energy, well-flushed salt marsh and sand flat environment. This area is completely flooded at high tide and at low tide the creek meanders through a series of sand flats before meeting Pleasant Bay.

Muddy Creek has historically been known to have a significant shellfish resource – primarily for soft-shelled clams (*Mya arenaria*). The entirety of Muddy Creek is DMF Designated Shellfish Growing Area SC58, with SC58.1 below Route 28 and SC58.2 above. Soft-shelled clams and quahogs (*Mercenaria mercenaria*) were historically abundant and commercially harvested both upstream and downstream of Route 28 in both Chatham and Harwich. Several other species of shellfish are noted to be present in Muddy Creek besides the commercially and recreationally important Mya and Mercenaria. For example, during the site visit on April 27, 2011 blue mussels (*Mytilus edulus*) were observed spawning in the channel just downstream of Route 28.

In 1988 DMF classified the areas upstream of Route 28 (SC58.2) as "restricted" for shellfishing as a result of bacterial concentration exceedances of water quality standards for shellfishing areas. In 1995 DMF downgraded this classification to "prohibited." No DMF sampling has been conducted upstream of Route 28 since the 1995 surveys and classification and no legal harvest has occurred since the 1995 classification. Shellfish Constables in both towns recalled significant commercial shellfish harvesting in these areas prior the closure and also noted that illegal harvesting continued following the closure, requiring frequent enforcement.

Downstream of Route 28 (SC58.1) the 1988 DMF classification was "Approved" but was changed to "Conditionally Approved" following the 1995 survey. This classification stands to date. The Towns of Chatham and Harwich manage the resource with a harvesting season from December 1st to May 31st. This restriction serves two primary functions: 1) as a protective measure for the potential of elevated bacterial concentrations associated with summertime, and 2) as a winter commercial harvest area allowing shellfishermen an opportunity to harvest in the relatively warm, shallow, protected area at the mouth of Muddy Creek.

The beach areas around the mouth of Muddy Creek are also important recreational "family" shellfish flats with both resident and non-resident permits available and popular. Following National Shellfish Sanitation Program (NSSP) guidance, DMF conducts bacterial sampling at one station within SC58.1 five times per year during the December - May harvesting season.

Shellfish constables from both towns were interviewed regarding the historical and current presence, extent, and abundance of shellfish upstream of Route 28. Neither constable reported to have evaluated resources in this area in the recent past, with the most recent observations in the mid-1990s when illegal harvesting was continuing in these areas and frequent closure enforcement was required. Both constables reported that at that time there were significant numbers of shellfish present immediately upstream of the culverts in the mid-1990's and suspect that the numbers have only increased with the lack of harvest activity. Harwich Constable Thomas Leach recounted some 'reconnaissance' trips he did in the 1970s to investigate the upstream extent of shellfish in Muddy Creek. His recollection was that soft-shells and quahogs continued to be present at moderate densities as far up as the second embayment but not further upstream.

1.6.2.2 Shellfish Survey Methods

Samples were taken on May 20, 2011, using one 12-inch modified bull rake (*Figure 12*). The bull rake was covered on the inner surface with 0.25 inch mesh as recommended by the DMF in previous shellfish surveys conducted by Saquish. The shellfish survey consisted of four transects that ran perpendicular to the creek channel (*Sheet RC-101*).

Two transects (A and B) were surveyed downstream of the culvert and two additional transects (C and D) were surveyed upstream of the culvert. The location of Transect D was shifted slightly downstream due to the existence of organic-rich mud in the vicinity of the original planned location. This change in location was made due to soft, unwadeable mud. Visual inspection from the borders of the creek and from a kayak indicated high levels of organic matter (leaf litter, etc.) and soft bottom throughout. No shellfish were observed and the bottom type was generally unsuitable for shellfish. Each transect terminus was determined from just beyond the lateral extent of observed shellfish habitat on each end of the creek channel (e.g., from salt marsh bank to opposite salt marsh bank). PVC stakes were labeled and placed at each end of each transect, which were subsequently surveyed.

Figure 12 - Modified 1-cubic foot Bullrake for Shellfish Sampling

Samples were taken at 10-foot intervals along each transect (*Figure 13*). For each sample plot, the bull rake was utilized to obtain an approximately 1 ft^2 sample to a depth of approximately 1 foot, resulting in a 1 ft^3 volume of sample. The samples were then sifted through the basket of the rake to allow for identification of individual species of shellfish. For each sample plot, data were recorded with respect to substrate characteristics, species observed, number of standard species, the size of species, as well as other pertinent characteristics of the habitat. All sampled material and species were returned to the sample area from which they were taken.

Figure 13 - Typical Layout of Transect Line Sampled at 10-ft Intervals

1.6.2.3 Shellfish Survey Results

The sediment characteristics range from fine to course sands in transects A and B (downstream of culvert), to muddy sand and anoxic mud in Transects C and D (upstream of culvert). A blue mussel bed extends from the southern end of Transect A to the culvert. The bed widens to approximately 40 to 50 feet in the vicinity of the culvert. A discrete boundary between sandy mud and soupy, anoxic mud was observed about 50 feet upstream of Transect D.

Within all sample plots varying amounts of pebbles and shell fragments were observed. Within the intertidal and subtidal, softshell clam and quahog and fragments were observed.

The results of the May 20, 2011 shellfish survey conducted by Saquish are summarized below, with tables summarizing the observed number of *Mya arenaria* (the most prominent species) by size at 10-foot distances along each transect.

1.6.2.3.1 Transect A

Transect A is located at the furthest downstream area of Muddy Creek. It extends across intertidal and subtidal habitat between two high intertidal flats. Sediments were primarily medium to coarse sand with pebbles and gravel mixed in. Clear demarcation between aerobic and anaerobic sediments (vertical) were observed approximately one-inch below the surface. Patches of shell hash were also present within the creek channel.

Sampling began from south to north (from markers A1 to A2). For example, interval "0" was located at the southern end of the transect at marker A1.

Table 23
Numbers of Live Softshell Clams (*M. arenaria*) Observed in Transect A

Interval (feet)	Length (inches) =< 0.25	0.5	1.0	1.5	2.0	2.5	3.0	3.5	4.0
0	0	1	1	0	0	0	0	0	0
10	0	0	0	0	2	0	0	0	0
20	0	3	0	0	0	0	0	0	0
30	0	8	0	0	0	0	0	0	0
40	3	0	0	0	0	0	0	0	0
50	0	1	1	0	0	0	0	0	0
60	1	0	0	0	0	0	0	0	0
70	1	0	1	0	0	0	0	0	0
80	0	2	0	0	0	0	0	0	0
90	0	0	0	0	0	1	0	0	0
100	0	0	3	0	0	0	0	0	0
110	0	0	0	0	0	0	0	0	0
120	1	0	0	0	0	0	0	0	0
130	2	0	1	2	1	1	0	0	0
140	4	1	1	0	1	0	0	0	0
150	0	0	1	0	0	0	0	0	0
160	0	10	0	0	0	0	0	0	0
170	2	0	0	0	0	0	0	0	0
180	0	0	0	0	0	0	0	0	0
190	3	0	5	2	1	2	1	0	0
200	13	13	24	4	7	0	2	1	0
210	0	1	4	1	1	4	1	1	3
Total	**30**	**40**	**42**	**9**	**13**	**8**	**4**	**2**	**3**

[a]Total number of M. arenaria in transect: 151
[b]Total number of samples taken: 22
[c]Number of *M. arenaria*/ft^2: 6.86

1.6.2.3.2 Transect B

Transect B is located just downstream of the culvert, extending across the Muddy Creek channel between two areas of low marsh (*S. alterniflora*). Sediments were primarily coarse sand along the margin of the salt marsh and fine sand and mud in the middle of the creek channel. Most samples had pebbles and gravel mixed within the sand. Some samples on the northern side of the creek channel had relatively higher levels of organic material and anoxic sediments. Patches of shell hash were also present within the creek channel.

Samples were taken from south to north along the transect. For example, the interval value "0" coincides with transect marker B1.

Table 24
Numbers of Live Softshell Clams (*M. arenaria*) Observed in Transect B

	Length (inches)								
Interval	**=< 0.25**	**0.5**	**1.0**	**1.5**	**2.0**	**2.5**	**3.0**	**3.5**	**4.0**
0	0	0	0	0	0	0	0	0	0
10	0	0	0	1	0	0	0	0	0
20	5	0	1	2	0	0	0	0	0
30	0	2	0	0	0	0	0	0	0
40	0	0	2	1	1	1	0	0	0
50	2	0	1	1	1	0	1	0	0
60	1	0	0	0	0	2	0	0	0
70	1	0	0	0	1	5	0	0	0
80	3	0	0	0	0	0	1	0	0
90	0	0	0	0	0	0	0	0	0
100	4	0	1	0	0	0	0	0	0
Total	**16**	**2**	**5**	**5**	**3**	**8**	**2**	**0**	**0**

[a]Total number of M. arenaria in transect: 41
[b]Total number of samples taken: 11
[c]Number of *M. arenaria*/ft^2: 3.73

1.6.2.3.3 Transect C

Transect C is located just upstream of the culvert. It extends across the Muddy Creek channel between two areas of low marsh (*S. alterniflora*). Sediments were somewhat similar to Transect B, primarily coarse sand along the margin of the salt marsh and fine sand and mud in the middle of the creek channel. Most samples had pebbles, gravel, and shell hash mixed within the sand. Most samples on the edges of the creek channel, along the salt marsh had relatively higher levels of organic material and anoxic sediments.

Samples were taken from north to south along the transect. Sampling began ten feet from marker C1 due to the presence of salt marsh. This is the reverse direction of previously described Transects A and B.

Table 25
Numbers of Live Softshell Clams (*M. arenaria*) Observed in Transect C

	Length (inches)								
Interval	**=< 0.25**	**0.5**	**1.0**	**1.5**	**2.0**	**2.5**	**3.0**	**3.5**	**4.0**
0	0	0	2	0	8	1	0	0	1
10	0	0	0	0	2	1	0	0	0
20	0	1	0	0	2	0	0	0	0
30	0	0	1	0	2	0	3	0	1
40	0	0	1	0	0	0	2	1	0
50	0	0	2	0	1	0	0	0	0
60	0	0	2	0	2	0	1	1	0
70	0	0	1	0	6	0	1	0	0
80	0	0	0	0	0	0	0	0	0
90	0	0	1	0	4	3	1	0	1
100	0	0	2	0	8	1	0	0	1
Total	**0**	**1**	**10**	**0**	**27**	**5**	**8**	**2**	**3**

[a]Total number of M. arenaria in transect: 56
[b]Total number of samples taken: 10
[c]Number of *M. arenaria*/ft^2: 5.60

1.6.2.3.4 Transect D

Transect D is located further upstream of the culvert from Transect C. It extends across a wider section of Muddy Creek channel between two areas of low marsh (*S. alterniflora*). Sediments were somewhat similar to Transect C: primarily coarse sand along the margin of the salt marsh and fine sand and mud in the middle of the creek channel. But sediments were notably softer and contained higher levels of organic matter. Most samples had pebbles, gravel, and shell hash mixed within the sand. Most samples on the edges of the creek channel, along the salt marsh (particularly along the southern edge) had relatively higher levels of organic material and anoxic sediments.

Samples were taken from north to south along the transect. Sampling began ten feet from marker D1 due to the presence of salt marsh. This was also sampled in the reverse direction of previously described Transects A and B.

Table 26
Numbers of Live Softshell Clams (*M. arenaria*) Observed in Transect D

	Length (inches)								
Interval	**=< 0.25**	**0.5**	**1.0**	**1.5**	**2.0**	**2.5**	**3.0**	**3.5**	**4.0**
10	0	0	1	0	3	0	1	2	0
20	0	0	1	0	2	5	5	3	0
30	0	2	8	0	22	3	0	0	2
40	0	0	5	0	3	4	0	0	0
50	0	0	2	0	0	1	3	0	0
60	0	0	0	0	2	5	2	0	2
70	0	0	2	0	3	0	0	1	0
80	0	0	0	0	0	2	1	1	0
90	0	0	0	0	0	0	0	0	0
100	0	0	0	0	0	0	0	0	0
110	0	0	0	0	0	0	0	0	0
Total	**0**	**2**	**19**	**0**	**35**	**20**	**12**	**7**	**4**

[a]Total number of M. arenaria in transect: 99
[b]Total number of samples taken: 11
[c]Number of *M. arenaria*/ft^2: 9.00

1.6.2.3.5 Shellfish Habitat Summary

M. arenaria clams dominated all four transects. Other species observed included *M. mercenaria* (five individuals, *Table 27*), one *Petricolaria pholadiformis* (false angel wing), and two *M. edulis* (blue mussel) outside of the 90' sampling station of Transect C. The mussel bed just upstream of the culvert occupied approximately 50% of the creek bed (the southern 50%) between Transect C and the culvert. The bed consisted of 1 to 3" mussels in very high densities (not measured).

Table 27
Summary of *M. mercenaria* Observed

Size (in.)	Transect A	Transect B	Transect C	Transect D
< 0.25	0	0	0	0
0.5	0	0	0	0
1.0	1	0	1	1
1.5	0	0	0	0
2.0	0	0	1	0
2.5	1	0	0	0

1.7 Anticipated Post-Construction Natural Resource Changes

Previous hydrodynamic modeling (White et al., 2008; Kelley, 2010) identified replacing the culvert with a 24-foot wide hydraulic opening in order to achieve the desired tidal flux into the Muddy Creek system. Under a separate technical memorandum prepared for this study, a review of the alternatives available to replace the existing Route 28 culvert are evaluated in further detail. This technical memorandum, in general, and this section specifically addresses the potential effects of enlarging the culvert on existing vegetative communities and fishery/shellfish resources.

1.7.2 Anticipated Vegetative Community Changes

1.7.2.1 Hydrology and Salinity

In regions such as New England that are subject to a semi-diurnal tidal pattern the lower elevations of the salt marsh (or "low marsh") are subject to daily inundation by tidal waters while higher salt marsh elevations (or "high marsh") are subject to tidal inundation only during spring high tides and storm events. Each of these zones has a characteristic set of plant species adapted to conditions resulting from specific tidal flooding regimes. The following sketch depicts a typical profile of an estuarine habitat extending from a tidal river channel landward to upland habitat (*Figure 14*).

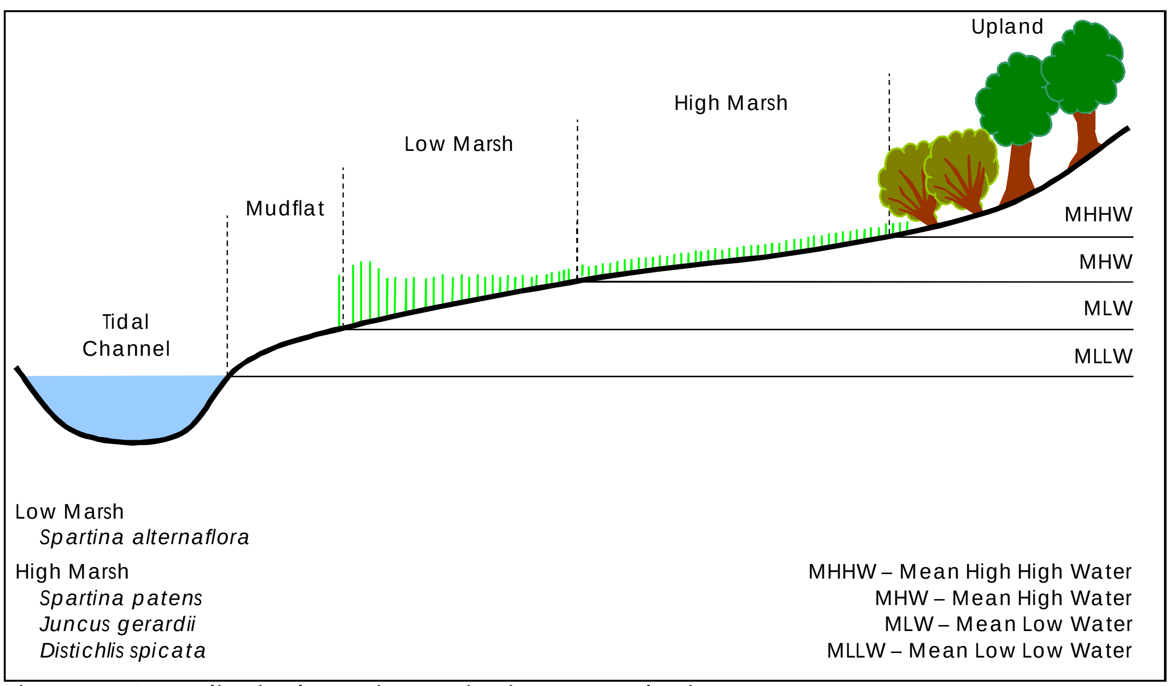


Figure 14 - Generalized Salt Marsh Zonation in New England

Numerous factors influence the formation of a salt marsh, including climate, hydrology, and physical factors. Climatic factors include precipitation and temperature, hydrologic factors include tides, wave energy and patterns of fresh groundwater discharge and physical factors include elevation, slope, sediment and soil composition, surface water, and salinity. Salt marshes form in protected shallow-waters between the land and ocean and both salt and freshwater inputs affect their development. Generally, these areas are physically protected, with slowly flowing waters, sediments carried both downstream from rivers and upstream by flood tides accumulate.

Over extended periods areas of accumulated sediment are colonized by saltwater grasses (Warren 1997). Consequently, the vegetated communities create habitat for other organisms. *Spartina alterniflora*, for example, creates habitat for organisms such as ribbed mussels (*Guekensia demissa*) and fiddler crabs (*Uca* spp.), which then create a positive feedback for cord-grass, which increases sediment deposition and helps to form the saltmarsh community (Warren 1997). Over time, the salt marsh develops into a rich, complex, and diverse community. Saltmarsh habitats play an important role in pollution control, storm surge protection, fish and shellfish nursery habitat, waterbird use, and overall near-shore marine productivity. Therefore, as tidal range increases so does salt marsh productivity (Steever et al. 1976).

Salt marsh vegetation communities are the most consistent indicator of tidal limits in the estuarine environment. *Spartina alterniflora* is tolerant to wide fluctuations in inundation and but generally requires consistent salinity levels, making it well suited for, and dominant in, low marsh areas. *Spartina patens*, *Distichlis spicata* and *Juncus gerardii* are three species that are less tolerant of long durations of inundation; however, they are tolerant of higher salinity levels typical in high marsh areas (Mitsch & Goselink, 2000).

Elevations of the salt marsh surface were collected when salt marsh vegetation community transects were established (*Sections 1.4.4.4* and *1.4.4.5*). Specifically, surface elevations were taken at areas of distinct transitions from one vegetation community to another. For example, elevations were taken at the transition from un-vegetated marsh edge (proximal to the tidal channel) to the low marsh community; from the low marsh community to the high marsh community; and from the high marsh community to the upland community.

To account for variability in the measurement of salt marsh surface elevations (e.g., microtopography, sinking, compression, etc.) the transition elevations between major salt marsh communities were averaged. The major tidal conditions or elevations (i.e., Mean High High Water (MHHW), Mean High Water (MHW), Mean Low Water (MLW), and Mean Low Low Water (MLLW)) were then estimated. These elevations were compared to observed tidal elevations from the SMAST-ACRE report (White et al, 2008). Lastly, the estimated changes in tidal elevations associated with the construction of a 24-foot wide culvert were assessed to identify areas of anticipated changes in salt marsh communities. All elevations are reported in NAVD 88.

A semi-quantitative approach was applied to Lower Muddy Creek where the altered hydrology would have a more substantial effect on salt marsh communities. A qualitative evaluation was applied to Upper Muddy Creek. The following vegetation-based tidal conditions were determined based on elevations at transitions between existing vegetative communities (*Table 28*).

Table 28
Vegetation-Based Tidal Elevations for Existing Conditions

Vegetation Transition	Tidal Condition Equivalent	Estimated Tidal Elevation
High Marsh/Upper Border Vegetation	MHHW	1.2
Low Marsh/High Marsh	MHW	0.8
Edge of Water/Low Marsh	MLW	0.4
Edge of Water/Mudflat	MLLW	0.1
Elevations are reported in feet NAVD88		

According to the 2008 SMAST-ACRE report (White et al., 2008), tidal elevations were collected during two complete tidal cycles on June 16 and July 16, 2008. A detailed hydrodynamic model was generated for Muddy Creek from these data sets as well as extensive data from tidal gauges around Pleasant Bay (White et al., 2008; Kelley, 2009). Based on these two periods of observation, the tidal amplitude in Muddy Creek (both the upper and lower portions) was 0.6 feet, which is significantly dampened by the existing culvert. This dampening is apparent when the ranges in Muddy Creek are compared to the tidal amplitudes observed in Pleasant Bay immediately downstream of the culvert, which were 2.8 and 2.3 feet on June 16 and July 16, 2008, respectively. *Table 29* shows the tidal elevations for respective tidal conditions as reported by Kelley (2009, originally presented by White et al. (2008)).

An evaluation of the vegetation communities and the observed tidal amplitudes showed incongruities in the data sets. There is a notable discrepancy between the updated tidal elevations reported by Kelly (2009) and the observed ranges of saltmarsh vegetation communities, as shown in *Table 29*.

Table 29
Comparison of Modeled and Vegetation-Based Tidal Elevations

Tidal Condition	2009 Model	Vegetation-Based	Difference
MHHW	1.6	1.2	0.3
MHW	1.5	0.8	0.6
MTL*	1.3	0.6	0.7
MLW	1.0	0.4	0.5
MLLW	1.0	0.1	0.8
		Average	0.6
*MTL is calculated as the midpoint between MHW and MLW Elevations reported in feet NAVD88			

An average difference of 0.6 feet is a substantial difference in elevation on a salt marsh especially in a system where tidal fluctuations are dampened because of the culvert restriction and the range between largest tidal conditions (MHHW to MLLW) is approximately 1.1 feet. As such, the difference between the measured tidal conditions and vegetation–based tidal conditions is relatively significant.

A closer look at the data and the relative ranges of the tidal elevations results in the following comparisons, shown on *Table 30*.

Table 30
Comparison of Tidal Ranges between Modeled and Vegetation-Based Tidal Elevations

Range of Tidal Conditions	2009 Model	Vegetation-Based
MHHW – MLLW	0.6	1.1
MHW – MLW	0.5	0.4

While the absolute elevations are not equivalent, the relative elevations are slightly more comparable. For this reason, rather than relying on the absolute elevations to estimate the effects on vegetation communities, greater consideration was given for the range of tidal conditions and the associated relative elevations (*Figure 15).*

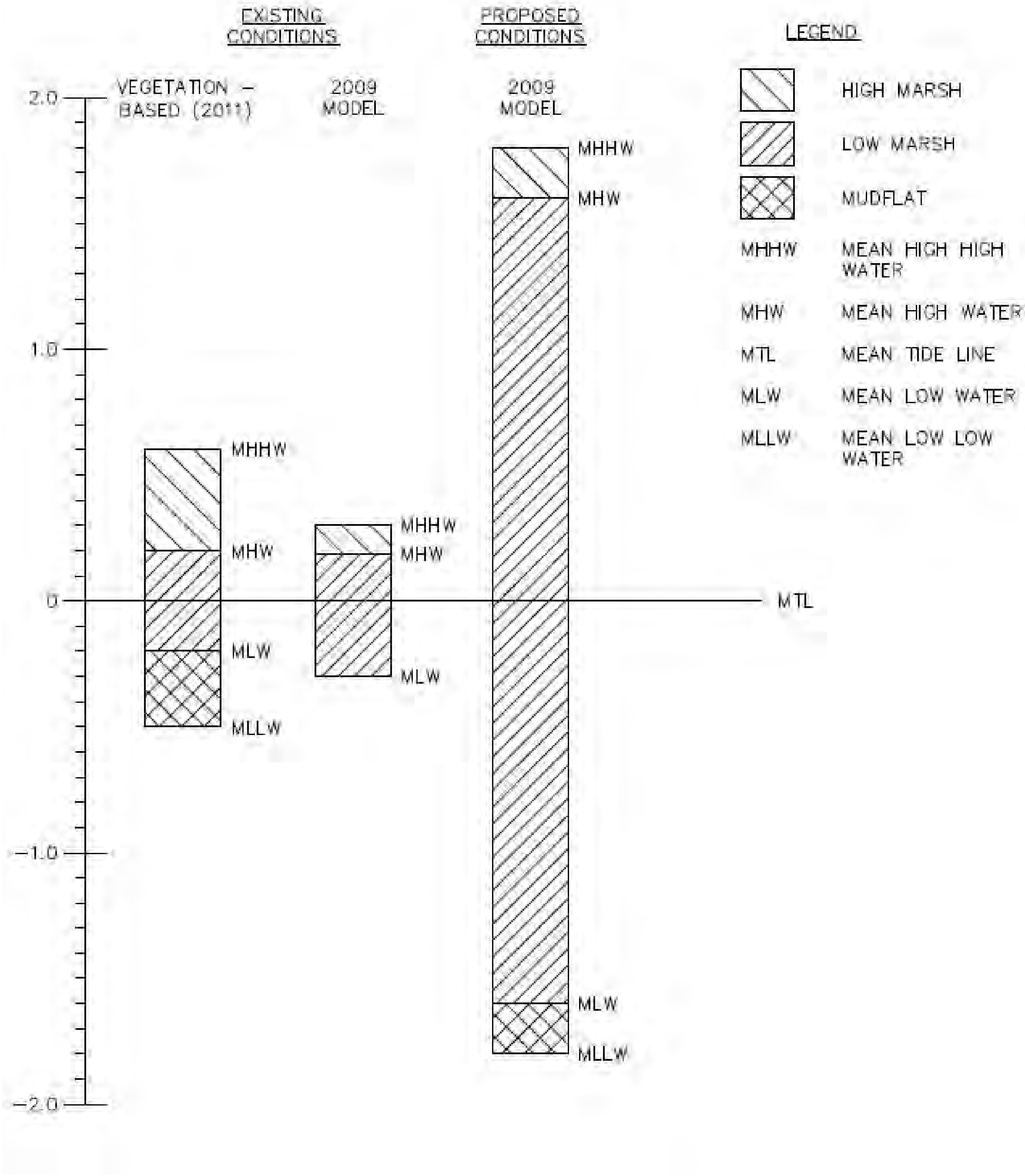


Figure 15 - Relative Tidal Ranges Using a Vegetation-Based Reference. Units based on feet NAVD88

These elevations are based on the assumptions that the Mean Tide Level (MTL) is the baseline measurement (or zero point) for all tidal elevations, that the vegetation-based tidal elevations accurately represent the hydrologic dynamics of the site, and that the difference in the MTL from existing to proposed conditions is 0.3 feet NAVD88.

Replacing the existing culverts with a 24-foot single culvert will result in the approximate changes in vegetation-based tidal elevations shown in *Table 31*.

Table 31
Vegetation-Based Tidal Elevations
for Proposed 24-foot Single Culvert

Tidal Condition	Existing Conditions	Proposed 24-ft. Single Culvert
MHHW	1.2	2.1
MHW	0.8	1.9
MTL*	0.6	0.3
MLW	0.4	-1.3
MLLW	0.1	-1.5
*MTL is calculated as the midpoint between MHW and MLW Elevations reported in NAVD88		

Installation of a 24-foot single culvert will result in an increased tidal amplitude of 3.6 feet between MHHW and MLLW (increased by 2.5 feet) and 3.2-foot range between MHW and MLW. The latter is an eight-fold increase in the tidal amplitude compared to existing conditions. These tidal elevations reflect those which would be expected on a regular, lunar cycle and do not account for storm surges or sea level rise.

Salinity will also have a significant influence vegetative community changes within Muddy Creek. White et al (2010) reported that salinity concentrations in Lower Muddy Creek (PBA 5, *Table 1*) were, on average, 25.3 parts per thousand (ppt). Further upstream beyond the former dike in Upper Muddy Creek (PBA 5A), salinities were on average 13.6 ppt. While surface water salinity data was not collected upstream of PBA 5A, sediment salinity was measured in several locations throughout the basin. Salinities ranged from 25.1 ppt near the culvert (MC-5, *Table 1*) to 0.5 ppt in an upstream backwater area (MC-8).

Using sediment salinity as a proxy to surface water salinity, concentrations decrease at a rapid rate as tidal flood waters move through the upper half of Upper Muddy Creek. This is likely due to the dampened tidal fluctuations in the creek as well as a significant freshwater input component. The increase in tidal range associated with the proposed 24-foot single culvert will certainly result in significant increase in saltwater concentration in Upper Muddy Creek as eight-times more head of tidal water will advance upstream during flood flows.

1.7.2.2 Lower Muddy Creek

In the Lower Muddy Creek basin, during periods of high tide the increased tidal range are expected to result in flooding up to the existing toe of slope that confines the Muddy Creek estuary. During low tide, large areas that are currently sub-tidal are expected to become exposed.

Given the anticipated range in tidal elevations compared to the existing tidal conditions, low marsh communities will likely see the greatest immediate expansion. In the short term, it is expected that sub-tidal areas will become mudflats and areas that are high marsh will become low marsh. In the midterm, it is expected that low marsh vegetation (i.e. *Spartina alterniflora*) will colonize areas of mudflats (waterward expansion) and out-compete areas of high marsh species (landward expansion).

Losses of high marsh area, however, are not expected to be permanent. Instead, as flooding and, more importantly, salinity levels increase, existing stands of *Typha* and *Phragmites* are expected to contract and woody vegetation along the toe of slope retreat landward, helping to improve the wetland system's overall biodiversity. In these areas, new stands of high marsh communities are expected to become established dominated by species such as *Spartina patens*, *Distichlis spicata* and *Juncus gerardii*. Similarly, native shrub and tree communities will move landward where the effects of salinity and tidal fluctuation are minimal. Over time, accretion due to the establishment of a more expansive low marsh system and inputs of sediment associated with increased tidal flushing will allow for the expansion of high marsh communities from their new position in a waterward direction.

Sheets RP-101 to *RP-103* in *Attachment D* depict the estimated extent of changes expected in the Lower Muddy Creek system.

1.7.2.3 Upper Muddy Creek

The existing vegetation in the upper basin of Muddy Creek is strongly influenced by several existing and historical factors including freshwater inputs from upstream sources, historic impoundment of Upper Muddy Creek, and ditching and draining of wetland areas. These factors combined with changes in hydrologic conditions shared with Lower Muddy Creek, make this a more dynamic system. As such, predicting the changes in vegetation is more complicated as the system transitions from a mixed freshwater and brackish system to a predominantly brackish system.

As described in *Section 1.4*, much of the Upper Muddy Creek vegetation communities are brackish to freshwater assemblages. Previous investigations have shown that salinity levels in the very upper reach of this section of the creek are low (less than 10 ppt) to very low (1 ppt). These low salinity concentrations coupled with a history of disturbance have resulted in extensive areas of *Phragmites* and *Typha* colonization.

The future enlarged culvert replacement will result in an increased tidal range from the existing 0.6 feet to the predicted 3.6 feet. Using the vegetation-based estimated tidal elevations, it is expected that substantial flooding during high tides and marsh exposure during low tides will occur in the existing Upper Muddy Creek marshes.

While *Phragmites* can tolerate inundation of upwards of three feet, especially temporary inundation as seen in tidal area, it typically can only tolerate salinities of less than 15 ppt. Even under those circumstances *Phragmites* will typically exhibit signs of stress (e.g. stunted growth, chlorosis, etc.). Salinity levels less than 10 ppt are characteristic of locations where *Phragmites* is most typically successful.

Though not estimated in this or previous studies to date, the anticipated post-construction tidal conditions will certainly increase the reach of the brackish water into Muddy Creek. It is likely that salinity concentration of 10 ppt or more will regularly inundate Upper Muddy Creek up through transect UBT-06. Moreover, salinity concentration greater than the typical 1 ppt will be likely further into the upper reaches of Muddy Creek.

Under existing conditions the reach of Muddy Creek near transects UBT-9 through UBT-11 becomes very shallow such that exposed mudflats are common under normal tidal conditions. Under anticipated tidal conditions, the backwater effect caused by the existing undersized culverts will be removed and the extent of mudflats through this reach will increase over the short term. Over the long term, these mudflat areas will be colonized first by low marsh species while more landward areas, where freshwater inputs are greater, will be vegetated by brackish marsh or high marsh assemblages.

Sheets RP-104 to RP-107 in *Attachment D* depict the estimated extent of changes expected in the Upper Muddy Creek system.

1.7.3 Anticipated Fisheries Changes

The anticipated change in tidal amplitudes following enlargement of the Route 28 culvert are associated with a number of predicted changes which may affect fish and shellfish in the system. The most relevant changes relate to water velocities, increased tidal amplitude, and improved water quality. The following sections provide a qualitative estimate of how these physical changes will influence fish and shellfish following this work.

1.7.3.1 American eel (Anguilla rostrata)

Increased water velocities are predicted at and near Route 28 following the installation of the larger culvert, with peak velocities anticipated to be up to 5 ft/sec. These velocities exceed the burst speed of elver eels (2-3 ft/sec), and length of the culvert is much longer than top burst speeds can be maintained (<5-ft) (McCleave, 1980). However, as mentioned previously, elvers employ a strategy of utilizing flood tides for upstream travel then maintain position on the bottom during ebb tides. It is not anticipated that the increased ebb velocities would limit upstream migration of American eel.

The modeled changes in tidal amplitude predict that there will be both an increase in high water levels and a decrease in low water levels. The increase in tidal heights will result in greater upstream salinities. American eel are tolerant to a range of salinities and are unlikely to be affected by this change. Decrease in the mean low water and lower low water may result in short-term impediments to both upstream and downstream passage through the shallower sections of the system (former dike and Upper Pond entrance). However, eels need very little water for travel and it would only be brief periods during low tide when this would be an issue, if at all. It is not expected that changes in tidal amplitude will have an overall impact to eels (except as it relates to water quality).

A anticipated benefit of the enlarged culvert is improved water quality within the upper system by increased tidal exchange and flushing. If this does in fact occur and nutrient concentrations decrease, algal blooms will also diminish, dissolved oxygen will increase, sediment movement will increase, and other natural functions will be restored. All of these are an improvement over the existing conditions for American eel. Water quality improvements in degraded areas will expand the overall available suitable habitat.

While habitat conditions within Muddy Creek will be improved, the lack of adequate access to inland freshwater habitats will be unchanged by the project. The outlet pipe from Minister's Pond into Muddy Creek may currently pass some eels, however it is far from optimal. American eel populations have declined throughout most of their range and habitat loss has been a contributing factor. Long term local restoration objectives may include improvements to the structure, flow regulation, maintenance plans, and habitat assessments further inland.

1.7.3.2 Alewife (Alosa pseudoharengus)

Increased water velocities of up to 5ft/sec at the proposed culvert are well within the swimming abilities of alewife over short distances. Increasing the size of the culvert to the proposed 24-ft will increase light, space, and tidal opportunities for herring passage. The enlargement of the culvert, despite increased velocities, is anticipated to be a benefit to herring migration.

Increases in tidal amplitude may have a number of impacts to alewife in Muddy Creek. A decrease in low water elevations may result in some temporal restrictions to migration in existing shallow areas such as the former dike and the entrance to Upper Pond. However, these are likely to be minimal hindrances since water depth will be sufficient during the majority of the tidal cycle and will be greatly improved during higher tides as compared to the existing condition. Increases in tidal amplitude will also result in higher salinities at upstream portions of the Creek, which may have a negative impact on alewife spawning potential. Alewives require freshwater habitats to spawn with ponds and lakes being the ideal habitat. Increased salinity in the upper reaches of the Muddy Creek with further limit the availability of suitable spawning habitat.

Improvements to water quality as a result of the proposed culvert upgrade may improve conditions for alewife spawning and juvenile success. However, the reductions in spawning habitat as a result of increased salinity may offset the benefit. Due to the lack of access to suitable freshwater habitats Muddy Creek does not currently represent a significant alewife run. Improvements at Route 28 without further fish passage improvements at Old Queen Anne Road are not likely to change that. However, the improvements at Route 28 are anticipated to create a positive change in terms of water quality and fish passage. This would be a critical first step in a larger herring restoration improvement project that ultimately provided access to high quality upstream spawning areas.

1.7.3.3 Other Species

Other migratory species such as White Perch (*Morone americana*) and Blue Crab (*Callinectes sapidus*) are known to utilize Muddy Creek. While these species were not specifically assessed in this evaluation it is anticipated that water quality improvements as a result of the proposed culvert replacement would benefit all species currently utilizing the system.

1.7.4 Anticipated Shellfish Changes

As noted above, replacement of the Route 28 culvert will affect water velocities in the immediate vicinity of the culvert, increase tidal amplitudes throughout the system, and is expected to improve water quality over the long term. Modeling work completed by Kelly (2009) suggests that construction of a 24-foot culvert will significantly increase tidal influence behind Route 28. Tidal amplitude is predicted to widen appreciably (e.g., maximum range from 1.1 to 2.6 feet) and in increase in tidal current velocities is anticipated. Several results related to shellfish habitat can be expected under this scenario.

Increased tidal range (both high and low means and maximums) will result in changes in frequency and duration of submerged and dry conditions in the existing intertidal and subtidal zones. The increase in tidal influence, or communication, with Pleasant Bay will likely extend the existing salinity transition zone landward and alter the nature of stratification that presently exists. During calm conditions stratification within the water column is easily noticed from the upstream side of Route 28 up to the point where the creek bifurcates into northern and southern lobes. Increased tidal energy and the infusion of higher salinity water through the existing restriction, will likely result in higher mean salinities in the lower portions of the creek.

All species of shellfish that are currently common to the area should not suffer any direct undesirable responses due to changes in salinity in post-construction conditions both upstream and downstream of the culvert. The changes in tidal range may alter the local conditions enough to change recruitment of shellfish. Once spawning occurs, shellfish native to the area spend two to three weeks as free-swimming larvae where they can be transported appreciable distances from their parent beds (i.e., some portion of the current populations of shellfish species in the Muddy Creek system have originated from outside the system). Increased flushing will increase the likelihood that larval shellfish originating in Muddy Creek will be exported to Pleasant Bay, though some portion may flush back in, or remain in, and ultimately set there. The biophysical process that determine larval survival and setting are variable and complex. However, the important thing to consider is how suitable the post-construction habitat will be.

The increased flushing should aid in the removal of organic matter in the areas immediately upstream of the culvert. Currently there is a transition zone from sand and mud to organic-rich sediments where the creek bed widens (heading upstream from culvert) and along the edges of the salt marsh. Areas of anoxic mud are not usually conducive to shellfish setting. Some of these areas may transition to sediments lower in organic content and the increase in volumetric flushing should alleviate any existing hypoxia and anoxia.

Combined, these responses should ultimately enhance shellfish habitat area in this region by improving environmental conditions associated with the setting of shellfish larvae. However, the increase in tidal flushing, and resulting reduction in water residence time may have some effect on shellfish setting. But again, the nature of shellfish recruitment depends on larval health, abundance, predatory, and environmental conditions in addition to habitat conditions.

2 Geotechnical Investigation and Assessment

2.1 Introduction

The first known records of an engineered crossing over Muddy Creek's outlet to Pleasant Bay place construction of an elevated timber bridge in the 1870's. After this date the crossing was filled with soil excavated from the adjacent hill in Chatham with the installation of a single culvert around 1900. A photograph of this embankment being constructed (looking from Harwich into Chatham) is provided as *Figure 16*. From this photograph, it can be seen that the soils used to construct the embankment are from adjacent land, comprised of what appears to be predominantly sandy material.

Figure 16 – Embankment Construction across Muddy Creek Estuary (c. 1900)

The current conduit is comprised of twin box channels constructed of placed stone along the current channel alignment, running diagonally across the embankment and current roadway. This structure was reportedly constructed around 1930, and originally included mud flaps at the end discharging to Pleasant Bay, which are no longer in place. The current study to replace these box culverts with a larger structure requires an investigation of embankment and foundation soils below the current roadway in order to evaluate requirements for proper support and construction of this structure, including potential reuse of embankment soils as compacted fill adjacent to and over the culvert, if these materials are found to conform to current standards for use as structural fill materials.

A geotechnical investigation and evaluation of embankment soils has been completed in support of this current study, which will include an examination of potential culvert configurations and construction techniques that could be employed to most efficiently improve tidal flushing to the Muddy Creek estuary while minimizing wetland impacts and satisfactorily addressing other criteria under consideration. This investigation and evaluation are summarized in the sections below.

2.1.1 Program Objectives

The objectives of this investigation were to assess the subsurface conditions at the proposed location for the culvert replacement and provide recommendations for foundation design and construction. To achieve the objectives of the project, the following activities were completed:

- Completed two test borings on either side of existing culvert, which is centered on the anticipated alignment of the replacement culvert being considered;
- Submitted two soil samples to a soil testing laboratory for grain size testing, with a modified proctor laboratory density test being performed on an additional sample; and
- Performed an engineering analysis to provide an assessment of geotechnical parameters to be considered for selection and design of a replacement culvert.

2.2 Field Investigation Findings

Observations and test results obtained from the field investigations are described in the following sections.

2.2.1 Test Borings

Fuss & O'Neill subcontracted Soil Exploration Corp of Leominster, Massachusetts to drill test borings at the site. These borings were completed on May 20, 2011, after securing a non-vehicular access permit from MassDOT. The application package transmitted to MassDOT and the issued permit are both provided in *Attachment E*. The locations of the two test borings were surveyed at the site and are depicted on *Figure 17* below.

The test borings were advanced to depths of 33 feet and 39 feet below the existing ground surface. The borings were advanced using a truck-mounted drill rig and standard hollow stem auger techniques. Each test boring was observed and logged by a Fuss & O'Neill engineer. Boring logs are provided in *Attachment F*.

Soil samples were obtained and standard penetration tests (SPTs) were performed continuously in the test borings. The SPT consists of driving a 2-inch outside-diameter split spoon sampler 24 inches with a 140-pound hammer free-falling 30 inches. The number of blows required to drive the sampler from 6 to 18 inches is the Standard Penetration Resistance, also known as the SPT N-value, which is a relative indicator of the in-place soil's relative density.

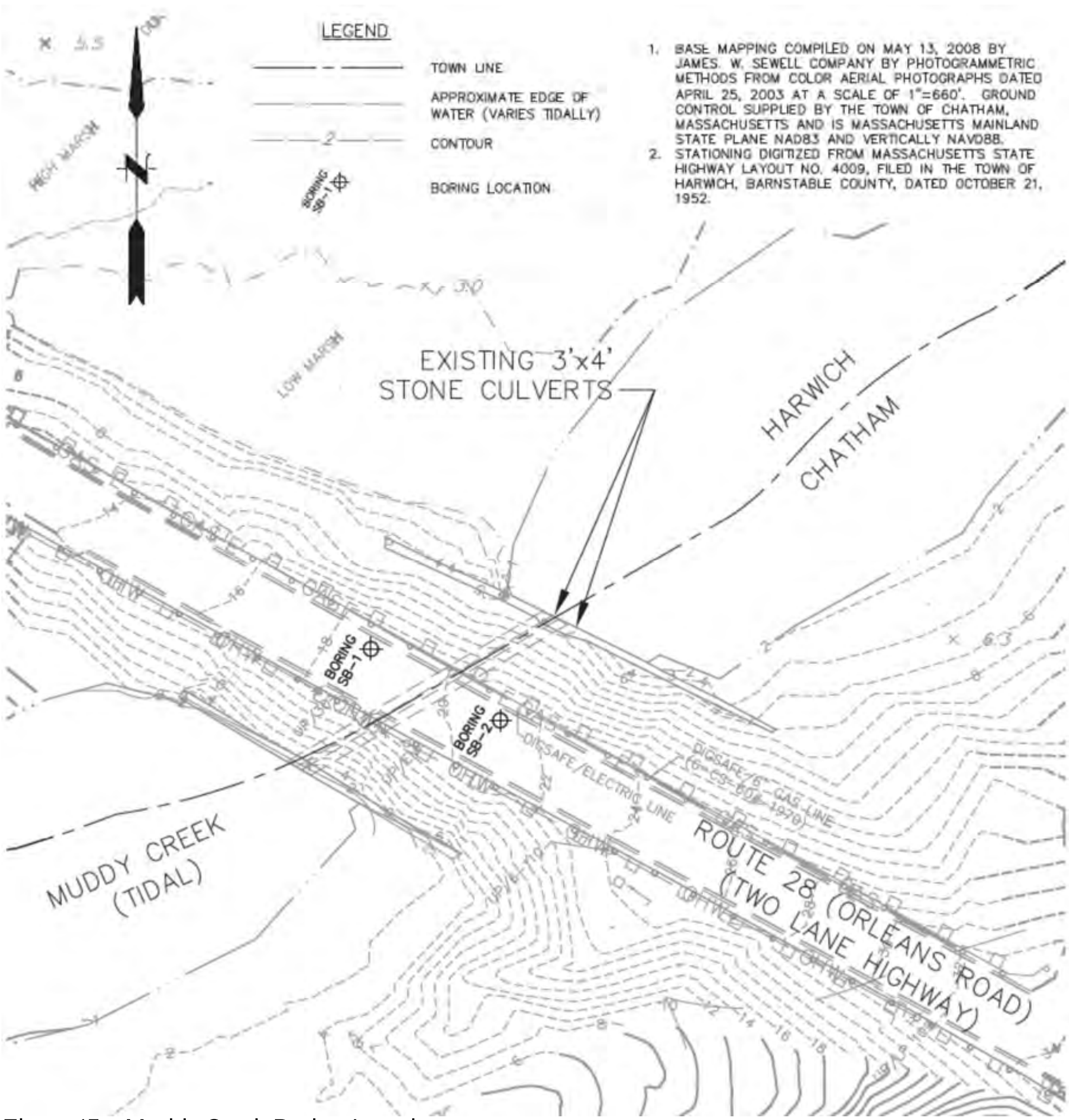


Figure 17 – Muddy Creek Boring Locations

As seen in the boring logs, subsurface conditions adjacent to the culvert generally consist of fine to medium sand, with coarse sand and gravels encountered in some horizons. Results of SPTs indicated the sand density ranges from very loose to medium dense, with the majority of the tests indicating relatively loose conditions in the embankment and through encountered foundation soils. Small amounts of silt and clay material were observed in each boring between approximately four to seven feet below the bottom of the existing culverts.

Groundwater was encountered at depths of 17 and 20 feet below existing ground surface. Note that groundwater levels may be higher or lower during future construction, depending on precipitation, tidal conditions, and other factors.

2.2.2 Laboratory Test Results

Laboratory testing was performed on soil samples selected from the drilling activities to suitably characterize soils observed in embankment and foundation strata, such that the suitability of embankment soils for reuse during the future construction of the replacement culvert. As noted previously, the majority of soils encountered in the borings above the elevation of the existing culvert base elevation consist of sand with relatively small amounts of silt, which was confirmed by testing indicating silt fractions less than 10 percent silt of the sample's mass.

Laboratory sieve test results are provided as *Attachment G*. Sample S-1 was obtained approximately 10-12 feet below the ground surface and Sample S-2 was prepared as a composite of soils encountered from approximately 3 to 19 feet below the ground surface.

A Modified Proctor test performed on embankment material indicates a maximum dry density of 124 pounds per cubic foot at an optimum moisture content of 8.0 percent. This test report is also provided in *Attachment G*. These values can be used as a starting point for compaction testing of field placed material. If any changes in the material are noted, additional testing laboratory compaction will be required to assess what, if any, revision to these parameters are required for construction quality control.

2.3 Interpretation of Test Results and Recommendations

Based on a review of the test results and soils observed during the boring program, an assessment of parameters for design and construction of the replacement culvert was completed, as described in the following sections.

2.3.1 Classification and Potential Reuse of Embankment Soils

Based on a review of the laboratory sieve test results and specifications in Section M1 of the MassDOT Standard Specifications for Highways and Bridges, the embankment material appears to meet the specifications requirements for use as Ordinary Borrow (M1.01.0), Special Borrow (M1.02.0), Sand Borrow (M1.04.0 Types a and b), and Sand Borrow for Subdrains (M1.04.1).

For this project, the existing material should be suitable for use as backfill above and adjacent to a replacement culvert, as well as backfill behind any retaining structures that may be required (e.g., headwalls or training walls). Since this testing was performed based on a relatively small sample of embankment soil, additional observation and assessment by a qualified professional engineer and/or grain size testing may be necessary when soils are excavated to confirm the consistency of the soil types in the embankment.

2.3.2 Foundation Design Recommendations

The following foundation design recommendations have been developed based on a review of subsurface data collected, our engineering evaluation, and our current understanding of the structures being considered for this project (e.g., pre-cast concrete box culverts).

As with any subsurface investigation program, the nature and extent of variations between these borings may not become evident until during construction. If variations appear evident at that time, it will be necessary to reevaluate these recommendations and make revisions based on the new observations, test data and analyses.

- Notwithstanding any subsequent evaluations of scour potential at the project site for respective culvert configurations being considered, culvert and headwall loads could be supported with appropriately designed conventional spread footing foundations bearing on existing undisturbed inorganic soils or compacted structural fill placed over inorganic soils. Consideration of scour potential may result in the structures being protected by slope/channel armoring (e.g., riprap or other armor protection system), or being supported by deep piles driven below the culvert/wall foundations. Specific design size/spacing of any piles could be determined from conservative derivations of soil properties from soil maps and data from other local explorations.

- Interior embankment soils are predominantly fine to medium sand with relatively low unit weight, and are thus prone to scour conditions if exposed to sufficient discharge velocities through the culvert. A *Muddy Creek Culvert Scenarios* memorandum (Applied Coastal, 2009) indicated discharge velocities of approximately 6.75 feet per second for a single 24-foot span culvert, which would be sufficient for scour development in unprotected, uniform soils as observed within the embankment. The sizing of armor units and lateral extent of this protection would need to be evaluated and identified through subsequent design of the culvert structure.

- Proportion footings based on a net allowable bearing pressure of 2,000 pounds per square foot (psf) where footings are founded on the existing sand strata. Where footings are founded on compacted structural fill above natural deposits, proportion footings based on a net allowable bearing pressure of 4,000 psf. For footings narrower than three (3) feet, the net allowable bearing pressure should be reduced in direct proportion to the reduction in dimension below three (3) feet or to one-third times the minimum footing dimension, in feet. Continuous footings should be a minimum of two (2) feet wide.

- Footings should be founded at least four (4) feet below the adjacent exterior ground surface for frost protection. Footings and footing subgrades should be protected against freezing during construction where silt content warrants such protection.
- Backfill behind wing walls should be designed for active earth pressures using an "equivalent fluid pressure" of 40 pounds per cubic foot (pcf).
- A friction factor of 0.55 between soil and concrete should be used to evaluate resistance to sliding.
- In the event that culvert or bridge structures are considered where seismic loadings are required to be considered, soils at the site should be considered Site Class E as defined by Table 1613.5.2 of the International Building Code.

2.3.3 Construction Methods and Recommendations

The following controls or methods should be employed during construction to ensure the culvert structures are not compromised by inadequate structural fill or improper construction approaches.

- Organic materials, if encountered, should be removed to a firm, inorganic subgrade from within the area of the proposed construction and to a distance beyond the outside edge of the proposed footings equal to the depth of the footings below finished grade.
- Prior to construction of footings, the subgrade soil should be improved by proof-rolling. Proof-rolling should consist of at least six passes with a 2,000-pound vibratory, walk-behind roller or larger vibratory roller.
- Fill used to backfill below footings (structural support material) should consist of gravel meeting the gradation requirements of MassDOT Item No. M1.03.0 Type b and should be free of organic material, construction debris, ice, snow, and other deleterious material.
- Fill used to backfill above footings should consist of sand meeting the gradation requirements of MassDOT Item No. M1.04.0 Type b and should be free of organic material, construction debris, ice, snow, and other deleterious material. Existing site soils in general should be suitable for reuse as bedding and backfill materials adjacent to the culvert structure.
- Fill placed below or above footings should be placed in loose lifts not to exceed 12 inches in thickness and should be compacted to 95 percent of maximum dry density as determined by American Society of Testing and Materials Test 1557, Method C.
- Excavation, fill placement, and footing construction should be conducted under dry conditions. Excavation shoring and side slopes, where used, should be in accordance with Occupational Safety and Health Administration (OSHA) standards. This will require methods be developed and implemented to bypass culvert flows through temporary structures while the culverts are being constructed, as well as cutoff and drawdown of groundwater within the excavated areas until constructed features are backfilled to a high enough elevation that structures and materials are not potentially compromised by natural

high surface water and/or groundwater conditions (e.g., floods, seasonal high tides, storm surges, etc.).

Dewatering within excavated areas would likely most efficiently be completed through installation and operation of appropriately sized/spaced conventional groundwater dewatering sumps, which would be employed in concert with cutoff provided by driven cofferdam/shoring sheets, to maintain water levels sufficiently below the ground surface to allow placement of soil materials and structures under controlled conditions.

3 Water Quality Assessment Modeling

3.1 Introduction

A modeling evaluation of the potential influence of replacement of the Route 28 culvert on bacteria concentrations in Muddy Creek and at its outlet to Pleasant Bay was completed to assess potential effects on water quality at the nearby Pleasant Bay Beach and Jacknife Harbor Beach.

Historic water quality data and modeling results are reviewed, providing a brief background of water quality issues in Muddy Creek and Pleasant Bay. A description of the modeling approach, development, and results of a "medium complexity" modeling exercise to assess bacteria concentrations within Muddy Creek and its discharge to Pleasant Bay under existing conditions and under a 24-foot culvert replacement scenario are also described.

The model objective was to assess the relative impact of the Route 28 culvert replacement on bacteria concentrations due primarily to an increase in tidal density mixing. A one-dimensional, steady-state transport model was applied to the Muddy Creek system using a finite difference approach at a level of complexity that matches the limited data that is available from prior data collection and modeling studies.

3.2 Summary of Water Quality Data

Information about water quality in Muddy Creek and Pleasant Bay consists of both monitoring data collected by state agencies and volunteers and modeling analyses conducted primarily under the Massachusetts Estuaries Program (MEP). This section of the technical memo provides a concise summary of the water quality monitoring data collected since 2000 with a focus on Muddy Creek, describes major findings of recent water quality modeling of Muddy Creek, and offers recommendations for future monitoring efforts.

3.2.1 Water Quality Monitoring

Water quality monitoring in Muddy Creek and Pleasant Bay has been conducted by the Pleasant Bay Alliance as part of the implementation of a resources management plan for Pleasant Bay and by the Massachusetts Division of Marine Fisheries (DMF) to assess shellfish habitat in designated shellfish growing areas. In addition, water quality monitoring at Jacknife Harbor Beach and Pleasant Bay Beach occurs throughout the summer swimming season. As discussed below, the focus of the Pleasant Bay Alliance monitoring has been on nutrients. In contrast, DMF and beach monitoring focus on the fecal indicator organisms' fecal coliform and *Enterococcus*, respectively, to assess potential risks to public health.

Water quality monitoring for bacteria can be considered in the context of the Massachusetts Surface Water Quality Standards (SWQSs) for Class SA waters like Muddy Creek. Class SA waters are designated in 314 CMR 4.05(4) as an excellent habitat for fish, other aquatic life and wildlife, including for their reproduction, migration, growth and other critical functions, and for primary and secondary contact recreation. In certain waters, excellent habitat for fish, other aquatic life and wildlife may include, but is not limited to, seagrass. Where designated for shellfishing, these waters shall be suitable for shellfish harvesting without depuration (Approved and Conditionally Approved Shellfish Areas). These waters shall have excellent aesthetic value.

Regulatory standards are established to protect both shellfish habitat (314 CMR 4.05(4)(a)4) and bathing beaches (105 CMR 445.000) in Class SA waters. Based on the SWQS, fecal coliform criteria for coastal and marine Class SA waters specify that waters approved for open shellfishing shall not exceed a geometric mean most probable number (MPN) of 14/100 mL, nor shall more than 10 percent of the samples exceed a MPN of 43/100 mL. With regard to safeguarding public health relative to primary and secondary contact recreation, no single *Enterococci* sample shall exceed 104 colonies/100 mL[1] and the geometric mean of the most recent five (5) *Enterococci* levels within the same bathing season shall not exceed 35 colonies/100 mL.

3.2.1.1 Ambient Water Quality Monitoring

The Pleasant Bay Alliance has been conducting water quality monitoring since 2000 and the *Pleasant Bay Alliance Water Quality Monitoring Program: Statistical Analysis of Multi-Year Water Quality Monitoring Data* (Cadmus Group, 2010) provides a summary of both site specific analysis of data collected at sites throughout the bay and bay-wide trends in water quality. *The Pleasant Bay Citizen Water Quality Monitoring Program Interim Report (2000-2008)* (Pleasant Bay Resource Management Alliance, 2009) provides an excellent summary of the water quality collected over that eight year period and the relationship of the parameters monitored to water quality in the estuary system. There are two water quality monitoring sites located in the upper (PBA-5A) and

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[1] Note that colonies/100 mL can be considered equivalent to CFU/100 mL.

lower (PBA-5) portions of Muddy Creek. Samples collected in Muddy Creek as part of the Pleasant Bay Alliance program were analyzed for dissolved oxygen, phosphate, dissolved inorganic nitrogen, total nitrogen, bioactive nitrogen, and pigment. Salinity, temperature, and secchi disk depth are also measured. Muddy Creek is one of the monitoring locations in Pleasant Bay with data both before and after the 2007 "break" in Nauset Beach following the Patriot's Day storm on April 15-16.

The *Pleasant Bay Alliance Water Quality Monitoring Program: Statistical Analysis of Multi-Year Water Quality Monitoring Data* (Cadmus Group, 2010) reports no statistically significant trend in Muddy Creek for any of the parameters monitored. However, the individual parameter information presented in *The Pleasant Bay Citizen Water Quality Monitoring Program Interim Report (2000-2008)* is also useful for characterizing water quality in Muddy Creek.

Total nitrogen values in Muddy Creek and throughout Pleasant Bay exceeded the background level of 0.29 mg/L for Atlantic Ocean waters. Bioactive nitrogen (the combination of dissolved organic nitrogen and particulate organic nitrogen) is another useful water quality indicator. The thresholds for bioactive nitrogen established for the Pleasant Bay restoration are 0.16 mg/L for eelgrass restoration and 0.21 mg/L for benthic infauna. The level of bioactive nitrogen met or exceeded the 0.21 mg/L threshold (and therefore the 0.16 mg/L threshold) every year of the monitoring program (2000-2008). Total nitrogen levels are typically between 1-1.5 mg/L at PBA-5A. Total nitrogen concentrations measured at PBA-5 in 2000-2005 were 0.5-1 mg/L but have been in the range of 1-1.5 mg/L since 2006.

Phytoplankton pigment concentrations above 5 µg/L are indicative of impacts from watershed development. In Muddy Creek and throughout Pleasant Bay, stations with restricted flushing tend to have higher pigment concentrations. At PBA-5, pigment concentrations have ranged from between 5 and 23 µg/L and at PBA-5A between 9 and 30 µg/L.

Dissolved oxygen (DO) is measured at the monitoring station in Pleasant Bay. A value of 6 mg/L is the water quality standard for Class SA waters like those in Pleasant Bay. DO levels below 3 mg/L indicate extremely stressful conditions for aquatic plants and animals. DO measurements were reported at PBA-5 for January and July of most years of the period of record and for July during the period of record at PBA-5A. In lower Muddy Creek (PBA-5), from 2000-2009 values ranged between 1-9 mg/L and 29-83% of the samples collected did not meet the 6 mg/L DO standard. DO concentrations are typically lower in July and often fall below the Class SA criterion. DO values at the upper Muddy Creek station (PBA-5A) range between 1 to 11 mg/L and 29-83% of the samples did not meet the DO standard.

Oxygen saturation (calculated from DO, temperature, and salinity) is another measure of suitability for aquatic life. Oxygen saturation values should ideally be close to 100%. Values of 60% are considered "warning" levels and values less than 40% are dangerous for aquatic life. Values of 20-80% were typically measured at both the upper and lower Muddy Creek sampling stations throughout the period of record.

Although not reported in *The Pleasant Bay Citizen Water Quality Monitoring Program Interim Report (2000-2008)*, the 10 year summary report (Cadmus Group, 2010) also includes information on the geometric mean phosphate concentrations. In upper Muddy Creek (PBA-5A), these ranged from 20-57 μg/L and in lower Muddy Creek from 16-62 μg/L. There is no criterion for phosphate in the Massachusetts Surface Water Quality Standards.

Data from the monitoring program are also used to calculate a eutrophication index, which provides a single value to characterize the relative water quality of a given embayment (i.e., monitoring area). Oxygen saturation, transparency (calculated from secchi disk depth), chlorophyll, dissolved organic nitrogen and total organic nitrogen are scored relative to standards of good and poor water quality and then the scores for the five parameters are combined into a composite eutrophication index. Values of the index less than 35 indicate eutrophic conditions; fair water quality conditions are indicated by index values of 35-65. Good to excellent water quality is indicated by scores of 65-100. *The Pleasant Bay Citizen Water Quality Monitoring Program Interim Report (2000-2008)* reports that the eutrophication index for the Muddy Creek stations was less than 35 (poor) throughout the sampling period.

The DMF sampling data (O'Neil, 2011) obtained by the Fuss & O'Neill project team for the shellfish growing area SC58 (Muddy Creek) for the period May 2001 through February 2011 show that in the conditionally approved shellfishing area downstream of the culvert, fecal coliform concentrations are usually less than 5 CFU/100 mL. The highest value reported was 81 CFU/100 mL for a sample collected on March 16, 2009.

3.2.1.2 Beach Water Quality Monitoring

Beach monitoring in Massachusetts varies from monthly to daily monitoring, with weekly being the most common monitoring frequency. If the *Enterococcus* concentration in a sample exceeds 104 CFU/100 mL, the single sample maximum (SSM) allowable for contact recreation, daily sampling continues until the concentration falls below 104 CFU/100 mL.

Jacknife Harbor Beach, located east of the Muddy Creek outlet in Chatham, has been sampled weekly during the beach season since 2003. A review of Massachusetts Department of Public Health data for the beach shows no exceedances of the 104 CFU/100 mL SSM for *Enterococcus* over the period of record. Geometric mean values are also below the water quality standard of 35 CFU/100 mL for the period of record. The maximum reported concentration since 2003 was 54 CFU/100 mL, reported on August 27, 2008. No values greater than 10 CFU/100 mL were reported in 2010.

Pleasant Bay Beach, located immediately west of the Muddy Creek outlet in Harwich, was monitored weekly from 2003-2006 and monthly in the 2007-2010 summer beach seasons. A review of Massachusetts Department of Public Health data for the beach shows five (5) exceedances of the 104 CFU/100 mL SSM for *Enterococcus* over the period of record, with the highest reported value of 195 CFU/100 mL on July 15, 2003. The SSM was exceeded once in 2010, when the *Enterococcus* concentration was 106 CFU/100 mL on August 25, 2010. Geometric mean values were below the water quality standard of 35 CFU/100 mL for 2010.

3.2.2 Modeling Analysis of Nutrients

As part of the Massachusetts Estuaries Project (MEP), a linked watershed-embayment model was developed to determine critical nitrogen loading thresholds for the Pleasant Bay system, including Muddy Creek (Howes et al., 2006). The goal of that work was to identify nitrogen threshold limits to assist wastewater master planning and nitrogen management alternatives in the towns of Orleans, Harwich, Chatham, and Brewster. One goal of the model development was to assist in the analysis of "what if" scenarios for evaluating nitrogen management options and assist in the process of establishing a Total Maximum Daily Load (TMDL) for Total Nitrogen in Pleasant Bay. A Total Maximum Daily Load, or TMDL, is a calculation of the maximum amount of a pollutant (in this case nitrogen) that a waterbody can receive and still safely meet water quality standards.

The modeling approach was a two-dimensional, depth-averaged, hydrodynamic model based upon tidal currents and water elevations, which was then integrated with a two-dimensional water quality model to predict the dispersion of nitrogen. In Muddy Creek, as with other embayments in Pleasant Bay, wastewater was assumed to be the greatest source of nitrogen loading, approximately 72% of the overall load. Summertime mean total and bioactive nitrogen concentrations for the period 2000-2005 were calculated for upper and lower Muddy Creek and used to calibrate the model.

Using restoration of benthic animal habitat as a target, nitrogen concentration thresholds were calculated for Muddy Creek. Under that restoration scenario, a bioactive nitrogen threshold of 0.21 mg/L, a dissolved organic nitrogen threshold of 0.331 mg/L and a total nitrogen threshold of 0.541 mg/L in lower Muddy Creek (PBA-5) were identified. This is the lowest total nitrogen threshold of all eight embayments considered in the modeling study. Based on the loading associated with this threshold, a total watershed load (i.e., septic, runoff, and fertilizer) reduction of nearly 75% would be required in lower Muddy Creek and 54% in upper Muddy Creek.

The potential influence of the increased tidal flushing from a 24-foot replacement culvert at the outlet of Muddy Creek was evaluated through updated hydrodynamic-water quality modeling in 2010. Eicher et al. (2010) considered two modeling scenarios. The first considered existing watershed nitrogen loading and updated nitrogen attenuation rates in Muddy Creek with the replacement of the current culverts with a single 24-foot culvert. The second scenario was the same as the first, but using nitrogen loading associated with the build out of the watershed. The modeling analysis revealed the following:

- Under existing loadings, installation of the 24-foot culvert would result in a 20% reduction in the difference between existing bioactive nitrogen concentrations and the threshold concentration of 0.21 mg/L in the lower Muddy Creek (PBA-5), bringing nitrogen concentrations to within 23% of the threshold concentrations.

- Under build-out conditions, the wider culvert would bring nitrogen concentrations to within 36% of the threshold concentrations.

- While the replacement of the existing culvert with a 24-foot culvert at the outlet of Muddy Creek would improve nutrient water quality in Muddy Creek, it would not result in any significant changes in the Pleasant Bay water quality.

- Additional nitrogen reductions would still be required to reach the nitrogen threshold established for Muddy Creek, but the magnitude of the reductions would be reduced with the 24-foot culvert in place.

3.2.3 TMDL Summary

Two TMDLs have been developed that are relevant to water quality conditions in Muddy Creek - *Bacterial TMDL for Muddy Creek, Chatham and Harwich* (Saminy et al, 2005) and *Pleasant Bay System Total Maximum Daily Loads for Total Nitrogen* (MassDEP, 2007).

3.2.3.1 Fecal Coliform TMDL

This TMDL is based on the results of water quality sampling data collected in Muddy Creek from the period 1985-2003. Data collection was performed primarily by the Town of Chatham at four stations along the length of Muddy Creek during 1996-1998 and by the Division of Marine Fisheries (DMF) form 1985-2001. DMF sampling was performed for the entire period at the Chatham Town Landing, but for shorter periods ending in the mid- to late-1990s for other upstream sampling locations. In addition, the School for Marine Science and Technology (SMAST) at the University of Massachusetts Dartmouth collected fecal coliform, *E. coli*, and *Enterococcus* data at the Route 28 culvert from November 2002 – August 2003.

The TMDL concluded that summer bacteria inputs to Muddy Creek were greater than winter inputs, especially at the Route 28 culvert and the upstream portions of Muddy Creek. Under summer conditions geomean values exceeded the 14 CFU/100 mL water quality standard for shellfishing habitat at the upstream-most and Route 28 stations and at all stations greater than 10% of samples exceeded 43 CFU/100 mL in both the 1985-1995 and 1996-2003 time periods. The highest observed summertime fecal coliform geomean value was 70 CFU/100 mL computed from 17 samples at the Route 28 culvert.

In winter, none of the fecal coliform geomeans exceeded the Class SA criterion and only the Route 28 station had greater than 10% of samples exceeding 43 CFU/100 mL. At the Route 28 monitoring station, *E.coli* and *Enterococcus* concentrations were approximately seven (7) times higher in the summer than in the winter. The wintertime geomean concentration at that location was 12 CFU/100 mL, computed from 22 samples.

Summertime geomean concentrations of *E.coli* and *Enterococcus* at the Route 28 culvert were 53 and 35 CFU/100 mL, respectively, and 41% of the 17 *Enterococcus* samples exceeded the SSM of 104 CFU/100 mL for contact recreation. In contrast, the wintertime geomean was 5 CFU/100 mL and only 5% of the 22 *Enterococcus* samples exceeded the SSM.

The TMDL hypothesized that seasonal differences were attributable to increased waterfowl activity in the upper reaches of Muddy Creek during the summer months and runoff related to

Route 28 in the lower portions of Muddy Creek. Wet weather and dry weather sampling data is limited, especially at stations in the middle portions of Muddy Creek. Nevertheless, the TMDL concluded that wet weather concentrations of fecal indicator bacteria were higher than those observed in dry weather and that summertime wet weather conditions were those most likely to be associated with exceedances of water quality standards for shellfishing or contact recreation.

It should be noted that the data described in the TMDL was collected over a multiyear time span that concluded nearly a decade ago and multiple years of data were combined to produce single geometric mean values to characterize water quality conditions. In addition, only fecal coliform values were collected throughout the length of the creek. In addition, the downstream-most stations are those with the greatest number of samples, but still only approximately 50-100 samples were collected at these locations over the period from 1985-2003. Wet weather and dry weather data is even less abundant, with some stations having only two (2) measurements to attempt to characterize the water quality.

3.2.3.2 Nitrogen TMDL

The linked watershed-embayment model (Howes et al., 2006) described above formed the basis for the nitrogen TMDL that establishes threshold nitrogen levels to restore or maintain Class SA water quality in each embayment system of Pleasant Bay, including Muddy Creek. For Muddy Creek, this is a target threshold bioactive nitrogen concentration of 0.21 mg/L in lower Muddy Creek (PBA-5) and 0.41 mg/L in upper Muddy Creek (PBA-5a).

For Muddy Creek, the TMDL reports that a 54% and 75% reduction in controllable watershed loads is needed in upper and lower Muddy Creek, respectively, to meet the threshold loads for nitrogen. As a result, the TMDL loads for nitrogen in upper and lower Muddy Creek are 7 kg/day and 2 kg/day, respectively. These loads related directly back to the bioactive concentrations identified in the MEP modeling of the Pleasant Bay system.

3.3 Water Quality Modeling

3.3.1 Approach

Bacteria, including fecal coliform and *Enterococcus*, show significant spatial and temporal variation under ambient conditions, making them among the most difficult water quality constituents to accurately model. While there is a wide range of potential modeling approaches to assess bacteria concentration on the Muddy Creek system, calibration and validation of complex water quality models is data intensive, and without sufficient information for calibration, the results of more complex models modeling can be misleading, appearing to provide a level of detail that is not supported by available data.

Muddy Creek and Pleasant Bay have been the subject of extensive nutrient water quality analysis over the past decade as discussed in *Section 2*. Specifically, changes in tidal density mixing under a 24-foot replacement culvert scenario have already been assessed (SMAST, 2010) and our approach is to utilize that existing information in the model development. There is limited bacteria data available for model calibration and validation included in the *Report*

Massachusetts Estuaries Project Bacterial TMDL for Muddy Creek, Report # MA 96-51-2004-01 (Samimy, 2006) ("TMDL"). Either additional bacteria data would need to be collected to specifically support model calibration and validation, which would require a field effort, or a combined RMA-2V and RMA-4 model could be applied using hypothetical bacterial loadings to examine the range of bacterial water quality conditions that may be observed. However, model complexity must match data availability and due to the absence of adequate data to calibrate and validate such a model, the use of a more complex model like RMA-4 would not yield results that are truly useful and could actually be misleading.

This technical memorandum presents a simpler mass-balance approach (Thomann and Mueller, 1987) that provides a more meaningful quantitative estimate of bacteria concentrations. By dividing Muddy Creek into several segments for modeling, with each segment interface located at a sampling location identified in the TMDL (as shown conceptually in *Figures 16 and 17* below), the model complexity is matched to the spatial distribution of available bacteria data. Then information already developed from hydrodynamic modeling for the 24-foot replacement culvert, coupled with published bacteria decay rates, is used to estimate bacteria concentrations in Muddy Creek and at its outlet.

3.3.2 Model Development

A mass-balance, finite difference approach is used to model the advection-dispersion processes in the Muddy Creek estuary system. Within a river-estuary complex, like Muddy Creek, the mass-balance approach assumes that each segment is a well-mixed box. A mass-balance equation is then solved which calculates the mass or concentration of a parameter based on the net advective transport, the net dispersive transport, loss due to decay, and sources and sinks as illustrated in *Figure 18. Figure 19* shows the finite difference segments and land use in the vicinity of Muddy Creek and Pleasant Bay.

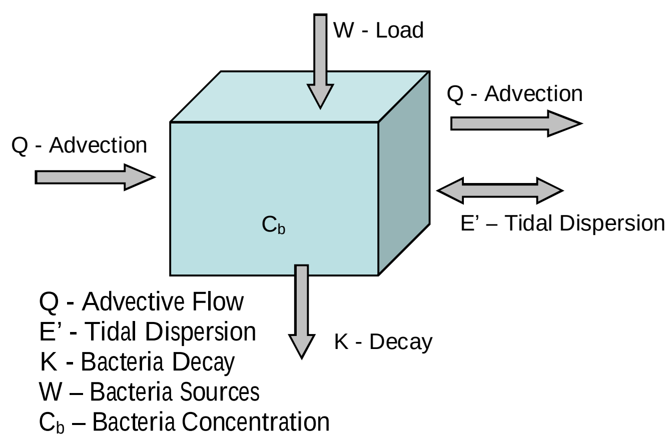

Figure 18 – Illustration of the mass-balance approach for finite difference representation of the river-estuary complex

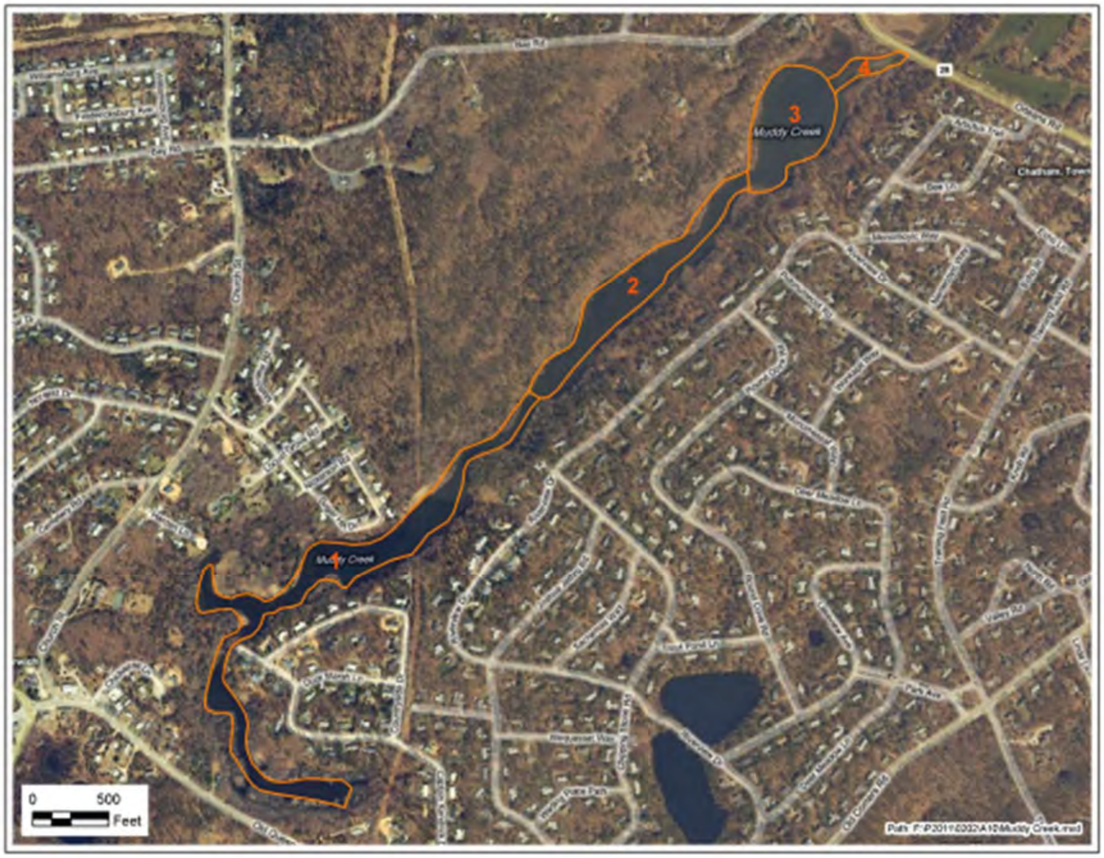

Figure 19 – Muddy Creek model segments 1 through 4 and surrounding land use

The system is assumed to be at steady-state and a one day time step is used. Therefore, the governing equation for mass transport around any segment *i* is as follows (Thomann and Mueller, 1987):

$$0 = Q_{i-1,i}s_{i-1} - Q_{i,i+1}s_i + E'_{i-1,i}\left(s_{i-1} - s_i\right) + E'_{i+1,i}\left(s_{i+1} - s_i\right) - K_i V_i s_i \pm W_i$$

where:

V_i =	Volume of segment *i* (ft^3)
$Q_{i,i+1}$ =	Advective flow between segments *i* and *i*+1 (ft^3/day)
s_i =	Concentration at segment *i* (CFU/day)
$E'_{i,i+1}$ =	Dispersion density mixing at the interface of segment *i* and segment *i*+1 (ft^3/day)
K =	Bacterial decay rate (1/day)
W^i =	Source to segment *i* (CFU/day)

The techniques and assumptions used in the Muddy Creek bacteria model, including system geometry, bacteria decay rates, and advection and dispersion parameters are described in the following sections.

3.3.2.1 System Geometry (L, d, V, A)

The Muddy Creek system is represented by four (4) finite-difference segments. A representation of the finite-difference model and associated system parameters are shown in the conceptual model diagram (*Figure 20).* For purposes of this modeling study, the characteristics of a segment are assumed to be uniform throughout the segment. The four sampling locations referenced in the *Report Massachusetts Estuaries Project Bacterial TMDL for Muddy Creek, Report # MA 96-51-2004-01* (Samimy, 2006) are located approximately at the interfaces between segments shown in *Figure 20*.

The segments are assumed to be uniformly mixed, so the bacteria concentration (s) at the downstream interface of a segment is equal to the bacteria concentration within the segment. The average depth (d) of each segment was approximated using bathymetric mapping from the memorandum *Muddy Creek Culvert Scenarios* (Kelley, 2009). The length (L) of a segment is used to calculate the tidal dispersion coefficients (E') and is based on the approximate length of the segment measured from GIS data provided by MassGIS. The volume of the segment (V) was calculated from the area (A) of each segment obtained from the GIS mapping and the average depth of the segment from the bathymetry map.

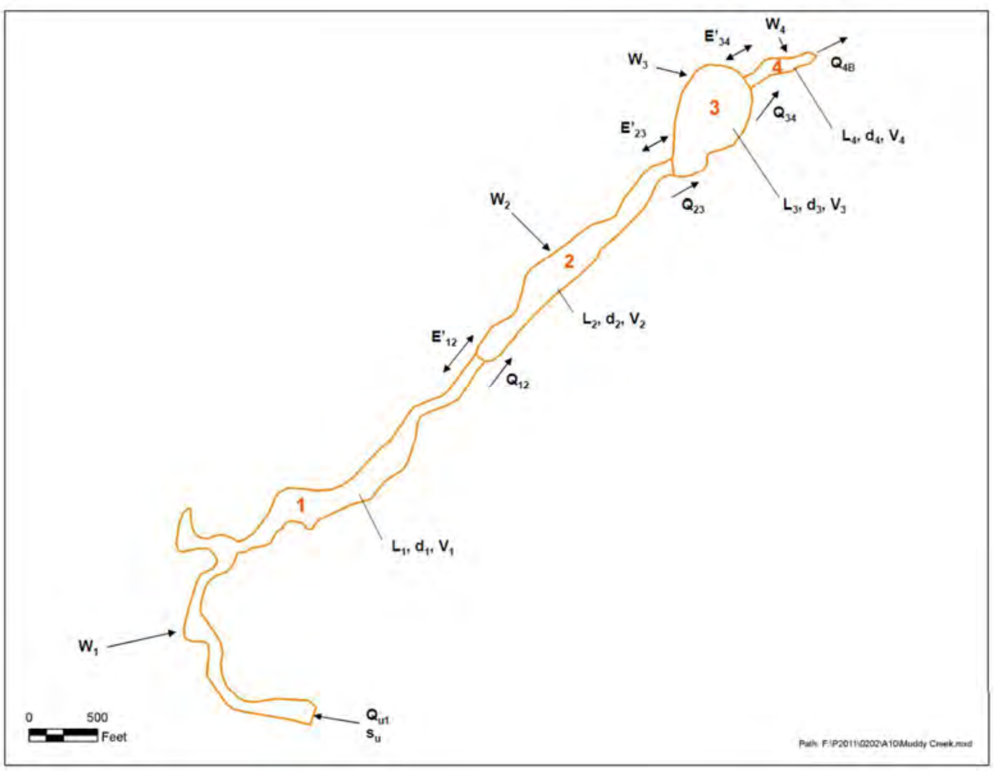

Figure 20 – Conceptual model of the Muddy Creek segments and associated model parameters.

3.3.2.2 Bacteria Decay Rates (K)

The fecal coliform and *Enterococcus* bacteria die-off rates, or decay rates, vary depending on environmental conditions such as ambient water temperature, solar radiation levels, salinity, water turbidity, and predation. In the absence of site specific rates, decay rates obtained from literature values provide a reasonable estimate for modeling. A range of literature values were used to model the decay rate of fecal coliform and *Enterococcus* in the Muddy Creek system.

Based on literature values reported by the U.S. Environmental Protection Agency for Long Island estuaries, fecal coliform decay rates used in the model varied from 0.5/day to 8/day (EPA, 1985). *Enterococcus* decay rates ranged from 0.3/day to 4.2/day and are taken from the work of Lessard and Sieburth (1983) and Anderson et al. (2005) for fresh, estuary, and marine waters.

3.3.2.3 Bacteria Concentrations (s)

Bacteria concentrations at each segment (including segment 4 which is the concentration at the Route 28 culvert) and in Pleasant Bay were taken from the geometric mean values reported in the TMDL (for the sampling stations in Muddy Creek) and the Division of Marine Fisheries (DMF) sampling data for the outlet of Muddy Creek in the report *Data from Samples collected at Classification Station #1 in Muddy Creek (in the Conditionally Approved sub-area SC:58.1)* (O'Neil, 2011). Fecal coliform was sampled at multiple locations during both winter and summer (Samimy et al., 2006; O'Neil, 2011). *Enterococcus* concentrations were only measured at the Route 28 culvert during the summer season (Samimy et al., 2006).

In order to estimate *Enterococcus* concentrations at other sampling locations in Muddy Creek, the ratio of the fecal coliform concentrations at the Route 28 culvert to the other upstream sampling locations is computed and then applied to the *Enterococcus* concentration at the Route 28 sampling location to generate estimates of *Enterococcus* concentrations at upstream locations. This approach assumes that the ratio of fecal coliform at upstream and downstream locations in Muddy Creek is also representative of the distribution of *Enterococcus* concentrations in the creek.

The limitations of the data should be acknowledged in the evaluation of model results. First, the geometric mean bacteria concentrations used in the modeling are based on sampling data collected over a several year period from 1985 - 2003 (as reported in the TMDL). This data is not recent, and there is the possibility that they may not represent current conditions in Muddy Creek. In addition, as mentioned above, the *Enterococcus* data is limited to sampling at one sampling location. While use of proportional relationships to estimate *Enterococcus* concentrations at other locations is a reasonable approach, since the summer to winter relationships between *Enterococcus* and fecal coliform follow similar patterns. However, it is possible that the concentrations of *Enterococcus* at upstream sampling locations do not follow the same pattern as those of fecal coliform.

The geometric mean bacteria concentrations reported in the 2005 TMDL are used to calibrate the source concentration inputs at each segment. Although the tidal volume exchange will increase at the culvert following the culvert replacement, it is assumed that the upstream flow rates and sources of bacteria inputs for each segment are constant from the existing conditions to the future culvert replacement scenario. That assumption would need to be revised, if implementation of best management practices or wildlife harassment programs that may alter or reduce sources of bacteria in the Muddy Creek watershed are implemented.

3.3.2.4 Advection (Q)

The advection through the Muddy Creek system includes only the freshwater contribution. Since the time step of the model is 1 day, the tidal density mixing effects are captured entirely in the dispersion term as discussed in *Section 3.3.2.5.*

The flow rate through the Muddy Creek system is based on estimated freshwater input rates for the upper (segment 1) and lower (segments 2 through 4) Muddy Creek at 3.53 ft^3/s and 2.71 ft^3/s, respectively, as reported in *Massachusetts Estuaries Project [MEP]. Linked Watershed-Embayment Model to Determine Critical Nitrogen Loading Thresholds for the Pleasant Bay System, Massachusetts.*(Howes et al., 2006, p. 140).

It is assumed that any point source at the upstream boundary of the first segment, Qu1, is negligible and instead the headwaters of Muddy Creek are characterized by groundwater and overland flow inputs. The freshwater flows into the four segments are assumed constant under existing conditions and all scenarios modeled.

3.3.2.5 Dispersion (E')

The bacteria concentration dilution is assumed to be due entirely to dispersion from tidal mixing. The dispersion coefficients (E') for the upper and lower segments of Muddy Creek are based on values of the longitudinal dispersion (E) reported by Howes et al. (2006, pp. 136) of 10 m^2/s for the upper segment and 50 m^2/s for the lower portion (segments 2 through 4). The area and length of each segment is used to convert the dispersion coefficient E to E' as follows (Thomann and Mueller, 1987):

$$E'_{i,i-1} = \frac{E_{i,i-1} A'_{i,i-1}}{\overline{\Delta x}_{i,i-1}}$$

where:

$E'_{i,i+1}$ =	Dispersion density mixing at the interface of segment i and segment i+1 (ft^3/day)
$E_{i,i+1}$ =	Dispersion density mixing at the interface of segment i and segment i+1 (ft^2/day)
$A'_{i,i+1}$ =	Interface area between segments i and i+1 (ft^2)
$\overline{\Delta x}_{i,i+1}$ =	Concentration at segment i (CFU/day)

The modeled future conditions are for the replacement of the existing culvert with a 24-ft wide culvert, and the dispersion under the 24-ft culvert scenario is assumed to increase proportionally to the increase in the tidal prism volume. In the absence of dispersion estimated by post-culvert hydrodynamic modeling, this assumption is justified because tidal exchange is the source of dispersion in the model and tidal prism volume is a direct representation of exchange. The tidal prism volume is the volume of water in an estuary or inlet between the mean high tide and mean low tide. The existing and future conditions (with the 24-ft culvert replacement) tidal prism volumes are given by Kelley (2009, p. 6) as follows:

Existing tidal prism: 713,000 ft^3
Tidal Prism with 24-ft culvert: 4,972,000 ft^3

Assuming that the tidal dispersion density mixing between segments increases in proportion to the tidal prism volumes from the existing to future conditions, the dispersion between segments is presented in *Table 32*. Note that there are two (2) tides per day.

Table 32
Dispersion (E') between Model Segments

	Existing Conditions	Future Conditions (24-foot culvert replacement)
Tidal dispersion density mixing from segment 1 to 2 (E'12)	269,829 ft^3/day	1,881,613 ft^3/day
Tidal dispersion density mixing from segment 2 to 3 (E'23)	1,264,926 ft^3/day	8,820,774 ft^3/day
Tidal dispersion density mixing from segment 3 to 4 (E'34)	15,491,892 ft^3/day	108,030,414 ft^3/day
Tidal dispersion density mixing from segment 4 to bay (E'4b)	6,289,198 ft^3/day	43,856,790 ft^3/day

3.3.2.6 Sources (W)

The existing bacteria concentrations are used to calibrate the model to determine the constant source concentrations (W) into the four segments of the system. Note that this is different from typical water quality modeling approaches that present loadings to a system in units of mass. In this case, because the TMDL uses bacteria concentrations to represent loadings, the calibrated source "loadings" are represented as concentrations of bacteria with units of CFU/100 mL. Excel Solver is used to minimize the residual sum of squares (RSS) between the measured and predicted (using the finite difference model) bacterial concentrations for the existing conditions in each segment.

Calibrated source values were determined for fecal coliform and *Enterococcus* under summer and winter conditions using the measured bacteria concentrations shown in *Table 33*, assuming a typical decay rate of 5/day for fecal coliform and 2/day for *Enterococcus*, and the calibrated source concentrations (W) for each segment are shown in *Table 34*.

Table 33
Measured Bacteria Concentrations (O'Neil, 2011)

	Fecal Coliform (CFU/100 mL)		*Enterococcus* (CFU/100 mL)	
Segment	Summer Conditions	Winter Conditions	Summer Conditions	Winter Conditions
1	72	5	36	2
2	22	3	11	1
3	14	4	7	2
4	70	12	35	5
Bay	15	3	8	1

Table 34
Calibrated Source Concentrations (W) Under Summer and Winter Conditions

	Fecal Coliform (CFU/100 mL)		Enterococcus (CFU/100 mL)	
Segment	Summer Conditions	Winter Conditions	Summer Conditions	Winter Conditions
1	1,214	83	269	10
2	114	19	0	0
3	0	0	0	0
4	14,731	2,782	5,267	3,862

3.3.2.7 Model Scenarios

The system is modeled over a 1 day time step so that the tidal effects can be modeled as dispersion. For this reason, the magnitude of the tidal dispersion is related to the daily tidal prism volume. As discussed above, it is assumed that the increase in tidal dispersion in the segments will be proportional to the increase in tidal prism as modeled by Kelley (2009). The existing tidal prism is 713,000 ft^3/day and the tidal prism under the 24-ft culvert replacement scenario is estimated to be 4,972,000 ft^3/day, approximately seven (7) times the existing conditions.

The concentration of fecal coliform and *Enterococcus* was predicted for both the existing conditions and the future conditions with the 24-foot culvert replacement. Model runs were completed using the source concentration values (W) calibrated for both summer and winter conditions, and a range of decay rates. The model scenarios considered are summarized in *Table 35.*

Table 35
Summary of Model Scenarios

Model Scenario	Conditions	Bacteria	Season	Decay Rate
1	Existing Culvert	Fecal Coliform	Summer	0.5/day
2	Existing Culvert	Fecal Coliform	Summer	8.0/day
3	Existing Culvert	Fecal Coliform	Winter	0.5/day
4	Existing Culvert	Fecal Coliform	Winter	8.0/day
5	Existing Culvert	Enterococcus	Summer	0.3/day
6	Existing Culvert	Enterococcus	Summer	4.2/day
7	Existing Culvert	Enterococcus	Winter	0.3/day
8	Existing Culvert	Enterococcus	Winter	4.2/day
9	24-foot Culvert Replacement	Fecal Coliform	Summer	0.5/day
10	24-foot Culvert Replacement	Fecal Coliform	Summer	8.0/day
11	24-foot Culvert Replacement	Fecal Coliform	Winter	0.5/day
12	24-foot Culvert Replacement	Fecal Coliform	Winter	8.0/day
13	24-foot Culvert Replacement	Enterococcus	Summer	0.3/day
14	24-foot Culvert Replacement	Enterococcus	Summer	4.2/day
15	24-foot Culvert Replacement	Enterococcus	Winter	0.3/day
16	24-foot Culvert Replacement	Enterococcus	Winter	4.2/day

3.3.3 Model Results

The range of bacteria concentrations under the existing and potential culvert replacement scenarios are provided in *Table 36* for winter and summer conditions and a range of bacteria decay rates. Given the limitations associated with the bacteria data discussed above, the results of this simple mass balance model are intended to provide a relative comparison between the existing conditions, as represented in the TMDL, and potential post-culvert replacement conditions. *Table 37* provides the modeled percent reduction in bacteria concentrations from the existing conditions at the Route 28 culvert to the future conditions after the culvert replacement.

Table 36
Summary of Modeled Bacteria Concentrations at the Culvert Under Existing and Future Conditions

	Existing Culvert				24-foot Culvert Replacement			
Mean Tidal Prism Volume	**713,000 ft^3***				**4,972,000 ft^3***			
	Fecal Coliform		**Enterococcus**		**Fecal Coliform**		**Enterococcus**	
	Summer	**Winter**	**Summer**	**Winter**	**Summer**	**Winter**	**Summer**	**Winter**
Range Concentration of Bacteria at the Culvert (CFU/100 mL)	45 - 95	8 - 15	19 - 33	14-20	11 - 19	2 - 3	4 - 6	3

Table 37
Summary of Modeled Percent Reduction of Bacteria Concentrations Under Existing and Future Conditions

	Fecal Coliform		Enterococcus	
	Summer	**Winter**	**Summer**	**Winter**
Range % Reduction	76% - 80%	77% - 82%	78% - 82%	79% - 85%

3.4 Evaluation of Water Quality Modeling Results

The results of the Muddy Creek modeling evaluation can be used to assess relative changes in water quality following the culvert replacement and assess those changes in the context of the Massachusetts Surface Water Quality Standards and the fecal coliform TMDL established for Muddy Creek.

According to the TMDL for Muddy Creek (Samimy et al., 2006), the highest bacterial concentrations in Muddy Creek were observed at the culvert monitoring location during wet weather in the summer season (fecal coliform geometric mean of 253 CFU/100 mL) and reductions of up to 95% in fecal coliform loadings will be necessary to meet the water quality standard. Note that in the TMDL "loadings" are expressed as a concentration. A 95% reduction from a geometric mean of 253 CFU/100 mL would be approximately 13 CFU/100 mL. In the winter months, when monitoring has shown that the concentration of fecal coliform is typically less (geometric mean of 65 CFU/100 mL at the culvert and maximum geometric mean of 83 CFU/100 mL in the upstream segment.1), a reduction of 78% in the fecal coliform concentration at the culvert would be required to meet the water quality standard for shellfish habitat.

Reductions in fecal coliform concentrations in Muddy Creek can result from reductions in bacteria source loading and dilution resulting from increased tidal flushing. The results of the modeling (*Tables 36* and *37*) suggest that even using a conservative fecal coliform decay rate of 0.5/day, relative reductions of 76% and 77% are anticipated in the summer and winter, respectively. While this does not meet the 95% reduction established as a goal in the bacteria TMDL it does represent a substantial anticipated decrease in fecal coliform concentrations. With bacteria source loading remaining unchanged, the only primary factors affecting bacteria concentrations are the amount of time bacteria spend in Muddy Creek (i.e., residence time) and the volume of tidal water diluting the point and non-point sources of bacteria inputs to the waterbody.

Based on the hydrodynamic modeling of culvert scenarios by Kelley (2009), the anticipated residence time in the creek will be reduced from approximately 4 days to 0.5 day. This means that the time for in-situ decay (i.e., die off) of bacteria will be reduced compared to present conditions. Actual decay rates vary depending on environmental conditions and a reasonable range was used in the modeling based on a review of literature data. Lower, estimates of decay provide a conservative estimate of expected geometric mean fecal coliform concentrations at the culvert, based on data available for model development. Under existing conditions, *Table 36* shows that is a summertime high value of 95 CFU/100 mL for fecal coliform. Even if a higher decay rate were used, providing a best case scenario of in-situ decay conditions, the summertime value of fecal coliform is 45 CFU/100 mL under existing conditions. These are well over the geometric mean standard of 14 cfu/100 mL for shellfishing areas, yet monitoring for the shellfishing area downstream of the culvert has not reported fecal coliform values this high (O'Neil, 2011). This provides evidence that existing dilution downstream of the culvert is already acting to reduce the elevated fecal coliform concentrations leaving the culvert under existing conditions.

With a 24-foot culvert in place, using the same range of decays rates and the greater tidal exchange (i.e., shorter residence time and time for decay), the modeled bacteria concentrations at the culvert are substantially lower than existing conditions. This is due to the larger tidal volume. Even with a shorter time for decay in the creek itself due to the removal of the restriction, the significantly larger volume of low fecal coliform water entering Muddy Creek from Pleasant Bay and mixing with water upstream of the culvert results in the lower predicted concentrations at the culvert. Even if it is assumed that no further decay or mixing occurs after leaving the culvert, the modeled concentrations are basically at the water quality standard for shellfishing.

As discussed above, if the same assumptions of no further decay or dilution were made under existing conditions, then it would be expected that the geometric mean concentrations in the SC58 conditionally approved shellfishing area would be within the range of existing conditions values presented in *Table 36* and there is no evidence from the monitoring of that area that fecal coliform concentrations are that high. Again, this is evidence for the dilution that already occurs for the higher fecal coliform waters currently exiting Muddy Creek and that mechanism with continue to act on the water with lower fecal coliform concentrations leaving Muddy Creek under the culvert replacement scenario. Therefore, there is no evidence from the water quality modeling evaluation to suggest that negative impacts to the SC58 shellfishing area will result from the culvert replacement.

In the finite difference model developed for this study, *Enterococcus* concentrations modeled at the culvert are used to represent the concentrations in Pleasant Bay. These concentrations could be used as a conservative surrogate for water quality at nearby Pleasant Bay Beach and Jacknife Harbor Beach. In that case, under existing conditions summertime *Enterococcus* concentrations, which are of most interest in terms of comparison with the primary contact recreation standards, are estimated to range from 19-33 CFU/100 mL, below the SWQS of 35 CFU/100 mL for bathing beaches. In the wintertime, geometric mean *Enterococcus* concentrations are approximately half of the summertime values.

Review of the water quality data for Pleasant Bay Beach and Jacknife Harbor Beach shows relatively few exceedances of the SWQS for bathing beaches. Similar to the fecal coliform results discussed above, this is likely due to a combination of dilution with relatively "clean" Pleasant Bay water, additional die-off, and the pathway of flow from the Muddy Creek culvert outlet to the beaches. Although hydrodynamic modeling or dye studies would be needed to confirm, on the basis of the water quality data alone the water quality conditions in Muddy Creek appear to have relatively little influence on water quality at the nearby beaches. Given that observation and the results of the water quality modeling data which indicated a reduction in bacteria concentrations under the culvert replacement scenarios to an order of magnitude less compared to existing conditions, there is no evidence to suggest that negative impacts to the nearby beaches will result from culvert replacement.

The results of this modeling evaluation are similar to those observed in the modeling of nitrogen concentrations in Muddy Creek and Pleasant Bay with the replacement of the existing culverts with a 24-foot culvert. The modeling results indicate that culvert replacement will improve water quality in Muddy Creek, but will have no significant impact on water quality in Pleasant Bay (in this case at the nearby beaches). Similar to what Eichner et al. (2010) found relative to the nitrogen TMDL goals, the culvert replacement is anticipated to result in a reduction in the difference between existing bacteria concentrations and the TMDL target concentration, but additional bacteria reductions would still be required to reach the TMDL fecal coliform concentration established for Muddy Creek. However, the magnitude of the reductions would be reduced with the 24-foot culvert in place.

Based on both the modeling results and a review of the historic water quality data and modeling for nutrients and bacteria, the following recommendations are made regarding the water quality monitoring program for Muddy Creek:

- Collection of more recent fecal indicator organism data. Although some fecal coliform data is still collected in the shellfishing area, the last collection of data along the length of Muddy Creek appears to be in 1998, over a decade ago.

- Collection of fecal coliform as well as *Enterococcus* data would allow for confirmation of the modeling assumption that the fecal indicator organisms covary along the length of the creek and would alternatively allow for recalibration of the model for *Enterococcus* with observed data.

- Alignment of the historic DMF and Town of Chatham stations with the Pleasant Bay Alliance PBA-5 and PBA-5A monitoring locations. These locations may be near each other, but consolidation would be useful for long term analysis and comparison of bacteria with other water quality parameters.

- Since source reductions will still be necessary to meet the TMDL goals for fecal coliform, microbial source tracking methods may be a useful next step to prioritize source reduction actions in the watershed.

4 Culvert Replacement Alternatives Assessment

4.1 Introduction

A number of potential alternative configurations exist to replace the existing culverts below Route 28. Previous hydrodynamic modeling (Kelly, 2009) determined that replacing the existing culvert with a 24-foot wide hydraulic opening would achieve the desired tidal flux into the Muddy Creek system. Several alternatives are available to replace this culvert that would achieve this desired hydraulic opening, however, several other criteria are also important in order to maximize the end value of this project to the public and habitat restoration.

Any future culvert replacement will need to comply with the current Massachusetts Department of Transportation (MassDOT) Load Resistance Factor Design (LRFD) Bridge Manual. As a result, this evaluation used that manual as a basis for identifying alternatives and design requirements.

This section identifies and evaluates alternative construction approaches to replacing the culverts. Three alternative approaches were initially evaluated based on the results of previous modeling specifying a 24-foot wide culvert opening. Upon reviewing the alternatives with MassDOT and the project partners in September 2011, it was determined that other bridge configurations with a modified geometric channel section (i.e., armored slopes forming an open channel) would be acceptable provided hydrodynamic modeling confirmed scour/channel configuration requirements could be met under this configuration. Following an additional modeling evaluation in December 2011 (Kelly, 2011) a revised recommended approach was developed, reflecting a single-span bridge over an open channel across the Route 28 embankment.

4.2 Design and Construction Requirements

The future design and construction of this culvert will be required to satisfy several specific criteria both for the final design of the structure as well as during its construction. These design and construction criteria are described in the following paragraphs. The criteria listed herein are not selection criteria but are the minimum standards by which any future design and construction will follow.

4.2.1 Design Requirements

The design of this structure must comply with the requirements of the MassDOT LRFD Bridge Manual, and the American Association of State Highway and Transportation Officials (AASHTO) LRFD Bridge Design Specifications. For the purpose of this report, the following design criteria have been identified:

- Provide a 24 foot channel width (or equivalent hydraulic width) for tidal exchange and channel maintenance.
- Provide a 75 year design life.
- Provide adequate clearance during high tide for kayak and canoe passage (minimum 4 feet).
- Provide adequate clearance for a potential sea level rise of up to 3 feet during the design life (The 3 foot increase has been applied to the Maximum Tide elevation reported for post-construction conditions downstream Rt. 28 in SMAST-ACRE's hydraulic modeling analysis for a 24 foot wide box culvert).
- Provide a stream bed elevation of approximately -3.0 feet NAVD88.
- Preserve the current alignment and profile of Route 28 (Elev. varies between approx. 16 and 24 feet NAVD88 within the project site)
- Accommodate existing utilities through the Route 28 right-of-way.

A full hydraulic and scour analysis as well as a full geotechnical analysis will be required to determine the appropriate extent and configuration of scour countermeasures and pile foundations. It is anticipated that some form of scour countermeasures will be required due to the findings of the previous hydrodynamic modeling. It is also anticipated that pile supported foundations will also be required. The cost estimates for each of the alternatives has taken into account the potential need for piles and scour countermeasures where applicable and included allowances for these items.

4.2.2 Construction Requirements

Construction requirements are generally focused on minimizing temporary impacts during the construction period. These include:

- Maintaining existing hydraulic capacity through the embankment.

- Provide a means for traffic to continue through or around the proposed site.
- Minimize temporary impacts to wetland resources.

4.3 Site Constraints

4.3.1 Tidal Range

The tidal characteristics for both the existing and proposed conditions were previously developed as part of an evaluation by the Towns and the Pleasant Bay Alliance (PBA) to determine a culvert configuration would provide the best tidal flushing upstream of Route 28.

The current tidal elevations (NAVD88) upstream of the existing culverts are provided below:

Maximum Tide:	2.02'
Mean Higher High Water:	1.62'
Mean High Water:	1.52'
Mean Tidal Level:	1.32'
Mean Low Water:	1.02'
Mean Lower Low Water:	1.02'
Minimum Tide:	0.72'

The tidal elevations (NAVD88) upstream of the proposed 24 foot channel width are provided below:

Maximum Tide:	3.92'
Mean Higher High Water:	3.12'
Mean High Water:	2.72'
Mean Tidal Level:	1.12'
Mean Low Water:	-0.48'
Mean Lower Low Water:	-0.48'
Minimum Tide:	-0.58'

The proposed bridge alternatives were configured based the proposed maximum high tide of 3.92 feet for a 24 foot wide channel, with consideration given to the anticipated future increase in sea level.

4.3.2 Excavation Depths

The geotechnical investigation indicated that the soils underlying the existing culvert would be capable of providing an allowable pressure of 2,000 pounds per square foot (psf) if the structure is founded directly on the native soils. If the subgrade is over excavated and compacted structural fill is placed below the footing, the allowable bearing pressure would be 4,000 psf. Therefore the construction of the bridge alternatives with foundations located below the proposed stream bed will require excavating to an elevation between -7 and -9 feet (NAVD88) with a total excavation depth of approximately 26 feet to 31 feet depending on the structure type. The required depth of excavation within the upstream and downstream channels will be approximately 6 feet.

The soils in the embankment are relatively loose and will require the use of piles to support substructure elements for alternatives that do not have foundations below the bottom of the proposed streambed, such as conventional bridges supported on pile bents adjacent to the channel and abutments located higher up the embankment slope. For alternatives that do not have foundations located below the streambed the bottom of the excavation will be approximately elevation -4.0 in order to remove the existing culverts, with a total excavation depth of approximately 23 feet to 28 feet.

4.3.3 Structure Width

Regardless of which structure type is chosen for the proposed bridge, the entire width of the embankment supporting Route 28 along the centerline of the existing culverts, approximately 100 feet between the existing culvert headwalls, must be excavated to remove the existing culverts and construct the required replacement structure.

The width of the proposed structure along the centerline of the streambed will vary depending on the structure type selected. For example, with a required minimum roof elevation of 11 to provide adequate clearance for small watercraft, the overall width of a buried structure, such as a pre-cast 3-sided bridge or box culvert, would be approximately 68 feet. The overall width of a buried structure is ultimately determined by site topography such as embankment width and height, and the proposed height of the roof, headwalls and wing walls. With the current site conditions, the shorter a proposed buried structure is the taller the headwalls and wing walls will need to be in order to retain the embankments. While a reduction in the width of the structure will reduce the cost of the main structure, it will increase the cost and complexity of the headwalls and wing walls.

The width of a conventional bridge along the centerline of the streambed will typically be significantly less than that of a buried structure given the current site configuration. One item that will affect the width of a conventional bridge is the need to accommodate existing buried utilities. If a multi-stringer steel beam bridge with a concrete deck is used, the structure will only need to be wide enough to carry the roadway. The existing utilities can be accommodated by placing them between adjacent stringers. If an adjacent pre-cast deck beam bridge is used, a 6 foot wide sidewalk will likely be necessary in order to accommodate the existing utilities. The sidewalk will allow for a separation of the adjacent deck beams under the sidewalk, creating a bay for the installation of the utilities.

The width of a multi-stringer steel beam bridge will be approximately 31 feet along the centerline of the stream. The width of an adjacent pre-cast deck beam bridge will be approximately 37 feet. Although increasing the width of a conventional bridge with splayed wingwalls beyond the required minimum would reduce the length of the wingwalls, doing so offers little cost benefit because a wider bridge would require wider abutments and cost more to construct than the savings realized by reducing the length of the wingwalls.

4.3.4 Utilities

Underground utilities known to exist in the vicinity of the culverts carrying Route 28 over Muddy Creek include a gas main and a telecommunications conduit. Overhead utilities are also located along the southern side of Route 28. The actual size and configuration of the utilities and presence of ancillary structures is not fully known at this time.

The excavation for the construction the proposed bridge will impact all of the utilities, both underground and overhead. Provisions for the temporary abandonment, temporary relocation, or provisions to temporarily expose, support, and maintain the existing utilities will need to be developed in subsequent phases of planning and design in order to construct the proposed bridge.

4.3.5 Construction Storage and Staging

Because of limited shoulder widths, a maximum of approximately 8 feet along the northern shoulder, and steep embankment slopes, the amount of space available for construction storage and staging is limited. Temporarily disturbing wetlands to construct storage and staging areas by adding temporary fill along the embankments and within extensive wetland areas was assumed to not be feasible for this project. As a result, storage and staging areas are limited to portions of Route 28 east and west of the project site, within the limits of the road closure.

A storage and staging area could be available below the access road to the beach on the Chatham side of the site. However, this area would require re-grading, may be subject to inundation, and prove difficult for a contractor to access and use effectively.

In general the project site is considered to have limited available space due to the proximity of regulated wetlands and the steep embankment slopes along both sides of the roadway. In addition, due to the site location, soil conditions, and depth of excavation, excavation shoring and cofferdamming and dewatering to protect the construction area from tides will be required, further impacting the sites limited space constraints.

4.4 Alternative Construction Techniques

In general, there are three methods of installing a culvert replacement over Muddy Creek due to the active roadway supported by the embankment. These are staged construction, road closure with a detour around the site, and box jacking. Options such as slip lining are not applicable in this situation as the size of the proposed structure is significantly larger than the existing culverts being replaced. A brief description of the construction techniques is provided below.

4.4.1 Staged Construction

The staged construction of a bridge entails construction of the bridge in multiple phases in order to maintain the flow of traffic through the construction site. This method of construction basically requires that half of the bridge is constructed in one side of the site while the other side is used to maintain traffic. Given the existing site constraints, the staged construction of the proposed bridge will required that the top of the embankment be widened to the north or south in order to shift traffic and provide enough space to construct a portion of the bridge. This initial portion of the bridge construction would need to be wide enough to accommodate a temporary road while the remaining portion of the bridge is completed.

Because of the limited shoulder widths on this project site and steep slopes that fall away from the shoulders, this alternative would require temporarily filling above the sideslopes along Route 28 in order to accommodate a minimum 22 foot wide temporary roadway. The overall length of the temporary roadway would have to be of adequate length to accommodate safe transitions of the roadway in and out of the construction site and to provide for storage and staging areas along existing right-of-way.

The following is a typical construction sequence for staged construction maintaining 2-way traffic through the construction site.

- Stage No. 1
    1. Set up maintenance and protection of traffic devices
    2. Construct water bypass consisting of temporary manholes, pipes and pumps.
    3. Add fill to the northern slope to widen the top of the embankment approximately 15 feet to accommodate the required travel lanes.
    4. Construct temporary travel lanes and shift traffic north.

- Stage No. 2
    1. Install excavation support system and excavate the southern portion of the embankment
    2. Remove the existing culverts and construct the southern portion of the bridge
    3. Backfill and construct temporary travel lanes over the new structure and shift traffic to the south

- Stage No. 3
    1. Install excavation support system and excavate the northern portion of the embankment
    2. Remove the existing culverts and construct the northern portion of the bridge
    3. Backfill, remove excavation support system, construct permanent travel lanes over the new structure
    4. Transition traffic on to newly constructed roadway, remove traffic control devices
    5. Remove cofferdams and water handling devices

This approach will require the most time to complete, approximately twice the amount required for construction using a road closure and detour. Given the time required to implement this approach, an alternating one-way traffic scenario is assumed to be undesirable due to the delays it will create during summer months and peak traffic times. A two-way travel lane would therefore be required in order to minimize the impacts on traffic and keeping delays to acceptable levels.

Creating enough space for a two-way traffic scenario will require widening the top of the embankment approximately 22 feet. This can be accomplished by simply adding temporary fill with a maximum slope of 1.5H:1V, which would result in wetlands impacts several times greater than that associate with road closure, or by installing sheeting to support the widened embankment which significantly increase the cost of the project.

4.4.2 Road Closure

This approach consists of closing the portion of Route 28 between Bay Road in Harwich and Arbutus Trail in Chatham. Traffic would be detoured around the project site. A traffic bypass plan attached as *Sheet CT-101* in *Attachment H* provides a potential detour plan for traffic around the construction site, detouring traffic from Route 28 along the following roads:

- Route 28 South to
- Pleasant Bay Road to
- Orleans Harwich Road to
- Church Street to
- Old Queen Anne Road to
- Old Comers Road to
- Route 28

While this approach will result in the greatest traffic impacts, it minimizes the time required for construction to approximately 6-9 months for most alternatives. Because temporary construction is not needed to support travel lanes or jacking pits, it reduces the overall project cost, and eliminates safety concerns with traffic flow through a work zone. As a result, this approach also minimizes potential for temporary wetland disturbances during construction because it minimizes temporary construction impacts.

4.4.3 Box Jacking

Box jacking is a construction alternative that allows for the installation of a culvert through an existing embankment without an open excavation or shored excavation. This approach would allow two-way traffic to continue over Route 28 throughout construction.

This technique uses a large hydraulic jack to push a box culvert into an embankment while the soil is excavated at the leading edge of the box culvert and removed through the trailing end of the culvert. Jacking requires the construction of a temporary jacking pit. The pit consists of a braced backwall, also known as the reaction wall, upon which the hydraulic jacks will push against and a concrete launching slab upon which subsequent box culvert units will be set and aligned prior to jacking.

Jacking is a technique which requires the structure to have a continuous perimeter in order to maintain the alignment of the structure during installation. A three sided structure will be difficult to install with this method as it will not be able to distribute the forces imparted by the jacking system into the soils evenly and tend to drift out of position as it is advanced through the embankment. Although box jacking operations have been successfully completed with spans of up to 80 feet for the Central Artery Tunnel Project in Boston, MA, jacking a 24 foot wide box culvert is still considered a significant effort. This technique is typically used for smaller box culverts and pipes.

The best location for a jacking pit for this project site would be in the creek on the downstream side of the existing culvert because there is access to that location by means of the existing access road to the beach. No such access exists on the upstream side of the culvert. If the jacking pit is located on the upstream side, a temporary access road will need to be constructed. The benefit to locating the jacking pit on the upstream side of the roadway embankment is that it will be protected from storm tides, The negative of both locations is that the jacking pit will be constructed within the creek bed.

Because of the elevations required (culvert invert elevation of -3 feet), jacking at this site would require significant dewatering. Typically sheeting would not be used as a cutoff as part of a jacking operation, as a result, groundwater in the embankment would drain into the jacking tunnel. Techniques such as sheet piling and slurry cutoff walls can be utilized to minimize water flow into the tunnel. Also, well points can be drilled around the tunnel to remove water. These dewatering approaches will add significant costs.

Surface water will also need to be managed because the jacking operation will block flow through the existing culverts. In order to avoid building a new temporary culvert 30 feet below the embankment, an alternative would be to pump surface water from the upstream to downstream side of the embankment. This obviously would eliminate tidal flow into Muddy Creek for the duration of the jacking operation which could be between 3 to 5 months.

Typical applications for this construction technique include the installation of underpasses or drainage systems under the following conditions:

- Existing sensitive roadways, railways or runways where an interruption of service would represent a significant project constraint
- The depth of excavation is excessive and considered prohibitive
- Existing site constraints make conventional open excavation and backfill methods difficult or impractical

A typical construction sequence for this technique is outlined below:

1. Construct temporary roadway for access to jacking pit.
2. Install dewatering system and water control system.
3. Construct temporary jacking pit with shored sidewalls, portal wall, and with adequately braced reaction wall. This will also include cofferdamming to protect pit from storm tides.

4. Construct launch slab.
5. Set and align first box culvert unit, install protective shield on leading edge.
6. Jack box culvert unit into embankment and excavate soils at leading face simultaneously.
7. Proceed until space is available on launching slab for placement of subsequent box culvert unit, retract thrust members.
8. Place subsequent box culvert unit and repeat jacking and soil excavation process.
9. Repeat steps 6, 7 and 8 until the box culvert is in its final as designed location.
10. Excavate and construct the wingwalls and headwall at the leading end of the box culvert.
11. Remove the temporary jacking pit and construct the wingwalls and headwall at the trailing end of the box culvert.

4.4.4 Summary Evaluation of Alternative Construction Approaches

The following table summarizes advantages and disadvantages of the alternative construction approaches.

Table 38
Comparison of Alternative Culvert Construction Approaches

Potential Impacts	Staged Construction	Road Closure	Box Jacking
Traffic	Some level of impacts even with a two-way bypass constructed as traffic still has to navigate around the barricades of the site.	Greatest potential impacts as it would require a detour of approximately 6.5 miles around the project site for 6-9 months.	Almost no impacts. Only potential impacts from construction traffic entering jacking site.
Wetland	Greatest level of wetland impacts (approx. 0.2 acres) if fill is used for the construction of new bypass lanes on the south side of embankment (0.4 acres on the north side)	Least amount of wetland impacts which will be limited to those required for direct construction of the bridge and culvert.	Significant wetland impacts on downstream side of embankment where jacking pit would be located.
Cost	Typically represents the most costly conventional construction alternative.	Typically construction that detours traffic around the project site represents the least costly construction alternative.	Box Jacking is considered a specialty requiring skilled crews and knowledge and is typically more costly than conventional alternatives.
Construction Time	Typically requires the most construction time of conventional alternatives (approx. 13 to 15 months in this case)	Typically requires the least construction time of conventional alternatives (approx. 6 to 9 months in this case)	Potentially requires to the least amount of time for construction (3-5 months)

4.4.5 Alternative Excavation Techniques

If box jacking is not selected as the preferred method, there are several methods in which to create the 30 foot deep excavation required for the construction of the proposed bridge. This type of excavation can be achieved using one or a combination of the following techniques:

- Open Excavation
- Cantilever Support Walls
- Soil Nail Shoring
- Braced Support Walls
- Anchored Support Walls
- Secant walls

Each of the above methods is briefly described below. Note that the selection of these techniques are more contractor-directed as opposed to engineer-directed because they are related to the means and methods of installing the culvert/bridge. However, this discussion is included herein as these approaches will have some impact on costs and the extent of excavation.

4.4.5.1 Open Excavation

If there are no right of way conflicts, open excavations can be used in almost any soil condition. In general, a sloped open excavation is the most cost and schedule effective construction method because there is no need for shoring operations, or specialized shoring materials and equipment. Site conditions such as weak soil layers, elevated ground water, and utilities will dictate the configuration of open excavation including the slopes, need for benches and partial shoring.

Although the open excavation method is suitable for most soil conditions, a review of the site boring logs indicates that the soils in the vicinity of the project are weak sands, a condition that may produce running sands. This situation may have to be addressed by a geotechnical engineer to ensure that the slopes of the excavation are stable. In addition, the site has both underground and overhead utilities which will need to be addressed during the design phase in order to avoid construction conflicts.

One of the disadvantages associated with open excavations is that the volume of excavation and backfill is greater with this option than one using shoring. When the depth of excavation is excessively deep, expensive backfill materials are required due to unsuitable onsite materials, or the excavated soils are contaminated a vertical cut supported by shoring will likely be more cost effective. This alternative could only be used with full road closure approach.

4.4.5.2 Cantilever Shoring Systems

The cantilever shoring systems such as steel sheet pile walls and soldier pile and lagging walls rely solely on the passive resistance of the soil below the bottom of the excavation to support the sides of the excavation. A cantilever shoring system is the simplest and often most cost effective from a construction standpoint. If a cantilever system can be used without bracing there is no limit to the excavation width and length. Depending on the soil properties below the excavation, an un-braced or un-anchored cantilever shoring system is limited to a depth of approximately 20 feet. If the soils are weak such as on this site, the maximum depth of excavation that can be achieved without bracing or anchors is reduced.

The most common types of cantilever shoring systems in use are interlocking steel sheet piles and solider piles and lagging. Steel sheet piles are available in a variety of the shapes and sizes and offer a great amount of flexibility. They are installed with hammers or harmonic vibrators, depending the site conditions. They are limited in that they are not effective in areas with large boulders or shallow bedrock which prevent driving the piles.

Solider piles and lagging systems normally consist of driven or drilled H-piles with lagging consisting of wood, steel plate, or concrete planks. The piles are installed at intervals of 5 to 10 feet and lagging is placed between the flanges of the piles during the excavation process. As the excavation gets deeper, the soil below the lagging is removed and the lagging is pushed down. The system is well suited where dense hard soils exist below the excavation. In area with shallow bedrock, the system can be drilled and socketed into the bedrock and secured with concrete.

Given the dewatering that will be required as part of this project, it is likely to expect a cantilever shoring system to be employed at least to some extent. This system would provide both a cut-off for groundwater as well as retain soils.

4.4.5.3 Other Excavation Approaches

4.4.5.3.1 Soil Nails

Soil nailing is a technique used to stabilize slopes and excavations, and for the construction of permanent retaining walls from the top down. This technique is basically a method that reinforces the ground with the use of steel tendons which are drilled and grouted into the soil, inclined at an angle below the horizontal, to create a composite mass similar to a gravity wall. For temporary shoring of an excavation, shotcrete is typically applied to the exposed surface of the excavation in lieu architectural options such as pre-cast panels or vegetated cells which are typically used for permanent walls.

4.4.5.3.2 Braced Shoring Systems

Braced shoring systems typically utilize a series of whalers and struts along with the embedded portion of the cantilever shoring to support the excavation. This type of system is most often used with steel sheet pile walls. The whalers and struts are designed and configured to transfer forces from one side of the excavation to the other, effectively bracing the walls against each other. Bracing is useful in deep excavations, typically over 20 feet, which would require heavier sheet pile sections, or where the soils below the excavation are weak and can not adequately support a cantilever shoring system.

The larger an excavation is, the more difficult it is to configure the bracing system so it will not interfere with construction. Often times the bracing will need to be reconfigured during construction at different stages to avoid conflicts.

4.4.5.3.3 Anchored Shoring Systems

Anchored shoring systems typically utilize two types of anchors; active and passive. Active anchors typically consist of tiebacks using high strength steel bars or strands grouted into a drilled hole, similar to the method used in soil nail stabilization. These anchors are installed by drilling a hole into the soil behind the wall supporting the excavation, inserting a steel rod or tendon, and injecting the hole with grout to secure the anchor. Once installed, the anchor is secured to the wall supporting the excavation and tightened to impart an active force on the wall. Proprietary anchor systems also exist which utilize mechanical devices to engage the soil behind the wall to provide support. In general, the proprietary anchors function in the same manner as the grouted systems.

Passive anchors typically consist of steel bars, tie rods, secured to concrete deadmen or anchor piles placed a distance behind the wall. Although the tie rods are tightened, they typically only impart a small force on the wall, significantly less than that associated with an active anchor. Passive anchor systems typically experience more movement than active systems. This movement must be accounted for in the design of the shoring system.

4.4.5.3.4 Secant Walls

A secant wall is a pile type of retaining wall where the piles are formed by drilling a cased or uncased shaft with a drill rig and filling the shaft with concrete. The wall is formed by a series of closely spaced shafts that function in the same manner as steel sheet piling. The walls can be anchored using tiebacks if the existing soil conditions are not suitable for a cantilever installation. These walls are often best suited when designing a shoring system with for a specific site with difficult conditions and constraints such as high ground water, weak soils, or existing structures and roads.

The system can be installed with minimal vibrations if the correct soil conditions exist, minimizing the potential for settlement and damage to adjacent structures. This type of system considered a specialty system requiring contractors experienced with the installation of secant walls and is often used where a permanent wall is needed because their construction makes removal after construction costly and difficult.

4.4.5.4 Planned Approach

The construction bidders will have varying approaches to completing the excavation using one or more of these techniques. Given the limited space available for staging and storage, the required depth of the excavation, and the need to control water and dewater the site, a combination of open excavation and steel sheeting for exaction shoring will likely prove to be the best alternative. Open excavation alone at this site would not be practical due the depth of excavation below the streambed, the proximity to Pleasant Bay, and the need for a cofferdam in order to prevent inundation. Shoring the entire excavation would require that the shoring be capable of supporting a maximum excavation depth of approximately 30 feet.

Open excavation along a portion of Route 28 to approximately elevation 10 would reduce the maximum exposed height of the required shoring system to approximately 17 feet and provide areas adjacent to the sheeting for staging and construction activities. Open excavations lower than elevation 10 are possible, however the risk of inundation during a storm event is increased. The steel sheeting used to shore the remaining excavation would also serve as a cofferdam and a cutoff wall to control water. The use of steel sheeting would also allow for the construction of a bypass channel adjacent to the excavation, allowing tidal flushing to continue during construction.

Although there are numerous approaches that could be used for this project, the above is presented here for comparison of bridge alternatives. Upon selection of an alternative, the excavation, shoring, and water control methods can be revisited to better define their limits and optimize their use and implementation.

4.5 Culvert System Alternatives

In accordance with the MassDOT bridge design manual, the following bridge systems are acceptable alternatives for use on State Highways with a span of less than 40 feet:

- Pre-Cast Concrete Box Culvert
- Pre-Cast Three-Sided Culvert
- Bridge
    - Reinforced Concrete Slabs
    - Steel Stringers with Composite Concrete Deck
    - Adjacent Pre-stressed Concrete Deck Beams

A brief description of each of the above alternatives is provided in the sections below.

4.5.1 Pre-Cast Concrete Box Culvert

Pre-cast box culverts consist of reinforced concrete with a four sided square or rectangular configuration. These structures are readily available in standard sizes from several certified regional manufacturers (see *Figure 21* below for a typical configuration).

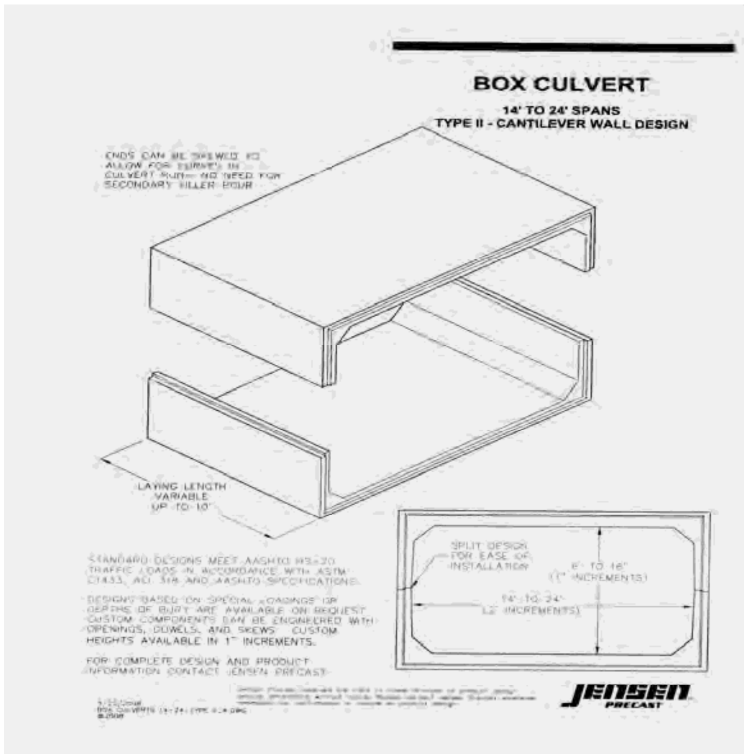

Figure 21: Typical Single Cell Split Pre-cast Box Culvert

Pre-cast box culverts are a very cost effective solution when used as in a suitable situation and environment. Their configuration does not require the construction of footings aside from those needed to support the wing walls. They may be installed in relatively quick succession once cut-off and return walls have been constructed to prevent undermining and the subbase has been prepared and approved. Being pre-cast, they do not require curing time in the field and may be backfilled immediately after placement.

The use of pre-cast concrete box culverts for this installation poses several challenges as follows:

- The minimum hydraulic channel width required at this site is 24 feet. Although pre-cast concrete culverts with a 24 foot span are available, this would be considered a larger than typical application. Finding a local pre-cast manufacturer capable of producing a system this large may prove to be difficult. Being a non-standard size may also mean that there will be a long lead time associated with the use of a 24 foot box culvert.

- The challenge with using a box culvert in this installation will be the required height of the box. If the floor of the box culvert is set at elevation -3 (NAVD88) and its roof is set at elevation 11 (NAVD88) to account for sea level rise and kayak/canoe passage during high tide, the total inside height will be fourteen feet. Adding approximately 40 inches, 20 inches for each wall and for the bottom and top slab, will yield a total structure measuring 27 feet 3 inches by 17 feet 4 inches. Shipping a structure with of this size will be costly.

  Typically, pre-cast units are limited to 8 feet in width to facilitate transportation without a wide load permit, and limited in height due to the vertical clearance of highway bridges under which it will travel. In general, MassDOT recommends that the dimensions of a box culvert be such that transportation conflicts are avoided. In order to facilitate transportation, a pre-cast concrete box culvert of this type can be cast as a split structure with separate top- and bottom-segments. This would reduce the individual component measurements to approximately 27 feet by 9 feet which can be shipped on a trailer with the 27 foot dimension laid on the long dimension of the trailer.

- Since the culvert can be constructed in a fashion that is transportable, a multiple culvert design is not being further considered. Multiple culverts would require an overall opening greater than the 24 foot clear channel width in order to provide an equivalent hydraulic capacity. This increase in overall width would mean a slightly larger excavation and area of disturbance.

- One other issue with a box culvert is that it will have a concrete floor as opposed to a more natural substrate. Even if the box culvert floor is lowered to allow stones and/or sand/gravel to be placed on the floor, our concern would be that certain storms would just scour this material. The risk of losing this material is minimized as the floor of the culvert is deepened and more substantial stones and material is placed over the floor. This however only increases the culvert's size, installation costs and difficulty to transport.

4.5.2 Pre-Cast Three-Sided Bridge

Three sided bridges consist of two support walls and a roof (see *Figure 22* for a typical configuration). The roof of a pre-cast three-sided bridge can be either flat or configured as an arch that is integral with the support walls. This configuration allows both the deck slab and the support walls to have a reduced thickness and reduces the amount of steel reinforcement when compared to a reinforced concrete slab supported by conventional abutments.

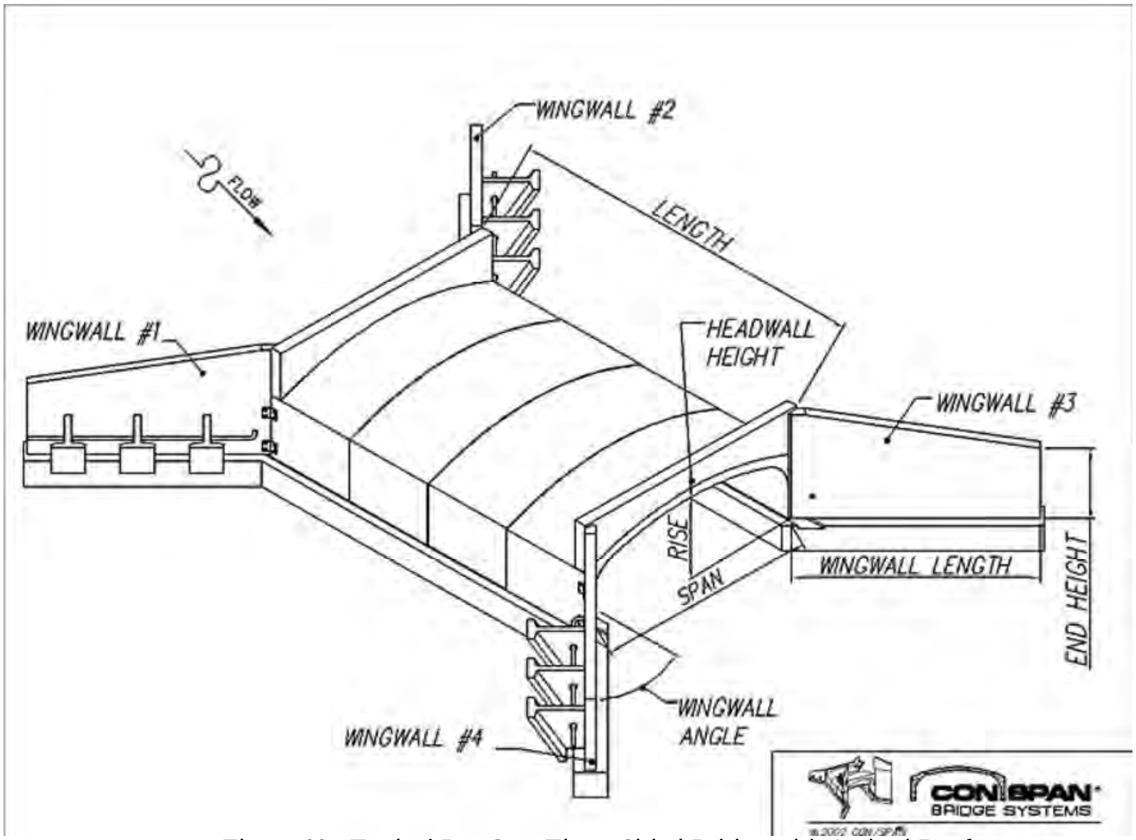

Figure 22: Typical Pre-Cast Three-Sided Bridge with Arched Roof

These structures have very similar structural integrity as compared to box culverts. The lack of a concrete bottom or invert often makes them a preferred choice when a natural stream bed is preferred. Several certified manufactures offer variations of this system capable of supporting the proposed fill above the structure at this site and the loads associated with the standard design vehicles.

This bridge system is supported on pre-cast or cast-in-place concrete strip footings. The height of the support walls and span lengths are variable up to approximately 10 feet and 40 feet respectively. Heights greater than 10 feet would typically be overcome with the use of pedestals cast on the top of the strip footings. The maximum span is typically governed by the amount of fill material placed above the deck, the bridge skew, and constraints limiting the thickness of the deck. For the proposed bridge and site conditions the height of the fill above the 3-sided bridge will be approximately 10 feet, which would require that the deck be approximately 20 inches thick in order to support the fill given a 24 foot span.

Pre-cast concrete three sided bridge systems offer similar decreases in installation time and cost savings as pre-cast concrete box culverts when compared to a conventional cast in place bridge system. However, several challenges exist with its implementation as follows:

- These systems can only be installed in an open excavation because of the need to install a strip footing on both sides of the culvert to support it. Jacking is not an option.

- This will require some over-excavation to install the footings below frost depth. This over excavation will just add additional effort required for dewatering.

Due to the same height/shipping constraints outlined for the box culvert, a three sided bridge for this project would be supported by pedestal walls that are cast onto the strip foundations allowing the roof to be placed at the prescribed elevation.

4.5.3 Bridge Systems

The MassDOT LRFD Bridge Manual identifies several allowable bridge systems for the proposed Muddy Creek installation that would provide a 24-foot wide hydraulic opening. The advantage of a bridge is that it would offer a clear span across the creek that would optimize the opening of the crossing. This would provide a more direct connection between the creek and beach systems for both wildlife and kayakers and canoeists. The disadvantage of this approach is that a bridge will be significantly more costly and take much more time to construct than the other alternatives.

All of these bridges require constructing significant abutments because of the depth of the channel below the road grade. The abutment height can be reduced by creating a channel with an equivalent hydraulic opening, sloping the embankments of the channel and placing the abutment foundations at a higher elevation, however this would increase the span length of the bridge.

The substructure alternatives for a bridge include stub abutments, spill through abutments, and integral abutments, piers and pile bents among others. The best abutment alternative is dependent on the type and configuration of the bridge, and the recommendations of future geotechnical evaluations and hydrologic/hydraulic studies and scour analyses. Considering the subsurface soil conditions and site location along the coast, it is likely that the substructure elements will need to supported on piles and incorporate scour countermeasures.

The following sections summarize these alternative bridge types.

4.5.3.1 Reinforced Concrete Slabs

A reinforced concrete slab is a bridge system where conventional abutments are used to support either a pre-cast or cast-in-place concrete slab. Formwork and shoring is erected to support the wet concrete used for reinforced slab spanning between the abutments. This formwork must remain in place until the slab has cured and gained enough strength to support itself and associated construction loads.

This type of system is considered inefficient for spans greater than 25 feet due to the depth of the slab and heavy reinforcement required to support vehicular loads. If the deck slab is made integral with the abutments the depth of the slab and amount of reinforcement may be reduced. This configuration is effectively the same design as a Three Sided Bridge, one where the deck is integral with the supports.

4.5.3.2 Steel Stringers with Composite Concrete Deck

A steel stringer bridge with a composite deck is a system where the stringers are supported by abutments and a concrete deck is formed and cast on top of the stringers. The concrete deck is secured to the top of the stringers with the use of shear studs welded to the top flange of the stringers. These shear studs allow the deck and stringers to move as a composite unit, increasing the strength of the system. This type of system is suitable for spans up to approximately 90 feet and is typically a preferred choice for spans over 40 feet in length.

4.5.3.3 Adjacent Pre-stressed Concrete Deck Beams

Adjacent pre-stressed concrete deck beams consist of pre-cast concrete beams which are placed side-by-side on conventional abutments and locked together using transverse post-tensioned steel wire. The wearing surface is comprised of either bituminous asphalt or an integral concrete wearing course. The system is well suited for shorter bridge spans over water crossings as the pre-cast beams require minimal maintenance. An example of this bridge type is shown in the photograph below as *Figure 23* (approx. 1.5 miles north of Muddy Creek on Route 28 in Orleans).

Figure 23: Example Pre-Stressed Concrete Deck Beam Bridge with Pile Bents

4.5.4 Summary

The following table summarizes the advantages and disadvantages of the alternatives described above.

Table 39
Comparison of Alternative Culvert Configurations

Alternative	Advantages	Disadvantages
Pre-Cast Concrete Box Culvert	• Shortest construction time. • Minimize time of road closure. • Requires less excavation than other options due to lack of strip footings. • Box jacking is an acceptable method for installation.	• Required span is not offered as a standard size by most manufacturers. • Natural streambed will not be feasible. • Pre-cast box culverts will have the greatest weight per linear foot of all pre-cast concrete options due to the concrete bottom requiring a greater number of narrower sections to reduce the weight of each unit or the use of a larger crane. • Aesthetics will look more like a culvert than a bridge. • Dewatering will be difficult or require the installation of additional sheeting to act as cutoff walls
Pre-Cast Three-Sided Culvert	• Shortened construction time compared to bridge. • Can be designed with shortened pre-cast walls to ease transportation. • Arch top configurations are capable of supporting a significant amount of fill and provide appearance of a larger opening. • Natural stream bottom.	• Additional excavation and time required for foundations. • Can only be installed in an open excavation.
Conventional Bridge (Steel Stringers with Composite Concrete Deck, Adjacent Pre-stressed Concrete Deck Beams with and without Bent Piles, Reinforced Concrete Slabs)	• Best connection between beach and creek for wildlife and people. • Lower potential sea level rise impacts to future kayak/canoe passage. • Natural stream bottom.	• Typically most costly alternative. • Requires most time to construct. • Will require longer-term closure impacts to Route 28 traffic.

Three alternatives were identified for further evaluation of this technical memorandum. These alternatives consist of the three approaches described above (pre-cast box culvert; pre-cast three-sided culvert; and conventional bridge). A three span adjacent pre-cast concrete deck beam bridge alternative supported on stub abutments and pile bents was evaluated as a variant of the conventional bridge approach, as it would reduce the amount of excavation required and require relatively short abutments.

This variant would require a longer bridge span and result in a trapezoidal channel cross-section, which would need to be evaluated under refined hydrodynamic modeling to determine channel dimensions required for this alternative configuration to provide equivalent flushing and tidal range as the rectangular 24-foot wide channel opening provided by other alternatives. This evaluation would account for this alternative's larger wetted perimeter and channel roughness resulting from channel scour protection likely required, and re-evaluate scour and sediment deposition potential at and immediately adjacent to the culvert, as compared to the other alternatives. As discussed in *Section 4.6.4* below, this additional modeling was completed as part of this current study to determine the channel dimensions required to provide an equivalent increase in tidal range and flushing volume provided by a rectangular 24-foot wide channel opening.

In order to highlight the differences in construction approaches, the pre-cast three sided bridge and both alternatives for a conventional bridge utilizing adjacent pre-cast deck beams will be evaluated as if constructed with a road closure using a combination of open excavation and shored excavation. The box culvert was evaluated as if constructed using box jacking to review the potential benefits of that technique.

4.6 Selected Alternatives

4.6.1 Pre-cast Concrete Box Culvert

A conceptual plan for a 24-foot wide rectangular pre-cast concrete box culvert that would be installed using box jacking method is provided as *Sheet RP-401* in *Attachment I*. The following paragraphs further describe the specifics of this approach.

4.6.1.1 Installation Approach

For the purposes of this evaluation, installation by box jacking was evaluated. If construction were competed using open excavation and excavation shoring methods, the installation of a box culvert would have the same challenges as those that would exist for a three-sided culvert.

Box jacking this culvert would consist of constructing a jacking pit and receiving pit on opposite sides of the embankment. Given the need to support the jacking pit reaction wall with a substantial amount of fill material, and protect this fill from storm tides and erosion, the upstream side of the existing culvert would likely be the preferred location. This location will also be less visible during construction. Whether the upstream or downstream side of the embankment is selected for the temporary installation of the jacking system, it will require temporary filling of the creek channel. The downstream side of the culvert is also an active shellfishing bed.

Temporary dewatering will be required within the jacking pit but also be required within the embankment. While a dewatering system will need to be designed, it is for this comparison assumed that eight well points would be used along the tunnel path for dewatering. The actual number of well points and need for a cutoff wall to effectively dewater the site will need to be defined during design.

Because of its size, the culvert would be delivered in a number of sections. Each culvert section would have to be split horizontally creating a top half and bottom half to facilitate transportation on flat-bed trucks. The sections would also need to be configured to accommodate the proposed skew between the end walls and side walls. While the skew is required to provide the proper alignment of the headwalls with embankment, minimize the overall length of the structure, and optimize the wing wall layouts, producing the pre-cast units to accommodate the skew makes the manufacturing process more difficult.

4.6.1.2 Site Layout

A temporary access road would be required to construct the jacking pit. This road will allow equipment and culvert sections to be delivered to the pit and for the removal of excavated soil.

Road closures would not be required with this scenario with two exceptions:

- A flagger would temporarily stop traffic as trucks back down the access road.
- A temporary, shallow culvert would be installed across the road to allow the upstream side to be dewatered.

With this scenario, water draining to the upstream end of the culvert of Muddy Creek would be pumped to a shallow culvert that is installed across Route 28. This shallow culvert can be installed and pavement patched within a few days. The advantage of pumping is that it eliminates the need to construct a culvert 30 feet deep through the embankment with the resulting road closures, construction costs and delays. The disadvantage of this approach is that it will not allow any tidal flushing into the Muddy Creek system throughout the culvert installation period.

Gas and telecommunication utilities within the Route 28 right-of-way would remain in-place, undisturbed during this installation.

4.6.1.3 Potential Impacts

The limit of disturbance will affect approximately 7,910 SF of jurisdictional resource areas within flagged wetlands. Of this disturbance area, there will be approximately 2,340 SF of direct disturbance to bordering vegetated wetlands and salt marsh areas, and approximately 5,570 SF of disturbance to Land Under Ocean. A plan showing these respective areas is provided as *Figure WET-A1* in *Attachment J.*

4.6.1.3.1 Vegetative Communities

There are four vegetative communities that are adjacent to the proposed alternative. These areas are characterized as Wetlands A, B, C and D, as described below.

- Wetland 'A' represents the upper limits of salt marsh-dominated coastal resources located north and east of the existing culvert. This area is the upper limits of the vegetated wetland community at upstream of the existing culvert and is dominated by salt marsh cordgrass *(Spartina alterniflora)* and salt marsh hay *(Spartina patens).* The salt marsh is abutted by a steeply sloping upland forest community including a mix of black oak *(Quercus velutina),* white oak *(Quercus alba)*, pitch pine, low bush blueberries *(Vaccinium sp.)*, and huckleberry *(Gaylussacia baccata).*

- Wetland 'B' represents the upper limits of salt marsh-dominated coastal resources located north and west of the existing culvert. The wetland line represents the Spring High Tide Line and includes areas of low marsh, high marsh, brackish marsh, barrier beach and dune. In this area, the low marsh is a monotypic plant community consisting of *S. alterniflora* while the high marsh zones include *S. patens* and glasswort (*Salicornia sp.).*

- Wetland 'C' defines the upper limits of a palustrine shrub swamp bordering on salt marsh, identified as a Bordering Vegetated Wetland (BVW). The wetland is dominated with highbush blueberry *(Vaccinium corymbosum)* and other species with Morrow's honey suckle (*Lonicera morrowii*) invading the upper limits of the wetland. Other common species include northern bayberry *(Morella pensylvanica)*, highbush blueberry, arrowwood *(Viburnum dentatum),* wild raisin *(Viburnum cassinoides)*, common greenbriar *(Smilax rotundifolia*). Common trees include black oak, white oak and pitch pine. Dead and stressed stands of Eastern red cedar and pitch pine are located intermittently throughout the salt marsh providing evidence of historic hydrologic changes. The wetland is abutted by a steeply sloping Pitch Pine – Oak Forest Woodland community including of a mix of black oak, white oak, pitch pine, low bush blueberry and huckleberry.

- Wetland 'D' represents the upper limits of salt marsh located south of Route 28 and west of the Creek. The salt marsh consists of a mix of low and high salt marsh communities. Dead and stressed stands of mature Eastern red cedar and pitch pine are located intermittently throughout the salt marsh providing evidence of historic hydrologic changes in the system.

Anticipated construction impacts to wetland areas regulated under the MA Wetland Protection Act within this alternative's limit of disturbance are reflected in *Table 40* below.

Table 40
Resource/Regulatory Area Impacts for Pre-Cast Concrete Box Alternative

Wetland Resource/ Regulatory Area[1]	Temporary Impact Area (sq. ft.)[2]	Permanent Impact Area (sq. ft.)[3]	Current Total Resource Area (sq. ft.)	Post-Construction Total Resource Area (sq. ft.)
Coastal Resource Areas				
Land Under Ocean	900	4,670	5,570	6,545
Salt Marsh	300	80	380	300
Land Containing Shellfish[4]	900	5,050	5,950	6,875
Fish Run[4]	900	4,670	5,570	7,415
Land Subject to Coastal Storm Flowage	11,445	1,450	12,895	11,630
Inland Resource Areas				
Bordering Vegetated Wetlands	1,890	70	1,960	1,890
Riverfront Area	41,850	3,570	45,420	44,150

Notes:
1. Resource/regulatory area impacts presented are direct impacts to resource areas with the limits of disturbance during and after construction.
2. Impact area for Land Under Ocean. Fish Run and Land Containing Shellfish is considered to be the area of the existing culvert channel, which will be restored to its original form/function following construction.
3. Permanent impact areas for Fish Run and Land Containing Shellfish represent the area bounded by the existing culverts, as these resource areas will be removed and replaced with the reconstructed culvert/channel centered along the axis of the existing culverts.
4. Due to the increased width of the proposed culvert/channel, additional Land Under Ocean, Fish Run and Land Containing Shellfish will be generated as a result of the proposed structure's layout.

During construction, the absence of a diurnal tidal cycle may have some impacts to the vegetation communities throughout Muddy Creek, if the pumping cycles are not modulated in frequency and amplitude sufficiently to mimic current natural tidal cycles. This pumping cycle would be defined as a specification for the contractor to implement through construction to the greatest degree possible, given capacity limitations of available pump equipment suitable to the site's scale, costs, and the overriding influence of the estuary's natural hydrology upstream of the site, especially during periods of high flows. The technical feasibility and cost-effectiveness of this pump cycle program would be evaluated during subsequent design phases, in concert with an evaluation of the impacts to vegetated communities expected through the period of discussion, and review of these impacts with regulatory agencies to determine if they can be sufficiently minimized or mitigated by other means in the project.

While there will be direct disturbance to these wetland areas, suitable restoration may be achieved through replication. A detailed planting plan and invasive species monitoring and management plan will be required as part of the permitting process and be implemented following construction in order to minimize long-term impacts.

4.6.1.3.2 Shellfish Communities

Muddy Creek has historically been known to have a significant shellfish resource – primarily for soft-shelled clams (*Mya arenaria*). The entirety of Muddy Creek is DMF Designated Shellfish Growing Area SC58, with SC58.1 below Route 28 and SC58.2 above. Soft shell clams and quahogs (*Mercenaria mercenaria*) were historically abundant and commercially harvested both upstream and downstream of Route 28 in both Chatham and Harwich.

This alternative would impact approximately 5,950 SF of Land Containing Shellfish, which includes Land Under Ocean and Salt Marsh areas within the limit of disturbance. Salt marsh areas are conservatively included since formal shellfish assessments of these areas has not yet been completed; if future surveys are performed and shellfish are found not to exist in these areas, the impacts assessment could be reduced accordingly.

The in-situ concentrations of salinity in the sediment and the brackish water previously measured upstream of the construction area will likely be sufficient to support existing shellfish populations through the period of construction. The extent of disturbance for this alternative will have short term loss of individual shellfish and sub-populations within and immediately adjacent to the project's construction footprint area; however, these affects would not extend to populations significantly beyond the limit of disturbance. All species of shellfish that are currently common to the area should not suffer any direct undesirable responses due to changes in salinity in post-construction conditions both upstream and downstream of the culvert. Additional Land Under Ocean created under this alternative would increase the shellfish resource area to approximately 6,875 SF.

4.6.1.3.3 Fisheries Migration

The primary fish species of concern in the Muddy Creek culvert improvement and restoration project are American eel (*Anguilla rostrata*) and alewife (*Alosa pseudoharengus).* Other migratory fish species such as White Perch (*Morone americana*) are well known to utilize Muddy Creek. However, White Perch have limited recreational or commercial value, and as a result little research has been completed to assess their abundance in tidal waters. Inland freshwater introduction of White Perch has been the primary area of concern for this species. In addition to the finfish discussed above, Blue Crab (*Callinectes sapidus*) are known to utilize Muddy Creek during summer months.

This alternative would impact approximately 5,570 SF of Fish Run area (determined as the Land Under Ocean within the limit of disturbance) which would have a significant disruption of fish migration over the course of construction. Because the water will be diverted by means of a pump system, there will be no upstream or, more critically, downstream migration pathway available to eel, alewife, perch or blue crab between Pleasant Bay and Muddy Creek. A fisheries management plan may be required under this alternative to temporarily provide alternative migration routes through an open bypass culvert, however installation of this culvert would be a significant cost given that it would require excavating an open trench to a significant depth, where otherwise such a trench is not required under this alternative.

Alternatively, a mitigation plan could be developed during construction to trap and release migrating species through the period of construction. Again, the technical feasibility of these approaches, costs and relative benefits to respective communities would need to be evaluated and discussed with project partners and regulatory agencies to identify the most appropriate approach to minimize impacts through the period of construction. Once construction is complete and the site is restored and stabilized, diadromous fish will return to Muddy Creek through the widened channel, increasing the total Fish Run area to approximately 7,410 SF.

4.6.1.3.4 Water Quality

Appropriate erosion controls can be implemented during construction to protect water quality. The greatest potential impact to water quality would be the loss of tidal flushing in the creek during construction.

4.6.1.3.5 Wildlife/Rare Species

The Massachusetts Division of Fisheries and Wildlife (MassDFW), Natural Heritage and Endangered Species Program (NHESP), was contacted to identify state-listed rare species in the vicinity of Muddy Creek. A letter report issued by MassDFW for this project identified the following state-listed rare species in the vicinity of Muddy Creek.

- Common Tern (*Sterna hirundo*)
- Eastern Box Turtle (*Terrapene carolina*)
- Water Willow (*Decodon verticillatus*), habitat for Water Willow Stem Borer (*Papaipema sulphurata*)

It is unlikely that, given the limited extent of construction activities, there will be adverse short-term or long-term effects on the species listed by NHESP in this area. Construction timing and best management practices can be employed to further minimize the likelihood of impact to these species.

4.6.1.4 Construction Costs

The order of magnitude opinion of cost for the design, permitting and construction of this alternative is provided below. Costs reflect 3% inflation for construction in Fall 2013, assuming design and permitting is completed by Spring 2013.

Construction:	$3,200,000
Design and Permitting:	$395,000
Construction Oversight (part-time resident representative):	$180,000
Total Cost:	$3,775,000

Although this option requires less excavation and excavation shoring overall, there are several factors that increase the cost of this alternative, including the fact that box jacking is a specialized operation requiring contractors with specific experience, knowledge and the proper equipment. In addition, the proposed bridge represents a relatively small jacking project with little economy of scale being only 68 linear feet in total length, the size of the proposed box culvert is considered large, handling water will prove to be difficult and costly, the reaction wall will require a significant amount of fill to be placed behind it in order to support the jacking operation.

4.6.1.5 Construction Schedule

It is anticipated that the installation of a 14'x24' pre-cast box culvert by box jacking can completed within a 3-5 month time frame. This represents the shortest construction time frame of the alternatives considered.

4.6.2 Pre-Cast Concrete Three Sided Bridge

A conceptual plan for a pre-cast three sided bridge that is installed in an open excavation is provided as *Sheet RP-402* in *Attachment I*. The following paragraphs further describe the specifics of this approach.

4.6.2.1 Installation Approach

For the purposes of this evaluation, installation using a combination of both open excavation and excavation shoring methods was evaluated. This consists of providing a sheet-pile wall between elevation -7 NAVD88 and elevation 10 NAVD88 for a total retained height of 17 feet. Total bury depth of sheet piling will be determined as part of the design. Box jacking is not feasible for a three sided bridge.

The open excavation of the embankment supporting Route 28 would be sloped at the outside limits at a maximum of 1 ½ (H) to 1 (V) from the road surface to elevation 10 NAVD88. Benched areas would be created adjacent to the sheeting lines across the embankment on either side of the proposed structure to provide a platform for construction equipment, facilitate equipment access to lower construction areas, and serve as storage and staging areas. This reduced embankment height resulting from these benches also serves to reduce the required height of the sheeting. The amount of sheet piling used versus the amount of open earth excavation completed would be dictated by the contractor and would be dependent on the most cost effective combination that would allow construction of the bridge.

Temporary dewatering will be required at the bottom of the excavation. The amount and type of dewatering will need to be determined during design. Typical designs would include sheet piling as a cut-off wall and one or more sump pumps. Given the loose sands at this site, a more complex method for dewatering may be required.

The culvert would be delivered with a maximum height of ten feet. With a bottom foundation elevation of -7 NAVD88, a pedestal height of 5 to 6 feet will be required to support the culvert. The extent of the wing wall required for this scenario will be approximately the same as those required for the pre-cast concrete box culvert.

4.6.2.2 Site Layout

This alternative would require the temporary closure of Route 28 and the detouring of traffic around the construction site. Staged construction and the use of temporary traffic patterns through the project site are not proposed herein due to the significant impact stage construction would have on costs, construction time and wetland and shellfishing resources.

Construction access within the shored excavation can be provided by either lowering equipment in and out of the excavation, or by modifying the sheeting to allow for construction of an access ramp into the excavation. This would require extending the sheeting approximately 30 feet to the east with regard to the layout provided on *Sheet RP-402* in *Attachment I.* The individual pre-cast concrete units will require placement with a crane located in the benched area of the open excavation.

With this scenario, a second row of steel sheeting would be placed to form a bypass channel. This channel would allow water to flow alongside of the primary excavation. The advantage of this approach is that tidal flushing would continue to occur throughout the construction process as it does today. Overhead utilities will need to be relocated during this project. Buried utilities will either need to be temporarily abandoned or temporarily bridged across the excavation.

4.6.2.3 Potential Impacts

The limit of disturbance will affect approximately 5,315 SF of jurisdictional resource areas within flagged wetlands. Of this disturbance area, there will be approximately 1,815 SF of direct disturbance to bordering vegetated wetlands and salt marsh areas, and approximately 3,500 SF of disturbance to Land Under Ocean. A plan showing these respective areas is provided as *Figure WET-A2* in *Attachment J.*

4.6.2.3.1 Vegetative Communities

Construction footprint impacts to respective vegetative wetland communities within this alternative's limit of disturbance are listed in *Table 41* below.

Table 41
Resource/Regulatory Area Impacts
for Three-Sided Concrete Bridge Alternative

Wetland Resource/ Regulatory Area[1]	Temporary Impact Area (sq. ft.)[2]	Permanent Impact Area (sq. ft.)[3]	Current Total Resource Area (sq. ft.)	Post-Construction Total Resource Area (sq. ft.)
Coastal Resource Areas				
Land Under Ocean	900	2,600	3,500	5,350
Salt Marsh	105	80	185	105
Land Containing Shellfish[4]	900	2,790	3,690	5,455
Fish Run[4]	900	2,600	3,500	5,350
Land Subject to Coastal Storm Flowage	9,815	1,450	11,265	9,995
Inland Resource Areas				
Bordering Vegetated Wetlands	1,560	70	1,630	1,560
Riverfront Area	40,045	3,565	43,610	42,340

Notes:
1. Resource/regulatory area impacts presented are direct impacts to resource areas with the limits of disturbance during and after construction.
2. Impact area for Land Under Ocean. Fish Run and Land Containing Shellfish is considered to be the area of the existing culvert channel, which will be restored to its original form/function following construction.
3. Permanent impact areas for Fish Run and Land Containing Shellfish represent the area bounded by the existing culverts, as these resource areas will be removed and replaced with the reconstructed culvert/channel centered along the axis of the existing culverts.
4. Due to the increased width of the proposed culvert/channel, additional Land Under Ocean, Fish Run and Land Containing Shellfish will be generated as a result of the proposed structure's layout.

While there will be direct disturbance to these wetland areas, restoration can be achieved through replication. A detailed planting plan and invasive species monitoring and management plan will be required as part of the permitting process and be implemented following construction. Otherwise, there will be negligible long term impacts on the vegetation communities once construction is complete, once the site is stabilized and the restoration plan is implemented.

4.6.2.3.2 Shellfish Communities

This alternative would impact approximately 3,690 SF of Land Containing Shellfish. The extent of disturbance for this alternative will have short term loss of individual shellfish in the area; however, these affects will not extend to the populations at large, as additional Land Under Ocean created under this alternative would increase the shellfish resource area to approximately 5,450 SF. Species of shellfish that are currently common to the area should not suffer any direct undesirable responses due to changes in salinity in post-construction conditions both upstream and downstream of the culvert.

4.6.2.3.3 Fisheries Migration

This alternative would impact approximately 3,500 SF of Fish Run area. While the proposed construction activities will disrupt fish migration over the course of construction, a temporary diversion channel is proposed to control water during construction that will provide a means for migrating eel, alewife, perch or blue crab to pass between Pleasant Bay and Muddy Creek. Once construction is complete and site is restored and stabilized diadromous fish will fully return to Muddy Creek, with additional Land Under Ocean created under this alternative increasing the total Fish Run area to approximately 5,350 SF.

4.6.2.3.4 Water Quality

Appropriate erosion controls can be implemented during construction to protect water quality. Surface water bypass can be designed to replicate hydraulic capacity of the existing Route 28 culverts, minimizing water quality impacts during the construction project.

4.6.2.3.5 Wildlife/Rare Species

It is unlikely that, given the limited extent of construction activities, there will be adverse short-term or long-term effects on the species listed by NHESP in this area. Construction timing and best management practices can be employed to further minimize the likelihood of impact to these species.

4.6.2.4 Construction Costs

The order of magnitude opinion of cost for the design, permitting and construction of this alternative is provided below. Costs reflect 3% inflation for construction in Fall 2013, assuming design and permitting is completed by Spring 2013.

Construction:	$2,930,000
Design and Permitting:	$420,000
Construction Oversight (part-time resident representative):	$190,000
Total Cost:	$3,540,000

This alternative would be constructed using a road closure, detouring traffic around the site, and a combination of open excavation and excavation shoring.

4.6.2.5 Construction Schedule

It is anticipated that the installation of an pre-cast three sided bridge with an overall length of 68 feet installed using conventional techniques will take approximately 6-9 months to complete.

4.6.3 Short Span Adjacent Pre-Cast Concrete Deck Beam Bridge

A conceptual plan for an adjacent pre-cast concrete deck beam bridge is provided as *Sheet RP-403* in *Attachment I*. The following paragraphs further describe the specifics of this approach.

4.6.3.1 Installation Approach

For the purposes of this evaluation, installation using a combination of both open excavation and excavation shoring methods was evaluated. This consists of providing a sheet-pile wall between elevation -7 NAVD88 and elevation 10 NAVD88 for a total retained height of 17 feet. Total bury depth of sheet piling will be determined as part of the design.

The open excavation of the embankment supporting Route 28 would be sloped at the outside limits at a maximum of 1 ½ (H) to 1 (V) from the road surface to elevation 10 NAVD88. Adjacent to the sheeting, a benched area would be created to allow for construction activities, provide equipment access, and serve as storage and staging areas. This reduction in the height of the embankment also serves to reduce the required height of the sheeting. The amount of sheet piling used versus the amount of open earth excavation completed would be dictated by the contractor and would be dependent on the most cost effective combination that would allow installation of the culvert.

Temporary dewatering will be required at the bottom of the excavation. The amount and type of dewatering will need to be determined during design. Typical designs would include sheet piling as a cut-off wall and one or more sump pumps. Given the loose sands at this site, a more complex method for dewatering may be required. This scenario represents the largest area within a confined excavation increasing the cost of dewatering when compared to that required for the three sided bridge.

The bridge would consist of cast-in-place concrete substructure elements and multiple pre-cast concrete deck beams. With a bottom of foundation elevation of -7 (NAVD88), the total height of the abutments would be approximately 25 feet. Due the height of the abutments, this scenario will require the most extensive wing walls of the evaluated alternatives.

4.6.3.2 Site Layout

This alternative would require the temporary closure of Route 28 and the detouring of traffic around the construction site. Staged construction and the use of temporary traffic patterns through the project site are not proposed herein due to the significant impact stage construction would have on costs, construction time and wetland and shellfishing resources.

Construction access within the shored excavation can be provided by either lowering equipment in and out of the excavation, or by modifying the sheeting to allow for construction of an access ramp into the excavation. This would require extending the sheeting approximately 30 feet to the east with regard to the layout provided in *Sheet RFP-403*. Placement of cast-in-place concrete will likely occur via a pump truck located on the benched area adjacent to the shored excavation. The individual pre-cast concrete beams will require placement with a small crane also located in the benched area of the open excavation.

With this scenario, a second row of steel sheeting will be placed to form a bypass channel. This channel would allow water to flow alongside of the primary excavation. The advantage of this approach is that tidal flushing will continue to occur throughout the construction process as it does today.

Overhead utilities will need to be relocated during this project. Buried utilities will either need to be temporarily abandoned or temporarily bridged across the excavation.

4.6.3.3 Potential Impacts

The limit of disturbance will affect approximately 6,300 SF of jurisdictional resource areas within flagged wetlands. Of this disturbance area, there will be approximately 2,320 SF of direct disturbance to bordering vegetated wetlands and salt marsh areas, and approximately 3,980 SF of disturbance to Land Under Ocean. A plan showing these respective areas is provided as *Figure WET-A3* in *Attachment J.*

4.6.3.3.1 Vegetative Communities

Construction footprint impacts to respective vegetative wetland communities within this alternative's limit of disturbance are listed in *Table 42* below.

Table 42
Resource/Regulatory Area Impacts for Short Span Adjacent Pre-Cast Concrete Deck Beam Bridge Alternative

Wetland Resource/ Regulatory Area[1]	Temporary Impact Area (sq. ft.)[2]	Permanent Impact Area (sq. ft.)[3]	Current Total Resource Area (sq. ft.)	Post-Construction Total Resource Area (sq. ft.)
Coastal Resource Areas				
Land Under Ocean	900	3,080	3,980	6,630
Salt Marsh	150	175	325	150
Land Containing Shellfish[4]	900	3,400	4,300	6,775
Fish Run[4]	900	3,080	3,980	6,630
Land Subject to Coastal Storm Flowage	9,965	2,145	12,110	9,530
Inland Resource Areas				
Bordering Vegetated Wetlands	1,665	330	1,995	1,665
Riverfront Area	40,430	4,150	44,580	42,000

Notes:
1. Resource/regulatory area impacts presented are direct impacts to resource areas with the limits of disturbance during and after construction.
2. Impact area for Land Under Ocean. Fish Run and Land Containing Shellfish is considered to be the area of the existing culvert channel, which will be restored to its original form/function following construction.
3. Permanent impact areas for Fish Run and Land Containing Shellfish represent the area bounded by the existing culverts, as these resource areas will be removed and replaced with the reconstructed culvert/channel centered along the axis of the existing culverts.
4. Due to the increased width of the proposed culvert/channel, additional Land Under Ocean, Fish Run and Land Containing Shellfish will be generated as a result of the proposed structure's layout.

While there will direct disturbance to these wetland areas, similar to the above alternatives, restoration can be achieved through replication/mitigation including a detailed planting plan and invasive species monitoring and management plan developed through the permitting process and implemented following construction. Following construction it is anticipated that there will be negligible long term impacts on the vegetation communities, once the site is stabilized and the restoration plan is implemented.

4.6.3.3.2 Shellfish Communities

This alternative would impact approximately 4,300 SF of Land Containing Shellfish. Similar to the alternatives described above, the extent of disturbance for this alternative will have short term loss of individual shellfish in the area but would not be expected to extend to the populations outside the area of immediate construction impact, as additional Land Under Ocean created under this alternative would increase the shellfish resource area to approximately 6,775 SF. Species of shellfish that are currently common to the area should not suffer any direct undesirable responses due to changes in salinity in post-construction conditions both upstream and downstream of the culvert.

4.6.3.3.3 Fisheries Migration

This alternative would impact approximately 3,980 SF of Fish Run area. As noted for the box culvert alternative, this approach would have a temporary impact on fish migration over the course of construction that would be mitigated by a temporary diversion channel construction to maintain passage of water during construction. Because the water will be diverted by means an open channel, there may be limited migration available to eel, alewife, perch or blue crab between Pleasant Bay and Muddy Creek. Once construction is complete and site is restored and stabilized diadromous fish will fully return to Muddy Creek, with additional Land Under Ocean created under this alternative increasing the Fish Run area to approximately 6,625 SF.

4.6.3.3.4 Water Quality

Appropriate erosion controls can be implemented during construction to protect water quality. Surface water bypass can be designed to replicate hydraulic capacity of the existing Route 28 culverts. As a result, no temporary impacts to bacteria and nitrogen concentrations would be expected.

4.6.3.3.5 Wildlife/Rare Species

As noted for the above alternatives, it is likely that due to the limited extent of construction activities there will not be adverse short-term or long-term effects on the species listed by NHESP in this area. Construction timing and best management practices can be employed to further minimize the likelihood of impact to these species.

4.6.3.4 Construction Costs

The order of magnitude opinion of cost for the design, permitting and construction of this alternative is provided below. Costs reflect 3% inflation for construction in Fall 2013, assuming design and permitting is completed by Spring 2013.

Construction:	$3,375,000
Design and Permitting:	$430,000
Construction Oversight (part-time resident representative):	$235,000
Total Cost:	$4,040,000

This alternative would be constructed using a road closure, detouring traffic around the site, and a combination of open excavation and excavation shoring.

4.6.3.5 Construction Schedule

It is anticipated that the installation of an adjacent pre-cast concrete deck beam bridge with a 24 foot span and an out-to-out dimension of approximately 33 feet will take approximately 10-12 months to complete. This alternative will take longer to construct than a pre-cast three sided bridge because the substructure elements are cast-in-place concrete, are much more labor intensive, and require appropriate curing time.

4.6.4 Long Span Adjacent Pre-Cast Concrete Beam Bridges

Conceptual plans for a three-span adjacent pre-cast concrete deck beam bridge supported by stub-type abutments and pile bent type piers and a single-span adjacent pre-cast concrete box beam bridge supported on stub-type abutments are provided as *Sheets RP-404* and *RP-404A*, respectively, in *Attachment I*. The following paragraphs describe the development of these alternatives, and provide details on construction issues, costs, resource area impacts and other considerations differentiating these approaches.

The investigation of a three-span bridge utilizing pile bent-type piers was initially discussed during a project partner meeting on July 15, 2011 that included MassDOT personnel. Prior to this meeting, alternatives under consideration reflected the hydraulic opening size recommended in the 2009 hydrodynamic modeling report (Kelly, 2009).

A conceptual layout of a long span bridge was developed utilizing a trapezoidal channel configuration that provided an equivalent geometric open-flow area to the original rectangular 24-foot wide box channel. This conceptual layout was discussed with project partners and MassDOT personnel at a September 30, 2011 progress meeting. Additional investigations were recommended to review and confirm the feasibility of a long span structure as part of this study, principally to investigate the actual hydraulic characteristics of a trapezoidal channel using the hydrodynamic model previously used by SMAST to adjust the geometric channel layout to match the hydraulic characteristics of the 24-foot wide rectangular box channel reflected in previous modeling (reflected on *Sheet RP-404*). The potential use of a single-span structure was discussed at this meeting, primarily regarding the factors affecting structural layouts of the respective three-span/single-span alternatives over the wider channel, which in turn affect the construction approaches, time and costs for each. It was noted that these considerations would be further evaluated upon receipt of the updated modeling results, and in subsequent design phases if needed.

The supplementary modeling analysis (Kelly, 2011; provided as *Attachment K*) determined through an iterative sizing analysis that the bottom of a trapezoidal channel would have to be 22 feet wide (assuming 1.5H:1V armored side slopes) in order to provide the equivalent tidal range and flushing volume as that provided by a 24-foot wide box culvert with vertical walls. It was also noted that although this channel configuration reduced the model's reported maximum tidal velocity through the channel opening by two feet per second (2 ft./s), as compared to the previously modeled 24-foot wide opening, currents were still sufficient to mobilize sand-sized particles and thus prevent shoaling in the channel. The lower maximum current velocity would also improve safety associated with recreational boat passage through the channel. A comparison of modeled future tidal elevations and volumes for the two channel configurations is provided in *Table 43* below.

Table 43
Modeled Future Tidal Elevations and Volumes for 24-ft. Box Channel and 22-ft. Trapezoidal Open Channel Configurations (Feet NAVD88)

Tidal Condition	Proposed 24-ft. Box Channel	Proposed 22-ft. Open Channel	Percent Change
Maximum Tide	3.92	4.02	2%
MHHW	3.12	3.32	6%
MHW	2.72	2.82	4%
MTL	1.12	1.22	8%
MLW	-0.48	-0.38	-26%
MLLW	-0.48	-0.48	0%
Minimum Tide	-0.58	-0.58	0%
Mean Range (ft.)	3.2	3.2	0%
Maximum Tidal Velocity (ft./s)	6.7	4.8	-40%
Mean Volume ($ft.^3/s$)	5,145,000	5,290,000	3%
Mean Prism ($ft.^3/s$)	4,972,000	5,059,000	2%
Residence Time (days)	0.5	0.5	0%

Note: 1. Elevations in NAVD88. Reported values from Kelly, 2011.

Due to MassDOT bridge layout requirements for a three-span bridge over the modeled trapezoidal channel, repositioning the pile bent type piers outside of the MHHW elevation (to avoid scour or potential safety issues with recreational boat passage during higher flow rates) would increase the ratio-dependent length of the outer bridge decks and thus further increase the overall bridge length. As this preliminary layout analysis indicated that the single-span bridge appears to be a more appropriate configuration versus the three-span alternative result, this configuration is reflected with the updated channel layout on *Sheet RP-404A*. Updated wetland assessment and construction costs presented below are also based on the 22-foot channel layout on *Sheet RP-404A*.

Further considerations associated with the single-span and three-span alternatives are discussed in the following sections.

4.6.4.1 Installation Approach

For the purposes of this evaluation, installation using a combination of both open excavation and excavation shoring methods was evaluated. This consists of providing a sheet-pile wall between elevation -6 NAVD88 and elevation 8 NAVD88 for a total retained height of 14 feet. The sheet piling would support the excavation required to remove the existing stone masonry culvert, the walls at the inlet and outlet of the existing culvert, and to serve as a cofferdam for the control of water. The total buried depth of sheet piling will be determined during final design of the bridge.

The sheeting would be installed in two stages. The first stage would be installed to the east of the existing culvert to allow excavation of the roadway embankment, construction of the eastern substructure elements, partial removal of the existing stone masonry walls, re-grading, and configuring the new channel and installation of rip-rap to protect and stabilize the embankments. Sheet pile returns into the embankment would act as cofferdams for purposes of dewatering. During this stage the existing culverts would remain in place and be used to control water. The bottom of the excavation would be at approximately elevation -6 within the proposed channel. The excavation would slope up to the existing roadway at a maximum of 1½ (H) to 1 (V).

Upon completion of the work to the east of the existing culvert, the second stage of the sheet piling would be installed. In this stage the northern and southern sheet pile cofferdam walls would be relocated to the west of the center sheet pile wall. This will allow water to flow along the east side of the center wall, diverting flow from the existing culvert. During this stage the existing culverts would be removed, the remaining portions of the stone masonry walls would be removed, the western substructure elements would be constructed, the area would be re-graded, the new channel would be constructed, and rip-rap installed on the face of the slope as channel scour protection and to stabilize the slope.

Temporary dewatering will be required at the bottom of the excavation. The extent and type of dewatering will need to be determined during final design. Typical designs would include sheet piling as a cut-off wall and one or more sump pumps in respective construction areas as work proceeds. Given the loose sands at this site, a more complex method for dewatering may be required. This alternative requires the largest total dewatering area of the four alternatives considered, including a higher dewatering cost compared to the three sided bridge alternative.

4.6.4.2 Site Layout

The long span bridges would utilize cast-in-place concrete stub type abutments, pile bent type piers for the three-span option, and adjacent pre-cast concrete beams. The single-span option would have a total span of approximately 94 feet along the centerline of the roadway. The three-span structure would have a total span of approximately 110 feet along the centerline of the roadway, comprising two 24'-9" end spans and a 42'-3" center span. Both bridge alternatives would have similar superstructure cross sections with an out-to-out width of approximately 33 feet. The bottom of abutment footing elevations for the single-span option will be approximately 8.4 for the east abutment and 10.4 for the west abutment. The bottom of footing elevations for the three-span option would be approximately 7.5 for the east abutment and 10.5 for the west abutment. The maximum height of the abutments will be approximately 9 feet measured from the bottom of the footing to the bridge seat.

Lane and shoulder widths for this bridge structure are consistent with the existing roadway's lane/shoulder widths for the stretch of Route 28 on the embankment over Muddy Creek. Current and currently proposed lane widths are reflected on *Sheet RP-404A*. It is noted that both existing and proposed lane/shoulder widths do not conform to current MassDOT Bridge Manual minimum criteria requiring 12-foot wide travel lane, 5-foot wide shoulders and at least one 5-foot wide sidewalk. These requirements will need to be addressed in future permitting with MassDOT, either through design modifications to the bridge's (and limited portion of the adjacent roadway's) width or through a waiver request process.

The pile bent type piers for the three-span bridge would consist of multiple driven piles. Each pile bent would incorporate a cast-in-place concrete pile cap to secure the tops of the piles and support the beams. The maximum exposed height of the pile bents will be approximately 15 feet, with the depth of the piles to be determined during final design. The use of long span bridges will require the least amount of excavation, backfill, and cast-in-place concrete of the four alternatives. As noted previously, the trapezoidal channel cross-section would need to be evaluated under further hydrodynamic modeling to refine layout requirements and other design parameters.

Similar to the short span pre-cast concrete deck beam bridge alternative, this use of a long span bridge would require the temporary closure of Route 28 and the detouring of traffic around the construction site. Staged construction and the use of temporary traffic patterns through the project site are similarly not proposed due to the previously noted impacts on project costs, schedule, and wetland/shellfishing resources.

Construction access within the excavated area could be provided along the sloped face of the excavation. The piles for the pile bent type piers used with the three-span option will be placed by a pile-driving rig located at the top of the excavation. Placement of cast-in-place concrete for the substructure elements will likely require a pump truck located at the top of the excavation. Placement of the individual pre-cast concrete beams will require the use of one or more cranes(s), also located at the top of the excavation.

Under this scenario, staged sheeting in respective work areas will allow control of water by using the exiting culverts in the first stage of work, and subsequently allowing the water to flow through the first stage area for construction of the second stage. The advantage of this approach is that tidal flushing will continue to occur throughout the construction period as it currently does.

As noted for the short span pre-cast concrete deck beam bridge alternative, overhead utilities will need to be relocated during this project and buried utilities will either need to be temporarily abandoned or temporarily bridged across the excavation. Due to the increased bridge span, temporary bypass of such utilities would require longer runs of pipe/cables around/through the construction area.

4.6.4.3 Potential Impacts

The limit of disturbance for the single-span alternative will affect approximately 4,320 SF of jurisdictional resource areas within flagged wetlands. Of this disturbance area, there will be approximately 1,925 SF of direct disturbance to bordering vegetated wetlands and salt marsh areas, and approximately 2,395 SF of disturbance to Land Under Ocean. A plan showing these respective areas is provided as *Figure WET-A4* in *Attachment J.*

4.6.4.3.1 Vegetative Communities

Construction footprint impacts to respective vegetative wetland communities within the limit of disturbance for the single-span bridge alternative are listed in *Table 44* below.

Table 44
Resource/Regulatory Area Impacts for Single-Span Adjacent Pre-Cast Concrete Beam Bridge Alternative

Wetland Resource/ Regulatory Area[1]	Temporary Impact Area (sq. ft.)[2]	Permanent Impact Area (sq. ft.)[3]	Current Total Resource Area (sq. ft.)	Post-Construction Total Resource Area (sq. ft.)
Coastal Resource Areas				
Land Under Ocean	900	1,495	2,395	3,840
Salt Marsh	130	5	135	130
Land Containing Shellfish[4]	900	1,635	2,535	3,970
Fish Run[4]	900	1,495	2,395	3,840
Land Subject to Coastal Storm Flowage	7,025	2,985	10,010	9,085
Inland Resource Areas				
Bordering Vegetated Wetlands	1,780	10	1,790	1,780
Riverfront Area	32,360	8,570	40,930	40,000

Notes:
1. Resource/regulatory area impacts presented are direct impacts to resource areas with the limits of disturbance during and after construction.
2. Impact area for Land Under Ocean. Fish Run and Land Containing Shellfish is considered to be the area of the existing culvert channel, which will be restored to its original form/function following construction.
3. Permanent impact areas for Fish Run and Land Containing Shellfish represent the area bounded by the existing culverts, as these resource areas will be removed and replaced with the reconstructed culvert/channel centered along the axis of the existing culverts.
4. Due to the increased width of the proposed culvert/channel, additional Land Under Ocean, Fish Run and Land Containing Shellfish will be generated as a result of the proposed structure's layout.

As was the case for the other alternatives, while there will be direct disturbance to these wetland areas, restoration can be achieved through replication/mitigation including a detailed planting plan and invasive species monitoring and management plan developed through the permitting process and implemented following construction. Following construction it is anticipated that there will be negligible long term impacts on the vegetation communities, once the site is stabilized and the restoration plan is implemented.

4.6.4.3.2 Shellfish Communities

This alternative would impact approximately 2,530 SF of Land Containing Shellfish. As with the alternatives described above, the extent of disturbance for this alternative will have short term loss of individual shellfish in the area but would not be expected to extend to the populations outside the area of immediate construction impact, as additional Land Under Ocean created increase the shellfish resource area to approximately 5,970 SF for the single-span alternative. Species of shellfish that are currently common to the area should not suffer any direct undesirable responses due to changes in salinity in post-construction conditions both upstream and downstream of the culvert.

4.6.4.3.3 Fisheries Migration

This alternative would impact approximately 2,395 SF of Fish Run area. Similar to the previous bridge alternatives, this approach would have a temporary impact on fish migration during construction that would be mitigated by a temporary bypass channel, which would provide a limited migration route for eel, alewife, perch or blue crab between Pleasant Bay and Muddy Creek. Once construction is complete and site is restored and stabilized diadromous fish will fully return to Muddy Creek, Land Under Ocean created under this alternative would increase Fish Run area to approximately 3,840 SF for the single-span alternative.

4.6.4.3.4 Water Quality

Appropriate erosion controls can be implemented during construction to protect water quality. Surface water bypass can be designed to replicate hydraulic capacity of the existing Route 28 culverts. As a result, no temporary impacts to bacteria and nitrogen concentrations would be expected.

4.6.4.3.5 Wildlife/Rare Species

As noted for the above alternatives, it is likely that due to the limited extent of construction activities there will not be adverse short-term or long-term effects on the species listed by NHESP in this area. Construction timing and best management practices can be employed to further minimize the likelihood of impact to these species.

4.6.4.4 Construction Costs

The order of magnitude opinion of cost for the design, permitting and construction of the single-span alternative is provided below. Costs reflect 3% inflation for construction in Fall 2013, assuming design and permitting is completed by Spring 2013.

Single-Span Bridge	
Construction:	$2,630,000
Design and Permitting:	$465,000
Construction Oversight (part-time resident representative):	$215,000
Total Cost:	$3,310,000

Similar to the other alternatives, the both long span alternatives would be require a road closure detouring traffic around the site, due to the open excavation and shoring involved in construction.

4.6.4.5 Construction Schedule

It is anticipated that the installation of a 94 foot single span adjacent precast concrete box beam bridge supported on stub-type abutments will take approximately 8-10 months to complete. The construction of a three-span adjacent precast deck beam bridge supported by stub-type abutments and pile bent type piers will take approximately 9-12 months to complete.

The construction of a long span bridge alternative will take longer to construct than the other options because the construction of the eastern and western substructure elements will be staged for control of water, the substructure elements are cast-in-place concrete, are more labor intensive than pre-cast alternatives, and require appropriate curing time.

4.6.5 Summary Evaluation of Culvert Alternatives

A summary listing of opinions of costs and wetland/regulatory resources area changes associated with construction of the respective alternatives is provided below in *Table 45*.

Table 45
Summary of Wetland/Regulatory Area Changes and Opinions of Cost for Replacement Alternatives

Comparative Category	**Alt. 1 – Pre-Cast Concrete Box**	**Alt. 2 – Three Sided Pre-Cast Concrete Bridge**	**Alt. 3 – Short Span Concrete Deck Beam Bridge**	**Alt. 4A – Single-Span Concrete Box Beam Bridge**
Resource/Regulatory Areas (SF)				
Land Under Ocean	975	1,850	2,650	1,445
Salt Marsh	-80	-80	-175	-5
Land Containing Shellfish	925	1,765	2,475	1,435
Fish Run	1,845	1,850	2,650	1,445
Land Subject to Coastal Storm Flowage	-1,265	-1,270	-2,580	-925
Bordering Vegetated Wetlands	-70	-70	-330	-10
Riverfront Area	-1,270	-1,270	-2,580	-930
Opinion of Cost	$3,775,000	$3,540,000	$4,040,000	$3,310,000

A comparison of the three alternatives described above against a number of review criteria is provided in *Table 46* at the end of this report. These criteria range from benefits to shellfish, fisheries and vegetation to construction costs and schedule to aesthetics and potential canoe/kayak passage, amongst others.

This table briefly describes the degree to which each of the alternatives meet the respective criteria and assigns a score of 1 to 5, reflecting the degree to which to criteria are met or not met. A score of 5 is assigned to those that best meet the criteria and a score of 1 is assigned to those that least meet the criteria. Scores are totaled at the end of the table. No weights were assigned to criteria so each score assumes that the criteria are weighted equally.

Based on this scoring, the single-span pre-cast concrete bridge was rated to best meet respective criteria. Future design evaluation of this approach should include an assessment of scour protection requirements for the proposed channel configuration and a global slope stability analysis for the channel banks to determine if 1.5H:1V slopes are stable or if 2H:1V slopes will be required. A refined evaluation of potential wetland and fisheries/shellfish benefits and impacts resulting from construction operations and post-construction tidal conditions will also be required in support of future project permitting. Permitting requirements that will likely need to be addressed prior to construction are listed below.

- Massachusetts Environmental Policy Act Certification ("expanded" Environmental Notification Form likely required only)
- MassDOT Access Permit
- Massachusetts Wetlands Protection Act
- 401 Water Quality Certification
- Public Waterfront Act (Chapter 91)
- CZM Federal Consistency Review
- U.S. Army Corps of Engineers Category II General Permit
- NPDES Dewatering Discharge General Permit for Construction (Notice of Intent only)
- Massachusetts Endangered Species Act
- Massachusetts Historical Commission (Project Notification Form likely required only)
- Coast Guard Bridge Permit

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