Executive Summary

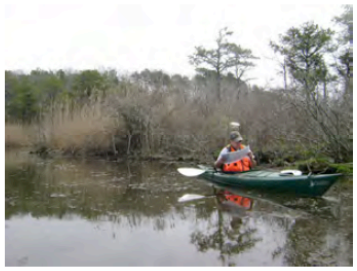
Pleasant Bay is a rich estuarine ecosystem with several tributaries and coves providing exceptional habitat for numerous shellfish and migratory fish species. Flushing in Muddy Creek, a tidal river and sub-embayment of the Pleasant Bay estuarine system, has been severely restricted by construction of 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.

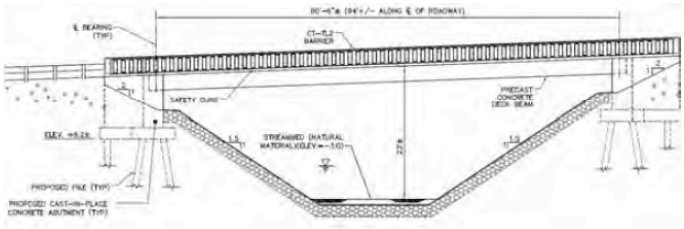
A modeling evaluation was completed to assess the potential effects of culvert replacement on bacteria concentrations in Muddy Creek and the nearby portion of Pleasant Bay. A one-dimensional, steady-state transport model was created using a finite difference approach at a level of complexity that matches 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.