Resource Assessment
to Evaluate Ecological & Hydrodynamic Responses
to Reinstalling a Water Control Structure
in the Muddy Creek Dike

University of Massachusetts Dartmouth
School for Marine Science and Technology

Applied Coastal
Research & Engineering

FINAL REPORT - DECEMBER 2008

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David S. White
Brian L. Howes

Sean Kelley
John Ramsey

Contributors:

SMAST Coastal Systems Program

David Schlezinger, Roland Samimy
Sara Sampieri, Michael Bartlett, Jen Benson, Dahlia Mederios, Lizabeth White

Applied Coastal Research and Engineering, Inc.

Sara Griffee

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Muddy Creek Resource Assessment

Introduction

Study Purpose
The purposes of this study are: (1) to address a lack of baseline information on the current extent of wetlands and related resources in the vicinity of the shoreline of Muddy Creek, and (2) to document anticipated changes to those resources and to private property and other upland areas bordering Muddy Creek should a water control structure (WCS) be installed within the existing earthen dike to enhance nitrogen attenuation in the upper portion of Muddy Creek.

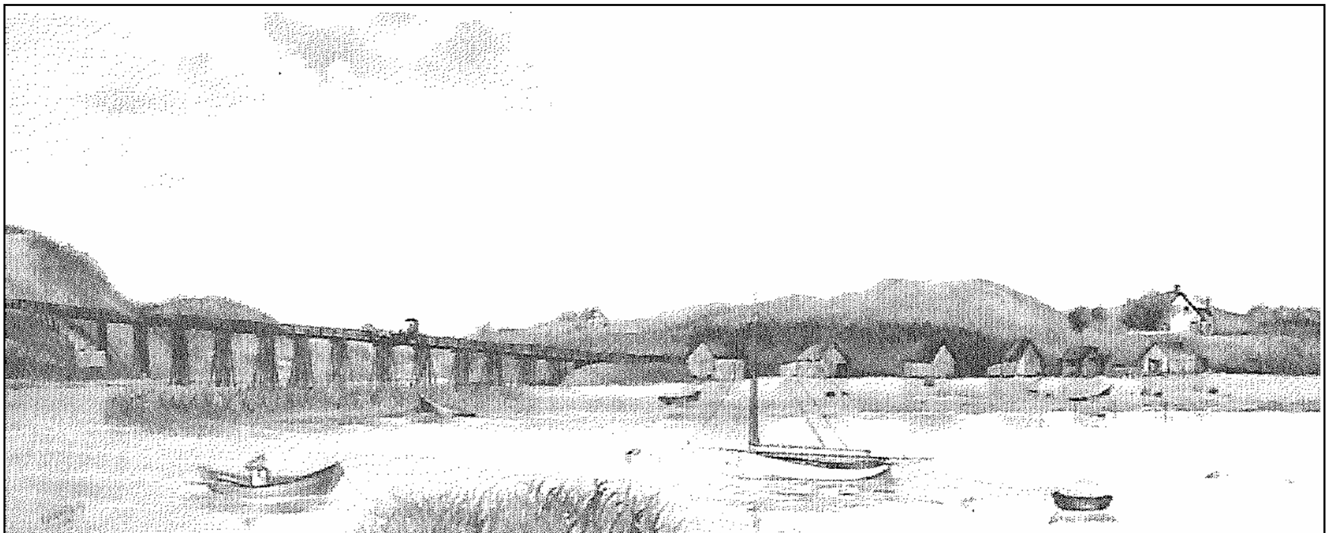
The study is not intended to encompass a detailed inventory of wetland vegetation, including species that are state listed as rare, endangered or of special concern. Nor does the study provide a comprehensive inventory of fisheries or wildlife in Muddy Creek or its vicinity. These and other issues would need to be addressed through separate studies if the concept of installing a WCS as a means of enhancing nitrogen attenuation is pursued by the Towns of Chatham and Harwich within the context of Comprehensive Wastewater Management Planning.

The concept of installing a water control structure was among a series of options identified for dealing with excessive nitrogen loading from surrounding land uses, which has resulted in severe eutrophication in Muddy Creek. Background on how community efforts to study and address nitrogen loading and other water quality concerns led to consideration of the WCS and other remediation alternatives is provided below.

Sponsorship
The study was undertaken by the Pleasant Bay Alliance (Alliance) through a grant from the Cape Cod Water Protection Collaborative (CCWPC) *Shared Watershed, Shared Responsibilities* grant program. By undertaking this study it should not be construed that either the Alliance or the Towns of Chatham or Harwich or The University of Massachusetts endorse or support the concept of installing a WCS. This study is consistent with the Alliance's mission of providing information to assist the towns and stakeholders in making informed decisions about a range of issues that affect the health of Pleasant Bay. The Alliance is the intermunicipal organization of the Towns of Chatham, Orleans, Harwich and Brewster formed to implement the resource management program for the Pleasant Bay study area. The study and report is structured to meet the requirements of the Request for Proposals to conduct the study and the subsequent scope of work.

Background
Muddy Creek (also known locally as Monomoy River) is a subembayment and tidal river that discharges into the main basin of Pleasant Bay and is within the Pleasant Bay Area of Critical Environmental Concern (ACEC). Muddy Creek serves as the boundary between the Towns of Harwich and Chatham, and the subwatershed for the Creek is shared by the Towns of Chatham (~25%) and Harwich (~75%).

Muddy Creek has been significantly altered over past centuries by human activities. In the late 1800's a roadway bridge was installed at the mouth of Muddy Creek, but from its appearance, it likely allowed much greater tidal flows than today. With the replacement of this early bridge, the largest existing modification took place, the restriction of tidal exchange by the installation of a culvert under Route 28 (such as exists today). An additional modification was created by the installation of a dike prior to 1899 (cf. Board of Harbor and Land Commissioner's License), creating upper and lower estuarine basins with freshwater conditions in the upper basin. The dike was breached very likely during the hurricane of 1938 (R. Duncanson, pers. comm.), returning brackish and tidal conditions to the upper basin.



The Wading Place Bridge at the Head of the Bay (Chatham-Harwich town line) painted by Elmer Crowell (1890). (Courtesy CC Five Cents Savings Bank) (p. 30)

(from "The Bay – as I see it" by W. Sears Nickerson, 1995, Friends of Pleasant Bay, South Orleans, MA)

The significant nutrient impairments of the upper and lower basins of Muddy Creek are well documented. Muddy Creek nutrient related water quality has been studied by the Town of Chatham and Alliance for almost a decade. Habitat assessments and water quality modeling by SMAST and ACRE scientists and engineers for the Town of Chatham (2000) and later by the MEP confirmed a significant level of nitrogen impairment and loss of habitat that requires a reduction in watershed nitrogen load for restoration of this system. Total Maximum Daily Loads established for upper and lower Muddy Creek require a 75% and 100% reduction in watershed septic load, respectively.

There are many possible ways to address nutrient-related habitat impairment: enhancing tidal flushing, enhancing freshwater attenuation, sewering, and other measures to control the flow of nutrients from watershed sources. As part of the analysis of restoration alternatives, the MEP looked at three alternatives (1) converting the entire Creek into a freshwater system, (2) converting a portion of the creek into a freshwater system and (3) enlarging the Route 28 culverts to enhance flushing. The second of these, the partial conversion to freshwater, was identified as having the greatest improvement in flushing along with ability to preserve salt marsh in the lower Creek. The point where this separation was modeled was approximately at the location of the pre-existing earthen dike. This effort was a screening analysis to determine if further investigation was worthwhile and it was envisioned that further study would be needed to fully evaluate the concept. This study, along with parallel studies to evaluate other restoration alternatives such as enlarging the Route 28 culverts, will help inform the towns' selection of the appropriate remediation strategy.

1.0 Wetlands Delineation and System Assessment: Existing Conditions

The sub-sections, below, detail the results of the wetlands delineation and system assessment conducted for the SMAST analysis of the Muddy Creek System relating to a potential re-installation of the water control structure (WCS) within the existing dike. The study serves also as a baseline from which to gauge future changes.

1.1. Wetland Vegetation and Delineation[1]

Methods

Using existing aerial photography, the latest topographic information available from the 2008 land-survey (provided by the Pleasant Bay Alliance) and ground-truth visual surveys, SMAST scientists identified the major vegetation types and their distribution within the Muddy Creek Estuarine System. This mapping effort focused on those wetland areas adjacent the open waters of Muddy Creek from the culvert at Route 28 to Queen Anne Road, including both salt water and fresh water areas that might potentially be affected by a change in the hydrodynamics within the estuary. Ground surveys were conducted along the shoreline, and as possible along transects from the upland border to open water. Locations of plant community borders and locations of "permanent" transects were logged using Digital GPS instrumentation (within 1 meter accuracy) and measuring tape. The measuring tape was staked at the upland border of each transect. The distances from border to transition points of major vegetation types was measured and recorded along the transect. Since wetland area sometimes graded from salt marsh into freshwater marsh to upland vegetation, the care was taken to locate the shoreside border of the salt marsh, the saltmarsh/freshmarsh border. The upland border (innermost edges of the freshwater marsh) was documented in 2 ways, (1) by on-site dGPS measurement and (2) by aerial photos coupled to topographic characteristics.

Results

The lower distribution of salt marsh plants is set by the salinity and range of tides which flood them. Salt marsh plants were generally found in small patches of fringing marsh rather than in salt marsh communities, particularly in upper basin. The largest areas of salt marsh were located in the lower basin in the region of the inlet. The steep topography of Muddy Creek shoreline greatly restricts freshwater marsh area inland of the salt marsh areas, particularly in the lower basin. In the upper basin, the existence of low lying areas at the head water region supports significant freshwater wetland areas, due to the low salinity of the waters and groundwater seepage. These freshwater marsh areas dominate the shoreline of the pond at the head of the

[1] In the original Project Scope the "wetland vegetation" and "wetland delineation" tasks were separated. Since the 2 are intimately related, they have been combined into this section for this report.

upper basin which has flow from Ministers Pond and in the wetland area on the Harwich shore in the region Harden Lane.

It should be noted that the upland border of freshwater species was not always an abrupt transition, since freshwater grasses, reeds and sedges transition to shrubs and then to upland species. However, the upper transitions are typically above the region that might be altered by reinstallation of a water control structure in the dike. In addition these innermost areas were generally the most inaccessible, due to the instability of sediments and overgrowth by shrubs and vines. Where inner wetland borders could not be directly measured by on-site surveys, the border was determined from aerial photographs and topographic information, after validating this approach using areas where on-site measurements were available as well.

The wetland species and distribution data were synthesized to produce a map overlay in GIS as seen in Figure 1. The overlay was divided into maps of upper and lower Muddy Creek and specific areas, transects and GPS points on each were labeled (Figures 2, 3) with corresponding vegetation descriptions in Appendix A. In addition, 3 ft. x 4 ft. posters of each map and all GIS data on CD were provided as part of this report.

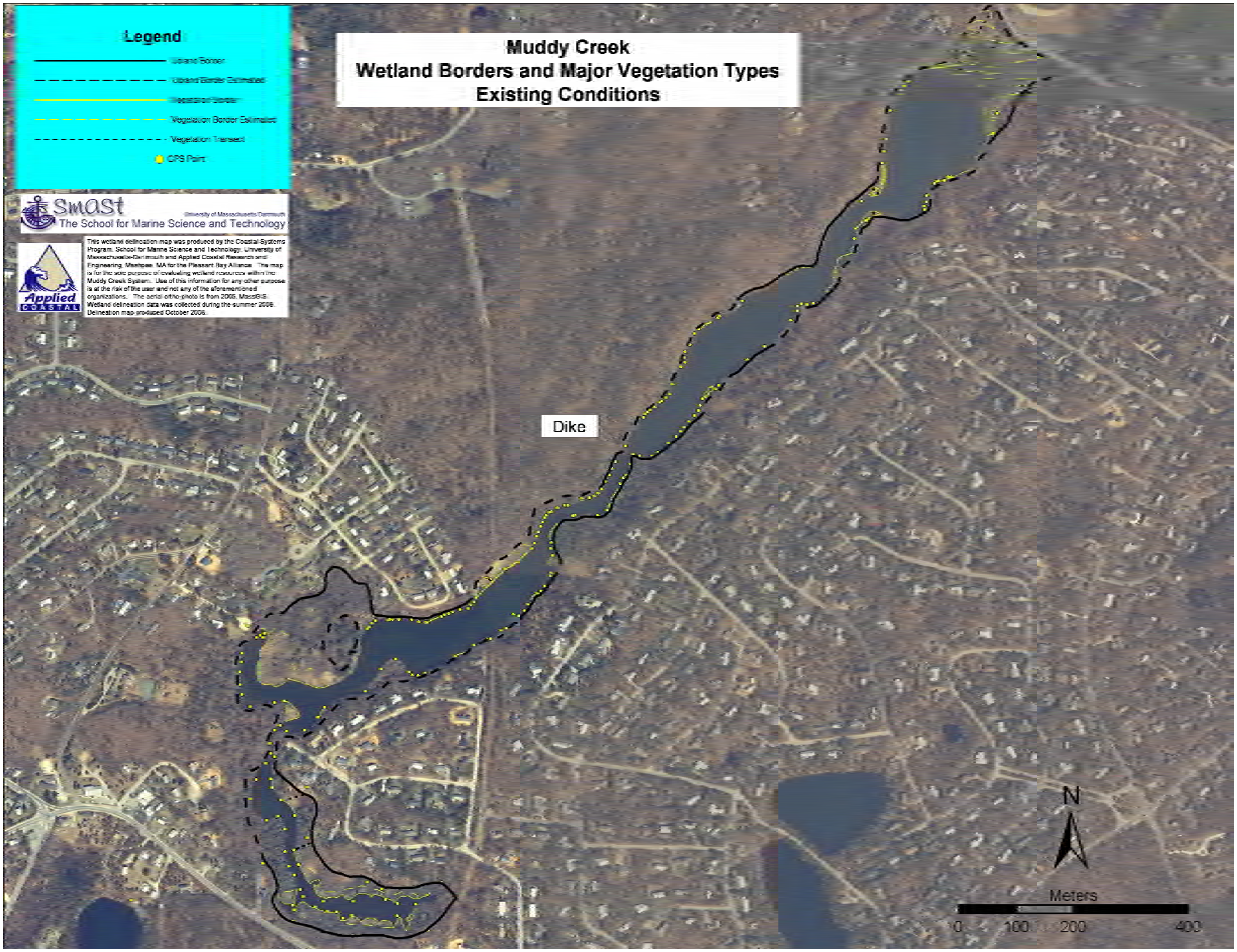


Figure 1. Fresh and Saltwater wetlands within the Muddy Creek System. Shoreline border was delineated in all cases, upland border was estimated in some areas (dashed lines), due to access issues. Note that this figure was provided in 36"x48" format and as a GIS file.

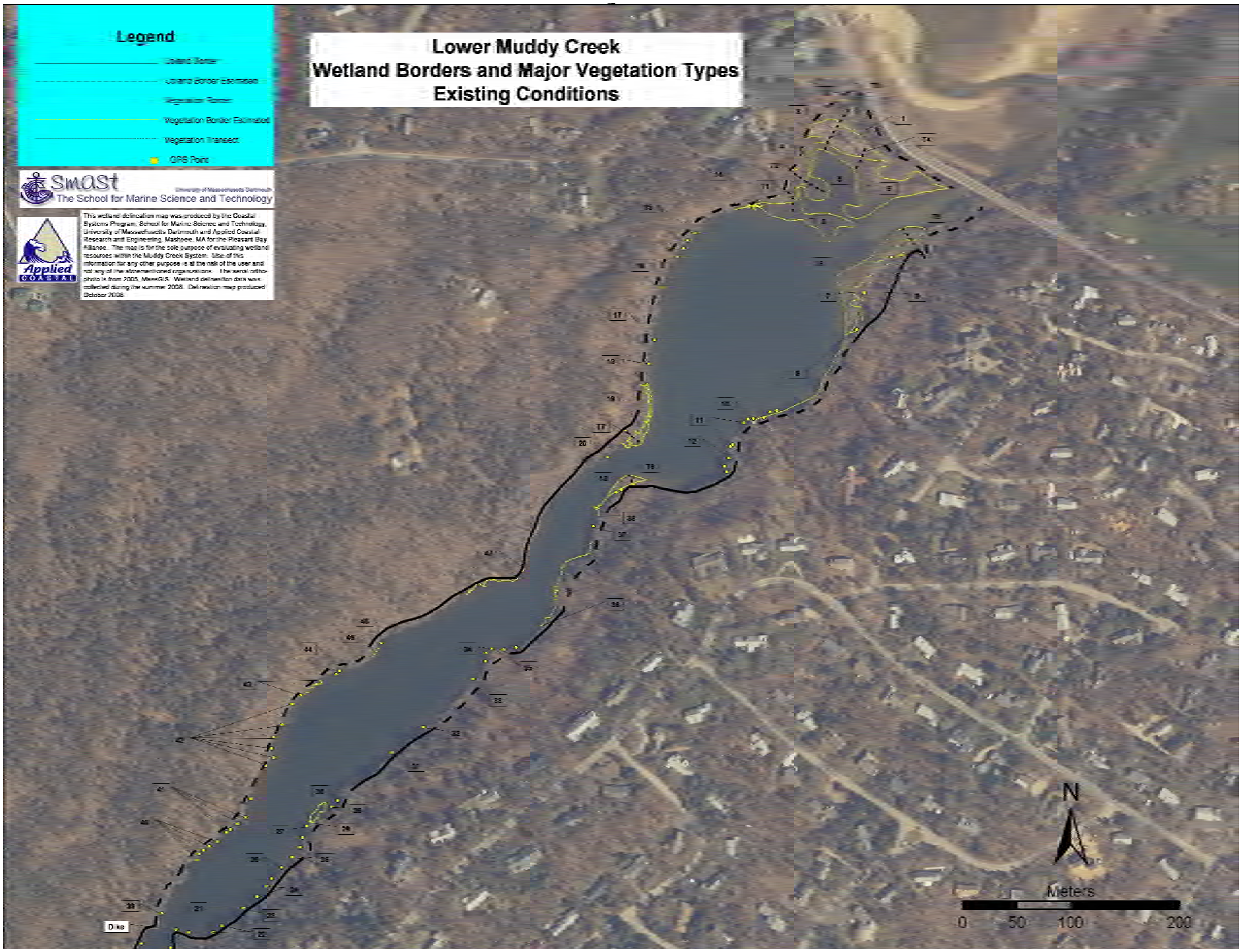


Figure 2. Fresh and Saltwater wetlands within Lower Muddy Creek. Call-out boxes denote the I.D. of the vegetation description provided Appendix A. Shoreline border was delineated in all cases, but upland border was estimated in some areas (dashed lines) due to access issues. Note that this figure was provided in 36"x48" format and as a GIS file.

Figure 3. Fresh and Saltwater wetlands within Upper Muddy Creek. Call-out boxes denote the I.D. of the vegetation description provided Appendix A. Shoreline border was delineated in all cases, but upland border was estimated in some areas (dashed lines) due to access issues. Note that this figure was provided in 36"x48" format and as a GIS file.

1.2 Wetland Sediments

The salinity of the sediments associated with the wetlands in Muddy Creek is an important determinant of the plant communities that are presently established. Sediment salinities can be useful in predicting potential plant community changes after events which alter "tidal" salt levels. The re-establishment of the dike at mid-Muddy Creek would result in a significant lowering of salinity within the open water areas adjacent each wetland area. For this reason, present salinity levels within the porewaters of the rooting zone of wetland areas within the Muddy Creek System were determined based upon collected core samples as part of this study.

Methods

A total of ten wetland sites were sampled, 5 above and 5 below the dike site (Figure 4, Table 1). Intact sediment cores were extracted from the sediments at each site using 6.5 cm (inside diameter) polycarbonate tubes. Cores were then cut into 5 cm sections to allow assay of the 0-5 cm, 5-10 cm and 10-15 cm depths within the root zone. Pore waters were extracted and analyzed for salinity based upon specific conductivity measurements at the SMAST Analytical Facility (see Appendix D).

Results

Lower Muddy Creek sites with salinities >10ppt were generally supportive of salt marsh vegetation, while more brackish sites were dominated by *Typha* and *Phragmites* (Figure 5). Salinities at the 0-5cm depth range ranged from 32.8 to 18.1 ppt in Spartina dominated areas, 9.4 ppt in Phragmites and 13.4 ppt in Typha areas, respectively (Table 2). Salinities at the 5-10 cm interval were generally lower than surface values and ranged from 26.3 to 15.8 ppt for Spartina, 7.2 ppt for Phragmites and 7.5 ppt for Typha (Table 2). Values at the 10-15 cm depth interval were generally lower than either 0-5 cm or 5-10 cm depth intervals, ranging from 26.3 to 15.2 ppt for Spartina, 2.5 ppt for Phragmites and 6.0 ppt for Typha (Table 2). The *Typha* site (MC-3) showed a steep salinity gradient with depth and most likely was supported by freshwater from below, as this is a relatively high salinity for a Typha marsh.. The *Phragmites* sites (MC-2 and in the upper Creek, MC-7) showed similar salinities, and were brackish, typical of this species.

The upper Muddy Creek sites with fresh porewaters (<1 ppt) supported a diverse assemblage of freshwater plants. There were no extensive salt marsh areas in upper Muddy Creek like those found in the lower creek close to the mouth. There were fringing bands of Spartina mixed with tracts of Phragmites, rushes and sedges along the creek bank, the largest tract being found in front of the large Phragmites tract under the power lines (MC 7). The patch of *Spartina* adjacent the dike (MC-6) was similar in salinity to the lower Creek areas. Surface salinities (0-5 cm) ranged from 15.4 ppt for Spartina, 11.0 ppt for Phragmites and 1.0 to 0.4 ppt for freshwater assemblages. Values at the 5-10 cm interval ranged from 12.8 ppt for Spartina, 9.5 ppt for Phragmites and 1.0 to 0.4 ppt for freshwater assemblages. Salinities at the 10-15 cm interval ranged from 11.2 ppt for Spartina, 8.9 ppt for Phragmites and 0.9 to 0.5 ppt for freshwater assemblages (Table 2).

It appears from this survey that the wetland plant distribution within the Muddy Creek System is significantly structured by the level of salinity dilution by freshwater from the watershed, and a freshening of waters associated with the salt marsh plants in the upper Muddy Creek will likely result in a conversion to coverage by brackish (40 ppt) or freshwater plants (<2 ppt).

At present it appears that there is freshwater entering the low lying areas colonized by wetland plants the Muddy Creek, as evidenced by the salinity gradients in areas with salt and brackish species and the occurrence of fresh porewaters in areas that at least periodically have saline tidal water in the adjacent basin.

Average salinities (0-15 cm) were highest in Spartina dominated areas with Phragmites and Typha occurring in more brackish environments and with fresh water assemblages restricted to areas where sediment salinities were approximately 1.0 ppt or less (Figure 5).

Table 1. GPS coordinates of sediment core sites, Muddy Creek

Core Site	Latitude	Longitude
MC1	041.7119138° N	069.9961611° W
MC2	041.7119444° N	069.9962250° W
MC3	041.7122199° N	069.9955611° W
MC4	041.7113305° N	069.9953750° W
MC5	041.7095277° N	069.9982083° W
MC6	041.7055001° N	070.0033861° W
MC7	041.7040862° N	070.0059471° W
MC8	041.7030890° N	070.0111738° W
MC9	041.7017175° N	070.0107214° W
MC10	041.6990469° N	070.0077044° W

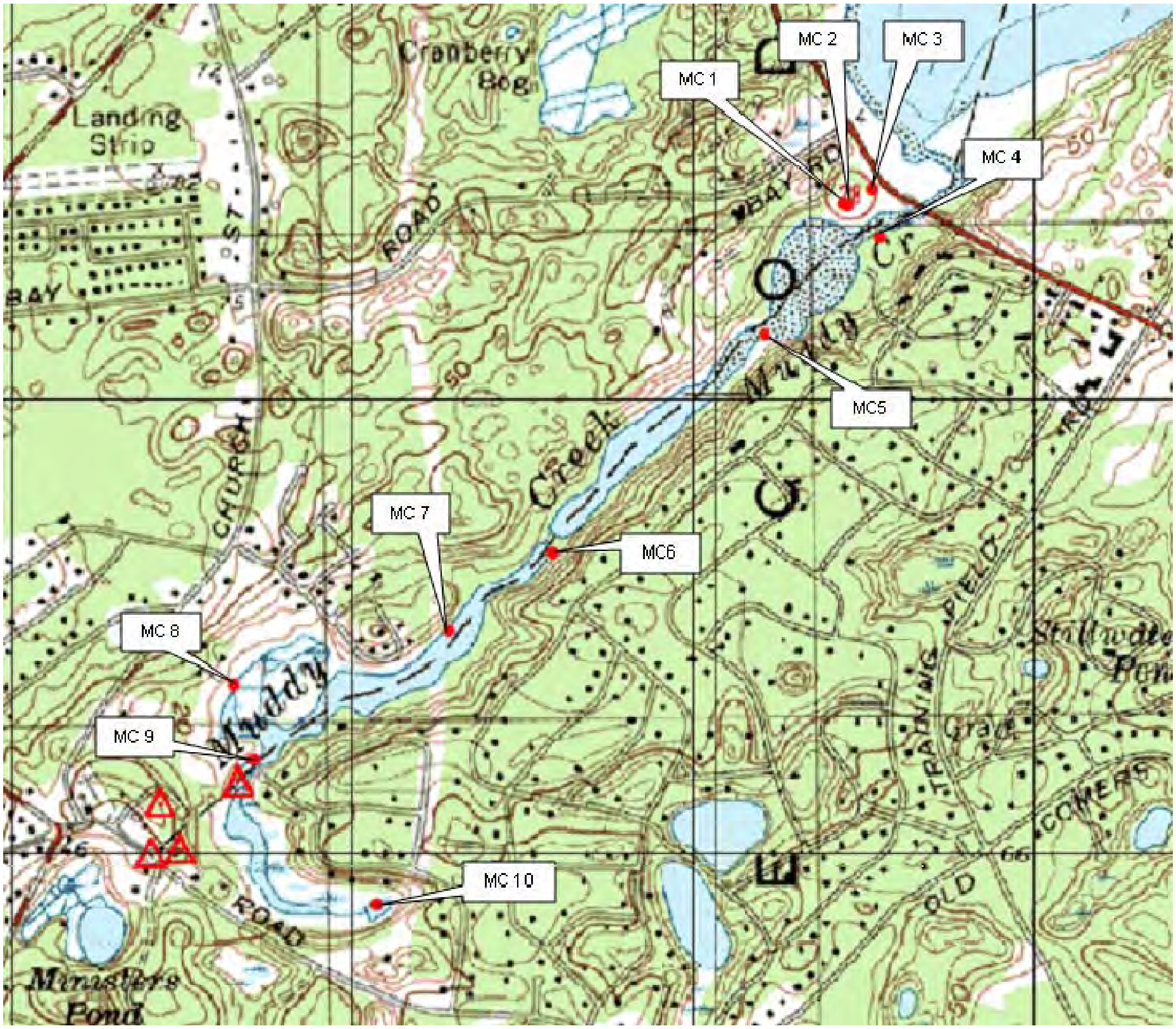


Figure 4 Locations of sediment core sites (red dots labeled MC 10) for determining porewater salinities of wetland areas within the Muddy Creek System. Red triangles show locations of benchmarks.

Table 2. Depth specific salinities in parts per thousand (ppt) of wetland sediments and associated vegetation in Muddy Creek.

Sample ID	**Salinity (ppt)**			**Vegetation Type**
	0-5cm	**5-10cm**	**10-15cm**	
Below the Weir				
MC 1	24.9	26.3	26.3	Spartina
MC 2	9.4	7.2	2.5	Phragmites
MC 3	13.4	7.5	6.0	Typha
MC 4	32.8	17.5	16.2	Spartina
MC 5	18.1	15.8	15.2	Spartina
Above the Weir				
MC 6	15.4	12.8	11.2	Spartina
MC 7	11.0	9.5	8.9	Phragmites
MC 8	0.6	0.4	0.5	Mixed freshwater assemblage
MC 9	0.4	0.7	0.6	Mixed freshwater assemblage
MC 10	1.0	1.0	0.9	Mixed freshwater assemblage

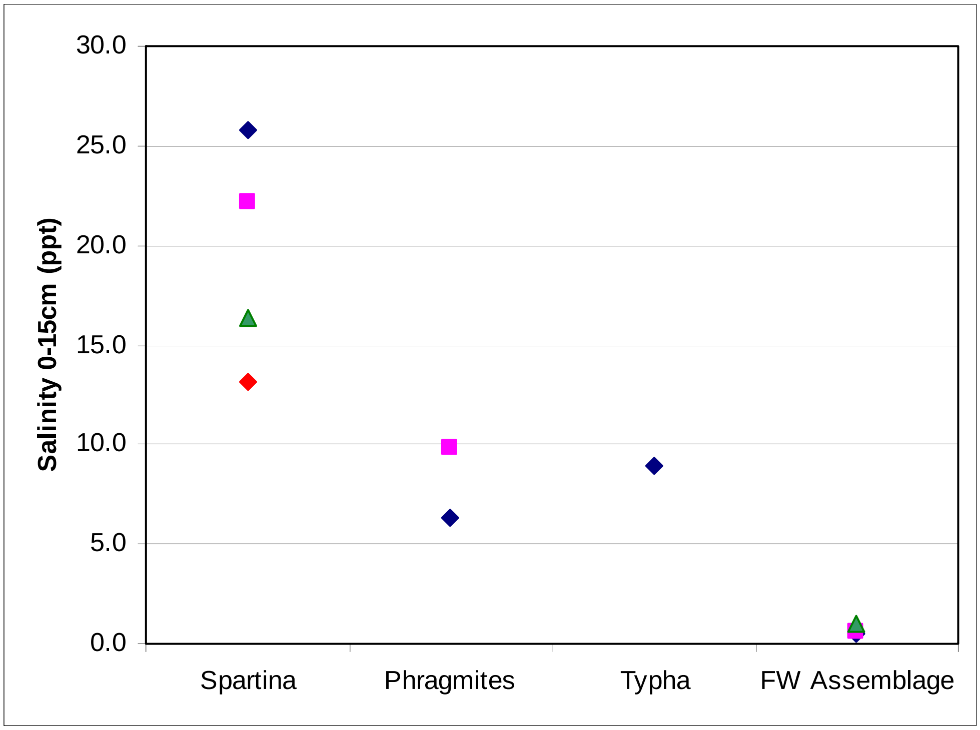


Figure 5. Average salinities (0-15cm) from core survey (Figure 4). It appears that salt marsh plants dominated at mean salinities >10 ppt, Typha and Phragmites at brackish conditions and the large freshwater assemblage areas at <1 ppt. The data show the same pattern in both upper and lower Muddy Creek sites.

1.3. Nitrogen Attenuation.

Not all nitrogen that enters Muddy Creek is transported to the adjacent waters of Pleasant Bay, or even from upper to lower basins within Muddy Creek. Since it is important for determining nitrogen related water quality to know the actual, not just the potential nitrogen reaching each basin, we conducted two (2) tidal studies at the dike location and at the system inlet (Rt. 28).

To quantify the amount of nitrogen attenuation in the upper and lower basins of Muddy Creek, prior to dike construction, we measured water, salt and nutrient flows into and out of each basin on both ebb and flood tides. We measured current freshwater and associated nutrient inputs to the head of Muddy Creek from the anadromous fish run from Minister's Pond and associated storm drains from Queen Anne Rd. and estimated inputs from groundwater sources.

MEP Watershed Nitrogen Loading to Upper and Lower Muddy Creek. The results of the MEP watershed modeling efforts in Muddy Creek (MEP Pleasant Bay Nutrient Technical Report 2006) estimated that annual attenuated nitrogen load from the watershed to Upper Muddy Creek is 3,860 Kg N/yr and to Lower Muddy Creek, 3,167 Kg N/yr.

Stream Discharge.

Methods

Freshwater discharge from the anadromous fish run from Minister's Pond was estimated July 16, 2008 during tidal flux measurements. Replicate measurements of water flow from the culvert at the head of Muddy Creek off Queen Anne Rd. were made by quantifying the volume of water discharged over a known time interval. Water samples were collected and analyzed for salinity, Chlorophyll a, ortho-Phosphate, Total Phosphorus, and nitrogen, including Ammonium, Nitrate/Nitrite, Dissolved Organic Nitrogen, and Particulate Organic Nitrogen (see Appendix D).

Results

It is estimated that approximately 641 m^3 per day of freshwater enter Muddy Creek from the fish run. Daily flux of Dissolved Inorganic Nitrogen (DIN, the sum of NH_4 and NOx) was approximately 27 g/day. Flux of Total Organic N (DON + PON) was approximately 358 g/day. The flux of Bioactive Nitrogen (DIN + PON) was approximately 66 g/day and the daily flux of all forms of N (TN) was approximately 384 g/day (Table 3).

Table 3 Daily (24 hr) flux of water and nutrients from the anadromous fish run at Queen Anne Rd. to Upper Muddy Creek

Fish Ladder	Water m3	Salt Kg	PO4 (g)	TP (g)	NH4 (g)	NO3 (g)	DIN (g)	DON (g)	PON (g)	BIOACTIVE N (g)	TON (g)	TN (g)
Flux In	641	64	1	2	17	10	27	319	39	66	358	384

Tidal Flux.

Methods

Measurements of tidal inflow and outflow were taken at the Route 28 culvert and at the site of the proposed dike installation (referred to as the weir) in Muddy Creek to provide an estimate of freshwater and nutrient flows into and out of upper and lower Muddy Creek. Two tidal nutrient flux samplings were conducted on June 16 and July 16 2008. Each sampling took place over a single complete tidal cycle beginning approximately 1 hour before low tide and ending approximately 1 hour after the next low tide (Figures 6 and 7). Before each tidal flux, it was determined that there was no precipitation for at least one complete tidal cycle prior to the first sampling to ensure that water and nutrient flux data would not be biased by rain-related flows. Tide gauges were installed in Pleasant Bay near the Route 28 culverts and in both upper and lower Muddy Creek near the Weir to obtain stage data for each tidal cycle. Water samples were collected at the culvert and at the weir at regular intervals over the course of the tidal cycle. Samples were analyzed for salinity, Chlorophyll a and nitrogen, including Ammonium, Nitrate/Nitrite, Dissolved Organic Nitrogen, and Particulate Organic Nitrogen (see Appendix D). Flood and ebb current velocity measurements were made concurrently with water samplings at both sites to determine flow characteristics during both flood and ebb tides. These flow data were then interpolated using the stage data to yield a detailed record of flow in and out of upper and lower Muddy Creek over the entire tidal cycle. Total flow during flood tide was calculated between slack low tide and slack high tide. Total flow out was calculated from slack high tide to the point at which the tidal height, as measured by the tide gauges during ebb reached the same level as that recorded at the previous slack low tide. Flow estimates during flood and ebb tides were used to calculate salt and nutrient flux into and out of both the upper and lower basins on each of the 2 sampling dates. Data from each collected water sample was paired with the corresponding flow rate to calculate a mass flux for each sampling event. These results were interpolated to yield a total mass flux for the entire tidal cycle. From these flux data, the magnitude and direction of the net flux of salt and nutrients were calculated.

Results

Tidal Ranges. Tidal ranges in Pleasant Bay and in Upper and Lower Muddy Creek on June 16 and July 16 2008 are shown in Figures 6 and 7. Due to the tidal restriction at the culverts in the Route 28 bridge, tidal range within the Muddy Creek basin is significantly dampened. On June 16, the tide range in Pleasant Bay near the Route 28 culverts was 2.8 feet while in both upper and lower Muddy Creek, the tidal range was 0.6 feet (Figure 6). On July 16, the tidal range in Pleasant Bay was 2.3 feet but only 0.6 feet in both Upper and Lower Muddy Creek (Figure 7).

Water Flux. Flux data were obtained on both dates using flow meter measurements made concurrently with water samplings. Current velocities were applied to the cross sectional area of the culvert and height of water at each sampling to obtain an instantaneous flow rate of water through the culverts and the Weir. These flow rates were then interpolated over the course of a single tidal cycle to yield an estimate of total water flux for both flood and ebb tides. Total flow into the lower and upper basins during the tidal cycle was calculated between slack low tide and slack high tide. Total flow out was calculated from slack high tide to the point at which the tidal height, as measured by a tide gauge during ebb reached the same level as that recorded at the previous slack low tide. On June 16, water flux during flood tide ranged from 19,145 cubic meters into Muddy Creek through the culverts (Table 4) to 8,594 cubic meters into Upper Muddy Creek at the Weir (Table 5). Water flux during tidal ebb was of a longer duration than during tidal flooding (Figure 6) and resulted in larger fluxes of water out of both basins to Pleasant Bay, 26,387 cubic meters, at the culverts (Table 4). Water flux during tidal ebb at the Weir was slightly smaller than during tidal flooding, 7,283 cubic meters (Table 5). As a result of this asymmetry, there was a net flux of water out of both basins of 7,242 cubic meters but only a slight net flux of water into the upper basin of 1,311 cubic meters. About 38% more water flowed out of both basins during ebb tide than flowed in during tidal flooding at the culverts. Approximately 15% more water flowed into Upper Muddy Creek than flowed out at the Weir.

On July 16, water flux during flood tide ranged from 17,577 cubic meters into both basins of Muddy Creek through the culverts (Table 6) to 6,146 cubic meters into Upper Muddy Creek at the Weir (Table 7). Water flux during tidal ebb was of a longer duration than during tidal flooding (Figure 7) and resulted in larger fluxes of water out of both basins, 22,312 cubic meters, at the culverts. Water flux during tidal ebb at the Weir was slightly larger than during flood tide, 6,538 cubic meters. As a result of this asymmetry, there was a net flux of water out of Muddy Creek of 4,735 cubic meters but a small net flux of water out of the upper basin of 392 cubic meters (Table 7). About 27% more water flowed out of both basins during ebb tide than flowed in during tidal flooding at the culverts. Approximately 6% more water flowed out of Upper Muddy Creek than flowed in at the Weir.

Salt Flux. Salt and nutrient concentrations were matched with flow data at each sampling during each tidal cycle to calculate instantaneous flux rates into and out of the upper marsh. These results were then interpolated to yield estimates of total flux during tidal flood and ebb. On June 16, salt flux during flood tide ranged from 492,301 Kg into Muddy Creek through the culverts (Table 4) to 135,951 Kg into Upper Muddy Creek at the Weir (Table 5). Salt flux during tidal ebb ranged from 462,547 Kg at the culverts to 101,836 Kg at the dike. As a result there was a small net flux of salt out of the Muddy Creek of 29,754 Kg or about 6% of the salt flux in. Therefore, salt flux into and out of Muddy Creek was reasonably in balance. The net flux out of Upper Muddy Creek was 34,115 Kg or about 25% of the salt flux into the upper creek.
On July 16, salt flux during flood tide ranged from 415,076 Kg into Muddy Creek through the culverts (Table 6) to 72,392 Kg into Upper Muddy Creek at the Weir (Table 7). Salt flux during tidal ebb ranged from 588,173 Kg at the culverts to 113,646 Kg at the Weir (Tables 6 and 7). As a result there was a net flux of salt out of Muddy Creek of 173,097 Kg or about 6% of the salt flux in (Table 6). The net flux out of Upper Muddy Creek was 41,254 Kg or about 57% of the salt flux into the upper creek (Table 7).

The net salt flux from the basins suggests a non-steady state condition, typical of tidal basins that do not empty at low tide. The periodic storage of salt (and nitrogen) in these systems constrains the use of attenuation calculated in this fashion. The issue derives from the fact that the volume of water in Muddy Creek is large relative to the amount of water exchanged with Pleasant Bay during a tidal cycle. When only a portion of the basin volume is replaced during a tidal cycle differences in salt and nitrogen concentrations between the tidal basin and the outflowing waters can result in a net positive or negative storage within the tidal basin. The result is that the accuracy of the nitrogen attenuation calculations is reduced

Nitrogen Flux: Dissolved Inorganic Nitrogen. There was a net export Dissolved Inorganic Nitrogen (DIN) out of both the upper basin and from Muddy Creek at the culverts on June 16 (Tables 4 and 5). DIN consists of NH_4 (Ammonium) and NO3/NO2 (Nitrate/Nitrite, also designated as NOx). NH_4 and NOx fluxes into Muddy Creek at the culverts during tidal flooding were 318 and 55 g, respectively (Table 4). During ebb tide NH_4 and NOx fluxes were 267 and 506 g, respectively. Net flux of NH_4 and NOx were 51 g import and 451 g export, respectively. Although there was a net import of NH_4, there was a net export of total DIN from Muddy Creek.

Fluxes of NH_4 and NOx into Upper Muddy Creek at the dike during tidal flooding were 36 and 665 g, respectively (Table 5). During ebb tide NH_4 and NOx fluxes were 156 and 1,525 g, respectively. Net export of NH_4 and NOx were 120 g and 859 g, respectively. Net loss of DIN was due largely to the net export of water during the tidal cycle. Both NH_4 and NOx concentrations (Appendix B) were significantly higher during tidal ebb than flood at the Weir which also contributed to a larger export of DIN out of Upper Muddy Creek

There was also a net export Dissolved Inorganic Nitrogen (DIN) out both the upper basin and from Muddy Creek at the culverts on July 16. NH_4 and NOx fluxes into Muddy Creek at the culverts during tidal flooding were 390 and 136 g, respectively. During ebb tide NH_4 and NOx fluxes were 1,141 and 116 g, respectively (Table 6). Net flux of NH_4 and NOx were 751 g export and 20 g import, respectively. Although there was a net import of NOx, there was a net export of total DIN from Muddy Creek. NH_4 and NOx fluxes into Upper Muddy Creek at the Weir during tidal flooding were 14 and 42 g, respectively (Table 7). During ebb tide NH_4 and NOx fluxes were 107 and 75 g, respectively. Net export of NH_4 and NOx were 93 g and 33 g, respectively. Net loss of DIN was due largely to the net export of water during the tidal cycle. Both NH_4 and NOx concentrations (see Appendix B) were significantly higher during tidal ebb than flood at the culverts and at the dike which also contributed to a larger export of DIN out of Upper Muddy Creek on July 16.

Nitrogen Flux: Dissolved Organic Nitrogen. Typically there was a net export of organic nitrogen in all its forms from both Upper and Lower Muddy Creek on both dates. On June 16, imports of Dissolved Organic Nitrogen (DON), Particulate Organic Nitrogen (PON) and Total Organic Nitrogen (TON, the sum of DON and PON) into Muddy Creek at the culverts were 5,735 g, 3,392 g and 9,127 g, respectively (Table 4). Export during ebb tide was 8,383 g, 7,739 g and 16,122 g, respectively. The result was a net export of 2,647 g of DON, 4,347 g PON and 6,995 g of TON from Muddy Creek to Pleasant Bay. At the Weir, imports of DON, PON and TON into Upper Muddy Creek were 2,362 g, 1,846 g and 4,206 g, respectively. Export during ebb tide was 2,887 g, 2,810 g and 5,697 g, respectively. The result was a net export of 525 g of DON, 964 g PON and 1,491 g of TON from Upper Muddy Creek to the lower basin.

On July 16, imports of DON, PON and TON into Muddy Creek at the culverts were 7,524 g, 2,488 g and 10,012 g, respectively. Export during ebb tide was 9,829 g, 3,084 g and 12,914 g, respectively. The result was a net export of 2,305 g of DON, 596 g PON and 2,902 g of TON from Muddy Creek to Pleasant Bay. At the Weir, imports of DON, PON and TON into Upper Muddy Creek were 2,668 g, 1,896 g and 4,564 g, respectively. Export during ebb tide was 3,255 g, 3,562 g and 6,817 g, respectively. The result was a net export of 587 g of DON, 1,666 g PON and 2,253 g of TON from Upper Muddy Creek to the lower basin. The export from both Upper Muddy Creek and from both basins to Pleasant Bay was due primarily to the greater export of water at the Weir and the culverts on both dates. Concentrations of DON, PON and TON were also somewhat higher during tidal ebb than during flood (see Appendix B).

Nitrogen Flux: Bioactive Nitrogen. Bioactive Nitrogen is the sum of DIN and PON. On both June 16 and July 16, there was a net export of Bioactive N from the Upper Muddy Creek basin at the dike and from both basins at the culverts. These data are consistent with the net export of both DIN and PON on both dates, again due primarily to greater export of water from the upper basin at the Weir and from both basins at the culverts.

Nitrogen Flux: Total Nitrogen. Total Nitrogen (TN) is the sum of all organic (TON) and inorganic (DIN) forms of N. As was the case for both DIN and TON, there was a net export of TN from the upper basin and from both basins at the culverts on both dates. On June 16, there was a net export of 7,393 g TN from the both basins at the culverts and of 2,466 g TN from the upper basin at the Weir (Tables 4 and 5). On July 16, there was a net export of 3,480 g TN from the both basins at the culverts and of 2,384 g TN from the upper basin at the Weir (Tables 6 and 7).

Chlorophyll a and Pheophytin. There was a net export of Chlorophyll a (Chla) and Pheophytin (Pheo) from the upper basin and from the both basins at the culverts on both dates except for July 16, when there was a slight net import of Pheophytin at the culverts (Tables 4-7). On June 16, tidal import of Chl a and Pheo during flooding varied from 0.4 and 0.7 g, respectively at the culverts to 5.2 g and 0.4 g, respectively at the dike (Tables 4 and 5). Export concentrations at the culverts were 11.6 g Chl a and 1.5 g Pheo, respectively and 5.4 g Chl a and 0.5 g Pheo, respectively at the dike. Consequently, there was a small net export of 11.2 g Chl a and 0.8 g Pheo at the culverts and of 0.2 g Chl a and 0.1 g Pheo at the dike. On July 16, concentrations of both Chl a and Pheo were significantly higher during the period of highest primary productivity and of the degradation of Chl a to Pheo in the warm summer months. Import values for Chl a and Pheo were 100 g and 67 g, respectively at the culverts (Table 6) and 104 g and 17 g, respectively at the Weir (Table 7). Export concentrations at the culverts were 184 g and 61 g, respectively and 196 g and 20 g, respectively at the dike. Net export of Chl a was significantly larger than in June. Net export of Pheo was somewhat larger at the dike but was actually a net import at the culverts. Net Chl a export was 84 g at the culverts and 92 g at the dike while net Pheo import was 6 g at the culverts and net export was 3 g at the dike.

Nitrogen Attenuation in the Muddy Creek system. Based on the results of the tidal flux studies conducted in Muddy Creek on June 16, 2008, there was a net tidal export of approximately 2.47 Kg N per tide, or 4.8 Kg N/day from Upper to Lower Muddy Creek and 7.39 Kg N per tide or 14.2 Kg/day from both basins to Pleasant Bay. Based on loading estimates from MEP modeling efforts in Muddy Creek, these fluxes represent a 55% attenuation of N loading from Upper Muddy Creek but only 1% attenuation from both basins (Table 8). On July 16, there was a net export of approximately 2.38 Kg N per tide or 4.6 Kg/day from Upper to Lower Muddy Creek and approximately 3.48 Kg N per tide or 6.7 Kg/day from both basins to Pleasant Bay. The July fluxes represent an attenuation of 57% of the N load from Upper Muddy Creek and 41% attenuation from both basins to Pleasant Bay (Table 8). The volume of water in Muddy Creek is large relative to the amount of water exchanged with Pleasant Bay during a tidal cycle. Such a low exchange relative to total basin volume results in a large amount of nutrient storage in the 2 basins, thus making an assessment of N attenuation difficult and is likely the reason there is such a large difference (variability) in total system attenuation between June and July (Table 8). The amount of nitrogen going into Muddy Creek from Pleasant Bay on a flood tide will not necessarily balance with the nitrogen returning to Pleasant Bay on the following ebb tide. However, the data appear to indicate that Upper Muddy Creek is presently reducing the nitrogen load it receives from its watershed prior to passing it along to the lower basin and Pleasant Bay. Based upon the results of the watercolumn-sediment exchange study (see section below on Benthic Nitrogen Flux), it appears that much of this uptake is in the upper freshwater portion of the upper basin. It is likely that interception of groundwater transported nitrogen with the wetland systems also removes nitrogen. It is the combination of nitrogen removal from discharging surface and groundwater by wetlands prior to entering the estuary and removal by sediment processes within the estuary that cause the relatively large attenuation rate seen for the upper basin.

Figure 6 Tidal elevations in Muddy Creek during the June 16, 2008 tidal study.

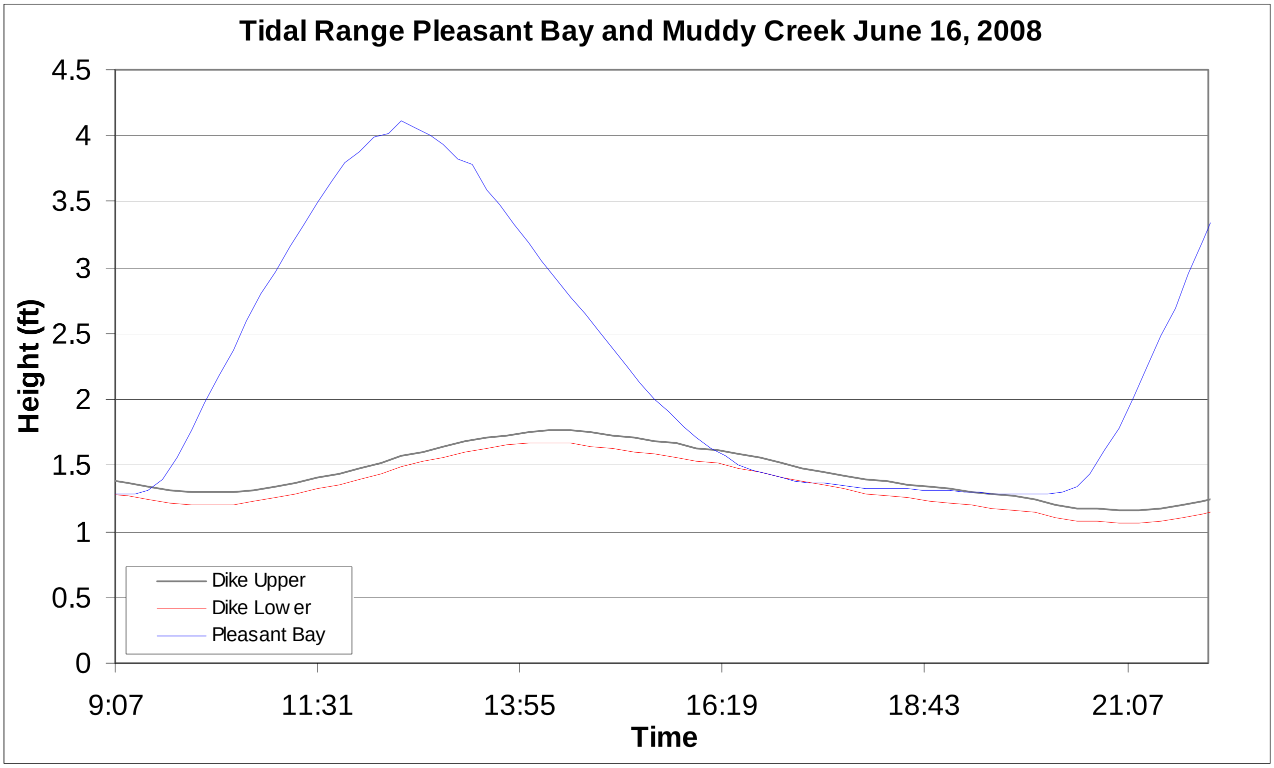


Table 4. Tidal exchange of water and constituents at the Route 28 culverts, June 16, 2008.

Both Basins	Water (m^3)	Salt (Kg)	NH4 (g)	NO3/NO2 (g)	DIN (g)	DON (g)	PON (g)	Bioactive N (g)	TON (g)	TN (g)	Chla (g)	PHEO (g)
Flux In	19,145	492,301	318	55	372	5,735	3,392	3,764	9,127	9,499	0.4	0.7
Flux Out	26,387	462,547	267	506	771	8,383	7,739	8,510	16,122	16,893	11.6	1.5
Net Flux	7,242	29,754	51	451	399	2,647	4,347	4,747	6,995	7,393	11.2	0.8
Direction	Out	In	In	Out	Out	Out	Out	Out	Out	Out	Out	Out

Table 5. Tidal exchange of water and constituents at the Dike, June 16, 2008.

Upper Basin	Water m3	Salt Kg	NH4 (g)	NO3/NO2 (g)	DIN (g)	DON (g)	PON (g)	Bioactive N (g)	TON (g)	TN (g)	Chla (g)	PHEO (g)
Flux In	8,594	135,951	36	665	702	2,362	1,846	2,548	4,206	4,908	5.2	0.4
Flux Out	7,283	101,836	156	1,525	1,678	2,887	2,810	4,488	5,697	7,375	5.4	0.5
Net Flux	1,311	34,115	120	859	976	525	964	1,940	1,491	2,466	0.2	0.1
Direction	In	In	Out	Out	Out	Out	Out	Out	Out	Out	Out	Out

Figure 7 Tidal range Muddy Creek

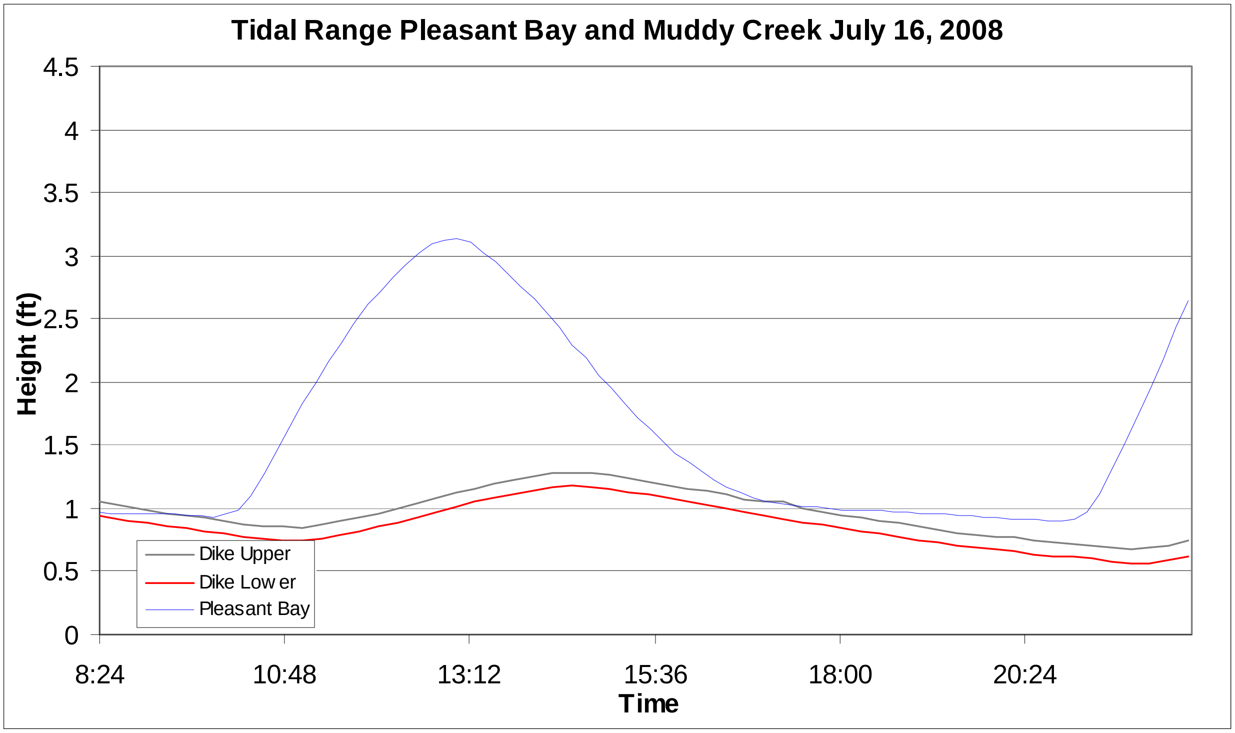


Table 6. Tidal exchange of water and constituents at the Route 28 culverts, July 16, 2008.

Both Basins	Water m3	Salt Kg	NH4 (g)	NO3 (g)	DIN (g)	DON (g)	PON (g)	BIOACTIVE N (g)	TON (g)	TN (g)	Chla (g)	PHEO (g)
Flux In	17,577	415,076	390	136	524	7,524	2,488	3,012	10,012	10,535	100	67
Flux Out	22,312	588,173	1,141	116	1,260	9,829	3,084	4,344	12,914	14,015	184	61
Net Flux	4,735	173,097	751	-20	736	2,305	596	1,332	2,902	3,480	84	-6
Direction	Out	Out	Out	In	Out	Out	Out	Out	Out	Out	Out	In

Table 7. Tidal exchange of water and constituents at the Dike, July 16, 2008.

Upper Basin	Water m3	Salt Kg	NH4 (g)	NO3 (g)	DIN (g)	DON (g)	PON (g)	BIOACTIVE N (g)	TON (g)	TN (g)	Chla (g)	PHEO (g)
Flux In	6,146	72,392	14	42	54	2,668	1,896	1,950	4,564	4,618	104	17
Flux Out	6,538	113,646	107	75	185	3,255	3,562	3,747	6,817	7,002	196	20
Net Flux	392	41,254	93	33	131	587	1,666	1,797	2,253	2,384	92	3
Direction	Out	Out	Out	Out	Out	Out	Out	Out	Out	Out	Out	Out

Table 8. Summary of nitrogen attenuation within Muddy Creek upper basin and Muddy Creek overall to Pleasant Bay under existing conditions. These values represent general removal and storage rates on 2 tidal cycles during the summer of 2008.

Muddy Creek Tidal Studies	Watershed N Load MEP kg/d	N Attenuation			
		June Flux kg/tide	July Flux kg/tide	June Flux kg/day	July Flux kg/day
Upper Muddy Creek	10.6	2.5	2.4	4.8	4.6
All of Muddy Creek	19.3			19.0	11.3
Total Attenuation				1%	41%
Upper Muddy Creek only				55%	57%

Water Quality Data

Methods

Water quality data was collected at the 2 water quality sampling sites in Muddy Creek established for the Pleasant Bay volunteer monitoring program. Station PBA 5 is located in Lower Muddy Creek near the culverts under Route 28 and Station PBA 5A is located in Upper Muddy Creek (Figure 8). GPS coordinates are located in Table 9. Data collection was carried out by SMAST during ebb tide on the 2 dates of the tidal flux (June 16 and July 16) and by the Town of Chatham on 5 other dates (see Table 10). All samples were analyzed at the SMAST Analytical Facility (see Appendix D).

Results

Salinity. Salinity was always higher at Station PBA 5 in Lower Muddy Creek than at PBA 5A in Upper Muddy Creek on all sampling dates (Table 3-7) due to mixing of higher salinity tidal water from Pleasant Bay with fresher water from the upper creek. Values ranged from 9.8 – 18.3 ppt with a mean of 13.6 ppt at PBA 5A and from 19.0 – 31.6 ppt with a mean of 25.3 ppt at PBA 5 (Table 10).

Watercolumn Nitrogen. Watercolumn nitrogen is a fundamental part of the various water quality samplings that have been conducted within the Muddy Creek System. Nitrogen is partitioned into Dissolved inorganic nitrogen (DIN=NH_4+NOx) and organic forms (dissolved organic nitrogen, DON; particulate organic nitrogen, PON). Total nitrogen is the combination of DIN+PON+DON and bioactive nitrogen is a combination of the most available forms that stimulate the eutrophication response (i.e. bioactive nitrogen= DIN+PON).

Recent measurements (2008) of DIN showed a significant gradient from the upper basin, PBA 5A, to the lower basin, PBA 5, on all sampling dates, ranging from 13.62 - 39.95 uM with a mean of 24.7 uM at PBA 5A to 0.60 – 2.59 uM with a mean of 1.5 uM at PBA 5 (Table 10). Concentrations of NH_4 and NOx showed similar decreases. All decreases were due largely to dilution of high nutrient water from the upper creek with relatively low nutrient water from Pleasant Bay closer to the culverts. Highest concentrations occurred during the height of biological activity in August and September. Values at PBA 5 on September 4 are much higher than on any of the other dates and are likely due to a sampling or contamination problem. Consequently, they were not used in this discussion.

All forms of organic nitrogen, or TON, (DON+PON) decreased in concentration from PBA 5A downstream to PBA 5. The decrease was not as great as it was for DIN, ranging from 53.51 – 107.94 uM with a mean of 77.5 uM at PBA 5A to 34.83 – 75.00 uM with a mean of 53.7 uM at PBA 5 (Table 3-7). As was the case with DIN, decreases in concentrations of organic nitrogen downstream were largely due to dilution from low nutrient water from Pleasant Bay. Concentrations were highest during the warm biologically active summer months of July, August and September. Values reported for PBA 5 on September 4 were not used in this discussion due to likely sampling or contamination problems.

Bioactive Nitrogen (DIN + PON) also showed a similar decrease downstream from PBA 5A to PBA 5 due to dilution of waters from the upper creek with low nutrient water from Pleasant Bay. Values ranged from 38.87 – 63.86 uM with a mean of 52.9 uM at PBA 5A to 15.34 – 22.59 uM with a mean of 17.7 uM at PBA 5 (Table 10). Highest values occurred in July, August and September. Data from PBA 5 on September 4 were not used due to likely sampling or contamination problems.

Total nitrogen (TN) is the sum of all forms of nitrogen. TN concentrations followed the same pattern downstream from PBA 5A to PBA 5 as DIN, organic nitrogen and bioactive nitrogen, ranging from 74.95 – 122.80 uM with a mean of 102.2 uM at PBA 5A to 37.42 – 77.42 uM with a mean of 55.2 uM at PBA 5 (Table 10). Again, data from PBA 5 on September 4 were not used due to likely sampling or contamination problems.

Chlorophyll a and Pheophytin. Chlorophyll a decreased slightly downstream from PBA 5A to PBA 5 except on Aug. 21 when there was a slight increase (Table 10). Values ranged from 0.53 – 42.44 ug/L with a mean of 20.8 ug/L at PBA 5A to 0.86 – 19.12 ug/L with a mean of 13.2 ug/L at PBA 5. Pheophytin a concentrations were mush smaller than Chlorophyll a, ranging from <0.05 - 2.34 ug/L at PBA 5A to <0.05 – 8.47 ug/L. Highest values of Chlorophyll a were measured in July. Observed decreases downstream were due to dilution from Pleasant Bay waters.

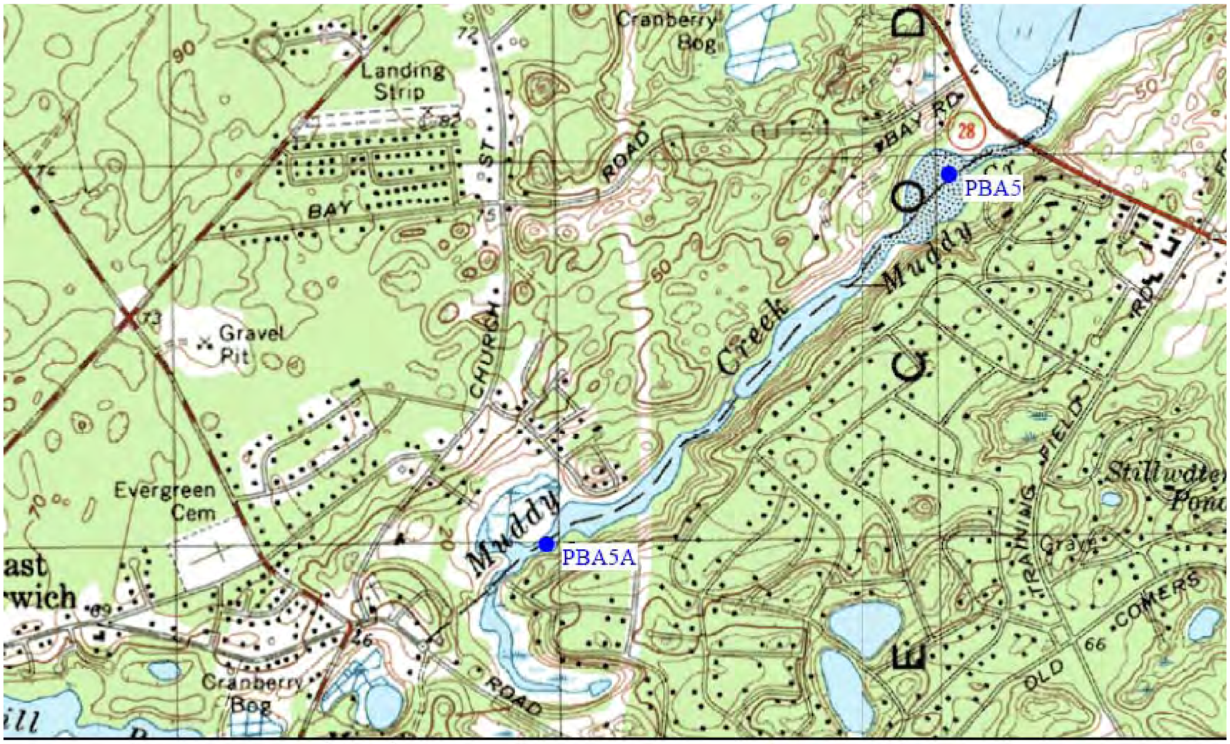


Figure 8. Locations of water quality stations, Muddy Creek, MA

Table 9. GPS locations of water quality stations, Muddy Creek, MA

Station ID	Latitude	Longitude
PBA 5	041° 42.6634' N	069° 59.7992' W
PBA 5A	041° 42.1398' N	070° 00.5578' W

Table 10. Water quality data* from 2 water quality stations, Muddy Creek, 2008

Sta	Date	Salinity (ppt)	PO4 (uM)	NH4 (uM)	NOx (uM)	DIN (uM)	DON (uM)	PON (uM)	Bioactive N (uM)	TON (uM)	TN (uM)	Chla (ug/L)	Pheo (ug/L)
PBA5A	6/16/2008	18.3	1.8	5.5	15.96	21.44	26.07	27.44	48.88	53.51	74.95	0.53	<0.05
PBA5	6/16/2008	28	1.3	0.9	1.69	2.59	21.40	13.43	16.02	34.83	37.42	0.86	<0.05
PBA5A	7/7/2008	15.1	0.4	2.3	24.27	26.58	48.98	21.12	47.70	70.10	96.68	22.12	2.34
PBA5	7/7/2008	22.3	<0.1	0.9	0.09	0.96	29.69	14.38	15.34	44.07	45.03	17.64	8.47
PBA5A	7/16/2008	14.8	0.5	4.7	8.91	13.62	30.16	45.42	59.04	75.58	89.20	31.43	<0.05
PBA5	7/16/2008	31.6	1.5	0.3	0.27	0.60	31.50	21.99	22.59	53.49	54.09	14.77	2.61
PBA5A	7/23/2008	9.8	1.3	5.5	15.32	20.83	65.09	28.19	49.03	93.28	114.12	42.44	<0.05
PBA5	7/23/2008	27.9	1.1	0.6	0.23	0.83	32.33	16.85	17.68	49.18	50.01	19.12	2.85
PBA5A	8/6/2008	11.0	1.3	12.4	2.46	14.87	83.93	24.00	38.87	107.94	122.80	17.26	1.28
PBA5	8/6/2008	22.8	1.3	1.2	0.45	1.69	49.37	16.03	17.72	65.40	67.09	13.94	<0.05
PBA5A	8/21/2008	14.4	0.7	18.5	21.49	39.95	50.84	22.85	62.80	73.69	113.64	10.99	1.01
PBA5	8/21/2008	25.2	1.4	1.1	1.29	2.42	60.58	14.43	16.85	75.00	77.42	12.88	<0.05
PBA5A	9/4/2008	11.7	0.9	14.6	21.39	35.96	40.23	27.90	63.86	68.13	104.09	20.59	1.47
PBA5	9/4/2008	19.0	5.2	11.8	4.94	16.74	350.21	17.80	34.54	368.01	384.75	12.98	2.87
PBA5A	**Mean**	13.6	1.0	9.1	15.7	24.7	49.3	28.1	52.9	77.5	102.2	20.8	1.5
PBA5	**Mean**	25.3	1.3	0.8	0.7	1.5	37.5	16.2	17.7	53.7	55.2	13.2	4.2

* Data from June 16 and July 16 collected by SMAST; all other data collected by Town of Chatham. Means do not include data from PBA 5 on Sept. 4.

Benthic Nitrogen Flux. Recycled nitrogen from sediments in Muddy Creek plays a role in the nitrogen enrichment of the overlying waters. In some systems it can be responsible for as much as one-third to one-half of the nitrogen supply to phytoplankton blooms during the warm growing season.

Methods

In order to determine the contribution of sediment regenerated nutrients to primary production during the summer, 16 sediment cores (15 cm inside diameter) were collected by SCUBA divers (Figure 9, Table 11)[2]. Cores were maintained at in situ temperatures during transport to the field laboratory (private residence) and throughout the incubation. Bottom water from each site was collected and filtered to replace headspace water of each core prior to the start of incubation. The headspace of each core was continuously mixed and periodic 60 ml samples withdrawn (volume replaced with filtered water), filtered into acid-leached polyethylene bottles and held on ice for analysis. Analysis followed the protocols detailed in the QAPP for the MEP. Flux rates were determined by linear rates of change of total dissolved nitrogen over the time course of the incubations.

Results

Muddy Creek tended to show net nitrogen uptake in its freshwater and brackish reaches (uppermost reach and mid reach) and net nitrogen release in the lower reach (from the dike to the tidal inlet). The magnitude of the watercolumn-sediment exchange was similar to other areas within the Pleasant Bay System (cf. MEP Pleasant Bay Report 2006). The watercolumn-sediment exchange rates (Table 12) were used in the water quality modeling scenario discussed below.

[2] The sediment regeneration work was part of a student project within the Coastal Systems Program at UMASS-Dartmouth and was integrated into this present study at no cost to the Pleasant Bay Alliance.

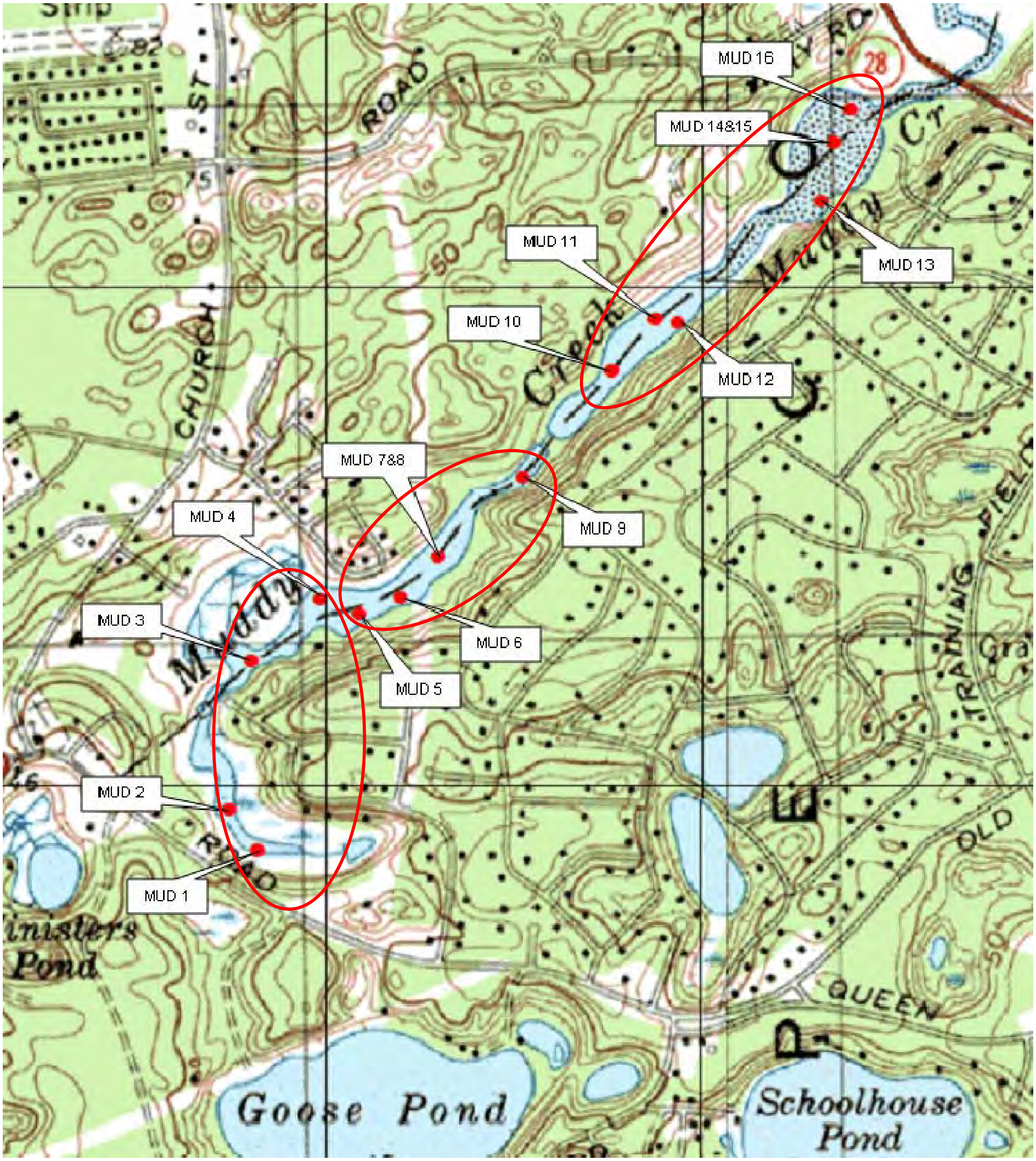


Figure 9. Locations of core sampling sites for measurement of sediment-watercolumn nitrogen exchange during July 2008 throughout the Muddy Creek Estuary. Circles enclose similar basin characteristics.

Table 11 GPS Locations of Benthic Flux Core Collection		
Core ID	Latitude	Longitude
MUD 1	041° 41' 56.00" N	070° 00' 35.30" W
MUD 2	041° 41' 58.40" N	070° 00' 37.70" W
MUD 3	041° 42' 07.30" N	070° 00' 35.80" W
MUD 4	041° 42' 11.10" N	070° 00' 30.40" W
MUD 5	041° 42' 10.20" N	070° 00' 27.20" W
MUD 6	041° 42' 11.20" N	070° 00' 24.00" W
MUD 7&8	041° 42' 13.50" N	070° 00' 21.00" W
MUD 9	041° 42' 18.40" N	070° 00' 14.00" W
MUD 10	041° 42' 24.90" N	070° 00' 06.90" W
MUD 11	041° 42' 28.00" N	070° 00' 03.40" W
MUD 12	041° 42' 27.80" N	070° 00' 01.60" W
MUD 13	041° 42' 35.10" N	069° 59' 50.10" W
MUD 14&15	041° 42' 38.60" N	069° 59' 49.10" W
MUD 16	041° 42' 40.60" N	069° 59' 47.80" W

Table 12. Net Sediment-Watercolumn Nitrogen Exchange. Negative values are uptake.

Table 12			Sediment Nitrogen Efflux (mg/m2/d)		
Muddy Creek	Description	Sta*	Mean	s.d.	N
Upper Basins	Fresh/Brackish	MUD 1-4	-78.0	12.1	4.0
	Brackish	MUD 5-9	-11.5	32.9	5.0
Lower Basin	Saline	MUD 10-16	76.6	19.9	7.0
* Station ID's refer to sites in Figure 3-4.					

1.4. Benthic Animal Communities

Methods

Sediment samples were collected at 6 sites in Muddy Creek (3 above and 3 below the dike) on May 14 and August 28 2008 (Figure 10, Table 13). Samples were collected by grab sampler representing a surface area of 0.0625 m^2. Samples were sieved and all individuals retained on a 300 μ mesh screen were collected and preserved in 10% formalin for sorting and identification. Samples were identified to species. Total numbers of individuals, species were counted and species richness and evenness were calculated at each site (Table 14).

Results

The upper basin benthic animal community supported slightly less species (29 total) than the lower basin (33 total). However in both cases there were moderate to high numbers of individuals comprising the community. Similarly, both basins showed similarly moderate to high species diversity, H'. However, again there was a tendency for slightly richer communities in the lower basin (upper = 2.2-2.4 versus lower 2.3-2.6).

While the numbers of species and individuals are moderate relative to high quality habitats, the actual species present are indicative of a nutrient impaired environment. Nutrient impairment in Cape Cod estuaries manifests itself through enhanced organic matter deposition and enrichment of sediments and periodic depletion of bottom water oxygen. Both of these conditions exist in Muddy Creek. The benthic communities of both the upper and lower basins are dominated by polychaete worms, with some crustaceans (amphipods in the upper basin, small bivalve, *Gemma*, in the lower basin). The communities observed in 2008 were indicative of a significantly higher quality habitat than observed in 2000, where only 6 species and 77 individuals were found in the upper basin and 8 species and 200 individuals in the lower basin. This change may result from either differing oxygen conditions in the 2 years, due to weather (light, rain, wind) effects or to the greater flushing of Muddy Creek in the post-2007 breach condition. It should be noted that while the community is moderately improved, it still clearly indicates organic enrichment due to nitrogen overloading. In addition, SMAST oxygen records from 2008, while improved over previous years, indicated hypoxic conditions in the upper, mid and lower reaches of the Muddy Creek estuary, consistent with the organic enrichment tolerant species which dominate this system.

Figure 10. Locations of benthic infauna sampling stations, Muddy Creek, MA.

Table 13. GPS Coordinates of Benthic Infauna Sampling Stations

Station Name	Latitude	Longitude
Muddy Crk 1	041° 42.6360' N	069° 59.8250' W
Muddy Crk 2	041° 42.4310' N	070° 00.0970' W
Muddy Crk 3	041° 42.3740' N	070° 00.1700' W
Muddy Crk 4	041° 42.2630' N	070° 00.3160' W
Muddy Crk 5	041° 42.1720' N	070° 00.4770' W
Muddy Crk 6	041° 42.1250' N	070° 00.6190' W

Table 14. Benthic Animal Communities in the Upper (Sta 4-6) and Lower (Sta 3) Muddy Creek Estuary. Stations refer to locations in the above location map.

	Mean Total Actual		Mean Total Actual		Species Calculated		Weiner Diversity		Evenness	
	Species 5/14/08	Species 8/28/08	Individuals 5/14/08	Individuals 8/28/08	@75 Indiv. 5/14/08	@75 Indiv. 8/28/08	(H') 5/14/08	(H') 8/28/08	(E) 5/14/08	(E) 8/28/08
MUDDY CREEK 2008										
Sta 1	12	18	307	261	9	12	2.25	2.13	0.63	0.52
Sta 2	18	N/A	636	N/A	11	N/A	2.51	N/A	0.60	N/A
Sta 3	13	17	302	732	10	10	2.60	2.07	0.71	0.51
Sta 4	15	N/A	1068	N/A	9	N/A	2.16	N/A	0.57	N/A
Sta 5	11	17	428	2230	10	13	2.44	2.09	0.72	0.52
Sta 6	10	N/A	200	N/A	9	N/A	2.44	N/A	0.77	N/A

1.5. Other Wetland Resources

The project team reviewed MassDEP and other Commonwealth agency documents to gather relevant resource maps that should be assessed as part of any dike restoration planning. The resource area maps are shown in Figures 11 through 16, below.

The Natural Heritage map appears to show priority habitats for protected rare species adjacent the waters of Muddy Creek (Figure 11). A next step would be to request that Natural Heritage clarify if this coverage extends to the edge of the water sheet, as it is unclear from the posting.

The Massachusetts Division of Marine Fisheries has identified anadromous fish runs throughout the Commonwealth, including. Within Muddy Creek the fish runs relate to the present (culvert at Rt. 28 and Minister's Pond fish ladder) and historical (dike) restrictions to fish passage (Figure 12). It is expected that any restoration of the dike within Muddy Creek would be engineered to support passage of anadromous fish to the new habitat within upper Muddy Creek and to the fish ladder to Minister's Pond.

MassDMF has determined areas suitable as shellfish habitat (Figure 13). At present, the assessment indicates that the only "suitable areas" within Muddy Creek are limited to the tidal channel associated with the tidal inlet. All areas inland of the culverts at Route 28 are closed to shellfishing due to poor water quality (“Prohibited”) or “Management Closure” (Figure 14). After Dike installation, flushing in lower Muddy Creek will improve and further testing for bacteria levels may be warranted to determine its suitability for shellfishing in the future.

Muddy Creek has been designated as a coastal river under the Massachusetts River Act. While this does not specifically designate species, it does carry regulatory protection in terms of riparian buffers. All of the Muddy Creek estuary is designated as a coastal river (Figure 15). The performance standards of the Act apply to the river reach inland of the tidal inlet to Pleasant Bay.

As a tidal estuary, Muddy Creek contains subtidal area designated as "land under the ocean". To show this region the project team referred to the bathymetric map in the Massachusetts Estuaries Project Report (2003) for Chatham's estuaries (Figure 16). "Land Under the Ocean" includes all land at a depth greater than Mean Low Water (MLW) or lower than +0.9 ft NAVD under existing conditions. Re-installing the water control structure in the dike will result in a greater tidal amplitude in the lower basin of Muddy Creek. The greater tidal amplitude results from higher high tides (1.58 versus 1.38 MHW, NAVD) and lower low tides (0.65 versus 0.88 MLW, NAVD). Therefore, there will be slightly less area under this designation in the lower basin. In contrast, isolating the upper basin from tidal flows with the result that it freshens will result in a loss of this area from this designation in the upper basin.

Muddy Creek has been designated an Area of Critical Environmental Concern (Figure 17). Under this designation, any project proposed within the boundaries of the ACEC must meet the performance standards outlined in the Wetlands Protection Act for ACECs.

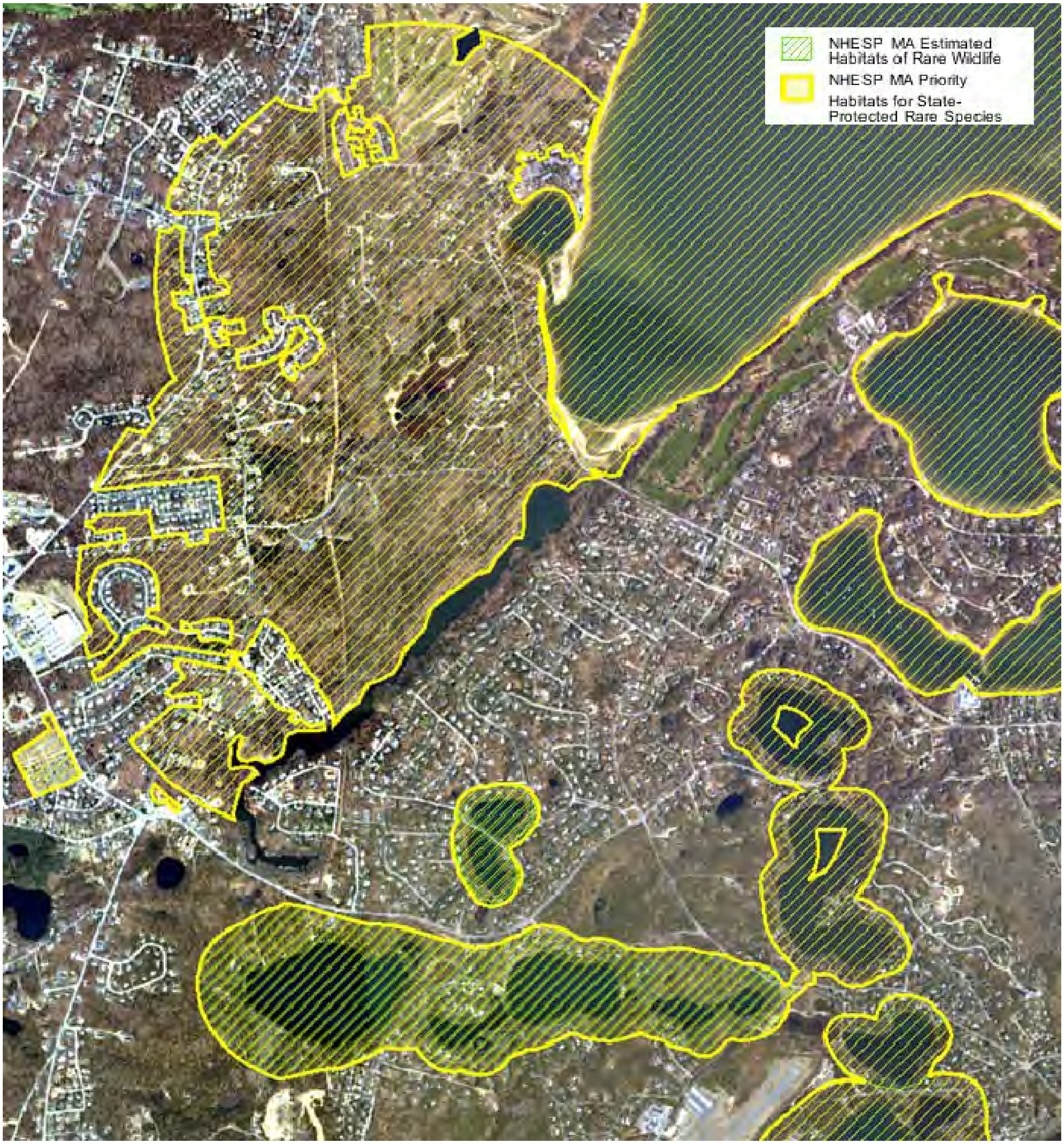


Figure 11. Estimated Habitats of Rare Wildlife and Priority Habitats for State Protected Rare Species. Map from Massachusetts Natural Heritage Endangered Species Program. The areas associated with Muddy Creek (north shore) are "priority habitats for State-protected rare species".

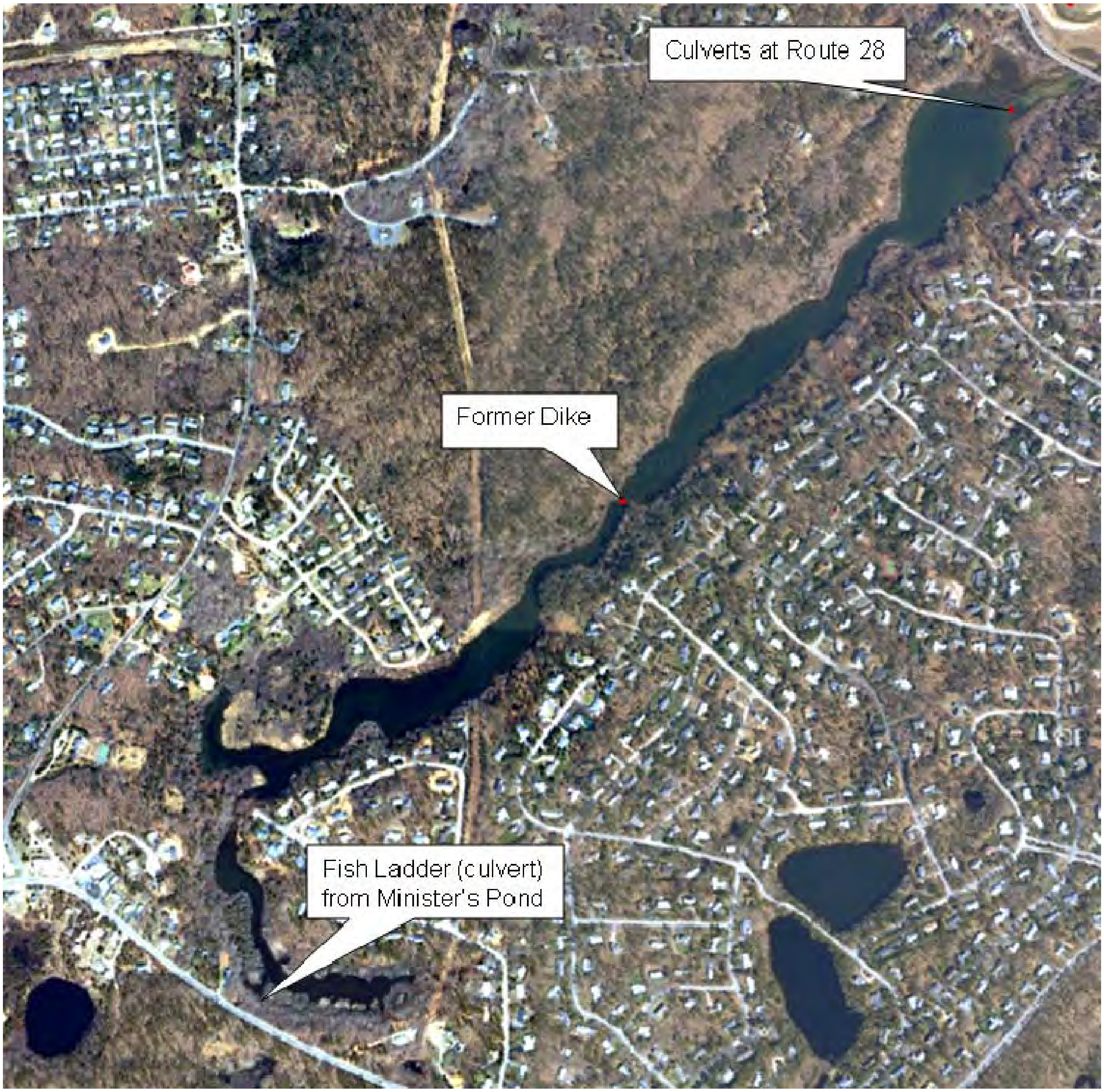


Figure 12 Anadromous fish runs, Muddy Creek. The fish runs relate to the present (culvert at Rt. 28 and Minister's Pond fish ladder) and historical (dike) restrictions to fish passage. Source, MassGIS.

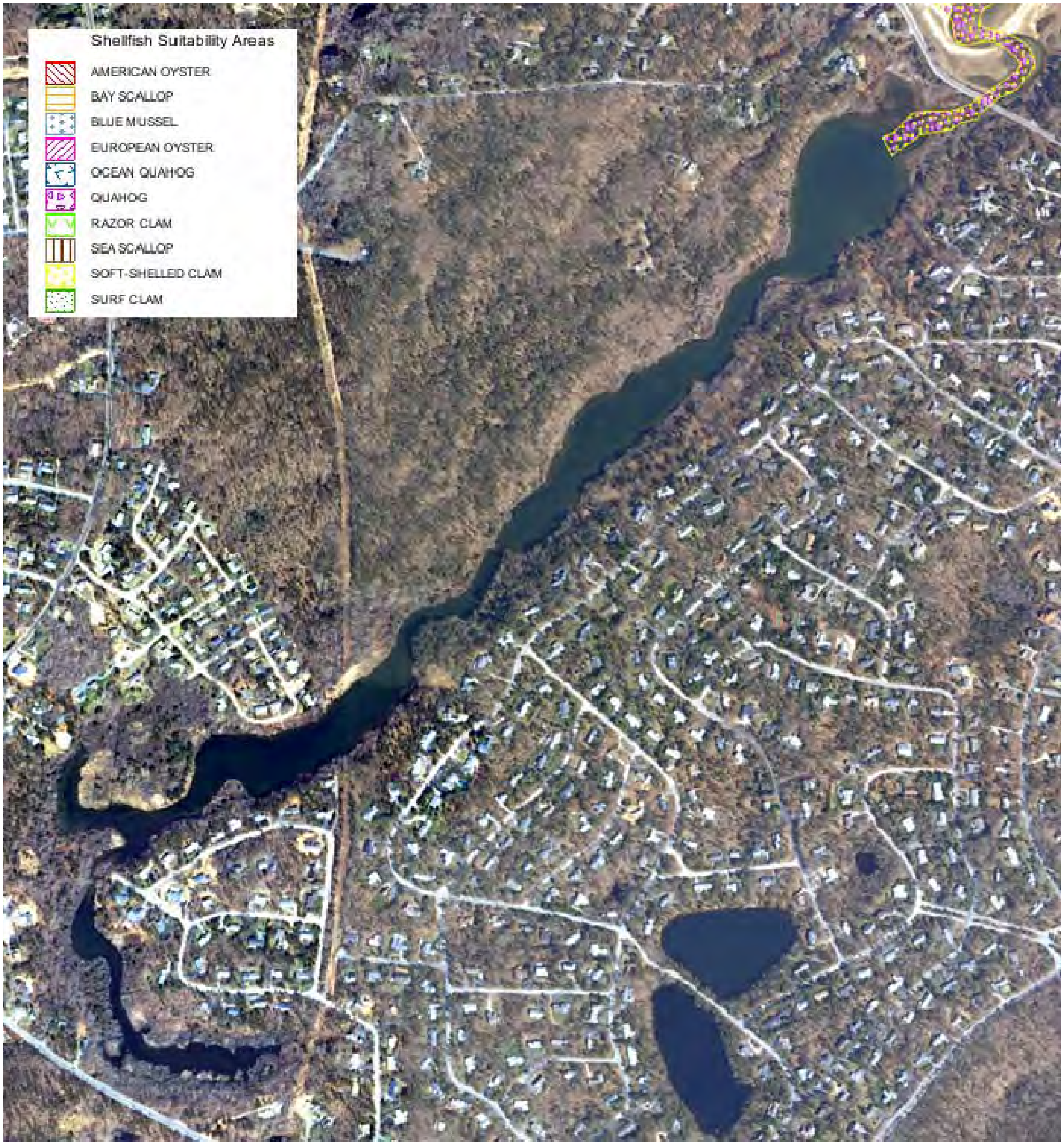


Figure 13 Suitable shellfish habitat from MassGIS, areas designated by Mass. DMF. The suitable areas within Muddy Creek are limited to the tidal channel associated with the tidal inlet only.

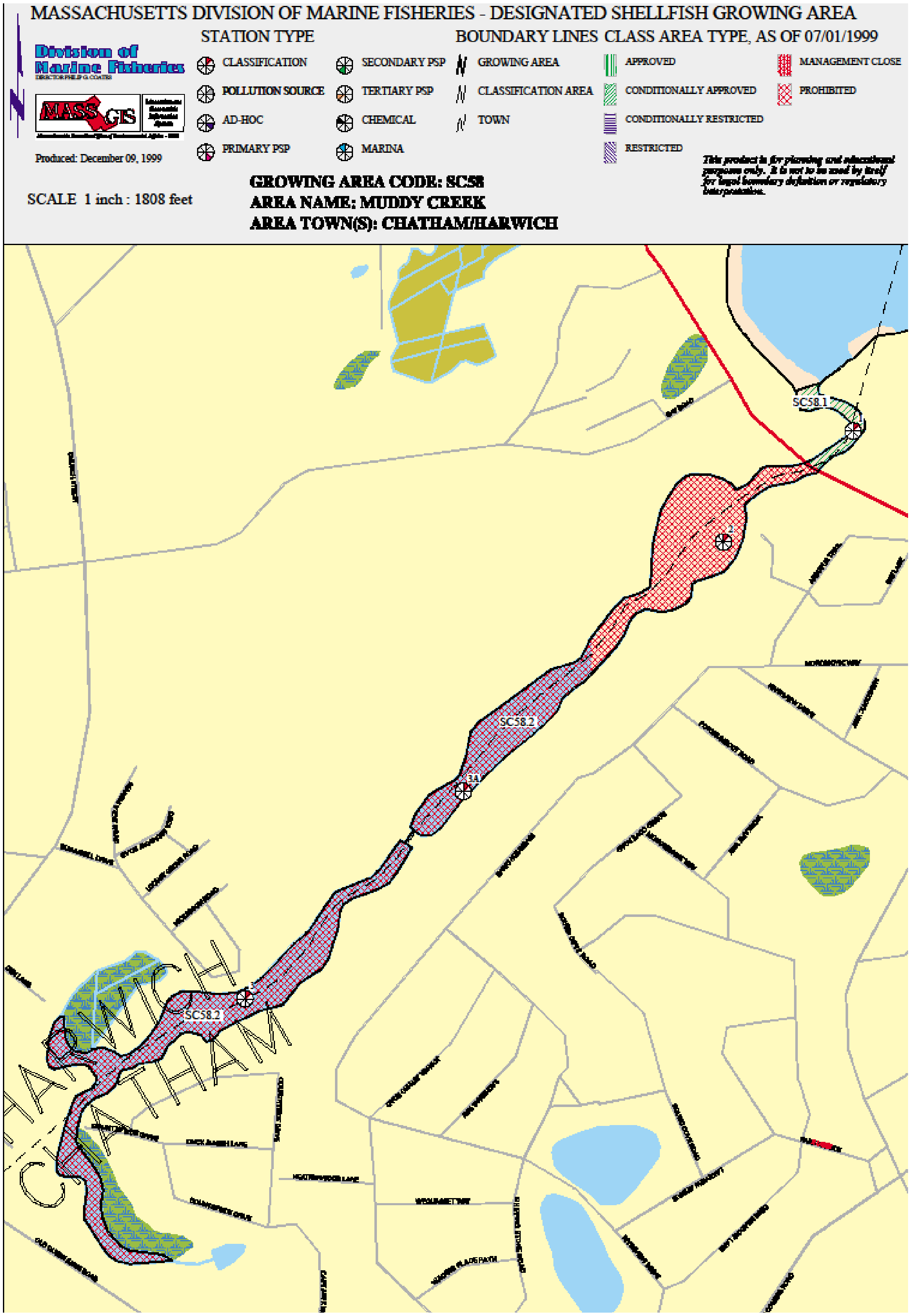


Figure 14 Designated Shellfish Growing Area within Muddy Creek by Mass. DMF. The red hatched area indicates that shellfishing is prohibited here due to poor water quality (i.e. Coliform bacteria levels exceed state water quality standards). Purple hatched areas indicate management closure by DMF.

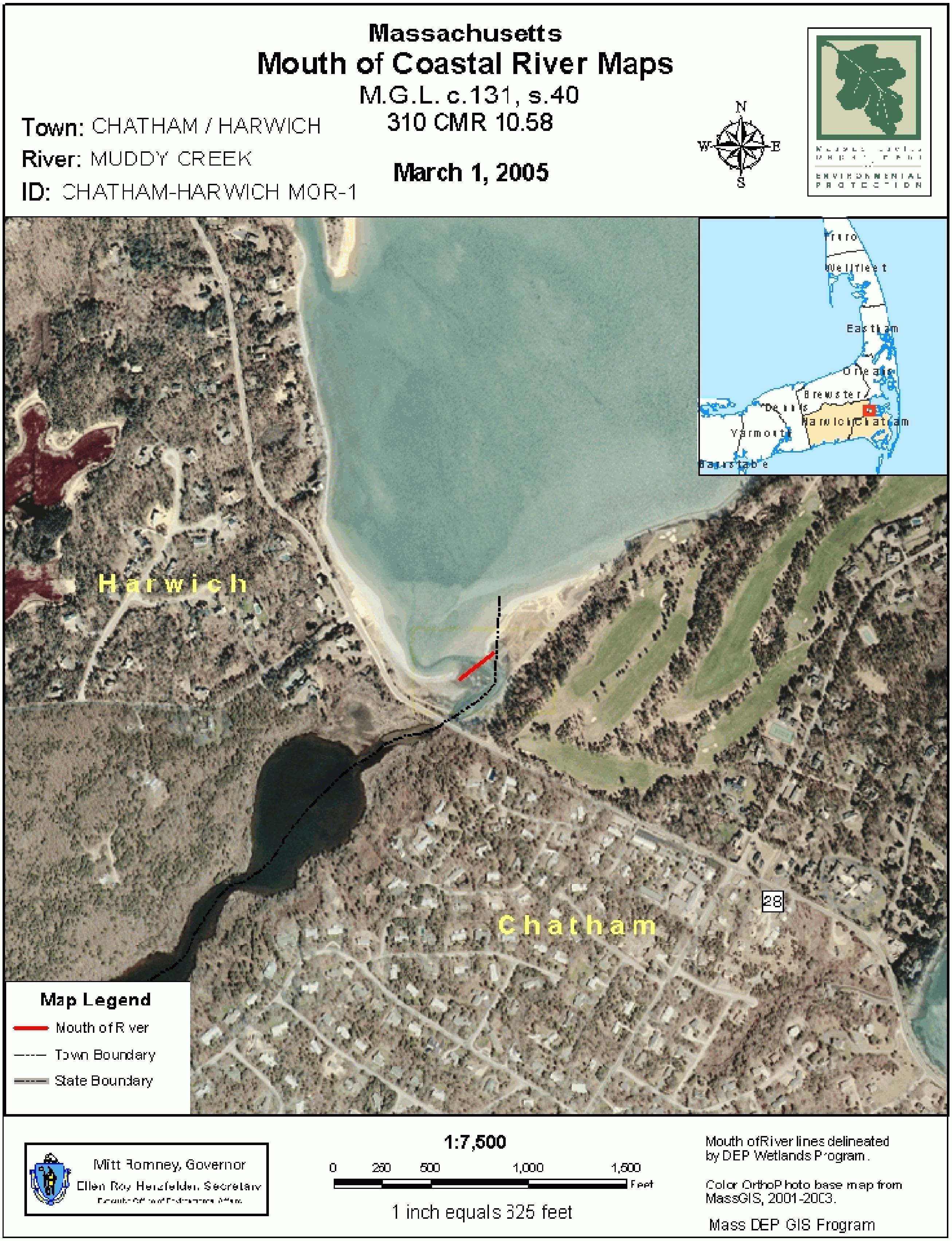


Figure 15 Mouth of a coastal river as designated by MassDEP under the Massachusetts Rivers Act. The Red Bar represents the furthest extent of the coastal river (drown river valley estuary), the performance standards of the Act apply to the river reach inland of the mouth.

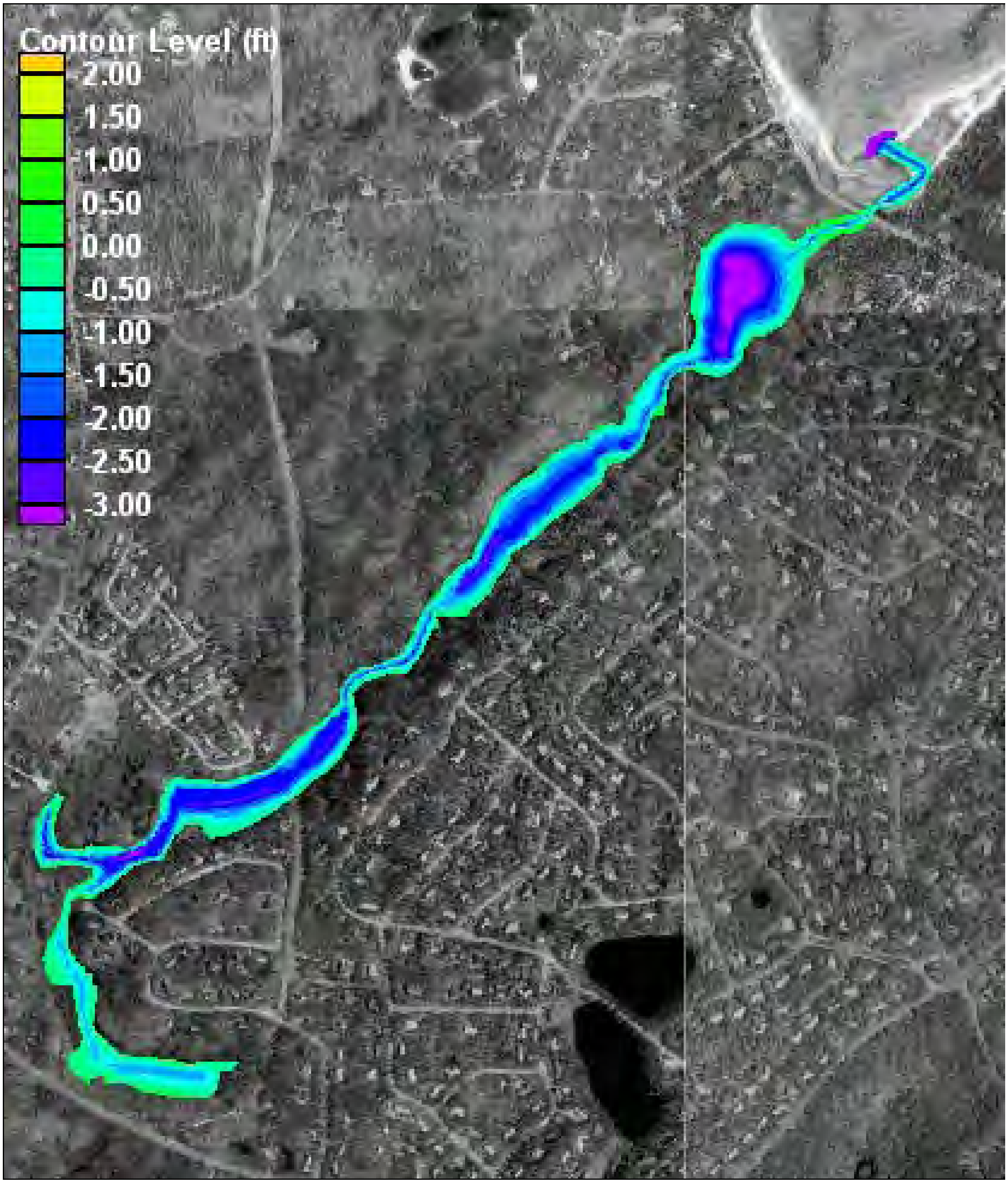


Figure 16 Bathymetric map of Muddy Creek. Land Under the Ocean includes all land at a depth greater than Mean Low Water (MLW) which is +1.8 ft NGVD. Data from SMAST/DEP Massachusetts Estuaries Project (2003).

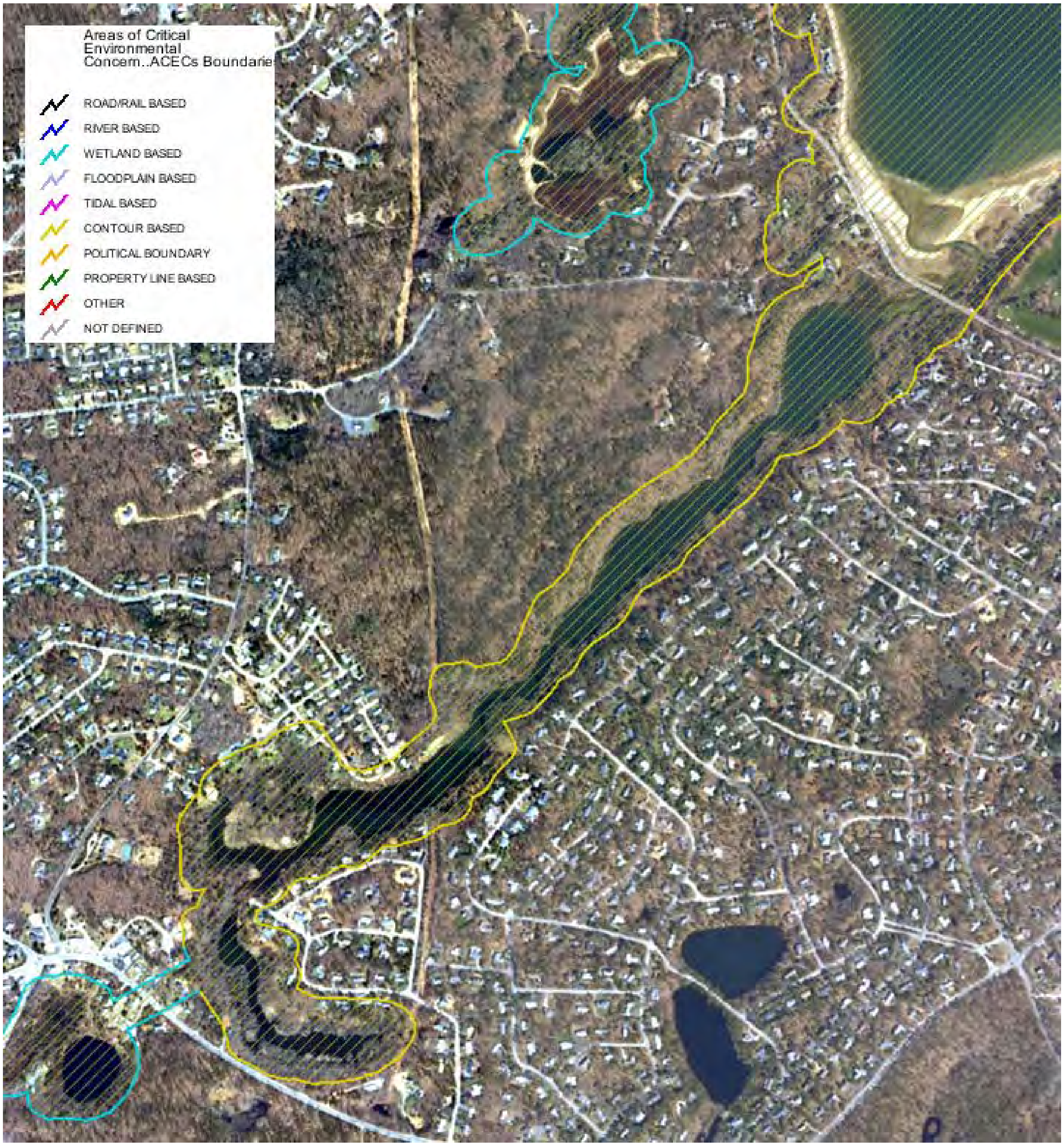


Figure 17 Area of Critical Environmental Concern from MassGIS, areas designated by Mass. DEP.

2.0 Anticipated Wetland Response and Rate of Change

Wetland plant communities tend to respond rapidly to changes in flooding duration and frequency or shifts in porewater salinity. Salt marsh zonation has been found to respond rapidly to changes in tidal hydrodynamics following storms or inlet reconfigurations. Initial shifts from fresh and brackish plant communities to salt marsh plants can frequently be seen within a year or two when tidal restrictions are removed in salt marsh restoration projects on Cape Cod. Freshwater communities began to shift in the first 2 growing seasons in such recent projects as Bridge Creek (Sandwich) or Bridge Street (Dennis), although colonization of the marsh plain by salt marsh plants can take several years. In contrast, shifts from salt marsh to brackish/fresh marsh take much longer. This asymmetrical response results from the fact that many salt marsh plants grow equally well in fresh versus salt water and the conversion to fresh/brackish marsh results from plant competitive interactions, rather than physiological response. In contrast, the shift from fresh/brackish to salt marsh plant communities is typically driven by physiology (water stress) induced by flooding with salt water, more than plant interactions.

Within the lower basin of Muddy Creek the total wetland area is expected to expand slightly if the water control structure is reinstalled in the dike. The smaller volume of the salt water basins will cause greater flushing and a larger tide range, with MHW increasing ~0.2 ft and MLW decreasing ~0.2 ft (see Section 3.0). The result will be a slight expansion, on the order of the change in MHW and MLW, of the existing salt marsh plant distribution. Conversely, there will be a retreat inland of the freshwater/saltwater plant border.

It is anticipated that the expansion of the salt marsh community in the lower basin will be rapid, moving to near completion within 5 years. These expansion areas refer to those areas which presently have salt marsh plants that can expand their coverage seaward and shoreward with the enhanced tidal range. The rare areas that presently do not have salt marsh plants (i.e. are not intertidal) that will become intertidal post-construction, are still expected to be colonized within 10 years, if not much sooner. It should be noted that we have not identified any of these latter sites in the present surveys, as the increased tide height is very small (2.4 inches) relative to the vertical scale of the topography data (Figure 18).

The ability of the salt marsh plants to move shoreward is supported by the already existing moderate salinity levels in the brackish marsh areas (Section 1.2). As salt water is already impinging on these wetland types, increased flooding should rapidly move the salinity of their rooting zones above their capacity to grow (ca. 15-20 ppt).

The major changes in the upper basin will be to lower the salinity of the basin waters to the point where freshwater wetland plants will dominate and raise the water level by 0.8 feet above present tidal high water, if the weir is set at 2.6 ft NAVD (3.5 ft NGVD). Note that this present high water is the highest flood tide that is astronomically driven. It was beyond the scope of the present effort to determine storm tides and how installing a water control structure in the dike might alter storm flood levels in the upper an lower basins. This anticipated rise in the water level of 0.8 ft is a maximum and could potentially be a little as 0 ft, depending on the type of WCS installed.

If the WCS that is installed at the Dike is designed to increase the water level in the upper basin by 0.8 ft, the wetland response will be to lose the small patches of salt marsh plants that currently exist and to reduce the distribution of brackish marsh plants. Post-construction salinities of upper basin waters should be either fresh or in the 1-4 ppt range, depending upon how the Towns and their citizens choose to approach hydrologic management of this system. In all cases, wetland areas in the upper basin that presently have rooting zone salinities $\leq$ 1 ppt are dominated by a mixed freshwater wetland assemblage. This assemblage does not include invasive plants or *Phragmites*. It is anticipated that the bulk of the freshwater marsh areas will remain in their present location because these are currently above the tidal reach. However, there will be some expansion inland. Areas of likely expansion can be seen in Figure 19, with the 4 ft NAVD contour being well above the basin water level (2.6 ft NAVD) and the 2 ft NAVD contour being slightly below. Checking the point elevation data supplied by the land-survey, most of the area between the 2 ft and 4 ft contours shown in Figure 19, are in the 3-3.5 ft NAVD range, or above the anticipated rise in basin level. Based upon these data it appears that the 2 ft contour provides a fairly good approximation of the new wetland coverage, with the understanding that it is a slight underestimate. Note that the 6 ft contour in Figure 19 is very close horizontally to the 4 ft contour, thus re-enforcing the prediction that the vertical rise in the basin level will not result in any further horizontal encroachment beyond the 4 ft contour. Refining the future aerial wetland coverage will require a re-contouring of the survey data.

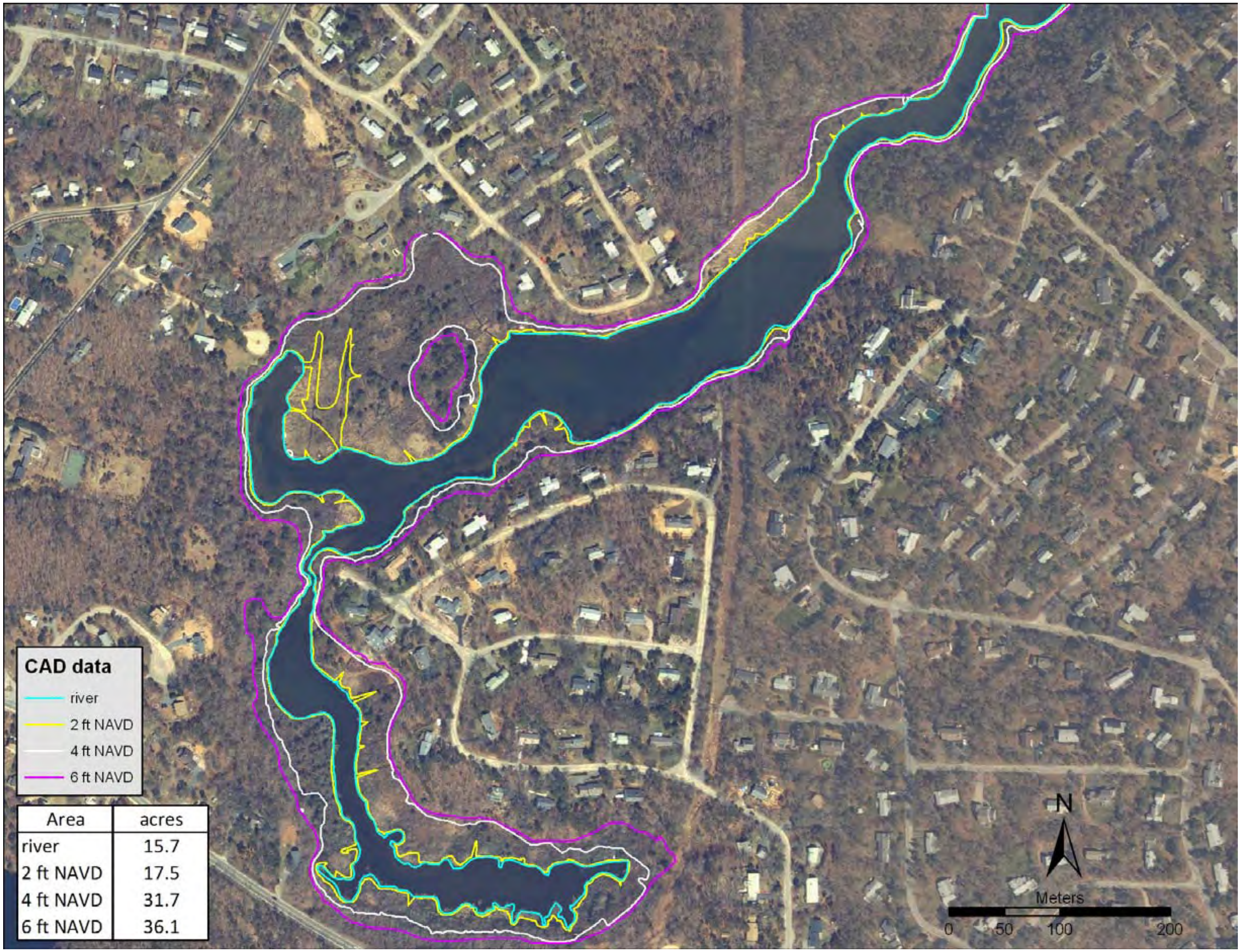


Figure 18. Elevation map of the watershed adjacent to upper Muddy Creek

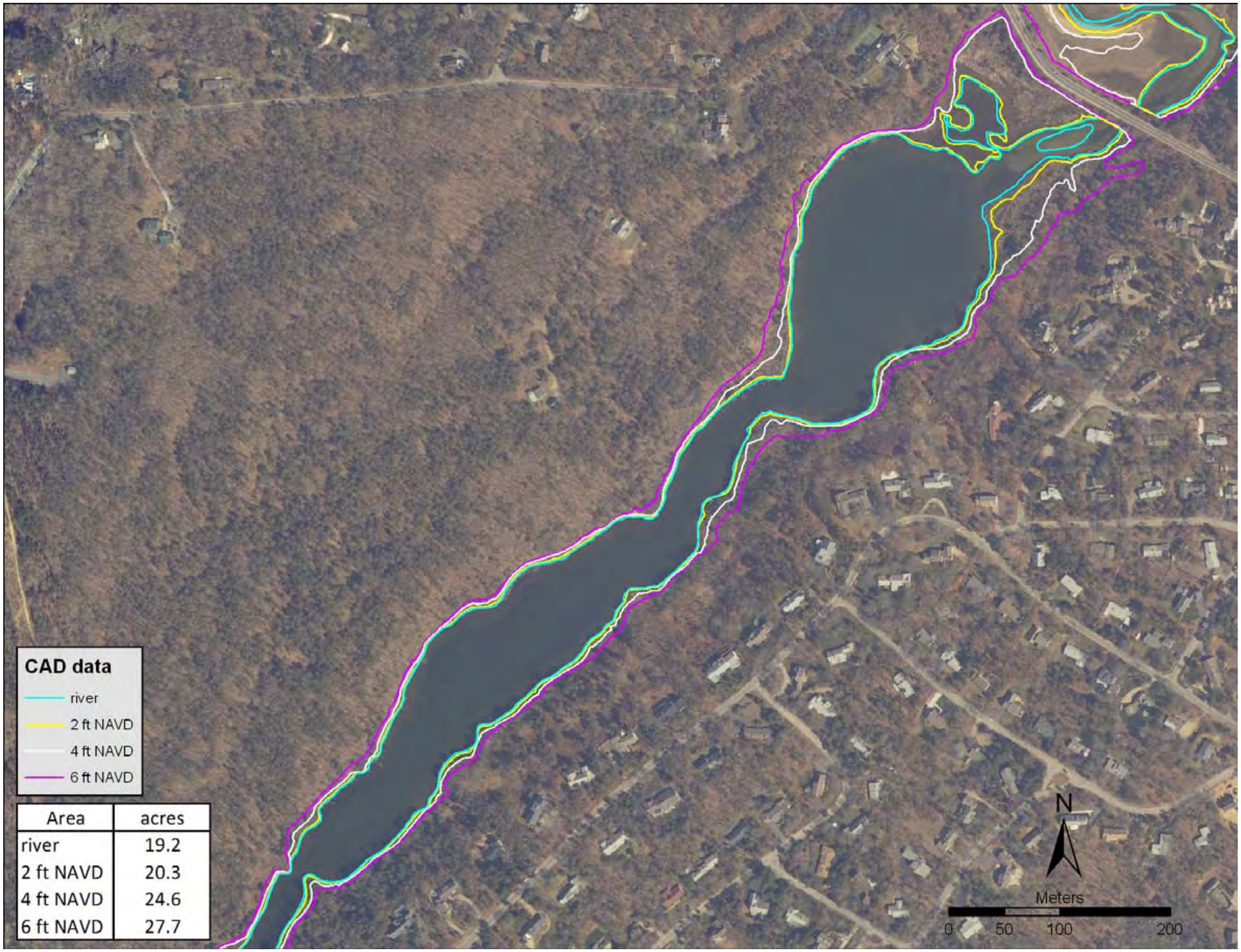


Figure 19. Elevation map of the watershed adjacent to lower Muddy Creek. Note that there are no apparent structures within the 4 ft or 6 ft contours in either basin, which is well above the anticipated water level post construction (2.6 ft NAVD).

3.0 Anticipated Changes to Estuarine Hydrology and Water Quality

In early 2008, an updated hydrodynamic analysis of the Pleasant Bay estuary was performed to determine the present state of the system since the formation of the north beach breach during the April 2007 Patriot's Day northeast storm. Geomorphic conditions that were represented by this updated modeling effort were based on information collected in 2007 (by both the U.S. Army Corps of Engineers and Applied Coastal). For the post-breach analysis, Applied Coastal relied on data assembled from a variety of sources. LIDAR bathymetry and topography data from the New England District of the U.S. Army Corps of Engineers (USACE) were made available from two separate surveys flown in April and October 2007. Tide data from established gauge stations at the Chatham Fish Pier (station T2 indicated in Figure 20, maintained by the Town of Chatham Department of Health and Environment) and Meetinghouse Pond (station T3 in Figure 20, maintained by the Provincetown Center for Coastal Studies) were also made available. To supplement available data from other sources, additional tide and Acoustic Doppler Current Profiler (ADCP) data were collected as part of this study. Tide data were collected in November 2007 at a station located offshore Nauset Beach (T1 in Figure 20), between the two inlets. An ADCP survey of currents was conducted on November 14, 2007. The ADCP survey was designed to measure the flow through each inlet during a single tide cycle. Two cross-channel transects (A1 and A2 shown in Figure 20) were followed during the course of the survey.

Following development of a calibrated Pleasant Bay hydrodynamic model that included the new north inlet, the water quality model also was updated to simulate N concentrations in the system to estimate the effect of the new breach on water quality. The dispersion coefficients determined in the calibration of the 2006 Massachusetts Estuary Project (MEP) report (Howes, *et al*., 2006) were used for the updated post-breach model and scenarios simulations. As with the MEP analysis, the bioactive component of TN (DIN+PON) was modeled for all the scenarios in this analysis.

As part of the original MEP analysis, modifications to the Muddy Creek system were presented as a possible nitrogen mitigation measure that would reduce potential future sewering requirements in Chatham and Harwich. To preserve the salt marsh and softshell clam resources in the lower portion of Muddy Creek and improve tidal flushing characteristics without altering the culvert configuration, a re-establishment of the dike approximately ½ mile upstream from the roadway embankment was proposed (see Figure 21). The region upstream of the dike would be maintained as a freshwater pond, again with a weir that only allowed unidirectional flow from the upper portion of Muddy Creek to the lower estuarine portion. Since the poor tidal exchange through the existing culverts is caused by the small cross-sectional area of the culverts relative to the surface area of Muddy Creek estuary, reducing the estuarine surface area would improve tidal flushing characteristics of the seaward portion. The hydrodynamic and water quality models were utilized to quantify alterations to the estuarine system, based on updated hydrodynamic and water quality information.

The hydrodynamic model was utilized to predict changes in water elevations and the tide range within the lower portion of Muddy Creek as a result of installing the dike to effectively bifurcate the system. Table 16 shows the change in tidal datums associated with the modification; however, storm conditions were not evaluated in the analysis. Therefore, the results reflect maximum and minimum tide levels are typical for the fluctuations of the astronomical tide, and do not represent any sort of storm event (e.g. during major northeast or tropical storm events).

Following development of the updated hydrodynamic model, the Pleasant Bay bioactive nitrogen model was run using the recently updated Muddy Creek fluxes, and all other N loads per the Pleasant Bay MEP report (Howes, *et al*., 2006). For the model run to simulate water quality conditions after reinstalling the water control structure within the existing dike, a nitrogen attenuation value was derived for the resulting conditions in the upper basin. Nitrogen attenuation above the dike consists of nitrogen uptake by sub-tidal sediments and removal by wetland sediments, primarily in the uppermost region of this basin. There are 2 approaches to estimating a future change in nitrogen attenuation: (1) Based upon the measured nitrogen efflux through the dike on the 2 tidal studies (mean= 4.7 kg/d, see Table 8) and the MEP watershed loading (10.6 kg/d, see Table 8), the total present attenuation is -5.9 kg/d (by difference, Table 15). The measured sediment uptake above the existing dike was measured in July 2008 to be -1.7 kgN/d, based upon the core incubations and the area of the basin (Table 15). Therefore, a potential estimate of the present summer wetland (and other related sources) attenuation would be -4.2 kgN/d, calculated by difference (Table 15). As this value is not anticipated to change with the re-installation of a water control structure (WCS) at the dike, our projection of the future attenuation used the -4.2 kgN/d value for wetlands. The N attenuation value for the post-WCS re-installation was derived from the measured sediment-watercolumn N exchange measurements from the uppermost region, which supported very low salinities. The measured exchange rate for the uppermost section was distributed throughout the entire basin above the dike, as the product of the N flux (-78 mg N/m^2/day and the area of the upper section (63,536 m^2), or -4.9kgN/d. The resulting total N attenuation from the upper basin would then become -9.1 kgN/d, (-4.2 kgN/d from wetlands and -4.9 kgN/d from sediment uptake, Table 15) which represents an additional attenuation of approximately 30%. (2) A more conservative approach is to use only the increased attenuation in the sediments which would result from the installation of a WCS. The present measured attenuation in the upper basin sediments is -1.7 kg N/day (Table 15). With the WCS in place we estimate that the attenuation would increase to -4.9 kg N/day (Table 15), an increase of 30%. Because of increased attenuation in the upper basin, system-wide attenuation will increase. The WCS will probably not have a significant impact on sediment attenuation in the lower basin (there was a net release of N out of the sediments, see Table 12) but it will cause increased tidal flushing to Pleasant Bay and will improve water quality as a result (see discussion on page 44).

Table 15. Existing and predicted attenuation in the Upper Basin of Muddy Creek after installation of a WCS

Upper Basin Areas	Updated Area m2	Existing Benthic Uptake mg/m2/d	Existing Attenuation kg/d	Predicted Benthic Uptake mg/m2/d	Predicted Attenuation kg/d
Wetlands	--	--	-4.2	--	-4.2
Fresh-Brackish	15,783	-78.0	-1.2	-78.0	-1.2
Brackish	47,753	-11.5	-0.5	-78.0	-3.7
Total	63,536	--	-5.9	--	-9.1
% Attenuation*			56%		86%

* Based on a watershed loading of 10.6 kgN/d

The MEP water quality model with post-breach adjustments (Kelley and Ramsey 2008) was used to estimate the potential change in bioactive nitrogen in the lower basin of Muddy Creek with a WCS re-installed in the dike. The modeling results are approximate, as the model has not been updated with new sediment regeneration rates or re-calibrated with the lower watercolumn nitrogen concentrations resulting from the 2007 breach. The results of the bio-active N models of Pleasant Bay show that tidally averaged bioactive nitrogen concentrations would decrease 11.6% over background (0.094 mg/L) bioactive nitrogen concentrations. These changes are comparable to those computed in the original scenario run of the dike in the Chatham MEP report.

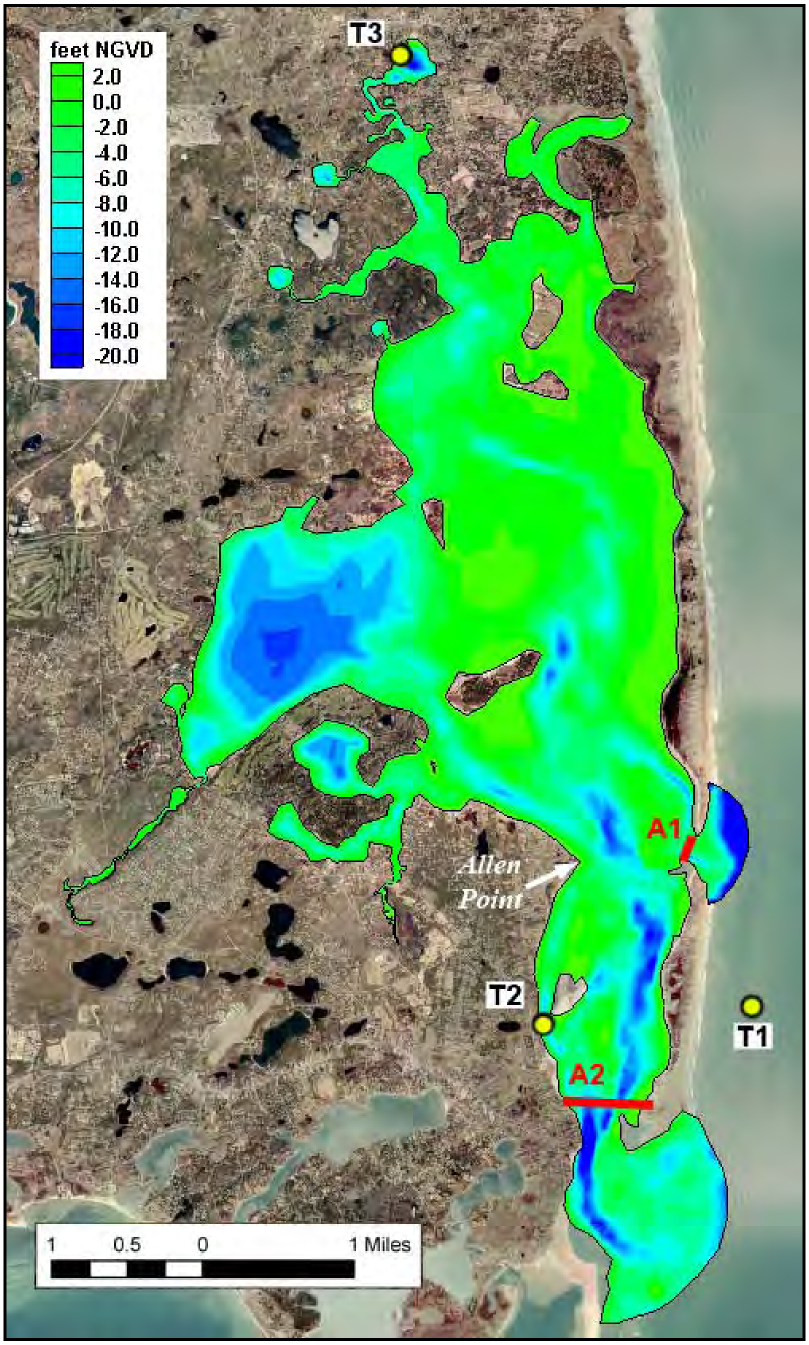


Figure 20. Plot of Pleasant Bay bathymetry, with tide stations (T1 through T3) and ADCP survey transects (A1 and A2).

Table 16. Tidal datums in lower Muddy Creek for the existing 2007 hydrodynamic conditions and potential future conditions after the water control structure is installed in the existing dike.

	Muddy Creek Lower Basin	
	Existing October 2007 (ft, NAVD)	**With Water Control Structure (ft, NAVD)**
Maximum	**1.81**	**2.24**
MHW	**1.38**	**1.58**
MTL	**1.13**	**1.12**
MLW	**0.88**	**0.65**
Minimum	**0.63**	**0.40**
Average Range	***0.50***	***0.93***
Maximum Range	***1.18***	***1.84***

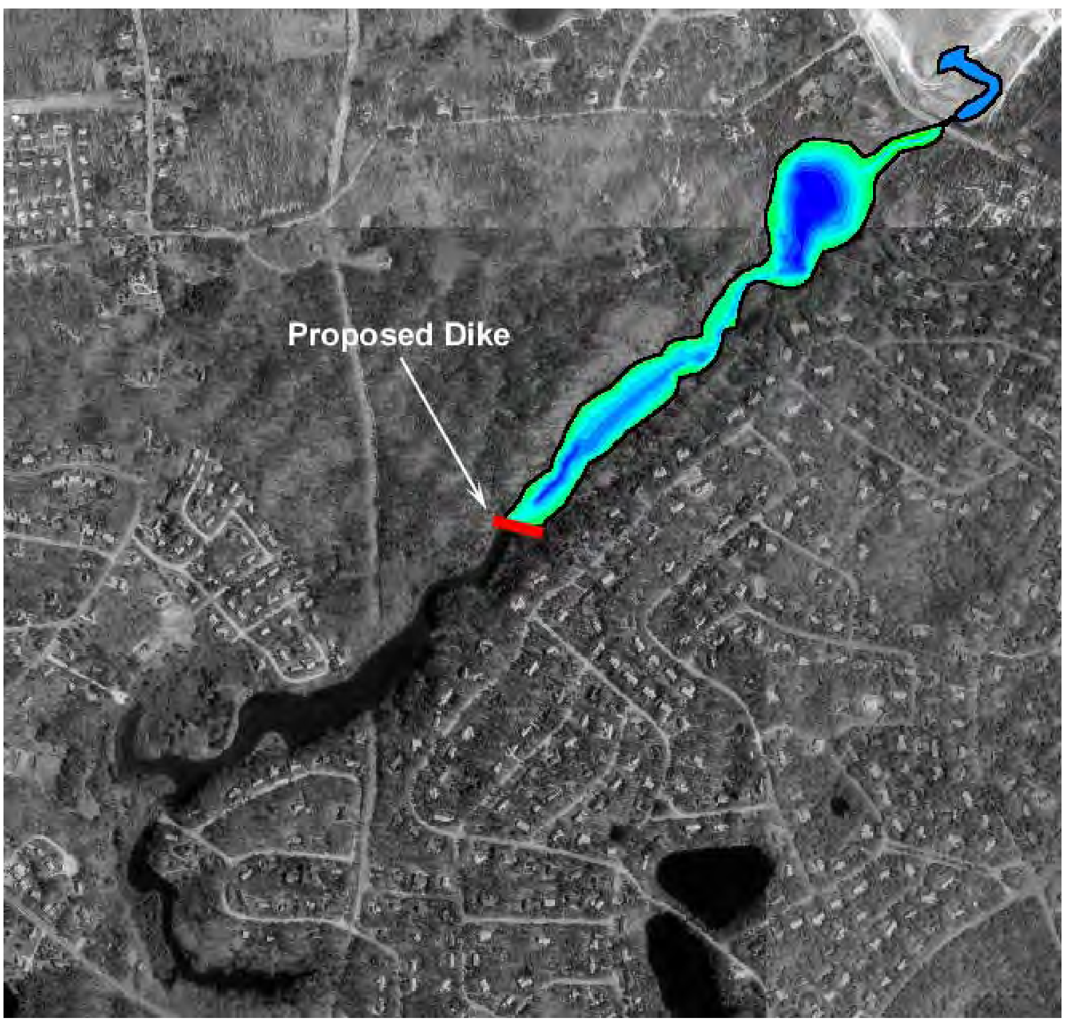


Figure 21. Muddy Creek illustrating the approximate position of the dike separating the upper and lower basins. The dike location was selected based on the location of a historical structure that previously had been established to hydraulically bifurcate the system.

4.0 Anticipated Impacts to Private Property and Upland Resources

Based upon the hydrodynamic analysis in Section 3 and the aerial and topographic survey data presented in Section 2, it appears that all man-made structures (homes, sheds, roads) associated with the upper Muddy Creek basin are well above the 2.6 ft NAVD maximum potential water elevation anticipated from reinstallation of a water control structure in the Muddy Creek dike (Figure 19). Similarly, the even smaller maximum increase in tidal elevation anticipated for the lower basin and the topography, does not indicate any flooding of hard structures adjacent the lower Muddy Creek basin (Figure 18). It should be noted that these conclusions are based upon a water control structure set at 2.6 ft NAVD, the 2005 MassGIS aerial survey data, the 2008 land-survey data, and the hydrodynamic modeling results. As stated above in Section 2, the fact that the 6 ft vertical contour in both Figures is very close horizontally to the 4 ft contour supports the prediction that the maximum water level rise anticipated by the installation of the WCS will not result in any horizontal encroachment beyond the 4 ft. contour but rather will be confined to the 3.0-3.5 ft NAVD range, well within the 4 ft countour. Modeling of storms effects was not part of the present study.

5.0 Post-Construction Monitoring Plan

It is important to monitor the response of the Muddy Creek System should the water control structure be reinstalled in the dike at mid-estuary. Monitoring will support both "adaptive management" of the system, where it may be necessary to refine the water level in the upper basin over the first few years of emplacement. In addition, confirming the attenuation of nitrogen within the upper basin will aid the Towns in meeting the MassDEP TMDL for this system and water quality measurements are needed to confirm compliance.

To meet the monitoring needs we have developed a 5 year comprehensive monitoring plan to quantify changes to the wetland and estuarine resources on each side of the proposed dike after it is installed. While the components of the plan are relatively straightforward, the specific intensity of sampling to be undertaken requires discussion with the Towns. Generally, Monitoring Plans account for the rate of temporal change in each key parameter. Water Quality parameters tend to change rapidly and require frequent sampling (several times per year). In contrast, animal and plant communities change more slowly and predictably, generally requiring only periodic detailed analysis, for example at 3 and 5 years after construction. However, it should be noted that plant communities should receive low-level surveys during the growing season in the initial 2 years to ensure that the level of the weir in the dike is maintaining proper water levels in the upper basin relative to the elevation of plant areas (Table 17). To the extent possible, the monitoring program should incorporate previous monitoring stations and data from the Town of Chatham, Pleasant Bay Alliance and Massachusetts Estuaries Project studies previously conducted in Muddy Creek.

Wetlands: We will use the permanent transects established for the wetlands vegetation map to monitor annual vegetation changes on both sides of the dike after installation. In the first 2 years after Dike installation, we will monitor the permanent vegetation transects established in both Upper and Lower Muddy Creek to track any short-term changes in vegetation. In years 3 and 5 post-installation, using the same methods for creating the current vegetation map showing existing conditions, we will create updated vegetation maps to track changes to all the major vegetation types due to changes in water levels and salinity above and below the dike. These maps will be compared to the current vegetation map for comparison to the baseline data gathered in 2008.

Wetland Sediments: We will monitor annual pore water salinity changes in the permanent plots above and below the dike to monitor salinity in the sediments as the tidal regime changes for 5 years after dike installation. Pore water samples will be taken at depths of 0-5, 5-10 and 10-15 cm. Each sample will be analyzed for salinity. These data will indicate the point at which the sediments have “freshened” sufficiently to be able to support freshwater wetland plants (as opposed to brackish and salt marsh species). These measurements are very low cost, but help to determine if expansion of freshwater marsh is proceeding as it should.

Water Quality and Nitrogen Attenuation: Water quality monitoring should continue as part of the on-going Chatham program. The placement of sampling stations and the frequency of sampling will be linked to on-going efforts, as appropriate. During years 1, 3 and 5 post-installation, we will conduct tidal cycle studies (2/yr) at the dike and at the system’s tidal inlet to quantify the amount of nitrogen attenuation achieved in the upper and lower basins presently and post-construction. This effort will include sub-tidal sediment core incubations as described in Sub Task 1 to measure nutrient flux to the water column and denitrification, both important components in quantifying nitrogen attenuation. This assessment relates directly to the mission of reconstruction of the weir and targets outlined in the Muddy Creek TMDL.

Benthic Infauna: Benthic infauna samples will be taken in the upper and lower basins (as divided by the dike) in years 3 and 5 after construction. The locations will be the same as for the pre-construction study. These measurements will quantify the positive changes in the abundance and diversity in the benthic community after construction of the weir in the dike. This information relates directly to the restoration goal for the Muddy Creek system of "restoring benthic infauna habitat". The approach is that the dike will result in improved fresh water habitat in the upper basin, with an increase in nitrogen attenuation. As a result of the increased nitrogen attenuation and increases in flushing of the lower basin, benthic animal habitat will also be improved. It is critical that the sampling program document the level of improvement relative to the restoration target of the TMDL.

Table 17. Five Year Monitoring Plan for Muddy Creek Post- Installation of Dike

Year	Wetlands	Wetland Sediments	Water Quality and Nitrogen Attenuation			Benthic Infauna
			Water Quality	Tidal Flux	Benthic Flux	
1	Monitor Transects	Pore Water Salinity	Sampling	2	1	NS
2	Monitor Transects	Pore Water Salinity	Sampling	NS[a]	NS	NS
3	Wetlands Map	Pore Water Salinity	Sampling	2	1	Sampling
4		Pore Water Salinity	Sampling	NS	NS	NS
5	Wetlands Map	Pore Water Salinity	Sampling	2	1	Sampling

[a] Not Sampled (NS)

Appendices

Appendix A

Vegetation Descriptions from Numbered Areas and Transects on GIS Overlay Maps

Vegetation Descriptions of numbered areas on GIS overlay maps

1 Shrub swamp

2 Phragmites 100% dominant

3 Typha 100% dominant

4 Phragmites 100% dominant

5 Spartina 100% dominant

6 Spartina 100% dominant S. alterniflora along seaward edge, mixing with and then transitioning to S. patens toward the upland

7 Typha (100%) in north end mixing with and transitioning to Phragmites (95%) toward south end

8 Shrub swamp

9 Fringing band of Spartina alterniflora (100%) 2-5 meters wide

10 Fringing band of Spartina alterniflora (100%) 2-3 meters wide

11 Fringing band of Typha (100%) 2-3 meters wide

12 Fringing band of Spartina alterniflora (100%) 2-3 meters wide

13 Spartina alterniflora 2-3 meters wide at north end mixing with and transitioning to Typha toward south end. Pure Typha (100%) in back landward of Spartina 2-3m wide.

14 Fringing band of Spartina alterniflora (100%) 2-3 meters wide

15 Fringing band of Spartina alterniflora (100%) approximately 1 meter wide

16 Spartina (100%) 10 meters long x 1 meter wide

17 Spartina (100%) 1x2 meters

18 Fringing small bands of Spartina alterniflora (100%)

19 Spartina (100%) for approximately 10 meters then mixing with Typha (70/30)

20 Spartina (100%) approximately 10 meters long and 2 meters wide

21 Fringing band of Spartina alterniflora (100%) approximately 1 meter wide

22 Two small stands of Spartina alterniflora (100%) approximately 3x3 meters

23 Fringing band of Rushes (Scirpus) (100%) 2-3 meters wide

24 Mix of Rushes and Spartina (80/20) 2-3 meters wide

25 Fringing band of Rushes (Scirpus) (100%) 2-3 meters wide

26 Fringing band of Spartina alterniflora (100%) with mixed Rushes (80/20) at northern end

27 Fringing band of Spartina alterniflora (100%)

28 Spartina alterniflora (100%) with narrow band of Rushes (Scirpus) (100%) approximately 1 meter wide along the landward edge

29 Fringing band of Sedges (100%) approximately 8 meters long and 2 meters wide

30 Fringing band of Spartina alterniflora and Sedges (50/50) approximately 5 meters long and 2 meters wide

31 Fringing band of Spartina alterniflora (100%) approximately 10 meters long and 2 meters wide

32 Fringing band of Spartina alterniflora (100%) approximately 3 meters long and 3 meters wide

33 Fringing band of Spartina alterniflora (100%) approximately 2 meters long and 2 meters wide

34 Fringing band of Spartina alterniflora mixed with Typha (80/20) approximately 2 meters wide

35 Fringing band of Typha (100%) approximately 2 meters wide

36 Fringing band of Spartina alterniflora (100%) approximately 2 – 3 meters wide

37 Fringing band of Spartina alterniflora (100%) approximately 3 meters long and 3 meters wide

38 Fringing band of Spartina alterniflora (100%) approximately 1 – 2 meters wide, mixes with Typha (75/25) last 10 meters at the north end

39 Small stand of Spartina alterniflora (100%) approximately 1 x 1 meter

40 Fringing band of Spartina alterniflora (100%) approximately 2 – 3 meters wide

41 Fringing band of Phragmites (100%) approximately 2 – 3 meters wide

42 Freshwater assemblage of grasses and herbacious plants

43 Fringing band of Spartina alterniflora (100%) approximately 3 – 4 meters wide

44 Fringing band of Spartina alterniflora (100%) approximately 1 – 2 meters wide

45 Fringing band of Spartina alterniflora (100%) approximately 2 – 3 meters wide

46 Small stand of Spartina alterniflora (100%) approximately 1 x 1 meter

47 Fringing band of Phragmites (100%) 2 – 3 meters wide with outer band of Spartina alterniflora (100%) 1 – 2 meters wide

48 Fringing band of Spartina alterniflora (85%) approximately 10 meters long and 3 – 4 meters wide mixed with Rushes (Scirpus) (15%)

49 Stand of Spartina alterniflora (50%) mixed with Sedges (25%) and Rushes (Scirpus) (25%) approximately 15 meters wide and 8-10 meters deep transitioning to shrub swamp

50 Small band of Spartina alterniflora (100%) approximately 3-4 meters long and 1 – 2 meters wide

51 Stand of Spartina alterniflora approximately (100%) approximately 2x2 meters

52 Stand of Sedges (100%) approximately 3x3 meters

53 Mixed stand of Sedges (50%) and Rushes (Scirpus) (50%) approximately 10 meters long and 2 – 3 meters wide

54 Stand of Phragmites (60%) approximately 20 meters long and 4 – 5 meters wide with shrubs (40%)

55 Mixed freshwater assemblage of grasses, herbacious plants and shrubs

56 Corrugated pipe approximately 15 inches diameter with a mix of Spartina alterniflora (50%) and Rushes (Scirpus) (50%) approximately 3 x 3 meters

57 Mix of Spartina alterniflora (30%) and Phragmites (70%) approximately 7 – 8 meters long and 2 – 3 meters wide

58 Band of Phragmites (100%) approximately 4 – 5 meters wide transitioning to a mix of Phragmites (50%) and Spartina alterniflora (50%) at the north end

59 Mix of Spartina alterniflora (30%) and shrubs (70%)

60 Mix of Phragmites (70%) and shrubs (30%)

61 Mix of Sedges (25%) and shrubs (75%)

62 Band of Spartina alterniflora (100%) approximately 10 meters long and 1 meter wide

63 Stand of Spartina alterniflora (100%) approximately 4 meters long and 1 meter wide

64 Band of Spartina alterniflora (100%) approximately 1 – 4 meters wide in front of a large tract of Phragmites (100%)

65 Band of Phragmites (100%) approximately 7 – 8 meters long and 1 meter wide

66 Mix of Phragmites (50%) and shrubs (50%)

67 Mix of Spartina alterniflora (60%) and shrubs (40%)

68 Shrub swamp with Rushes (Scirpus) (20%) mixed in at north end

69 Small stand of Phragmites (100%) approximately 1 x 1 meter

70 Band of Spartina alterniflora (100%) approximately 1 meter wide

71 Band of Spartina alterniflora (100%) approximately 2 – 3 meters wide

72 Narrow band of Spartina alterniflora (100%) approximately 1 meter wide

73 Shrub swamp

74 Shrub swamp

75 Small stand of Spartina alterniflora (100%) approximately 1 x 1 meter

76 Small stand of Spartina alterniflora (100%) approximately 1 x 1 meter

77 Band of Spartina alterniflora (80%) and Sedges (20%) approximately 3 meters long and 1 – 2 meters wide

78 Band of Spartina alterniflora (100%) approximately 1 – 2 meters wide

79 Band of mixed Spartina alterniflora (90%) and Rushes (Scirpus) (10%) approximately 2 – 3 meters wide

80 Shrub swamp

81 Small stand of Spartina alterniflora, (100%) approximately 2 x 2 meters

82 Band of Spartina alterniflora approximately (100%) 1 – 2 meters wide

83 Small stand of Spartina alterniflora (100%) approximately 2 x 2 meters

84 Band of Phragmites approximately (100%) 1 – 5 meters wide

85 Band of Rushes (Scirpus) (100%) approximately 4 – 5 meters wide

86 Band of mixed Spartina alterniflora (40%), Sedges (30%) and Rushes (Scirpus) (30%) approximately 1 – 2 meters wide

87 Small stand of Rushes (Scirpus) (100%) approximately 1 – 2 meters wide

88 Band of mixed Rushes (Scirpus) (30%) and Spartina alterniflora (70%) approximately 1 – 2 meters wide becoming all Spartina at the south end

89 Small band of Spartina alterniflora (100%) approximately 7 – 8 meters long and 3 – 4 meters wide

90 Small stand of Spartina alterniflora approximately 1 x 1 meter

91 Small band of Spartina alterniflora amongst a mix of shrubs and freshwater grasses and herbacious plants

92 Shrub swamp with fringing low lying grasses and herbacious plants

93 Band of Spartina alterniflora (100%) approximately 1 – 3 meters wide

94 Small band of Sedges (100%) approximately 5 meters long and 1 meter wide

95 Shrub swamp with fringing low lying grasses and herbacious plants

96 Upland

97 Stand of pure Phragmites (100%)

98 Shrub swamp

99 Small band of Rushes (Scirpus) mixed with Phragmites at water's edge

100 Band of Rushes (Scirpus) (100%) approximately 2 – 3 meters wide

101 Shrub/tree swamp along shoreline with freshwater grasses and herbacious plants

102 Shrub/tree swamp along shoreline with freshwater grasses and herbacious plants

103 Shrub/tree swamp along shoreline with freshwater grasses and herbacious plants with some Phragmites (10%) mixed in at the east end

104 Stand of pure Phragmites (100%)

105 Band of Sedges and Rushes (Scirpus) approximately 8 – 10 meters long with shrubs and freshwater grasses and herbacious plants

106 Shrub swamp

107 Shrub swamp

108 Shrub swamp

109 Small mixed band of Rushes and Phragmites transitioning to all Phragmites at east end

110 Fringing mixed band of Rushes and Typha with shrub swamp

111 Fringing band of Rushes along water's edge in front of large stand of Typha (90%) with small number of shrubs (10%)

112 Fringing band of Rushes approximately 2 – 3 meters wide

112A Fringing band of Rushes approximately 2 – 3 meters wide in front of large band of Typha approximately 2 – 7 meters wide

113 Fringing band of Rushes approximately 2 – 3 meters in front of large band of Typha approximately 2 – 7 meters wide

114 Fringing band of Phragmites approximately 1 – 2 meters wide

115 Fringing mixed band of Rushes (30%) and Phragmites (70%) approximately 2 – 3 meters wide

116 shrub swamp

117 Stand of Rushes (100%) approximately 2 x 2 meters

118 shrub swamp

119 Stand of Typha (100%) approximately 5 meters long and 3 – 4 meters wide

120 Shrub swamp

Vegetation descriptions along Transects on GIS overlay maps

1 shrub line thru Phragmites (100%) stand to edge of Spartina = 12 meters
thru Spartina (100%) to edge of the water = 7 meters

2 shrub line thru Phragmites (100%) stand to edge of Spartina = 14 meters
thru Spartina (100%) to edge of the water = 14 meters

3 shrub line thru Phragmites (100%) stand to edge of Typha = 20 meters
thru Typha (100%) to edge of Spartina = 15 meters
thru Spartina (100%) to edge of water = 5 meters

4 shrub line thru Typha (100%) stand to edge of Spartina = 12 meters
thru Spartina (100%) to edge of water = 14 meters

5 upland border thru shrub swamp to edge of Typha = 7 meters
thru Typha (100%) to edge of Spartina = 5 meters
thru Spartina (100%) to edge of water = 10 meters

6 upland border thru shrub swamp to edge of Typha = 2 meters
thru Typha (100%) to edge of Spartina = 2 meters
thru Spartina to edge of water = 5 meters

7 upland edge thru shrub swamp to edge of shrub/Spartina mix = 2 meters
thru shrub/Spartina mix (30%/70%) to edge of pure Spartina = 2 meters
thru Spartina to edge of water = 4 meters

8 shrub line thru Phragmites (100%) to edge of Spartina = 12 meters
thru Spartina to edge of water = 2 meters

9 edge of water to upland border (shrub swamp) = 2 meters

10 edge of water to upland border (shrub swamp = 2 meters

11 (open path to water) upland border thru shrub swamp and some cattails to edge of Rushes = 23 meters
thru Rushes/cattails transitioning to all Rushes to edge of water = 8 meters

12 (open path to water) upland border thru shrub swamp to edge of Phragmites/shrub mix = 14 meters
thru shrub/Phragmites mix (some cattails) to edge of pure Phrag = 30 meters
thru Phragmites to edge of water = 4 meters

Appendix B
Water Quality Data

Sample ID	Time Point	Time	Tide Stage	QA	Date	Flow Liters/sec	Salinity (ppt)	uM NH4	uM NOx	uM DIN	uM DON	uM POC	uM PON	uM TON	uM TN	Chla (ug/L)	Phaeo (ug/L)
WEIR	T0	10:00 AM	Ebb		6/16/2008	288.42	5.3	3.3	28.03	31.32	26.03	100.85	14.37	40.40	71.72	<0.05	<0.05
WEIR	T1	10:30 AM	Slack Low		6/16/2008	0.00	10.5	2.6	19.84	22.42	24.81	121.96	18.59	43.40	65.82	0.07	<0.05
WEIR	T2	11:30 AM	Flood		6/16/2008	436.00	20.8	0.2	4.79	4.98	30.67	96.50	16.98	47.65	52.63	<0.05	0.09
WER	T3	12:30 PM	Flood		6/16/2008	520.00	19.9	0.6	5.11	5.68	22.16	114.90	20.18	42.34	48.03	0.70	<0.05
WEIR	T4	1:30 PM	Flood	Sample	6/16/2008	642.00	20.8	0.4	7.20	7.60	22.84	94.79	17.35	40.19	47.79	1.55	<0.05
WEIR	T4	1:30 PM	Flood	FD	6/16/2008	NA	20.9	0.4	7.11	7.55	22.32	98.47	17.79	40.11	47.66	0.93	<0.05
WEIR	T5	2:30 PM	Flood		6/16/2008	312.00	15.8	0.2	12.39	12.62	23.90	131.71	23.83	47.73	60.35	0.90	0.13
WEIR	T6	3:30 PM	Slack High		6/16/2008	0.00	9.6	0.1	22.15	22.26	24.67	131.97	23.72	48.39	70.66	1.77	<0.05
WEIR	T7	4:30 PM	Ebb		6/16/2008	384.94	10.8	<0.1	20.47	20.52	24.10	151.16	27.69	51.79	72.31	0.54	0.23
WEIR	T8	5:30 PM	Ebb		6/16/2008	431.30	14.3	1.1	14.59	15.66	37.64	143.91	26.99	64.63	80.29	1.01	<0.05
WEIR	T9	6:30 PM	Ebb		6/16/2008	429.46	14.5	1.4	14.07	15.52	26.50	148.80	25.32	51.83	67.34	0.75	<0.05
WEIR	T10	7:30 PM	Ebb		6/16/2008	402.81	16.3	3.2	11.44	14.69	27.62	159.31	30.12	57.74	72.42	0.68	<0.05
WEIR	T11	8:30 PM	Ebb		6/16/2008	374.63	13.8	1.9	14.49	16.35	24.51	147.81	27.90	52.41	68.76	0.70	<0.05
WEIR	T12	9:30 PM	Slack Low		6/16/2008	0.00	14.7	2.3	11.86	14.19	24.07	168.35	31.09	55.15	69.34	0.30	<0.05
WEIR	T13	10:00 PM	Flood		6/16/2008	573.46	14.6	1.6	12.91	14.49	31.29	142.18	25.60	56.89	71.38	0.30	<0.05
WEIR	T14	10:30 PM	Flood		6/16/2008	548.64	14.6	0.2	12.07	12.23	24.30	151.78	26.38	50.68	62.90	0.12	<0.05

Sample ID	Time Point	Time	Tide Stage	QA	Date	Flow Liters/sec	Salinity (ppt)	uM NH4	uM NOx	uM DIN	uM DON	uM POC	uM PON	uM TON	uM TN	Chla (ug/L)	Phaeo (ug/L)
CULVERT	T0	8:48 AM	Ebb		6/16/2008	1,141.14	16.2	1.8	6.55	8.38	24.10	65.69	11.53	35.63	44.00	<0.05	<0.05
CULVERT	T1	10:10 AM	Slack Low		6/16/2008	0.00	15.4	2.7	7.43	10.09	24.11	81.36	14.27	38.38	48.47	<0.05	<0.05
CULVERT	T2	11:10 AM	Flood		6/16/2008	1,627.09	30.2	1.4	0.23	1.67	26.17	86.66	16.03	42.20	43.88	<0.05	0.06
CULVERT	T3	12:49 PM	Flood		6/16/2008	1,365.49	30.2	1.3	0.26	1.58	23.86	76.11	13.44	37.30	38.88	<0.05	<0.05
CULVERT	T4	2:10 PM	Slack High		6/16/2008	0.00	30.2	2.2	0.22	2.46	21.59	74.01	13.64	35.23	37.69	0.20	<0.05
CULVERT	T5	3:17 PM	Ebb	Sample	6/16/2008	1,336.03	18.7	<0.1	0.31	0.36	23.98	137.70	21.70	45.68	46.04	0.19	<0.05
CULVERT	T5	3:17 PM	Ebb	FD	6/16/2008	NA	18.6	<0.1	0.25	0.30	24.13	136.12	21.66	45.78	46.09	0.12	<0.05
CULVERT	T6	4:15 PM	Ebb		6/16/2008	1,380.84	17.0	0.2	0.37	0.52	23.14	142.10	20.42	43.56	44.08	0.16	<0.05
CULVERT	T7	5:30 PM	Ebb		6/16/2008	1,308.18	17.2	1.0	1.15	2.14	21.45	129.93	20.35	41.80	43.94	0.09	<0.05
CULVERT	T8	6:30 PM	Ebb		6/16/2008	1,251.49	17.1	1.6	3.21	4.83	23.30	114.90	21.49	44.79	49.62	0.52	0.22
CULVERT	T9	7:34 PM	Ebb		6/16/2008	1,130.58	17.3	1.2	2.69	3.93	20.88	110.28	20.71	41.59	45.52	1.59	<0.05
CULVERT	T10	9:08 PM	Slack Low		6/16/2008	0.00	17.1	2.4	3.85	6.22	23.94	94.51	18.63	42.57	48.79	0.54	<0.05
CULVERT	T11	9:45 PM	Flood	Sample	6/16/2008	828.04	17.4	4.3	3.43	7.77	23.84	77.26	14.68	38.52	46.29	0.17	<0.05
CULVERT	T11	9:45 PM	Flood	FD	6/16/2008	NA	17.4	4.4	3.44	7.86	23.73	77.81	14.76	38.48	46.34	0.11	0.10

Sample ID	Time Point	Time	Tide Stage	QA	Date	Flow Liters/sec	Salinity (ppt)	uM NH4	uM NOx	uM DIN	uM DON	uM POC	uM PON	uM TON	uM TN	Chla (ug/L)	Phaeo (ug/L)
WIER	T0	9:00 AM	Ebb		7/16/2008	591.00	19.6	1.0	1.52	2.49	36.04	134.05	26.67	62.70	65.19	18.03	0.78
WIER	T1	10:00 AM	Ebb		7/16/2008	551.00	17.5	2.1	2.52	4.58	38.62	521.97	85.46	124.07	128.65	84.83	14.54
WIER	T2	11:00 AM	Slack Low		7/16/2008	0.00	14.3	2.7	4.23	6.92	40.94	132.11	24.72	65.66	72.59	20.49	3.49
WIER	T3	12:00 PM	Flood		7/16/2008	380.00	14.6	0.6	2.08	2.63	39.98	167.07	31.53	71.51	74.14	25.37	6.10
WIER	T4	1:00 PM	Flood		7/16/2008	515.00	16.5	<0.1	<0.05	<0.10	37.31	171.93	30.87	68.17	68.22	22.01	2.49
WIER	T5	2:00 PM	Flood		7/16/2008	335.00	18.1	<0.1	<0.05	<0.10	28.18	159.19	27.60	55.77	55.82	21.93	3.01
WIER	T6	3:00 PM	Slack High	Sample	7/16/2008	0.00	18.8	4.8	0.45	5.25	40.28	218.66	41.92	82.20	87.45	30.95	7.02
WIER	T6	3:00 PM	Slack High	FD	7/16/2008	NA	18.7	5.0	0.36	5.36	32.19	219.26	41.33	73.53	78.89	20.37	0.47
WIER	T7	4:00 PM	Ebb		7/16/2008	543.00	19.0	2.2	0.17	2.41	38.29	190.10	33.33	71.61	74.02	30.09	2.39
WIER	T8	5:00 PM	Ebb		7/16/2008	467.00	18.4	0.6	0.27	0.91	28.07	211.75	37.66	65.73	66.65	27.73	2.31
WIER	T9	6:00 PM	Ebb		7/16/2008	383.00	16.9	0.6	0.34	0.93	37.01	238.22	42.33	79.34	80.27	27.20	1.45
WIER	T10	7:00 PM	Ebb		7/16/2008	359.00	15.4	1.1	1.21	2.35	40.84	261.78	42.92	83.76	86.12	30.86	3.16
WIER	T11	8:00 PM	Ebb		7/16/2008	317.00	11.2	0.5	9.24	9.70	31.01	300.79	50.59	81.61	91.31	34.33	12.97
WIER	T12	9:00 PM	Ebb		7/16/2008	261.00	15.9	5.1	7.03	12.10	42.19	322.47	59.31	101.50	113.60	36.37	3.83
WIER	T13	10:00 PM	Slack Low		7/16/2008	0.00	17.0	2.8	4.50	7.28	41.75	308.49	55.85	97.60	104.88	27.82	10.63
WIER	T14	10:30 PM	Flood		7/16/2008	456.00	16.8	1.6	5.46	7.11	39.59	245.23	45.92	85.51	92.62	28.41	2.63

Sample ID	Time Point	Time	Tide Stage	QA	Date	Flow Liters/sec	Salinity (ppt)	uM NH4	uM NOx	uM DIN	uM DON	uM POC	uM PON	uM TON	uM TN	Chla (ug/L)	Phaeo (ug/L)
CULVERT	T0	7:45 AM	Ebb		7/16/2008	1,314.78	26.5	3.6	0.77	4.38	36.32	64.90	11.30	47.62	51.99	4.25	4.50
CULVERT	T1	10:40 AM	Slack Low		7/16/2008	0.00	27.7	4.3	0.34	4.69	43.33	56.55	9.21	52.54	57.23	6.07	2.57
CULVERT	T2	11:54 AM	Flood		7/16/2008	1,659.40	27.5	3.9	1.21	5.09	43.36	67.87	12.63	55.99	61.08	5.05	5.16
CULVERT	T3	1:01 PM	Flood		7/16/2008	1,684.70	28.5	0.2	0.24	0.42	30.80	72.22	12.33	43.13	43.55	8.63	4.52
CULVERT	T4	2:08 PM	Flood		7/16/2008	448.95	29.6	1.3	0.27	1.59	33.72	46.65	7.84	41.56	43.15	5.51	1.74
CULVERT	T5	2:30 PM	Slack High		7/16/2008	0.00	29.8	2.1	0.29	2.44	39.59	48.57	7.59	47.18	49.62	4.51	2.41
CULVERT	T6	3:30 PM	Ebb		7/16/2008	1,571.00	28.8	3.6	0.45	4.07	25.95	53.11	8.75	34.71	38.77	7.08	3.53
CULVERT	T7	4:30 PM	Ebb		7/16/2008	1,417.65	27.3	3.1	0.28	3.39	35.72	64.36	10.54	46.26	49.65	7.36	3.43
CULVERT	T8	5:30 PM	Ebb		7/16/2008	1,254.21	25.9	3.4	0.31	3.74	37.12	57.48	9.49	46.61	50.35	8.98	1.91
CULVERT	T9	6:30 PM	Ebb		7/16/2008	1,252.38	24.2	4.0	0.35	4.38	34.73	61.57	10.66	45.39	49.77	10.33	1.98
CULVERT	T10	7:30 PM	Ebb		7/16/2008	858.14	23.7	4.7	0.49	5.15	19.04	58.38	10.33	29.36	34.52	7.42	2.35
CULVERT	T11	8:45 PM	Ebb		7/16/2008	195.97	23.1	4.9	0.61	5.55	32.39	61.35	10.29	42.69	48.23	7.45	1.49
CULVERT	T12	9:35 PM	Slack Low	Sample	7/16/2008	0.00	22.9	6.5	0.97	7.43	44.81	100.53	14.96	59.77	67.21	5.63	5.10
CULVERT	T12	9:35 PM	Slack Low	FD	7/16/2008	NA	22.6	6.2	1.13	7.33	41.12	133.51	23.66	64.78	72.12	5.54	6.48
CULVERT	T13	10:10 PM	Flood		7/16/2008	324.99	22.4	9.8	1.18	11.02	32.03	58.26	9.06	41.09	52.11	2.54	2.38

Sample ID	Time Point	Time	Tide Stage	Date	Flow Liters/sec	Salinity (ppt)	uM NH4	uM NOx	uM DIN	uM DON	uM POC	uM PON	uM TON	uM TN	Chla (ug/L)	Phaeo (ug/L)	uM TP
FISHLADDER	T1	6:12 PM	Ebb	7/16/2008	7.20	0.1	1.9	1.12	2.99	36.99	47.35	4.44	41.44	44.43	NS	NS	0.1
FISHLADDER	T2	7:55 PM	Ebb	7/16/2008	7.70	0.1	1.9	1.05	2.93	34.14	45.31	4.28	38.41	41.34	NS	NS	0.1

Sta	Date	Salinity (ppt)	uM PO4	uM NH4	uM NOx	uM DIN	uM DON	uM PON	uM TON	uM TN	Chla (ug/L)	Phaeo (ug/L)
PBA5A	6/16/2008	18.3	1.8	5.5	15.96	21.44	26.07	27.44	53.51	74.95	0.53	<0.05
PBA5	6/16/2008	28	1.3	0.9	1.69	2.59	21.40	13.43	34.83	37.42	0.86	<0.05
PBA5A	7/7/2008	15.1	0.4	2.3	24.27	26.58	48.98	21.12	70.10	96.68	22.12	2.34
PBA5	7/7/2008	22.3	<0.1	0.9	0.09	0.96	29.69	14.38	44.07	45.03	17.64	8.47
PBA5A	7/16/2008	14.8	0.5	4.7	8.91	13.62	30.16	45.42	75.58	89.20	31.43	<0.05
PBA5	7/16/2008	31.6	1.5	0.3	0.27	0.60	31.50	21.99	53.49	54.09	14.77	2.61
PBA5A	7/23/2008	9.8	1.3	5.5	15.32	20.83	65.09	28.19	93.28	114.12	42.44	<0.05
PBA5	7/23/2008	27.9	1.1	0.6	0.23	0.83	32.33	16.85	49.18	50.01	19.12	2.85
PBA5A	8/6/2008	11.0	1.3	12.4	2.46	14.87	83.93	24.00	107.94	122.80	17.26	1.28
PBA5	8/6/2008	22.8	1.3	1.2	0.45	1.69	49.37	16.03	65.40	67.09	13.94	<0.05
PBA5A	8/21/2008	14.4	0.7	18.5	21.49	39.95	50.84	22.85	73.69	113.64	10.99	1.01
PBA5	8/21/2008	25.2	1.4	1.1	1.29	2.42	60.58	14.43	75.00	77.42	12.88	<0.05
PBA5A	9/4/2008	11.7	0.9	14.6	21.39	35.96	40.23	27.90	68.13	104.09	20.59	1.47
PBA5	9/4/2008	19.0	5.2	11.8	4.94	16.74	350.21	17.80	368.01	384.75	12.98	2.87

Appendix C

Benthic Infauna Data

LOCATION:	Muddy Creek	MC1 5/14/2008	MC1 8/28/2008	MC2 5/14/2008	MC3 5/14/2008	MC3 8/28/2008	MC4 5/14/2008	MC5 5/14/2008	MC5 8/28/2008	MC6 5/14/2008
Crustacea	*Microdeutopus anomalus*	0	5.5	2.5	2.5	56	5	44	812	0
Polychaeta	tubificidae sp. 1	4	3	220	126	52	172	12	216	82
Mollusca	*Gemma gemma*	120	84	81.5	18	148	68	0	44	1
Mollusca	Onoba	14	52	29	0	252	60	4	60	0.5
Polychaeta	Polydora sp. 1	55	1	45	36	0.5	248	16	36	16.5
Polychaeta	*Tharyx acutus*	0	0	0.5	0	0	420	0	8	0
Polychaeta	Ampharete arctica	1	0	0.5	0	1.5	1	4	388	0
Polychaeta	*Capitella capitata*	12	0.5	127	24	7	1.5	24	144	4
Polychaeta	*Leitoscoloplos fragilis*	6	36.5	12	5.5	37	46	32	128	8
Polychaeta	*Streblospio benedicti*	50	24.5	11	16.5	71	11.5	12	88	5
Polychaeta	Tubificoides sp. 1	0	0	56	24	0	4	84	0	0
Polychaeta	*Paranais littoralis*	4	0	16	4	0	12	24	68	30
Crustacea	*Leptocheirus pinguis*	0	0	1	6	0	0	112	0	25.5
Others	anthozoa spp.	0	17	0	0	20	0.5	0	68	0
Polychaeta	Microphthalmus spp.	1	0.5	19	28	24	0	4	0	18.5
Crustacea	*Ampelisca abdita*	1	8.5	0.5	5	52	2	8	16	0
Polychaeta	*Nereis succinea*	38	13	4.5	2	2	6.5	0	4	1.5
Others	chirinomidae	0	0	0	0	0	0	0	60	0.5
Mollusca	*Mya arenaria*	0	1	0	0	2	1	0	44	0
Crustacea	*Corophium insidiosum*	0	0	2.5	1.5	0.5	1	28	0	5
Crustacea	*Edotea triloba*	0	0.5	0	0	0	0	0	24	0
Polychaeta	*Mediomastus ambiseta*	0	2	0.5	2	0	0	0	16	0
Polychaeta	*Eteone longa*	1	6.5	1	0.5	4	5.5	0	0	0
Polychaeta	*Melinna cristata*	0	0	0	0	0	0	16	0	2
Others	nemertea spp.	1	0.5	0	0	0	0.5	4	0	0
Polychaeta	*Podarke obscura*	0	0	0	0	0	0	0	4	0
Crustacea	*Leucon americanus*	2	0	1	0.5	0	0	0	0	0
Others	nudibranch spp.	0	0	3	0	0	0	0	0	0
Polychaeta	Harmathoe sp. 1	0	0	0.5	0	0	2	0	0	0
Crustacea	tanaidacea sp. 1	0	0	0	0	0.5	0	0	1	0
Mollusca	Cumingea	0	1	0	0	0.5	0	0	0	0
Polychaeta	*Pectinaria gouldi*	0	0	0	0	1	0	0	0	0
Polychaeta	Prionospio heterobranchia	1	0.5	0	0	0	0	0	0	0
Crustacea	*Mysidopsis bigelowi*	0	1	0	0	0	0	0	0	0
Mollusca	*Corbula swiftiana*	0	0.5	0	0	0	0	0	0.5	0
Polychaeta	*Spio setosa*	0	0.5	0	0	0	0	0	0	0
Mollusca	*Cylichna oryza*	0	0.5	0	0	0	0	0	0	0
Mollusca	*Mitrella lunata*	1	0	0	0	0	0	0	0	0

Appendix D
Laboratory Analytical Methods

Parameter	Matrix	Container	Processing & Storage	Method (Ref)	Units	Lower Detection Limits	Accuracy and Precision >*
Salinity	Surface water, porewater	60 CC acid washed polyethylene bottle	Filtered and stored in the dark at 4° C. 28 days	Potentiometric Conductivity Meter (g)	ppt	0.1	+ 0.1
Nitrate + Nitrite NO3 + NO2	Surface water,	60 CC acid washed polyethylene bottle	Filtered and stored in the dark at 4° C. 48 hrs	Automated Cadmium Reducation Method (a)	uM	0.05	5%
Ammonia, NH3	Surface water,	60 CC acid washed polyethylene bottle	Filtered and stored in the dark at 4° C. 12-24 hrs	Phenate Method (b)	uM	0.1	5%
Total Dissolved Nitrogen (Dissolved Organic Nitrogen, DON)	Surface water,	60 CC acid washed polyethylene bottle	Filtered and stored in the dark at 4° C. 12-24 hrs	Persulfate Digest & Automated Cadmium Reducation Method (a, c)	uM	0.05	5%
Ortho-Phosphate, PO4	Surface water,	60 CC acid washed polyethylene bottle	Filtered and stored in the dark at 4° C. 12-24 hrs	Ascorbic Acid Method (d)	uM	0.1	5%
Particulate Carbon/Nitrogen	Surface water	1 Liter acid washed polyethylene bottle	Stored at 4°C 12-24 hrs	Elemental analysis (e)	ug/L	10 ug	10%
Total Phosphorus	Surface water	60 CC acid washed polyethylene bottle	Sample acidified and stored at 4°C 28 days	Persulfate Method (a, c, d)	uM	0.05	5%
Chlorophyll a	Surface water	1 Liter acid washed dark polyethylene bottle	Stored in the dark at 4°C 12-24 hrs	Cold 90% acetone extract, acid corrected (f)	ug/L	NA	10%

References

a QuikChem Method 10-107-04-1-J (0-700uM) and 31-107-04-1-C (0-50 and 0-10uM)
Zellweger Analytics, Lachat Instruments Division, Milwaukee, WI USA.
Quik Chem method based upon the following techniques:
Method 4500-NO3- F. Automated Cadmium Reduction Method, Standard Methods
Wood, E., F. Armstrong and F. Richards. 1967. Determination of nitrate in sea water by cadmium copper reduction to nitrite. J. Mar. Biol. Ass. U.K. 47:23-31.
Bendschneider, K. and R. Robinson. 1952. A new spectrophotometric method for the determination of nitrite in sea water. J. Mar. Res. 11: 87-96.

b Ammonia method based upon the following techniques:
Scheiner, D. 1976. Determination of ammonia and Kjeldahl nitrogen by indophenol method. Water Resources 10: 31-36.
Method 4500-NH3 D. Phenate Method, Standard Methods.

c D'Elia, C.F., P.A. Stuedler and N. Corwin. 1977. Determination of total nitrogen in aqueous samples using persulfate digestion. Limnol. Oceanogr. 22: 760-764.

d. Murphy, J. and J.Riley. 1962. A mondified single solution method for the determination of phosphate in natural waters. Analytica Chimica Acta 27:31-36.
Method 4500-P E. Ascorbic Acid Method, Standard Methods.

e. Perkin-Elmer Model 2400 CHN Elemental Analyzer Technical Manual.

f. Parsons, T.R., Y.Maita and C.Lalli. 1989. Manual of Chemical and Biological Methods for seawater analysis. Pergamon Press, 173 pp.

g. Standard Methods for the Examination of Water and Wastewater, 17th edition, 1989. Pp. 2-57.