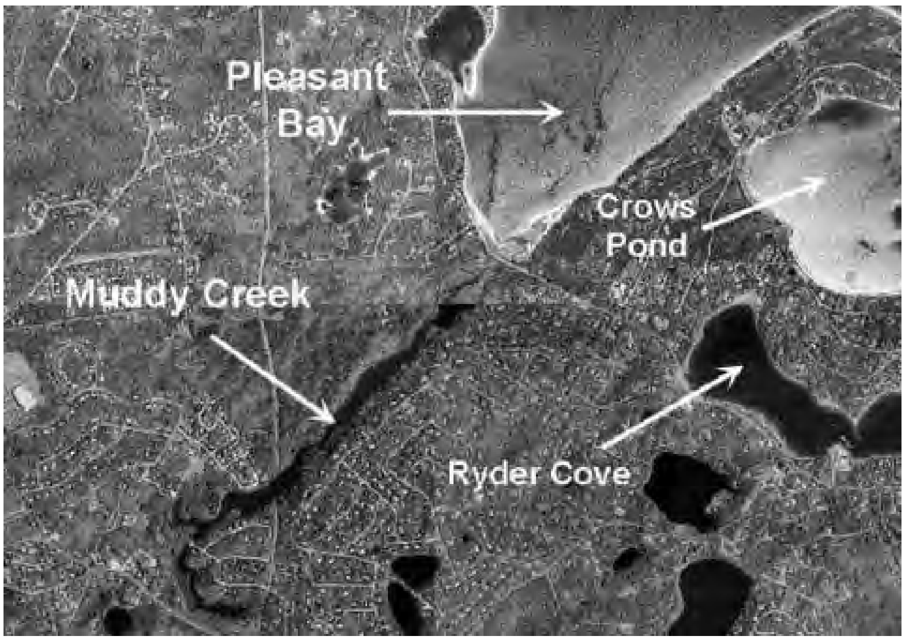
University of Massachusetts Dartmouth
The School for Marine Science and Technology

Massachusetts Department of Environmental Protection

THE MASSACHUSETTS ESTUARIES PROJECT

BACTERIA TMDL FOR MUDDY CREEK

Report # MA96-51-2004-01



Chatham & Harwich Massachusetts
Cape Cod Watershed

Prepared by University of Massachusetts/ Dartmouth School of Marine Science & Technology in cooperation with The Massachusetts Department of Environmental Protection

Submitted:
March 2005

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Key Feature:	**Fecal Coliform Bacteria TMDL for Muddy Creek**
Location:	**EPA Region 1, MA Cape Cod Watershed**
Land Type:	**New England Coastal**
303d Listings:	**Pathogens (MA 96-51 Outlet of small unnamed pond south of Countryside Drive and north-northeast of Old Queen Anne Road to mouth at Pleasant Bay, Chatham)**
Data Sources:	**University of Massachusetts – Dartmouth/School for Marine Science and Technology, Massachusetts Division of Marine Fisheries, Town of Chatham Water Quality Laboratory, Cape Cod Commission, GIS**
Data Mechanism:	**Massachusetts Surface Water Quality Standards for Fecal Coliform, Ambient Data, and Best Professional Judgment**
Monitoring Plan:	**Massachusetts Shellfish Sanitation Program**
Control Measures:	**Storm Water Management and Source Investigation**

This report was a collaboration between the School for Marine Science and Technology (SMAST) and the Massachusetts Department of Environmental Protection (MassDEP) prepared by Samimy, R.I., B.L. Howes, B.L., D.S. White and A. D. Langhauser

DISCLAIMER

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Acknowledgements

The Massachusetts Department of Environmental Protection and the Massachusetts Estuaries Project would like to express its gratitude to the Massachusetts Division of Marine Fisheries (DMF) for making available its valuable bacterial data and shellfish growing area maps. Additionally, the DMF has been very generous with its staff time for interviews, queries and discussions regarding interpretation of its historical bacterial data records. The Division of Marine Fisheries exemplifies the spirit of collaboration in environmental science to the joint goal of coastal habitat protection and restoration.

Similarly, the sustained efforts and dedication of the Town of Chatham Water Quality Laboratory in monitoring the water quality of all of the Town's embayments is very much appreciated. The additional bacteria data that is periodically collected was critical both to enhance this analysis and as an independent cross check. Both DMF and the Water Quality Laboratory data were critical to the development of this bacteria Total Maximum Daily Load (TMDL) for Muddy Creek.

Authors

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Citation

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Executive Summary

The Massachusetts Department of Environmental Protection (MassDEP) is responsible for monitoring the waters of the Commonwealth, identifying those waters that are impaired, and developing a plan to bring them into compliance with the Massachusetts Water Quality Standards (314 CMR 4.0). The list of impaired waters, formerly known as the "*303d list*" and now as "*Category 5 of the Integrated List*", identifies river, lake, and coastal waters that do not meet water quality standards and the reasons for the impairment.

Once a water body is identified as impaired, MassDEP is required by the Federal Clean Water Act to develop essentially a "pollution budget" designed to restore the health of the impaired body of water. The process of developing this budget, generally referred to as a Total Maximum Daily Load (TMDL), includes identifying the source(s) of the pollutant from direct discharges (point sources) and indirect discharges (non-point sources), determining the maximum amount of the pollutant, including a margin of safety, that can be discharged to a specific water body while maintaining water quality standards for designated uses, and outlining a plan to meet that goal.

This report represents the development of a TMDL relating to bacteria contamination within Muddy Creek in the Towns of Chatham and Harwich of the Cape Cod Watershed. Muddy Creek flows approximately 1.5 miles from Queen Anne Road in Chatham to the mouth at Pleasant Bay (*water body segment #MA-96-51*). The Creek exchanges tidal waters through twin culverts under Rt. 28 and functions as an estuarine tributary to the Pleasant Bay System. A second tidal restriction is located at a dike approximately ½ mile upstream of the Route 28 embankment whose weir has been removed or washed away. With a significant soft shell clam resource, Muddy Creek in its entirety has been classified by the Massachusetts Surface Water Quality Standards as Class SA waters. The shellfish bed at the mouth of Muddy Creek is the most productive and has been classified by the Division of Marine Fisheries (DMF) as "Conditionally Approved", only open for harvesting from December to May. Shellfish harvesting in the remainder of the creek, however, has been prohibited since the findings of the 1995 DMF Shellfish Survey; a downgrade from the earlier classification of "restricted" based on the findings of the 1988 DMF survey.

Muddy Creek was selected for water quality restoration efforts because data frequently exceeded the state's Water Quality Standards for the indicator bacteria, i.e. fecal coliform, during the summer months at the three historical sampling stations distributed along the long axis of the Creek. The DMF, the Town of Chatham Water Quality Department and the SMAST Coastal Systems Program collected fecal coliform data used in this report. E. coli and *Enterococcus* data are also available at Station SM by Route 28. Data was grouped by year, by season, and by weather conditions (when rainfall data were available). For each sampling station, tables are provided that identify the geometric mean, standard deviation, number of samples taken, with results highlighted when it exceeds the water quality standard for Class SA waters - a geometric mean of 14 CFU/100 mL with no more than 10% of the samples exceeding 43 CFU/100 mL. Using the range of ambient data for each station as the baseline, percent reduction and the 90% observation concentrations are also listed.

Overall, the present analysis supports the listing of Muddy Creek as impaired relative to bacterial contamination and also supports the limited winter harvesting of the shellfish beds in the lower basin. Even with the relatively limited number of samples, it is clear that summer bacterial inputs to Muddy Creek are higher than winter inputs, especially at the Route 28 culvert and adjacent to the wetlands in the head of Muddy Creek. Wet and dry weather data for summer samples show wet inputs significantly greater than comparable winter inputs at the Route 28 culvert and to a lesser degree by the Chatham Town Landing. At the other stations, dry weather inputs exceed wet inputs. Winter inputs all meet the bacterial criteria in wet and dry conditions with the exception of the Route 28 station where greater than 10% of the samples exceed 43 CFU/mL.

The goal of this report is to identify measures that will reduce bacterial contamination so Muddy Creek can achieve state water quality standards for Class SA waters. In order to meet this goal, effective implementation of this TMDL will require reducing bacteria sources from 43 to 95%. It is recommended that further focused investigations be undertaken in the most contaminated sections of Muddy Creek. Runoff from Route 28, a storm drain off Sugar Hill Road as well as other local roads, diffuse runoff from the Chatham Town Landing, and inputs from the wetlands at the head of the Creek are areas that should be investigated further. Waterfowl could be a significant source of bacterial contamination here in the summer, particularly cormorants roosting in the upper basin. Bacterial contamination attributable to wildlife is considered a natural condition that cannot be managed unless some form of human inducement such as feeding or improper trash disposal is causing the congregation.

Authority to regulate sources of bacterial pollution and thus the successful implementation of this bacterial TMDL generally rests with local government and will require cooperation and support from local volunteers, watershed associations, municipal government, and other entities as necessary. The most effective cooperative activities are expanded education, obtaining and providing funding for remedial actions, and enforcement of state and local environmental laws and regulations. Federal and state funds to assist implementation efforts are available on a competitive basis from MassDEP – including the Non Point Source Control Grants (Section 319), Water Quality Grants (Section 604(b), the State Revolving (Loan) Fund (SRF) – and the Coastal Zone Management (CZM) Office - Coastal Pollution Remediation Grants.

I. Introduction

The Commonwealth of Massachusetts is responsible under section 303 (d) of the federal and State adopted Clean Waters Act to evaluate the quality of its waters, place water bodies that exhibit poor water quality on a list of impaired water bodies, and to develop a plan with municipalities to return the waters to compliance with acceptable standards. Such a water quality restoration plan is called a Total Maximum Daily Loads (TMDL) report and is developed for each and every pollutant contributing to the impairment(s).

This TMDL concerns bacterial water quality in Muddy Creek within the Towns of Chatham and Harwich (*Water body Segment MA 96-51*). The University of Massachusetts - Dartmouth School of Marine Science and Technology (SMAST) and the Massachusetts Estuary Project Team provided technical data analysis and was a major collaborator[1]. The report synthesizes, presents, and discusses existing and new bacteriological water quality data. The amount of bacteria pollutant that Muddy Creek can safely assimilate without violating the water quality standards is determined and recommendations are included for future action based on comprehensive water quality and land use evaluation.

Fecal coliform bacteria are indicators of potential water resource contamination. While fecal coliform bacteria are not generally a direct public health risk, they are typically associated with pathogenic organisms in wastewater or fecal waste of warm-blooded wildlife such as mammals and birds. Standards in the Massachusetts Water Quality Classification have been established to protect human health when using waters for direct or indirect recreational contact, consuming shellfish, as well as other uses. As such, in order to prevent further degradation in water quality and to move toward bringing Muddy Creek to the water quality standards for Class SA waters, sufficient fecal coliform data has been assembled to establish the bacterial conditions of the water resource and to outline corrective actions to achieve the restoration goal.

Though ambient water quality data are available for comparison to state bacterial standards, limited data have been collected that allow for the definitive identification of contamination sources. As such, a primary objective is to point to geographic sections of the overall Muddy Creek system that are the most likely sites of bacterial entry that should receive targeted source identification efforts. This focusing of additional effort is primarily based upon spatial and temporal analysis of bacterial levels the creek and how they respond to rainfall.

This draft TMDL report is being distributed to the public for review and will be submitted to EPA Region 1 for approval. The approved TMDL will include recommended corrective actions that will be used to direct the activities deemed necessary to reduce bacterial loadings, minimize the human health risk and restore the historical beneficial uses of the water body. In this case to eventually reopen the Muddy Creek shellfish beds to harvesting - a goal that can only be achieved with the input and involvement from the communities abutting Muddy Creek.

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[1] Although the Massachusetts Estuaries Project focuses primarily on estuarine health as related to nutrient inputs, it was deemed cost effective by the Project's advisory and technical groups to simultaneously conduct bacterial evaluations of those estuaries that are listed also for pathogens.

II. Description of Muddy Creek

The Muddy Creek basin and surrounding watershed is located along the boundary of the Towns of Chatham and Harwich on Cape Cod, Massachusetts (Figure II-1). Muddy Creek is approximately 1.5 miles long from Queen Anne Road in Chatham to the mouth in Pleasant Bay (*water body segment #MA-96-51*). The Creek exchanges tidal waters through twin culverts under Rt. 28 and functions as an estuarine tributary to the Pleasant Bay System. This entire portion of the Chatham/Orleans coastline is separated from the Atlantic Ocean by Nauset Beach, a barrier beach truncated to the north at Nauset Harbor and to the south at Chatham Harbor.

Although Muddy Creek is not very large, there is a significant resource of soft-shelled clams (*Mya arenaria*) and a small population of blue mussels (*Mytilus edulis)* around the Route 28 culvert (Germano, 2001). It also supports a small anadromous fish (alewife) population.

II.1 Muddy Creek Sub-watersheds

The total Muddy Creek drainage area, at approximately 2100 acres, contributes significant fresh water through both surface and ground water pathways. The multiple sub-watersheds portrayed in Table II-1 and Figure II-2 were delineated by the United States Geological Survey for the Massachusetts Estuaries Project and utilize the most current physical information and modeling based upon MODFLOW/MODPATH. The sub-watersheds are grouped into the headwater ponds known as Mill Pond, Goose Pond and Trout Pond (sub-watersheds numbered 1,2 and 3 respectively), and the upper basin and lower basin of Muddy Creek (sub-watersheds 12-14 and 15-17 respectively). The two basins are separated by a second tidal restriction at a dike approximately ½ mile upstream of the Route 28 embankment which had a weir that was either removed or washed away. The US Geological Survey delineated Sub-watershed 11 separately as the area of groundwater supplying the Muddy Creek public drinking water well. The groundwater within Sub-watershed 11 flows into both the upper and lower Muddy Creek basins.

Table II-1: Muddy Creek Sub-watersheds

Sub-watershed Name	**Sub-watershed Number**	**Size (acres)**
Mill Pond	1	231 acres
Goose Pond	2	93 acres
Trout Pond	3	59 acres
Lower Muddy (total)	12, 13, 14	613 acres
Upper Muddy (total)	15,16,17	989 acres
Recharge Area to Water Supply Well	11	160 acres
	Total Acreage:	2145 acres

Figure II-1. Location of the Muddy Creek system, Cape Cod, Town of Chatham, MA.

II.2 Land Use Analysis

For the purpose of this bacterial TMDL, the land use data was derived from the assessor's maps of the Towns of Harwich and Chatham (2002 update) with land-use codes consistent with the MA Department of Revenue classification scheme. Land use analysis for the Muddy Creek watershed was performed on a parcel basis (Figure II-2). The land use was divided into several general categories that were further subdivided to refine land use descriptions for assessment purposes. For example, the residential land use grouping includes single family, two, three and multiple family dwellings, apartments, and boarding houses to name a few. In this report the primary groupings will be employed[2].

It is interesting to note that the predominant land use type within the upper and lower basins of Muddy Creek is residential development, primarily single-family dwellings with wastewater disposal through individual on-site systems. The land labeled as "Public Service" is exempt from taxation; in the Muddy Creek watershed these are mainly government and conservation properties. These large areas within Public Service and Undeveloped categories are essentially open space relative to evaluating potential sources of nutrient and bacterial contamination.

The densest residential and commercial/business development and the most extensive paved areas are located in the Upper Muddy watersheds. The most common sources of fecal coliform bacteria to coastal water bodies are, in general, "failing" septic systems, stormwater runoff from impermeable surfaces, combined sewer overflows and congregation of waterfowl. However, in the Muddy Creek watershed there are no sewers or combined sewer overflows. The domiciles and other land uses discharge wastewater into subsurface disposal systems.

Below is the general description for the types of land uses in the Muddy Creek watershed[3] and the spatial coverage's of those land uses. For further detail, see Tables II-2 and II-3.

Land Use	**Acreage**	**% of Watershed**
Residential	1127.9	56.8
Public Service Lands	339.1	17.1
Rights of Way/Roads	182.3	9.2
Multiple use	109.7	5.5
Commercial/Business	95.2	4.8
Forest Land	11.9	0.6
Cemetery	11.4	0.6
Water	107.5	5.4

Further investigation of this land-use distribution reveals that there is significant protected open space within the watershed. This open space is held within the "Undeveloped" and "Public

[2] For more detail on the land uses see Table II-3 through II-12 of the technical support document prepared by SMAST.

[3] Sub watershed #11, the recharge area for the Harwich public water supply well, is not included in this acreage.

Service" areas shown in Figure II-3. Within these two categories are 840 acres of open space (42% of watershed) of which 516 acres (25% of watershed) is "protected" as land owned by the local Water District, Conservation Commission, or Chatham Conservation Foundation. Even more significant to evaluating bacterial contamination within the creek is that within the 88 acres of undeveloped area along the Harwich shore (north side) of lower Muddy Creek, 68 acres are under conservation restriction and the contiguous shoreline moving up-Creek is protected Public Service parcels, presumably Harwich Conservation Commission lands. These findings indicate that relative to bacterial contamination, much of the Muddy Creek shoreline is currently open space that is not generating wastewater. This open space "buffer" around much of the Muddy Creek shoreline suggests a low potential for anthropogenic bacterial inputs.

Reviewing the specific parcel based land-use coverages indicates that potential anthropogenic bacterial inputs are most likely to occur along the Chatham shore (south side) of Muddy Creek, as well as surface water inflow from the upper developed watershed and runoff into the lower basin near Rt. 28. Natural bacterial inputs associated with wildlife are most likely generated in the fringing wetlands and avian habitat, particularly relative to cormorants.

Muddy Creek Sub-watersheds	Land Use Category and Acres of Coverage							
	Multiple Use (acres) Code 0*	**Residential (acres) Code 1***	**Comm/ Business (acres) Code 3***	**Forest Property (acres) Code 6***	**Public Service (acres) Code 9***	**Cemetary (acres)**	**Rights of way ROW (acres)**	**Water/ Ponds H2O (acres)**
Goose Pond (sub-watershed 2)	1.3	21.0	0.0	0.0	27.0	0.0	3.3	40.0
Mill Pond (sub-watershed 1)	2.0	142.0	0.0	0.0	43.4	0.0	20.0	23.5
Trout Pond (sub-watershed 3)	30.0	0.0	0.0	0.0	10.0	0.0	9.6	9.6
Lower Muddy (sub-watershed 12)	21.0	0.0	0.0	0.0	0.0	0.0	2.1	0.0
Lower Muddy (sub-watershed 13)	43.8	126.8	4.7	0.0	47.5	0.0	37.0	0.0
Lower Muddy (sub-watershed 14)	2.8	251.5	0.0	0.0	36.0	0.0	23.0	17.0
Upper Muddy (sub-watershed 15)	0.0	20.8	0.0	0.0	0.5	0.0	3.8	0.0
Upper Muddy (sub-watershed 16)	0.9	253.1	45.8	0.0	80.7	0.0	31.5	1.4
Upper Muddy (sub-watershed 17)	7.9	312.7	44.7	11.9	94.0	11.4	52.0	16.0
TOTAL	**109.7**	**1127.9**	**95.2**	**11.9**	**339.1**	**11.4**	**182.3**	**107.5**

Note: Land areas contributing to the Muddy Creek Well (sub-watershed 11) have been included in Upper and Lower Muddy calculations.
* Massachusetts Department of Revenue Property Type Classification Codes Revised November 2002

Table II-2 Land use distribution for the Muddy Creek Watershed

Muddy Creek Sub-watersheds	Land Use Category and % of Coverage							
	Multiple Use Code 0*	**Resident Code 1***	**Comm/ Business Code 3***	**Forest Property Code 6***	**Public Service Code 9***	**Cemetary**	**Rights of way ROW**	**Water/ Ponds H2O**
Goose Pond (sub-watershed 2)	0.1%	1.1%	0.0%	0.0%	1.4%	0.0%	0.2%	2.0%
Mill Pond (sub-watershed 1)	0.1%	7.2%	0.0%	0.0%	2.2%	0.0%	1.0%	1.2%
Trout Pond (sub-watershed 3)	1.5%	0.0%	0.0%	0.0%	0.5%	0.0%	0.5%	0.5%
Lower Muddy (sub-watershed 12)	1.1%	0.0%	0.0%	0.0%	0.0%	0.0%	0.1%	0.0%
Lower Muddy (sub-watershed 13)	2.2%	6.4%	0.2%	0.0%	2.4%	0.0%	1.9%	0.0%
Lower Muddy (sub-watershed 14)	0.1%	12.7%	0.0%	0.0%	1.8%	0.0%	1.2%	0.9%
Upper Muddy (sub-watershed 15)	0.0%	1.0%	0.0%	0.0%	0.0%	0.0%	0.2%	0.0%
Upper Muddy (sub-watershed 16)	0.0%	12.8%	2.3%	0.0%	4.1%	0.0%	1.6%	0.1%
Upper Muddy (sub-watershed 17)	0.4%	15.8%	2.3%	0.6%	4.7%	0.6%	2.6%	0.8%
TOTAL	**5.5%**	**56.8%**	**4.8%**	**0.6%**	**17.1%**	**0.6%**	**9.2%**	**5.4%**

Note: Land areas contributing to the Muddy Creek Well (sub-watershed 11) have been included in Upper and Lower Muddy calculations.
* Massachusetts Department of Revenue Property Type Classification Codes Revised November 2002

Table II-3 Land use distribution as percentage of the Muddy Creek Watershed

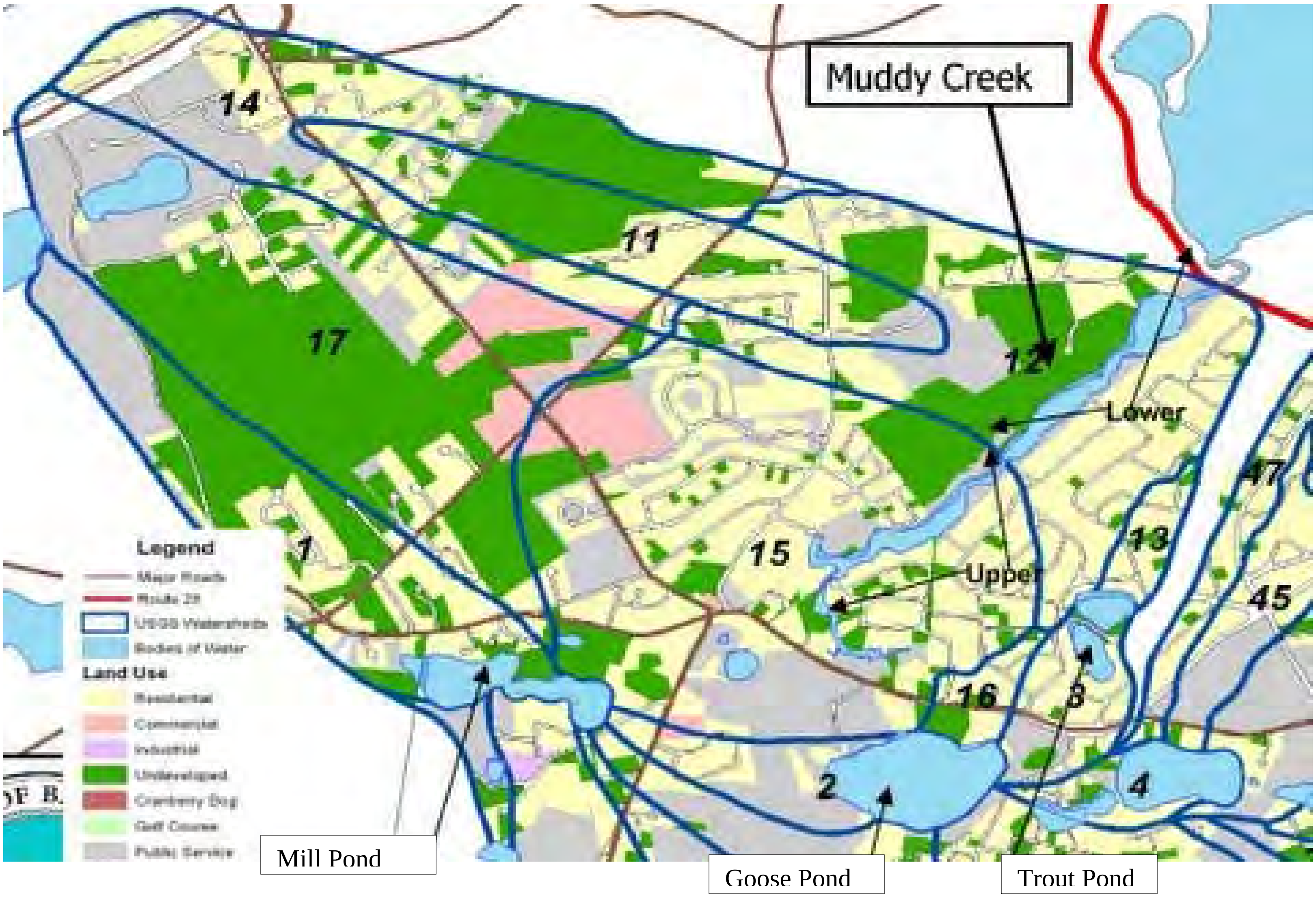


Figure II-2. Land-use by parcel for the Muddy Creek system (sub-watersheds 1,2,3,11,12,13,14,15,16, and 17).

III. Problem Assessment

A significant amount of bacteria related water quality information has been gathered for Muddy Creek in Chatham. This water body was one of seven selected to undergo further bacterial evaluation from the original list of 20 estuaries prioritized under the Massachusetts Estuaries Project. It was selected because the water segments exceeded the state's Water Quality Standards for indicator bacteria, i.e. fecal coliform, in historical samplings and analyses. The majority of the creek was "restricted" for shell fishing in 1988 by the Division of Marine Fisheries (DMF), due to bacterial concentrations exceeding Water Quality Standards for shell fishing areas. Subsequent to a sanitary survey by DMF in 1995 the area north of the Route 28 culvert was reclassified as "prohibited". At the same time the remaining portion of the creek, from the mouth at Pleasant Bay up to the Route 28 culvert, was classified as "Approved" based on the 1988 survey and was downgraded to "Conditionally Approved" - open to shell fishing from December 1st to May 31st – based on the analysis presented in the 1995 survey (Sherwood, 1995 and Whittaker, 2004). Fecal coliform data is also available for three stations sampled by DMF and the Town of Chatham from 1996-2001. DMF and the Town of Chatham Water Quality Laboratory regularly monitor the one station in the conditionally approved area (Station 1).

The State utilizes the same fecal coliform standard for maintaining open and fishable shellfish resource areas as is stated for Class SA waters – that a geometric mean of the data not exceed 14 CFU /100mL with less than 10% of the samples exceeding 43 CFU/100 mL. This standard has been exceeded frequently during summer months at the three historical sampling stations (>50% of samples) distributed along the long axis of the Creek. Observed exceedances decrease significantly during winter months, occurring in less than 10% of the samples collected within the basins.

The most likely sources of fecal coliform bacteria are waterfowl and storm water runoff from Rte. 28 and other roads and paved surfaces abutting or crossing the Creek. This is supported by the higher bacterial levels generally found at the sampling station adjacent the culverts (see Section V). There are no CSO inputs due to the absence of municipal sewers near the Creek. Integrating the land-use coverages indicates that potential anthropogenic bacterial inputs are most likely to occur along the Chatham shore of Muddy Creek, input from the upper developed watershed via surface water inflow and runoff into the lower basin near Rt. 28. The Harwich shore is predominately undeveloped having only one residential cluster. Natural bacterial inputs associated with wildlife are most likely sourced in the fringing wetlands and avian fauna, particularly relative to cormorants and seasonal waterfowl. The elevated summer bacterial concentrations are likely the result of increased waterfowl activity and also the increased potency of storm water runoff from roadways.

IV. Water Quality Standards

Muddy Creek (*Segment ID MA96-51_2002*) is a tributary sub-embayment to Pleasant Bay. It is in the coastal and marine Class and has been classified by the Massachusetts State Water Quality Standard as Class SA water. From the Massachusetts Year 2002 Integrated List of Waters (Massachusetts Category 5 Waters), Muddy Creek flows from the east side of Old Queen Anne Road to the tidal inlet at Pleasant Bay, Chatham.

At a regulatory level, two bacterial contamination standards must be met in order to safe guard the quality and value of the water resource and public health. The first regulatory standard (Massachusetts Surface Water Quality Standards 314 CMR 4.05(4)(a)4) is intended to protect the water resource and its shellfish habitat using fecal coliform as the indicator organism . The second is a minimum standard for bathing beaches (105 CMR 445.000) and is commonly regarded as a swimming standard aimed at protecting public health using *Enterococci* as the indicator organism in marine waters, or E. coli in freshwater.

Based on the Surface Water Quality Standard (SWQS), fecal coliform criteria for coastal and marine Class SA waters specify that waters approved for open shellfishing shall not exceed a geometric mean MPN of 14 organisms per 100 mL, nor shall more than 10 percent of the samples exceed a MPN of 43 per 100 mL[4]. With regard to safe guarding public health relative to primary and secondary contact recreation, as specified in 105 CMR 445.031(A)(1), for marine water, the indicator organism shall be *Enterococci* and no single *Enterococci* sample shall exceed 104 colonies per 100 mL and the geometric mean of the most recent five (5) *Enterococci* levels within the same bathing season shall not exceed 35 colonies per 100 mL.

From the point of view of protecting shellfish resources, currently, fecal coliform bacteria is the pathogenic indicator utilized by the State of Massachusetts as the measure to determine if a coastal marine water body is in compliance with bacteria based Water Quality Standards. The State anticipates replacing fecal coliform with *Enterococci* as recommended by EPA for the indicator organism in marine bathing waters. Fecal coliform will remain the standard relating to management of shellfish resources. The goal of this TMDL report is to decrease fecal coliform bacterial contamination, or determine that it is not wastewater derived (i.e. from wildlife), in order to protect human health when in direct contact with the water and to return these waters to their most beneficial use as a shellfish resource.

[4] Coastal waters not designated for shellfish harvest shall not exceed a geometric mean of 200 organisms in any representative set of samples, nor shall more than 10 percent of the samples exceed 400 organisms per 100 ml.

V. Fecal Contamination of the Muddy Creek System

The history of bacterial contamination in Muddy Creek is generally taken from the Sanitary Surveys performed by the MA Division of Marine Fisheries and has been summarized in *"The Massachusetts Estuary Project Embayment Water Quality Assessment Interim Report: Priority Embayments 1-20*" (MEP 2002). Muddy Creek has approximately 30.8 acres of shellfish in two mapped growing areas - DMF Areas SC58.1 and SC58.2. The outlet of Muddy Creek at Pleasant Bay up to the Route 28 culvert is within Area 58.1. This area is classified presently as "Conditionally Approved" and open to shellfish harvesting from December 1st through May 31st (D. Whittaker, 2004). The majority of the creek is within Area 58.2 and has been classified as "prohibited" for shell fishing since the 1995 Sanitary Survey due to bacterial concentrations exceeding the fecal coliform criteria for SA waters. The shellfish harvesting classification for both areas was downgraded in the 1995 DMF survey from an earlier classification based on the findings of the 1988 DMF survey due to bacterial concentrations exceeding the fecal coliform criteria for SA waters in the limited number of available samples. The 1988 classification for Area 58.1 was "Approved", for Area 58.2 "restricted".

Data on Fecal Coliform bacteria used in this report has been collected from three sources as summarized in Table V-1: the Massachusetts Department of Marine Fisheries, the Town of Chatham, and the Coastal Systems Program at SMAST. DMF sampled at its designated stations 1, 2, 3, and 3A up through 2001 (Figure V-1). The Town of Chatham Water Quality Department sampled at the DMF stations from 1996-1998. SMAST has sampled during ebb tide at its designated station (SM) upstream of the Route 28 culvert from November 2002 through August 2003. All groups collected samples for fecal coliform. Fecal coliform is a general classification of bacteria that are typically associated with animal and human waste. In addition, SMAST sampled for *E. coli* and *Enterococcus*. Fecal coliform bacteria and E. coli are typically found in the intestines of animals and humans. *Enterococcus* is thought to be a better indicator of human health risk than fecal coliform.

Table V-1: Description of the Sampling Stations in Muddy Creek sub-watershed

Station	Description	Data Source	Years Collected
1	Town Landing, Chatham	DMF Town of Chatham	1985 - 2001 1996-1998
2	Arbutis Trail, Chatham	DMF Town of Chatham	1985 – May 1999 1996-1998
3A	549 Riverview, Chatham (End of shellfish resource)	DMF Town of Chatham	1985 – Dec. 1998 1996-1998
3	Sugar Hill Drive, Harwich (Head of the creek)	DMF Town of Chatham	1985 - 1993 1996-1998
SM	Route 28 culvert	SMAST	Nov. 2002 – Aug. 2003

Data from all 3 sources have been compiled and analyzed for this TMDL report. Data was grouped by year (1985-1995 and 1996-2003), by season (November through April for winter and May through October for summer) and by wet weather or dry weather status (1996-2003 data only, where rainfall amounts were available). Wet/Dry samplings were based on the total rainfall amount at the site over the three days prior to sampling (less than 0.25 inches was considered to be a dry weather event and greater than 0.25 inches was designated as wet weather sampling).

For each sampling station, the geometric mean, standard deviation (SD) and number of samples taken (N) were computed for winter and summer for each time interval (1985-1995 and 1996-2003) and are presented in Tables V-1. Geometric means that exceeded the water quality standard for Class SA Waters of 14 CFU/100 mLs for fecal coliform and E. coli or 35 colonies/100 mL for *Enterococcus* are highlighted. In addition, data for sampling stations listed in Tables V-1 were highlighted when more than 10% of the samples exceeded the water quality standard of 43 CFU/100 mL for Fecal coliform and E. coli or where any sample exceeded the water quality standard for swimming of 104 colonies/100 mL. The ratio of the summer to winter geometric means was also determined for each sampling station to indicate seasonal variation in levels of bacterial contamination.

Wet and Dry data were compiled in the same manner for each station where rainfall data were available and is summarized in Table V-2. Geometric means and standard deviations were calculated seasonally for wet and dry weather data from each station during the years 1996-2003. Means that exceeded the water quality standards were highlighted in Table V-2. Data were highlighted when more than 10% of the samples exceeded the water quality standard of 43 CFU/100 mL for Fecal coliform and E. coli or where any sample exceeded the water quality standard of 104 colonies/100 mL for *Enterococcus*. The ratio of wet to dry geometric means for summer and winter data were also determined for each sampling station as indicators of the degree of summer versus winter contamination levels.

V.I Data Analysis

Summer Sample Analysis

From 1985-1996, there were a total of 47 summer sampling events. Summer geometric means of fecal coliform counts ranged from 11 CFU/100 mL at Station 1 at Pleasant Bay to 42 CFU/100 mL at Station 3 located in the upper basin of Muddy Creek nearest the wetland areas (Figures V-1, V-4a, Table V-2a). *Means at two upper basin stations exceeded the water quality standard of 14 CFU/100 mL in the summer. At all stations, more than 10% of the samples exceeded 43 CFU/100 mL* (Figures V-1, V-4a, Table V-2a). There is a clear trend of decreasing coliform counts moving downstream from Station 3 at the head of the Creek to the mouth at Pleasant Bay (Figure V-4a) indicating a dilution (and possible die-off) of contamination as it moves away from its likely source.

From 1996-2003 there were a combined total of 63 summer fecal coliform samples taken by DMF, Chatham Water Quality Dept. and SMAST. Summer geometric means ranged from 14 CFU/100 mL at Station 2 to 72 CFU/100 mL at Station 3 located near wetland areas (Figures V-2, V-4b, and Table V-2a). All summer means except the one at Station 2 exceeded the water quality standard of 14 CFU/100 mL. At all stations, more than 10% of the samples were greater than 43 CFU/100 mL. The added data from Station SM at the culvert shows high summer bacteria counts and suggest an association of contamination with the region of Route 28, potentially resulting from runoff (Figure V-4b).

Winter Sample Analysis

During the winter months of the 1985-1995 sampling period, there were 57 sampling events (Figure V-1). Winter geometric means for fecal coliform bacteria were lower than summer means at all stations and were less than the water quality standard of 14 CFU/100 mL. *None of the winter samples at any of the stations exceeded the water quality standard of 43 CFU/100 mL* (Figures V-1, V-4a, Table V-2a). The ratio of the summer geometric mean the winter mean ranged from 1.8 at Station 2 to 7.8 at Station 3A. Therefore, *summer concentrations appear to be 2 to 8 times higher than winter concentrations (*Table V-2a).

In the 1996-2003 sampling period, a total of 78 fecal coliform samples were taken at all stations during the winter. All geometric means were lower than the water quality standard of 14 and were significantly lower than summer means, ranging from 3 CFU/100 mL at Stations 1 and 3A to 12 CFU/100 mL at Station SM (Figures 2, V-4b, Table V-2a). Only at Station SM were more than 10% of the samples greater than the water quality standard of 43 CFU/100 mL (Table V2a). The ratio of summer to winter geometric means ranged from 3.2 at Station 2 to 13.7 at Station 3, indicating that *fecal contamination in the summer was approximately 3-14 times higher than the winter*.

Figure V-1 Summer and winter fecal coliform bacteria counts (CFU/100 mLs), 1985-1995. Numbers indicate geometric means for summer/winter from samplings by Massachusetts Division of Marine Fisheries.

igure V-2 Summer and winter fecal coliform bacteria counts (CFU/100 mLs), 1996-2003

Numbers indicate geometric means for summer/winter samplings by Massachusetts Division of Marine Fisheries, Town of Chatham Water Quality Department and SMAST (SM).

Wet and Dry Weather Analysis

Given the temporal distribution and number of samples during the years 1996-2003, it was possible to evaluate wet versus dry weather bacterial levels. Samplings were separated into wet and dry events based on the total rainfall for the 3 days prior to sampling (dry weather < 0.25 inches of rainfall > wet weather). A total of 19 wet samples and 40 dry samples were taken during the summer for fecal coliform. A total of 28 wet and 42 dry samples were taken during the winter (Figure V-3, Table V-2a). For the summer, wet geometric means ranged from 9 CFU/100 mL at Stations 2 and 3A to 253 CFU/100 mL at Station SM. Dry means ranged from 12 CFU/100 mL at Station 1 to 83 CFU/100 mL at Station 3 (Figures V-3 and V-6a). Wet means exceeded the water quality standard of 14 CFU/100 mL at Stations 1, 3 and SM. Dry means exceeded the standard at Stations 2, 3, 3A and SM (Table V-2a). More than 10% of samples at all stations for both wet and dry sampling were above the water quality standard of 43 CFU/100 mL (Table V-2a). The ratio of wet to dry geometric means ranged from 0.3 at Station 3A to 3.9 at SM. *Wet inputs were significantly greater than dry inputs at Stations 1 and SM only.* These results indicate that non-runoff sources are the dominant players in the upper basin and upper portion of the lower basin (Stations 2, 3, and 3A) and that runoff is a dominant player in the region of the tidal inlet and Route 28 (Stations 1 and SM).

For winter samplings, wet weather geometric means ranged from 3 CFU/100 mL at Station 1 to 13 CFU/100 mL at Station SM (there were no samples taken at Station 3 and only single samples were taken at Stations 2 and 3A). Dry geometric means ranged from 3 CFU/100 mL at Station 1 to 9 CFU/100 mL at Station SM (Figures V-3, V-6a, V-6b, Table V-2a). *In the winter, none of the geometric means for wet or dry samples exceeded the water quality standard of 14 CFU/100 mL and only at Station SM for both wet and dry samplings did more than 10% of samples exceed the water quality standard of 43 CFU/100 mL* (Table V-2a). Ratios of wet to dry means ranged from 1.2 at Station 1 to 2.9 at Station 2, indicating that wet bacterial inputs during the winter were 1-3 times dry inputs (Table V-2a). These results support the source indications found in the summer analysis, above.

Figure V-3 Wet and Dry fecal coliform bacteria counts (CFU/100 mLs), 1996-2003.

Numbers indicate geometric means of wet/dry data for summer (s) and winter (w) samplings by DMF, Town of Chatham and SMAST.

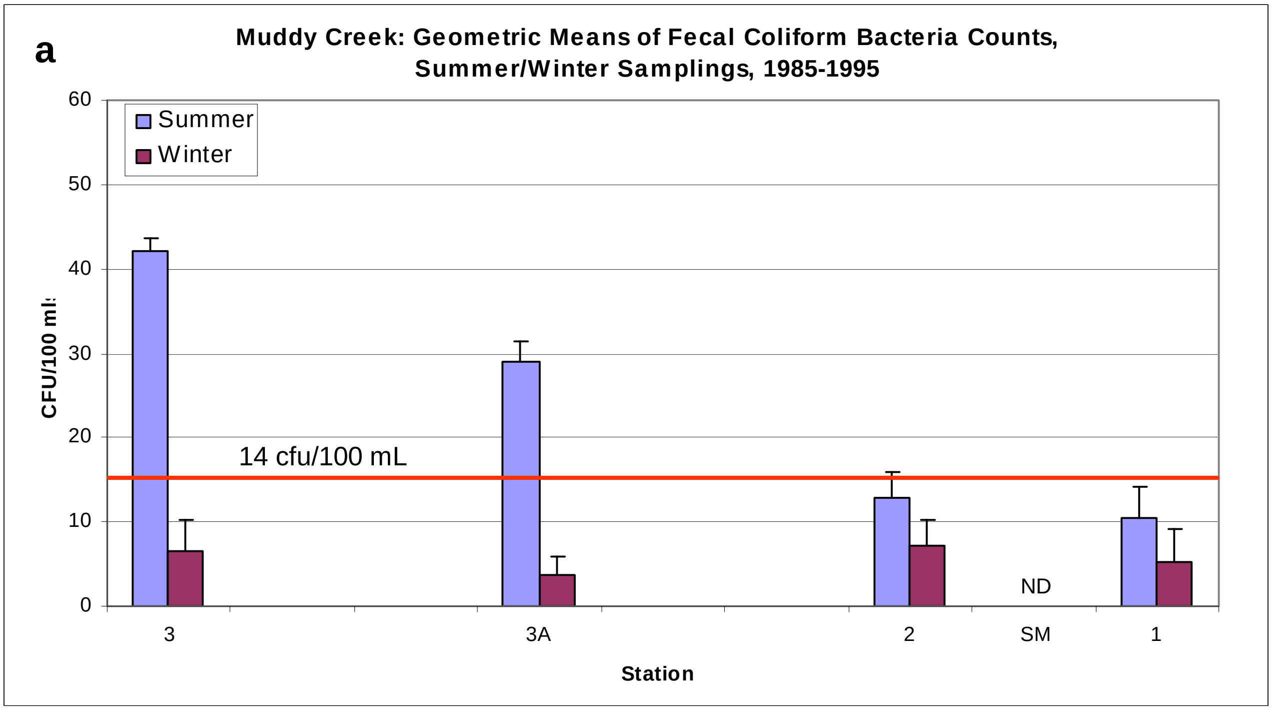
E. coli and *Enterococcus* Sample Analysis

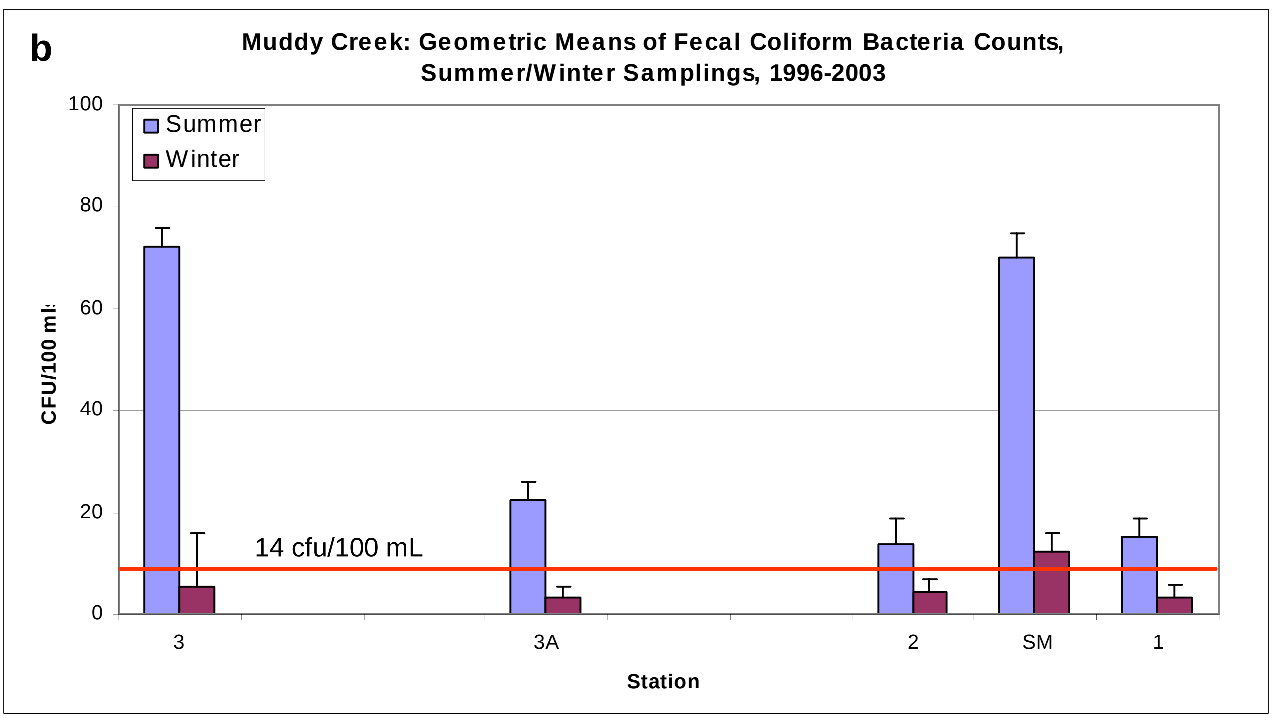
SMAST sampled at the Route 28 culvert (Station SM) for E. coli and *Enterococcus* as well as fecal coliform. A total of 17 summer E. coli samples and 17 summer *Enterococcus* samples were collected at Station SM (Table V-2b, V-2c). Summer geometric means for E. coli were also above the water quality standard. Geometric means for E. coli and *Enterococcus* samples at SM were 53 CFU/100 mL and 35 CFU/100 mL (equal to the water standard), respectively (Figure V-5a, V-5b, Table V-2b, V-2c). However, more than 10% of the samples exceeded the water quality standard of 43 CFU/100 mLs for E. coli, while 41% of the *Enterococcus* samples exceeded the water quality standard of 104 colonies/100 mL (Table V-2b, V-2c). The same decline in bacterial levels, moving downstream from Station 3 to Station 1 noted for the 1985-1995 data, is apparent at Station SM as well.

There were 22 E. coli and *Enterococcus* samples taken during the winter at the SMAST Station SM (Table V-2b, V-2c). Geometric means for E. coli and *Enterococcus* were 7 and 5, respectively. More than 10% of the samples exceeded 43 CFU/100 mL for E. Coli while 5% of the *Enterococcus* samples exceeded the standard of 104 colonies/100 mL (Table V-2b, c). The ratio of the summer to winter geometric mean was 7.7 for E coli and 7.2 for *Enterococcus*, indicating that summer inputs were approximately 7 times winter levels (Table V-2b, V-2c).

For E. coli, there were 4 wet and 10 dry samples in the summer, and 13 wet and 5 dry samples from the winter at Station SM. The summer wet weather geometric mean was 159 CFU/100 mL, while the dry mean was56 CFU/100 mL. Both means exceeded the water quality standard of 14 CFU/100 mL and more than 10% of the samples exceeded the water quality standard of 43 CFU/100 mL (Table V-3b). The wet mean to dry mean ratio was 2.8, indicating that *wet inputs were approximately 3 times higher than dry inputs in the summer.* The winter wet and dry geometric means at Station SM were 7 CFU/100 mL. Neither exceeded the water quality standard and only the wet samples had more than 10% above the water quality standard of 43 CFU/100 mL. *The wet mean to dry mean ratio at SM for the winter was 1.0, indicating that wet and dry inputs were equivalent* (Table V-3b).

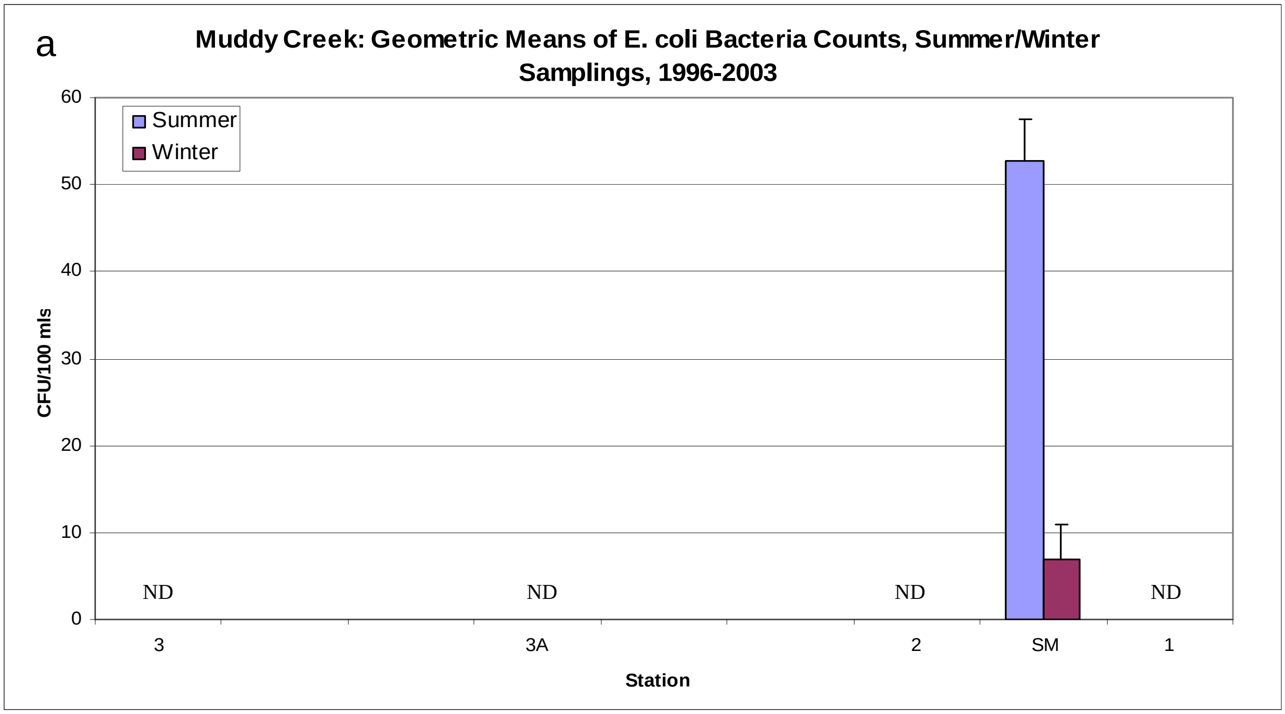
For *Enterococcus*, there were 4 wet and 10 dry samples in the summer and 4 wet and 5 dry samples in the winter. The summer wet mean at Station SM was 119 colonies/100 mL and the dry mean was 51 colonies/100 mL for a wet mean to dry mean ratio of 2.3, *indicating that wet inputs were approximately 2-3 times greater than dry inputs in the summer and both weather conditions exceeded the water quality standard of 35 colonies/100 mL*. Seventy-five per cent of the wet samples in the summer and 40% of the dry samples exceeded the water quality standard of 104 (Table V-3c). The winter wet mean was 8 colonies/100 mL and the dry mean was 12 for a wet mean to dry mean ratio of 0.7, indicating that wet inputs in the winter were slightly less than dry inputs (Table V-3c). Neither mean exceeded the water quality standard of 35 and 8% of the wet samples exceeded the water quality standard of 104 colonies/100 mL.

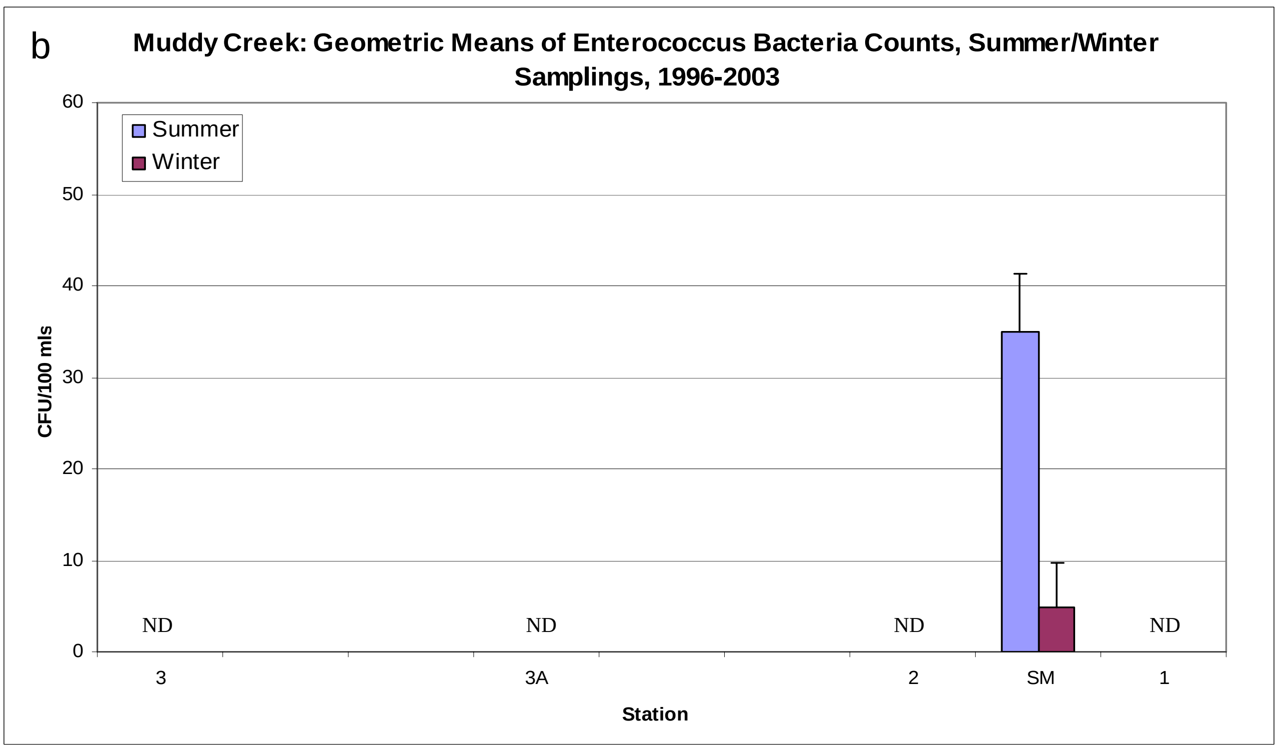




ND = No Data Available

Figure V-4 Summer and winter Fecal Coliform bacteria counts (CFU/100 mls) during the years (a) 1985-1995 and (b) 1996-2003. Numbers indicate geometric means for summer/winter samplings by Massachusetts Division of Marine Fisheries, Town of Chatham Water Quality Department and SMAST (SM).





ND = No Data Available

Figure V-5 Summer and winter *E. coli* (a) and *Enterococcus* (b) bacteria counts (CFU/100 mls) during the years 1996-2003. Numbers indicate geometric means for summer/winter samplings by SMAST (SM).

a

Fecal Coliforms Year	Station	Summer Geomean	SD	N	% Samples >14	% Samples >43	Winter Geomean	SD	N	% Samples >14	% Samples >43	Geomean Ratio: Summer/Winter
1985-1995	1	11	4	17	35%	24%	5	4	22	27%	5%	2.0
1985-1995	2	13	3	12	33%	25%	7	3	15	27%	7%	1.8
1985-1995	3	42	2	10	100%	50%	7	4	11	27%	9%	6.4
1985-1995	3A	29	2	8	88%	38%	4	2	9	0%	0%	7.8
1996-2003	1	15	3	28	57%	25%	3	3	34	6%	6%	5.0
1996-2003	2	14	5	8	63%	50%	4	3	13	0%	0%	3.2
1996-2003	3	72	3	4	100%	50%	5	11	2	50%	0%	13.7
1996-2003	3A	22	4	6	83%	50%	3	2	7	0%	0%	7.2
2002-2003	SM	70	5	17	82%	59%	12	4	22	27%	23%	5.8

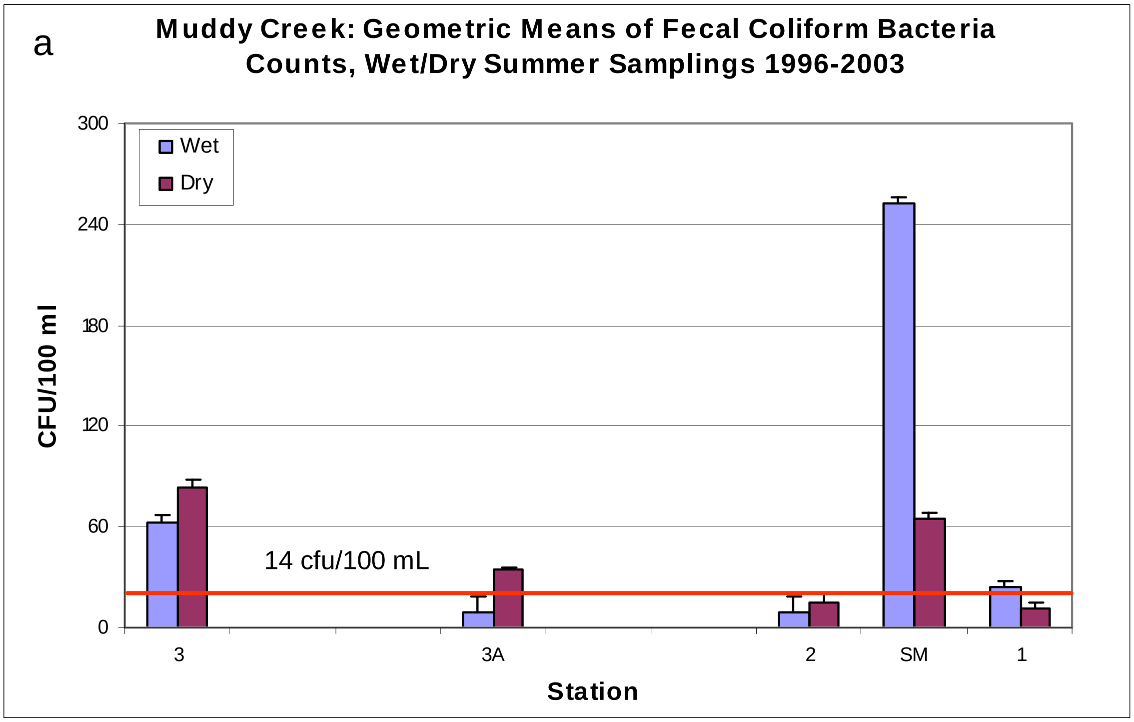
b

E. coli Year	Station	Summer Geomean	SD	N	% Samples >14	% Samples >43	Winter Geomean	SD	N	% Samples >14	% Samples >43	Geomean Ratio: Summer/Winter
2002-2003	SM	53	5	17	76%	65%	7	4	22	27%	14%	7.7

c

Enterococcus Year	Station	Summer Geomean	SD	N	% Samples >104	Winter Geomean	SD	N	% Samples >104	Geomean Ratio: Summer/Winter
2002-2003	SM	35	6	17	41%	5	5	22	5%	7.2

Table V-2 Comparison of geometric means (CFU/100 mls) of summer and winter samplings for (a) Fecal Coliforms, (b) E. coli and (c) Enterococcus bacteria (colonies/100 mL) by Massachusetts Division of Marine Fisheries, Town of Chatham Water Quality Department during the years 1985-1995 and 1996-2003, and SMAST 2002 - 2003.



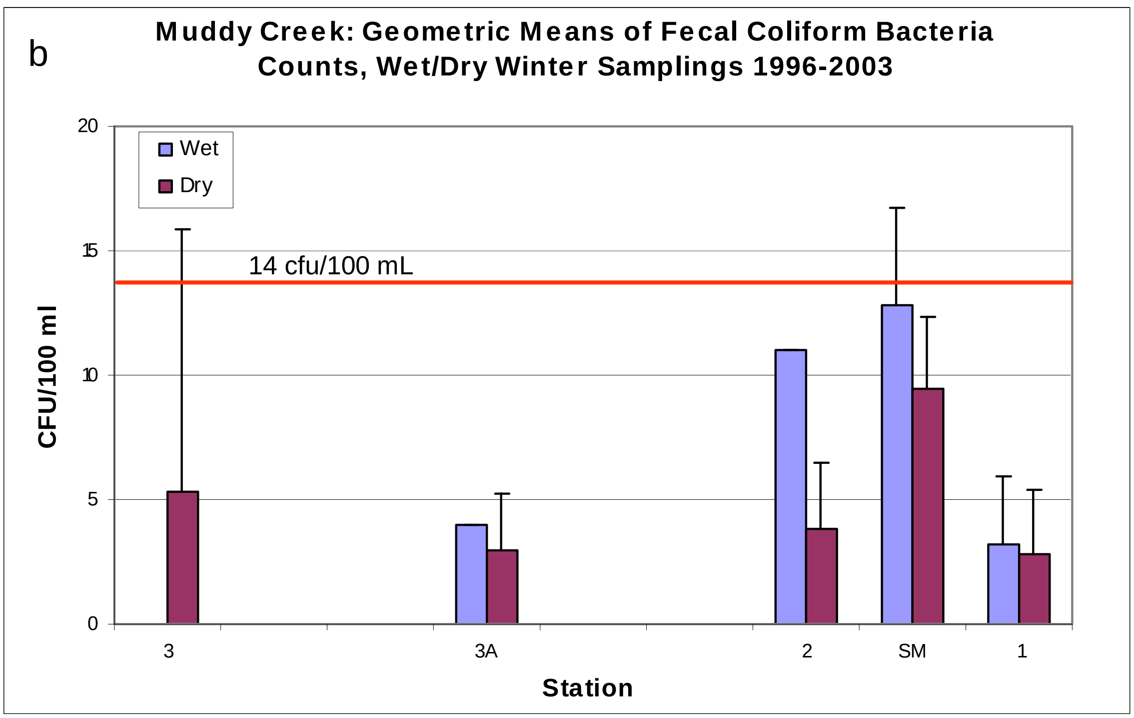


Figure V-6 Summer (a) and Winter (b) wet and dry weather fecal coliform bacteria counts (CFU/100 mls) during the years 1996-2003.

a

Fecal Coliforms Summer Year	Station	Wet Geomean	SD	N	% Samples >14	% Samples >43	Dry Geomean	SD	N	% Samples >14	% Samples >43	Geomean Ratio: Wet/Dry
1996-2003	1	24	3	9	67%	56%	12	3	18	50%	11%	2.1
1996-2003	2	9	9	2	50%	50%	16	5	6	67%	50%	0.6
1996-2003	3	63	4	2	100%	50%	83	5	2	100%	50%	0.8
1996-2003	3A	9	9	2	50%	50%	34	2	4	100%	50%	0.3
2002-2003	SM	253	4	4	100%	75%	65	3	10	90%	60%	3.9
Winter Year	**Station**	**Wet Geomean**	**SD**	**N**	**% Samples >14**	**% Samples >43**	**Dry Geomean**	**SD**	**N**	**% Samples >14**	**% Samples >43**	**Geomean Ratio: Wet/Dry**
1996-2003	1	3	3	13	53%	8%	3	3	18	6%	6%	1.2
1996-2003	2	11	0	1	0%	0%	4	3	11	0%	0%	2.9
1996-2003	3	ND	ND	ND	ND	ND	5	11	2	50%	0%	ND
1996-2003	3A	4	0	1	0%	0%	3	2	6	0%	0%	1.4
2002-2003	SM	13	4	13	80%	23%	9	3	5	20%	20%	1.4

b

E. coli Summer Year	Station	Wet Geomean	SD	N	% Samples >14	% Samples >43	Dry Geomean	SD	N	% Samples >14	% Samples >43	Geomean Ratio: Wet/Dry
2002-2003	SM	159	3	4	100%	75%	56	4	10	80%	70%	2.8
Winter Year	**Station**	**Wet Geomean**	**SD**	**N**	**% Samples >14**	**% Samples >43**	**Dry Geomean**	**SD**	**N**	**% Samples >14**	**% Samples >43**	**Geomean Ratio: Wet/Dry**
2002-2003	SM	7	4	13	31%	15%	7	3	5	20%	0%	1.0

c

Enterococcus Summer Year	Station	Wet Geomean	SD	N	% Samples >104	Dry Geomean	SD	N	% Samples >104	Geomean Ratio: Wet/Dry
2002-2003	SM	119	4	4	75%	51	4	10	40%	2.3
Winter Year	**Station**	**Wet Geomean**	**SD**	**N**	**% Samples >104**	**Dry Geomean**	**SD**	**N**	**% Samples >104**	**Geomean Ratio: Wet/Dry**
2002-2003	SM	8	4	13	8%	12	4	5	0%	0.7

Table V-3 Comparison of geometric means (CFU/100 mls) from both summer and winter wet and dry samplings for (a) Fecal Coliforms, (b) *E. coli* and (c) *Enterococcus* bacteria (colonies/100 mL) from 1996-2003.

Data Summary

All bacterial indicators[5] showed the same response to season and to rain events. With the modest number of samples available for analysis, it is clear that summer bacterial inputs to Muddy Creek are higher than winter inputs especially in the more recent sampling period. In this 1996-2003 sampling period, the overall summer geometric mean in the water quality standards is slightly exceeded at Stations 1 -downstream of Route 28 - and Station 3A – off Riverview Road. It is significantly exceeded at Stations SM - by the Route 28 culverts - and at Station 3 – off Sugar Hill Drive, Harwich - as Muddy Creek winds through fringing wetlands (see Table V-2). Data from 1985-1995 show a similar trend although summer inputs are not as high. Water quality standard is exceeded only at Stations 3A and 3. There is indication of a dilution (and die-off) of bacteria flowing downstream from likely source areas to the mouth of Muddy Creek at Pleasant Bay and winter inputs are all below the standard with the exception of Station SM which may be due to an input of additional sources.

Wet inputs during the winter were equal to or slightly higher than dry inputs and both were significantly less than summer wet and dry loads. There is clearly an enhancement of bacterial inputs after summer rain events, particularly in the region associated with Route 28.

[5] This includes fecal coliform and the *E. coli* and *Enterococcus* collected at Station SM.

V.2 Bacterial Contamination Relative to Watershed Land-use

As previously mentioned in Section II.1 (Land Use Analysis) and discussed by the Division of Marine Fisheries in both the 1995 *Sanitary Survey Report of SC: 58* (Sherwood, 1995) and the 2001 *Triennial Report of the Shellfish Growing Area, Muddy Creek SC: 58* (Germano, 2001), bacterial contamination in Muddy Creek appears to be related to road runoff and avian/wildlife habitat fringing the shores of Muddy Creek. Additionally, there is a higher occurrence of exceedances in summer bacterial samplings versus winter sampling. In analyzing the effect of runoff during rain events, summer wet weather was significantly higher than dry weather in the lowest portion of the creek by Route 28 and the Chatham Town Landing[6]. Non-runoff sources are dominant in the upper portions of the basin.

The fecal coliform bacterial concentration relative to land use for summer and winter conditions is illustrated in Figures V-7 and V-8 (1985 – 1995 and 1996 – 2003 respectively). The lower Muddy Creek basin is represented by DMF stations 1, 2, and 3A; the upper Muddy Creek by DMF station 3 at the head of the creek. The latter station 3 tends to show exceedances during the summer sampling events that are confirmed in the more current 1996 to 2003 sampling events (Figure V-8). Station 3 is proximal to a portion of the immediate upper Muddy Creek watershed that has been classified as residential, public service (municipalities, districts, charitable organizations, churches), and undeveloped (zoned residential). It is important to note that several roads within the residential portion of the shoreline of upper Muddy Creek either terminate at the shore or in one instance loop along the shoreline. Any of these three roads could potentially be a source of runoff related bacterial contamination that may be causing the exceedances seen at station 3. Moreover, there are undeveloped lands within the residential land use classification that may be supporting avian populations as well as wildlife that may be contributing to the exceedances seen at station 3 during summer months. In addition, there are substantial numbers of roosting cormorants on the shores and power lines overhanging the upper basin.

A similar trend to that of the upper basin is seen at station 3A in the lower Muddy Creek basin. Summer samplings in both 1985 – 1995 and 1996 – 2003 respectively show exceedances in the area of the immediate Muddy Creek watershed that has been classified as undeveloped land (zoned residential) or developed residential land. This portion of lower Muddy Creek also contains two roads that terminate on the shore of Muddy Creek, however, it is more likely that bacterial contamination seen at station 3A is dominated by the avian population and wildlife that is supported by the large area of undeveloped land on the northern shore of Muddy Creek. Additionally, SMAST station SM proximal to Route 28 (1996 – 2003 data set, Figure V-8) shows exceedances of

[6] None of the winter samples exceeded the water quality standard of 14 cfu/100 mL and only at Station SM did more than 10% of the samples exceed 43 cfu/100 mL.

bacterial criteria during summer sampling events in a pattern that makes a runoff source highly likely, possibly related to activities associated with Route 28.

The SMAST data set is incorporated into Figures V-9 and V-10 where bacterial concentrations relative to land use is identified at Station SM during summer wet/dry weather conditions and winter wet/dry conditions respectively as well as DMF stations 1, 2, 3A, and 3. During summer months exceedances occur primarily at stations 3 (DMF) and station SM (SMAST) during both wet and dry conditions. Station 3 is located in upper Muddy Creek (shoreline classified as residential, public service: municipalities, districts, charitable organizations, churches, and undeveloped: zoned residential). SMAST station SM is located in lower Muddy Creek proximal to the Route 28 culvert separating lower Muddy Creek from the mouth of Muddy Creek discharging to Pleasant Bay. As previously discussed, it is recommended that further focused investigations be undertaken in these “ most contaminated” sections of Muddy Creek. Runoff from Route 28, a storm drain off Sugar Hill Road as well as other local roads, diffuse runoff from the Chatham Town Landing, and inputs from the wetlands at the head of the Creek are areas that should be investigated further. Summer exceedances also occur at stations 3A and 2 (DMF) located in lower Muddy Creek under dry conditions. Both these stations are located proximal to a large portion of the lower Muddy Creek watershed that has been classified as undeveloped land (zoned residential). These exceedances may be the result of waterfowl and wildlife populating this undeveloped land during summer months. Data obtained under winter wet/dry conditions show no exceedances. The pattern of contamination and its response to rainfall support the contention that wildlife are important to bacterial contamination in the upper and general area of the lower basin and that runoff dominates the contamination found near the tidal inlet. The fact that conservation and undeveloped land forms a near continuous “buffer” around the Muddy Creek shoreline adds support to the source conclusions.

<u>DMF Studies</u>

The findings presented above are consistent with historical surveys conducted by the DMF in two separate reports, one conducted in February of 1995 (Sanitary Survey) and the more recent in March of 2001 (Triennial Report). As presented in the February 1995 Sanitary Survey, DMF identified the following potential pollution sources (Sherwood, 1995). The DMF recommendations in the 1995 Sanitary Survey were as follows.

- Wetland Discharges – Two of the potential sources identified in the shoreline survey were discharges from wetlands adjacent to the shellfish growing area. Results of samples taken from both wetland areas indicate the discharge is not a high source on fecal coliform contamination.

- Stormwater Runoff – Stormwater runoff enters directly into the shellfish growing area from three locations adjacent to DMF monitoring stations 3, 1, and at Route 28. Samples were collected to determine the impact of stormwater runoff at the site and results did not indicate elevated levels of fecal coliform contamination.

- Wildlife and Waterfowl – Muddy Creek is a haven for both wild animals and waterfowl. The combination of wildlife inhabitance and an abundance of waterfowl are probably a large contributing source of elevated fecal counts.

- Tidal Flushing - Grates placed across the culvert under the Route 28 bridge need to be regularly cleared of debris to improve tidal flushing within the creek; a sand bar has accumulated by the culvert. *Note: the grates were subsequently removed.*

It is important to note that the February 1995 Sanitary Survey recorded no failing septic systems observed during the shoreline survey. Only one residence was located close enough to the waters edge to warrant consideration of the type of septic system in use at that location.

In the more recent March 2001 Triennial Survey for Muddy Creek, only the shellfish area downstream of the Route 28 culvert was inspected and sampled. While a comprehensive shellfish survey is done every 12 years, a triennial report is completed every 3 years to check the progress on the recommendations of the previous shellfish survey. The 2001 triennial report identified the progress taken on the pollution remediation recommendations of the 1995 Sanitary Survey in the following manner (Germano, 2001). The DMF recommendations in the 2001 Triennial Survey were as follows.

- Stormwater Runoff – Stormwater runoff from Route 28 and the Chatham Town Landing had not been examined for remediation.

- Muddy Creek west of the Route 28 Culvert – That portion west of the Route 28 culvert was classified as “Prohibited” due to poor water quality and was not inspected in 2001.

- Tidal Flushing – DMF reported that the grates placed across the culverts under Route 28 had been cleaned of debris as often as possible. “The towns have not replaced the culverts to allow proper flushing of the area southwest of Route 28” (page 1, Germano 2001). *Note: MHD subsequently removed the grates. The MHD, not the Towns, is responsible for the culverts.*

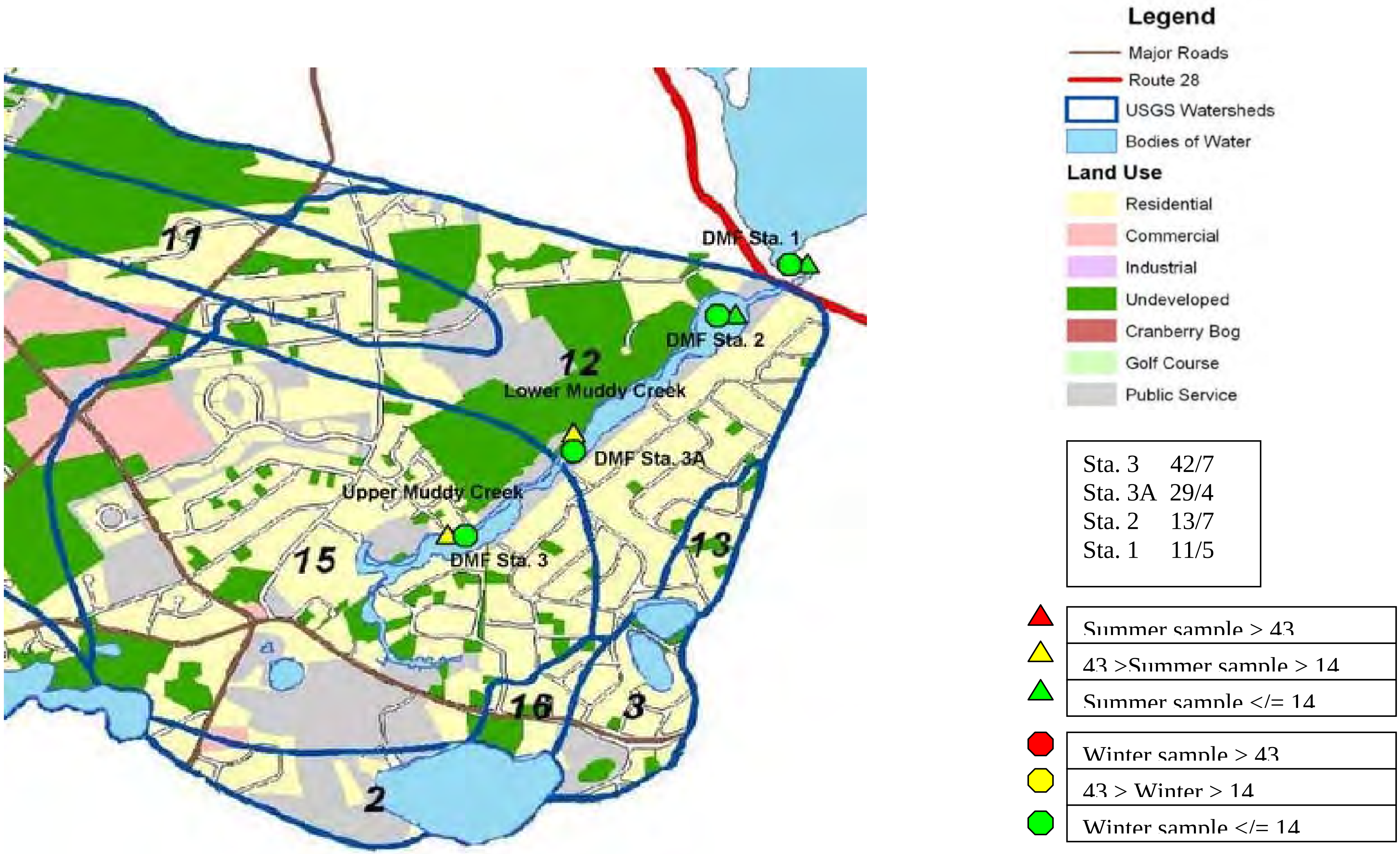
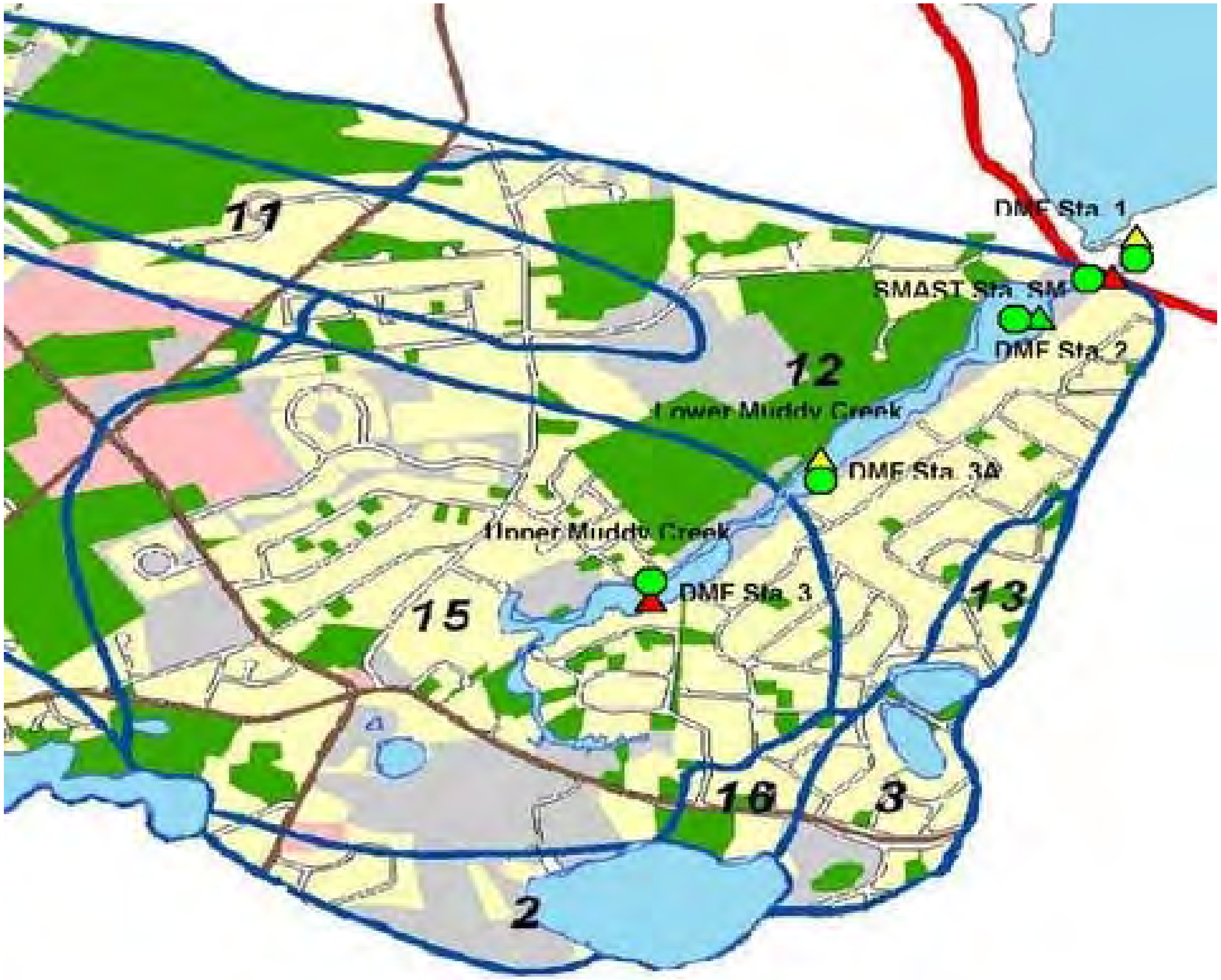


Figure V-7. Land-use by parcel for the Muddy Creek system relative to DMF sampling station locations. Numbers indicate geometric means for summer/winter fecal coliform samplings (CFU/100mL) during the period 1985 – 1995



Sta. 3	72/5
Sta. 3A	22/3
Sta. 2	14/4
Sta. SM	70/12
Sta. 1	15/3

▲ (red)	Summer sample > 43
▲ (yellow)	43 >Summer sample > 14
▲ (green)	Summer sample </= 14
⬣ (red)	Winter sample > 43
⬣ (yellow)	43 > Winter sample > 14
⬣ (green)	Winter sample </= 14

Figure V-8. Land-use by parcel for the Muddy Creek system relative to DMF and SMAST sampling station locations.

"Stop Light" symbols indicate geometric means for summer/winter fecal coliform samplings (CFU/100mL) during the period 1996 – 2003

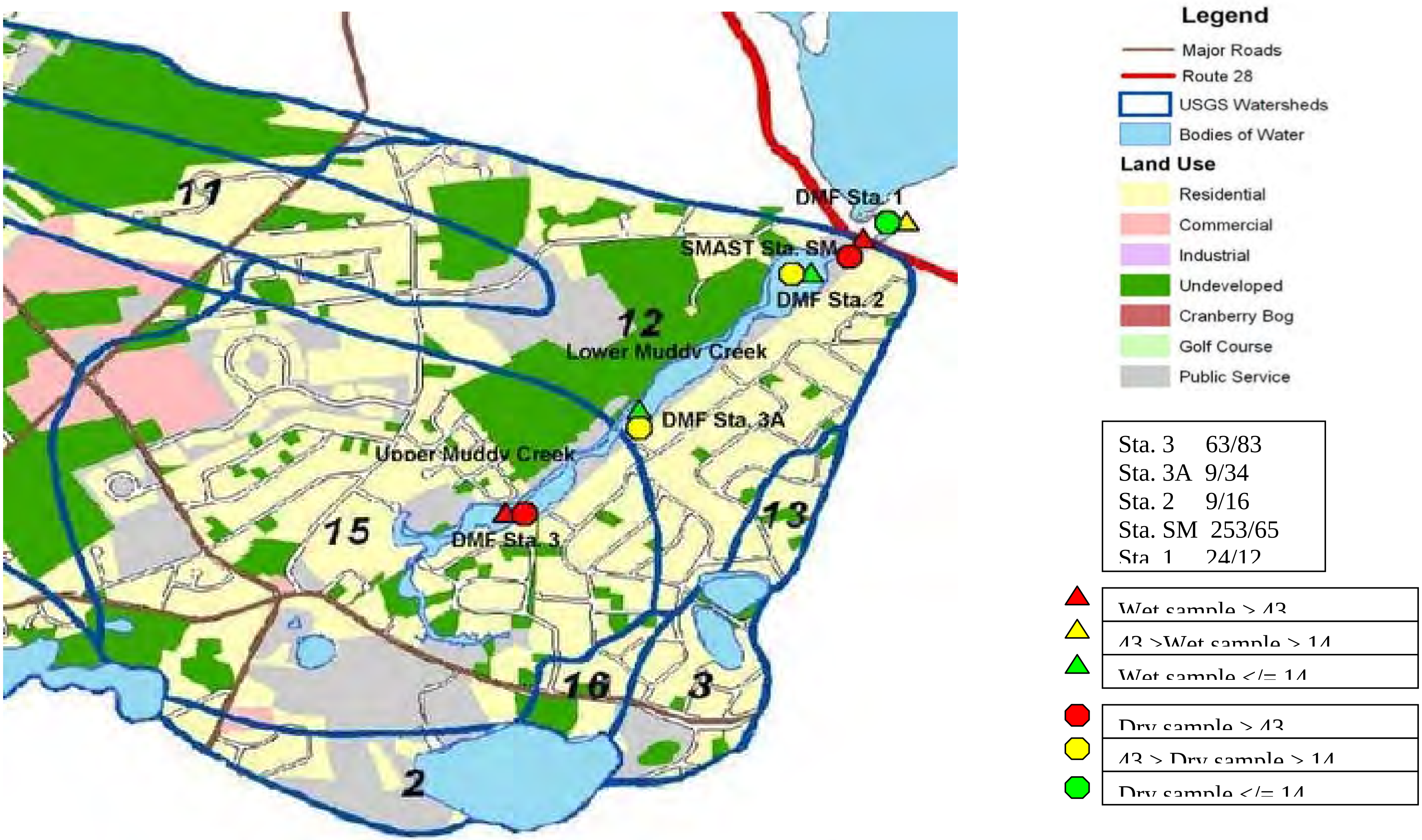
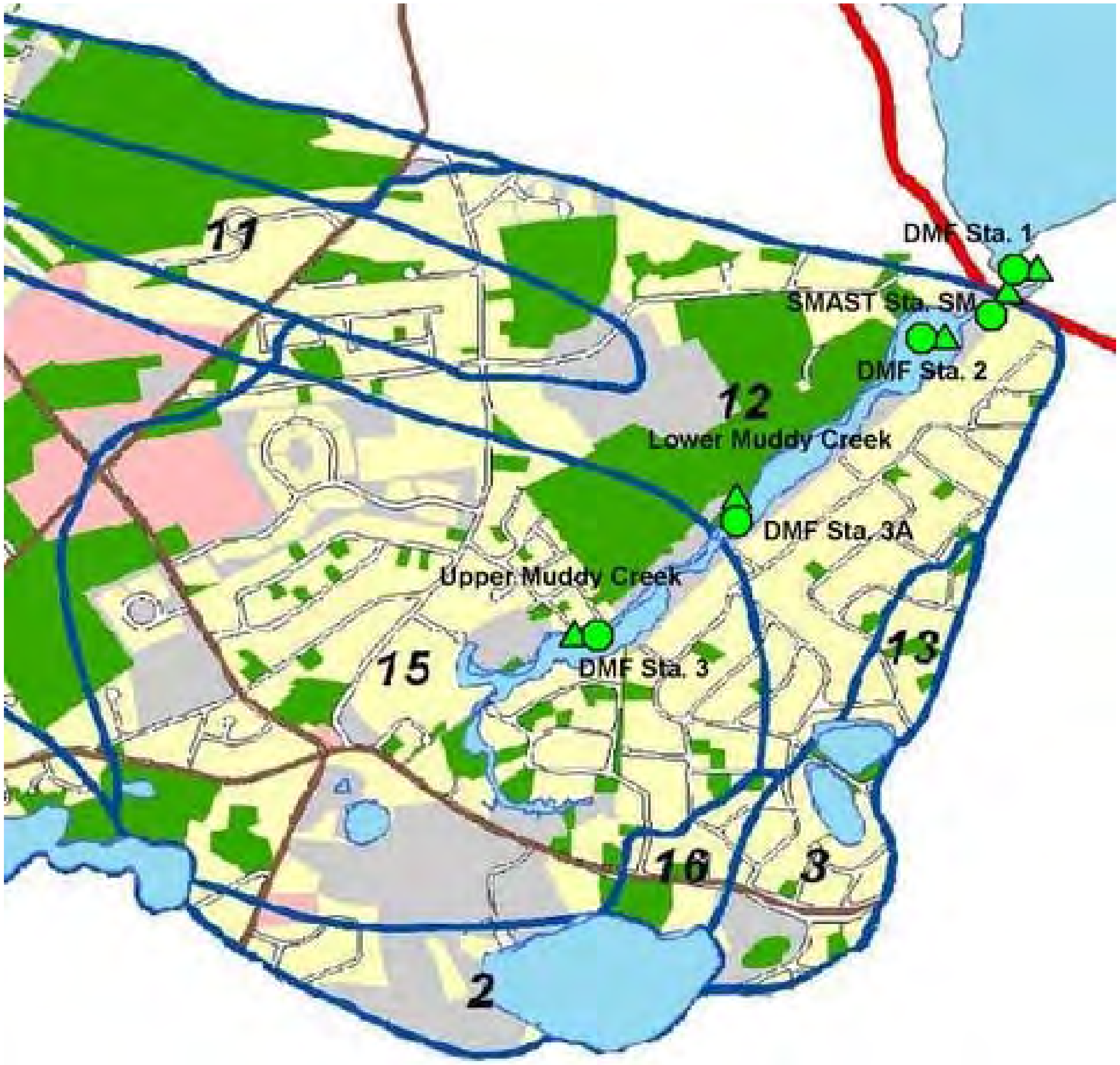


Figure V-9. Land-use by parcel for the Muddy Creek system relative to DMF and SMAST sampling station locations.

"Stop light" symbols indicate geometric means for wet/dry summer fecal coliform samplings (CFU/100mL) during the period 1996 – 2003



Sta. 3	ND/5
Sta. 3A	4/3
Sta. 2	11/4
Sta. SM	13/9
Sta. 1	3/3

▲ (red)	Wet sample > 43
▲ (yellow)	43 >Wet sample > 14
▲ (green)	Wet sample </= 14
● (red)	Dry sample > 43
● (yellow)	43 > Dry sample > 14
● (green)	Dry sample </= 14

Figure V-10. Land-use by parcel for the Muddy Creek system relative to DMF and SMAST sampling station locations.

“Stop light” symbols indicate geometric means for wet/dry /winter fecal coliform samplings (CFU/100mL) during the period 1996 – 2003

VI. Circulation and Nitrogen Attenuation in Muddy Creek

Hydrodynamic and water quality modeling was completed for Muddy Creek as part of a comprehensive nitrogen analysis and threshold development effort undertaken by the Massachusetts Estuaries Project for five of the Town of Chatham embayment systems (MEP, 2003). Though the findings of the MEP Nutrient Thresholds Report are not directly related to the development of a bacterial TMDL for Muddy Creek, if any of the alternatives studied were implemented it would effect water circulation, flushing and the degree to which portions of Muddy Creek are dominated by freshwater rather than saltwater. These considerations could be significant relative to efforts to reduce bacterial contamination and potential impacts on the shellfish resources. Since the restoration of this estuary to water quality standards for bacteria and nutrients needs integrated planning, a brief summary of the alternatives being discussed is included herein.

Muddy Creek exchanges tidal waters with the greater Pleasant Bay System through two culverts under Route 28 that restrict tidal flow. A second restriction occurs at a dike approximately ½ mile upstream of the Route 28 embankment whose weir has been removed or washed away. While both the upper and lower basins of Muddy Creek – defined by the location of the dike - are mapped shellfish resources, only that most downstream section of the lower portion (up to the Route 28 culverts) is conditionally open for shellfish harvesting. Shellfish harvesting is prohibited upstream of the Route 28 culvert. Muddy Creek is considered a highly eutrophic embayment based on a suite of ecological indicators (e.g. benthic community structure, dissolved oxygen, chlorophyll, water quality, eelgrass distribution) described in detail in the MEP Nutrient Threshold Report. Both upper and lower basins are highly eutrophic with frequent bottom water anoxia and large algal blooms (chlorophyll a frequently >50 ug L^{-1}) due to nutrient over-enrichment. The upper portion has a lower habitat quality than the lower portion, most likely as a result of access to the higher quality waters entering on the flood tide from Pleasant Bay.

Based on the previous hydrodynamic modeling performed by MEP of various engineering alternatives, it was anticipated that water quality improvements to Muddy Creek (specifically total nitrogen) could be achieved by nitrogen source reductions coupled with either resizing of Route 28 culverts or turning upper basin into a freshwater pond by restoring the weir (Kelley *et al*., 2001). Using the calibrated models for each system, the model grids were modified to reflect alterations in dimensions of the Route 28 culverts and/or bathymetry of Muddy Creek. Once the hydrodynamic simulations were completed, water quality modeling (specifically total nitrogen) of each scenario was performed by the MEP to indicate changes in water column nitrogen concentrations. Depending on the type of alteration and its effect on increasing or decreasing tidal exchange in Muddy Creek, the nutrient attenuation capacities of Muddy Creek could be compromised and transfer of bacterial contamination from Upper Muddy Creek to the shellfish beds located at the mouth of Muddy Creek accelerated.

The first of three alternatives modeled involved enlarging the two culverts running under Route 28. The culverts each have a height of approximately 2.6 feet and a width of 3.7 feet. Since the surface area of Muddy Creek is relatively large, these culverts are not of sufficient size to allow complete tidal exchange between Pleasant Bay and Muddy Creek thus resulting in poor circulation through the upper portions of Muddy Creek. This poor tidal exchange contributes to the water quality concerns for the Muddy Creek system and, when coupled with the very high watershed nutrient loading to the Creek (>10,000 Kg/yr), results in a highly eutrophic system. Replacement of these culverts will likely be an expensive alternative due to the large roadway embankment overlying the flow control structures. A second alternative considered was to turn Muddy Creek into a completely freshwater system since the elevation of the Route 28 embankment prevents a storm surge from overtopping the road and "shocking" the ecosystem in Muddy Creek with a pulse of higher salinity Pleasant Bay water. This is a viable alternative but would result in the permanent loss of shellfish habitat.

The third alternative considered was to turn a portion of the Creek into a freshwater system. As an example, to preserve the salt marsh and enhance the soft-shell clam resources in the lower portion of Muddy Creek, water turnover within the lower basin can be improved - without altering the present culvert configuration - by rebuilding the weir in the existing dike that divides the upper and lower basins (see Figure VI-1). The region upstream of the dike would be maintained as a freshwater pond, with an anadromous fish run 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 volume of Muddy Creek, reducing the estuarine volume (i.e. removing the tide from the upper basin) will improve water turnover in lower portion of Muddy Creek, reducing nitrogen concentrations. Further nitrogen concentration reductions should be provided by increased nitrogen retention/attenuation within the upper freshwater basin. MEP simulations of weir replacement indicate a reduction in the mean-tide estuarine volume by 55%, with very little reduction in tidal prism (Kelley *et al*., 2001). The modeled reduction in nitrogen concentration for both the existing and functioning dike conditions show a significant reduction in total nitrogen would occur in the lower portion of Muddy Creek as a result of modifying Upper Muddy Creek such that it converts to a purely freshwater regime.

That Upper Muddy Creek, if converted to a freshwater pond under a diked scenario, could potentially provide upwards of 40 percent nitrogen attenuation in and of itself does not have any direct bearing on the development of this bacteria TMDL. However, it brings up an important point regarding freshwater circulation and transport of bacterial contamination that must be reconciled in the design of bacterial contamination management approach. If circulation throughout Upper and Lower Muddy Creek is improperly enhanced, bacterial contamination from Upper Muddy Creek can be transferred to the conditionally approved shellfish beds at the mouth and nutrient attenuation capacities of the upper basin could be reduced leading to an even greater problem with increased water column nitrogen concentrations. However there also can be positive effects on both nutrients and bacteria levels. The example alternative involving dike restoration, along with the application of stormwater controls at Route 28, should reduce bacterial loading to the lower basin, since the retention time of water within the upper basin will be increased by the removal of tidal flows.

The alternatives discussed in this section do not represent recommendations of the MassDEP or the MEP. They merely represent how hydrodynamic and water quality models can be utilized to assess potential management alternatives. Prior to implementation of any alternative that alters the hydrodynamics of the system, a complete environmental assessment of potential positive and negative impacts will be required.

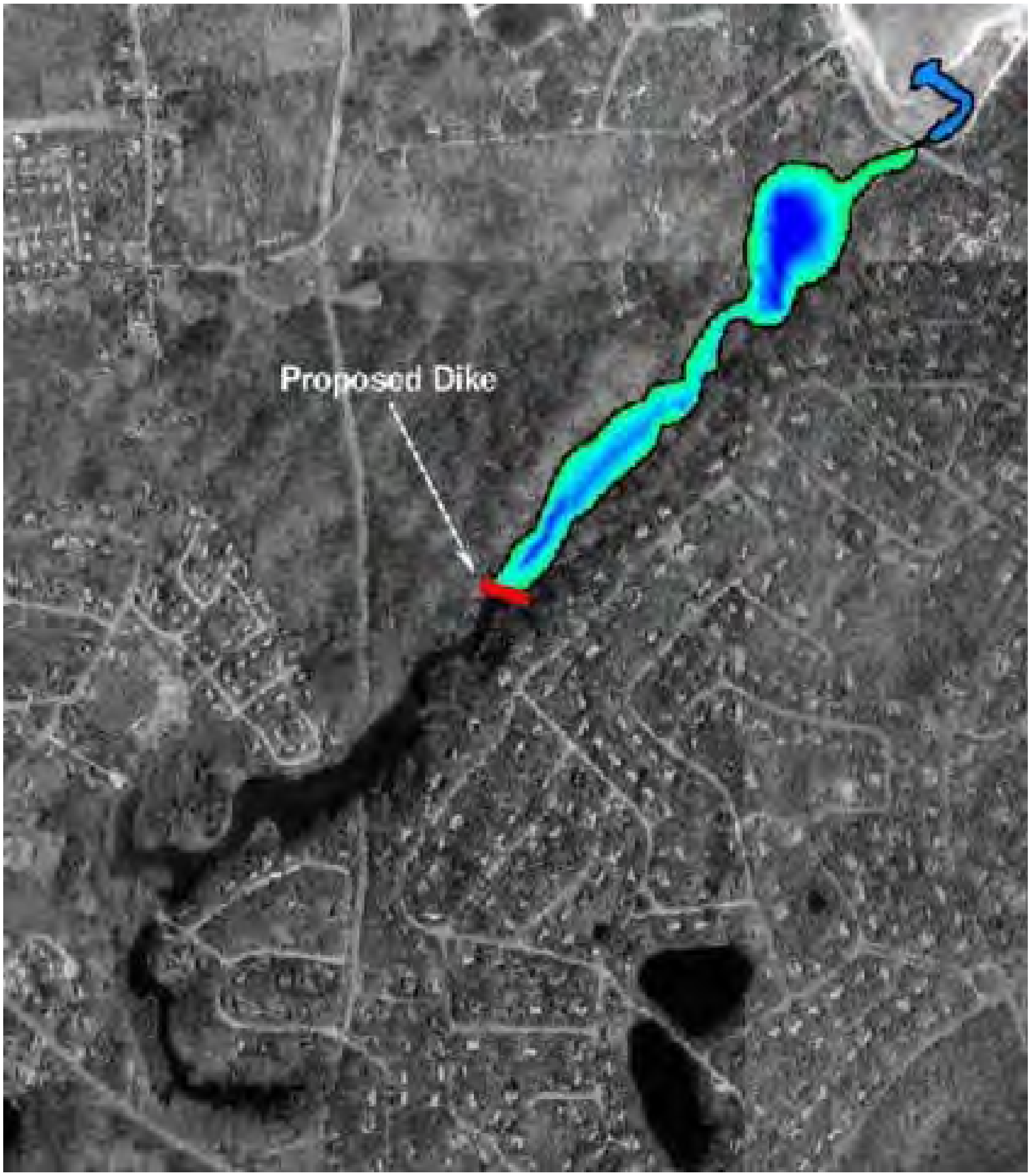


Figure VI- Muddy Creek Alternative 3 illustrating the approximate position of the dike that would have its weir replaced to separate a freshwater upper basin from an estuarine lower basin.

VII. Total Maximum Daily Load Development

Section 303 (d) of the Federal Clean Water Act (CWA) requires states to place water bodies that do not meet the water quality standards on a list of impaired water bodies. The CWA requires each state to establish Total Maximum Daily Loads (TMDLs) for listed waters and the pollutant contributing to the impairment(s). TMDLs determine the amount of a pollutant that a water body can safely assimilate without violating the water quality standards. Both point and non-point pollution sources are accounted for in a TMDL analysis. Point sources of pollution (those discharges from discrete pipes or conveyances) receive a waste load allocation (WLA) specifying the amount of pollutant each point source can release to the water body. Non-point sources of pollution (all sources of pollution other than point) receive a load allocation (LA) specifying the amount of a pollutant that can be released to the water body by this source. In accordance with the CWA, a TMDL must account for seasonal variations and a margin of safety, which accounts for any lack of knowledge concerning the relationship between effluent limitations and water quality. Thus:

TMDL = WLAs + LAs + Margin of Safety

Where

WLA = Waste Load Allocation which is the portion of the receiving water's loading capacity that is allocated to each existing and future point source of pollution.

LA = Load Allocation which is the portion of the receiving water's loading capacity that is allocated to each existing and future non-point source of pollution.

VII.1 Loading Capacity

The pollutant loading that a water body can safely assimilate is expressed as either mass-per-time, toxicity or some other appropriate measure (40 C.F.R. § 130.2(i)). Typically, TMDLs are expressed as total maximum daily loads. However, MassDEP believes it is appropriate to express bacteria TMDLs in terms of concentration because the fecal coliform standard is also expressed in terms of the concentration of organisms per 100 mL. Since source concentrations may not be directly added, the previous equation does not apply. To ensure attainment with Massachusetts' water quality standards for bacteria, the goal of this TMDL is to have all sources (at their point of discharge to the receiving water) equal to or less than the standard. Expressing the TMDL in terms of daily loads is difficult to interpret given the very high numbers of bacteria and the variation in flow conditions. Therefore, the magnitude of the bacteria load that is allowable within water quality standards will vary as flow rates change. For example, a very high number of bacteria may be allowable if the volume of water that transports the bacteria is high too. Conversely, a relatively low number of bacteria may exceed the water quality standard if flow rates are low.

For all the above reasons the TMDL is simply set equal to the standard and may be expressed as follows:

$$\textbf{TMDL = Fecal Coliform Standard} = \textbf{WLA}_{(p1)} = \textbf{LA}_{(n1)} = \textbf{WLA}_{(p2)} = \textbf{etc.}$$

Where:

$\textbf{WLA}_{(p1)}$ = allowable concentration for point source category (1)
$\textbf{LA}_{(n1)}$ = allowable concentration for non-point source category (1)
$\textbf{WLA}_{(p2)}$ = allowable concentration for point source category (2) etc.

For Class SA surface waters the fecal coliform TMDL goal is set to protect the shellfish use and includes two components: (1) the geometric mean of a representative set of fecal coliform samples shall not exceed 14 organisms per 100 mL; and (2) no more than 10 % of the samples shall exceed 43 organisms per 100 mL.

The goal of attaining water quality standards at the point of discharge is environmentally protective, and offers a practical means to identify and evaluate the effectiveness of control measures. In addition, this approach establishes clear objectives that can be easily understood by the public and individuals responsible for monitoring activities. Also, the goal of attaining standards at the point of discharge minimizes human health risks associated with exposure to pathogens because it does not consider losses due to die-off and settling that are known to occur.

VII.2 Allocations (WLAs) and Load Allocations (LAs)

Although, there are no permitted discharges of fecal coliform into Muddy Creek, direct storm water discharges from storm drainage systems do occur. Discharges from highway storm water pipes or channels are, by definition, point sources and are subject to the requirements of NPDES Phase II storm water permits. Therefore, a WLA set equal to the fecal coliform standard will be assigned to the portion of the storm water that discharges to surface waters via storm drains or channels.

WLAs and LAs to Muddy Creek are identified for all suspected sources in Table VII-1. Establishing WLAs and LAs that only address a dry weather bacteria sources would not ensure attainment of standards because the worst-case bacteria concentrations were found in wet weather during the summer months[7]. The primary wet weather point sources are storm water pipes and the Route 28 sluiceway; the non-point sources include diffuse storm water. It is noteworthy that the wet weather bacteria sources are not as significant a contribution to fecal coliform contamination as is commonly found in other areas of the state. The porous soils of this region do not support significant runoff from unpaved surfaces, with groundwater being the dominant pathway for rainwater to enter coastal waters The sandy soils greatly reduce the potential for bacteria contamination entering the estuary from residential property runoff and

[7] The highest geometric mean of all the samples was found at Station SM during the summer wet weather (253 cfu/100 mL). However, wet weather runoff was not found to be the dominant source in the upper portions of Muddy Creek.

failed septic systems. This is supported in the data for the upper portions of the creek where dry weather geometric means are higher than wet weather, likely due to nonpoint sources such as congregating wildlife and waterfowl in the fringing wetlands and other unidentified groundwater sources.

Table VII-1 presents the fecal coliform bacteria WLAs and LAs for the various potential source categories. Source categories representing discharges of storm water from distinct point sources (pipe or sluiceway) are set equal to the fecal coliform standard for SA waters in order to ensure that standards for shellfish harvesting can be met in the creek.

Table VII-1: Fecal Coliform Waste load Allocations (WLAs) and Load Allocations (LAs) for Muddy Creek

Potential Bacteria Sources	***WLA***	***LA***
	(organisms per 100 ml)	
Indirect Storm water Runoff Diffuse runoff from unpaved road way (Town Landing) Nonfunctional catch basins (Duck Marsh Lane)	NA	GM ≤ 14 10% ≤ 43
Flocks of waterfowl in winter, wildlife*	NA	NA
Direct Storm water Runoff Sluiceway at Route 28	GM ≤ 14 10% ≤ 43	NA
* Congregations of wildlife year round and waterfowl in the winter were observed at all stations. Given these are naturally occurring sources no allocation of fecal coliform is noted.		

A TMDL should provide a discussion of the magnitude of the pollutant reductions needed to attain the goal of water quality meeting the standards for human uses. Since accurate estimates of existing sources are generally unavailable, it is difficult to estimate the pollutant reductions for specific sources. For the illicit sources, such as failing septic systems, the goal is complete elimination (100% reduction). For regulated discharges, such as wet weather flow from storm water pipes, the goal is to meet the water quality standards at the end of the pipe. Overall wet weather bacteria load reductions can be estimated using typical storm water bacteria concentrations. Table VII-2 indicates that Station SM has the highest bacterial concentrations (geometric mean of 253 cfu/100 ml in wet weather during the summer sampling season) and reductions of up to 95% in fecal coliform loadings will be necessary. The principal suspected source of bacterial contamination is a sluiceway directing road runoff from the immediate section of Route 28 and the adjacent, albeit limited, commercial development.

Overall reductions needed to attain water quality standards can be estimated using the ambient fecal coliform data that are available. Using ambient data is beneficial because it provides more realistic estimates of existing conditions and the magnitude of cumulative loading to the surface waters. Table VII-2 presents the geometric mean of the samples taken as well as the reductions needed to meet the both aspects of the water quality standard for shellfish harvesting – that the geometric mean be no more than 14 cfu/100ml and that less than 10% of the samples exceed 43 cfu/100 ml.

The samples were separated by season (summer season is defined as May – October, winter season is November – April) and by level of precipitation (less than 0.25 inches was considered to be a dry weather event and greater than 0.25 inches a wet weather sample). Samples taken during the summer season were more likely to exceed the water quality standard. Therefore, summer season data for wet and dry weather has been examined separately as representative of worst-case scenario - the time period where the greatest reduction in bacterial concentration is needed. The elevated summer bacterial concentrations are likely due to the increased waterfowl activity and increased potency of storm water runoff from roadways. As indicated in Table VII-2, at stations that do not meet water quality standards, the necessary bacteria reductions range from a high of 95% (at Station SM) to 42% (at Station 1). Station 3 has moderate-high concentrations; an estimated reduction up to 78% is expected [8]. Bacterial concentrations in samples taken during the winter season were all within the water quality standard with the exception of Station SM, the Route 28 Bridge, where the geometric mean of 22 samples was 12 cfu/100ml but 23% exceeded 43 cfu/100ml.

Table VII-2: Estimates of Fecal Coliform Concentrations and Loading Reductions to the Muddy Creek

Station/ Season	Time Period (2)	1 cfu/100 ml	2 cfu/100 ml	3 cfu/100 ml	3A cfu/100 ml	SM Cfu/100 ml
Summer wet Geometric Mean (1)	1996-2003	24	9 (3)	63 (3)	9 (3)	253 (3)
% reduction		42%	0%	78%	0%	95%
Summer Dry Geometric Mean (1)	1996-2003	12	16	83 (3)	34(3)	65
% reduction		0%	12%	83%	59%	78%
Overall Summer Geometric Mean (1)	1985-1995 1996-2003	11 15	13 14	42 72 (3)	29 22	--- 70
% reduction		0% 7%	0%	67% 81%	52%/ 36%	--- 80%
Overall Winter Geometric Mean (1)	1985-1995 1996-2003	5 3	7 4	7 5	4 3	--- 12
% reduction		0%	0%	0%	0%	0%

(1) Geometric mean to be less than or equal to 14 organisms per 100 ml and no more than 10 % of the samples shall exceed 43 organisms per 100 ml.
(2) The Geometric Means for two discreet time periods can not be combined
(3) Too few data for accurate geometric mean (<5), but some samples exceeded either 14 or 43 cfu/100 ml

Units / Season (Station)	1 cfu/100 ml	2 cfu/100 ml	3 cfu/100 ml	3A cfu/100 ml	SM cfu/100 ml
Summer					
Data Range	1.5 – 90	2 - <90	18 - >246	2 - <90	<10 – 860
90% Observation	65	65	65	65	530
% Reduction	34%	34%	34%	34%	92%

[8] Concentrations at Station 2 and 3A generally meet or only slightly exceed water quality standards.

Winter Data Range 90% Observation **% Reduction**	0.85 – 128 33 0%	1.6 – 65 18 0%	0.85 – 65 30 0%	1.6 – 14 8.2 0%	<10 – 200 160 73%

The second part of the water quality standard for shellfish harvesting requires that no more than 10% of the samples exceed 43 cfu/100 ml. The 90% observation listed in Table VII-2 means that within the range of data collected for each station, 90% of the samples collected at that station fall below the stated value. For instance, data collected during the summer season at Station 1 ranged from 1.5 to 90 organisms per 100 mL with 90% of the samples having a concentration of 65 organisms per 100 ml. To meet the water quality criteria during the summer months, the 90% observation would have to be reduced to 43 organisms per 100 ml (or stated another way a reduction of 34% would be necessary). During the winter season, Station 1 data ranged from 0.85 – 128 organisms per 100 ml, with a 90% observation of 33 organisms per 100 ml. Even though individual samples showed elevated levels of bacteria, the water quality standard is met since less than 10% of the samples exceeded 43 organisms per 100 ml.

In summary, the highest bacterial concentrations in Muddy Creek are found at Station SM during wet weather of the summer season (geometric mean of 253 cfu/100 ml) and reductions of up to 95% in fecal coliform loadings will be necessary. The principal suspected source of bacterial contamination is a sluiceway directing road runoff from the immediate section of Route 28 and the adjacent commercial development. Samples taken during the summer season were always higher than the winter season and more likely to exceed the water quality standard. The necessary bacteria reductions in the summer months range from a high of 95% (at Station SM) to 42% (at Station 1). Station 3 has moderate-high concentrations; an estimated reduction up to 78% is expected. Concentrations at Station 2 and 3A generally meet or only slightly exceed water quality standards. The elevated summer bacterial concentrations are likely due to the increased waterfowl activity and increased potency of storm water runoff from roadways. Bacterial concentrations in samples taken during the winter season were all within the water quality standard with the exception of Station SM, the Route 28 Bridge, where the geometric mean of 22 samples was 12 cfu/100ml but 23% exceeded 43 cfu/100ml.

VII.3 Margin of Safety

For this analysis, margin of safety is implied. First, the TMDL does not account for mixing in the receiving waters and assumes that zero dilution is available. Realistically, influent water will mix with the receiving water and become diluted provided that the influent water concentration does not exceed the TMDL concentration. Second, the goal of attaining standards at the point of discharge does not account for losses due to die-off and settling that are known to occur with bacteria.

VII.4 Seasonal Variability

This TMDL recognizes that the concentration of bacteria, the pollutant of concern, is greater during the summer season. However, the WLAs and LAs for all known and suspected sources are set equal to the fecal coliform criteria independent of seasonal conditions. This will ensure the attainment of water quality standards regardless of seasonal and climatic conditions. Any controls that are necessary will be in place throughout the year, and, therefore, will be protective of water quality year round.

VIII. Conclusions and Recommendations

All bacterial indicators[9] showed the same response to season and to rain events. With the modest number of samples available for analysis, it is clear that summer bacterial inputs to Muddy Creek are higher than winter inputs especially in the more recent sampling period. In the recent 1996-2003 sampling period, the overall summer geometric mean in the water quality standards is slightly exceeded at Stations 1 downstream of Route 28 and Station 3A, but is significantly exceeded at Stations SM by the Route 28 culverts and at Station 3 at the head of Muddy Creek in the vicinity of adjacent wetlands (see Table V-2).[10] There is indication of a dilution (and die-off) of bacteria flowing downstream from likely source areas to the mouth of Muddy Creek at Pleasant Bay and winter inputs are all below the standard with the exception of Station SM which may be due to an input of additional sources.

Wet inputs during the winter were equal to or slightly higher than dry inputs and both were significantly less than summer wet and dry loads. There is clearly an enhancement of bacterial inputs after summer rain events, particularly in the region associated with Route 28. The elevated summer bacterial concentrations are likely the result of increased waterfowl flocking and roosting particularly associated with the fringing wetlands in the upper basin as well as the increased potency of storm water runoff from roadways. These data support the conclusion of higher contamination in the summer months as opposed to winter months and that the seasonal opening to shellfish harvest is protective. In addition, these data indicate that surface water runoff is an important pathway for bacterial entry primarily from the small-scale developed area along Route 28 and, to a lesser degree, from roads adjacent to the upper basin. It is likely that these sources will need to be addressed further and managed for the restoration of Muddy Creek resources.

The most likely sources of fecal coliform bacteria are waterfowl and storm water runoff from roadways and other paved surfaces directly abutting or, in the case of Route 28, crossing Muddy Creek. Review of current land-use within the watershed indicates only a slight potential for anthropogenic bacterial inputs, principally along the Chatham shore of the Muddy Creek upper basin and roadway runoff near Route 28 into the lower basin. The Harwich shore is predominately undeveloped with lands that are either privately owned with a Conservation Restriction or Public Service lands (presumably managed by the Harwich Conservation Commission) that is likely to harbor wildlife, another likely source of bacteria. Chatham Conservation Foundation also protects certain land along the Chatham shores of Muddy Creek. In addition, this region has generally porous soils and does not support significant runoff from unpaved surfaces, with groundwater being the dominant pathway for rainwater to enter coastal waters. These factors greatly reduce the potential for bacterial contamination entering the estuary from residential property runoff and failed septic systems. There are no CSO inputs due to the absence of municipal sewers near the Creek and no discharge from boats due to the shallow depth.

[9] This includes fecal coliform and the *E. coli* and *Enterococcus* collected at Station SM.
[10] Data from 1985-1995 show a similar trend although summer inputs are not as high. Water quality standard is exceeded only at Stations 3A and 3.

Further monitoring should focus on the road runoff from the four areas noted in the DMF shellfish surveys - Route 28, Chatham Town Landing, the Sugar Hill Drive area, and Duck Marsh Lane. In addition, bacterial entry through the stream at the head of the estuary should be determined along with wildlife inputs, primarily in the upper basin, where the wetlands are located. Focused sampling in these areas should target management of bacterial sources in runoff and stream inflow and confirmation of the importance of wildlife to overall contamination. Bacterial testing relative to targeting waterfowl as a potential source of contamination should consider analytical test to differentiate anthropogenic versus non-anthropogenic sources of bacterial contamination for definitive proof that waterfowl are the source. Finally, alterations of tidal exchange that reduce the transport of bacteria (and nitrogen) from the upper to the lower basin should be evaluated relative to long-term restoration of this resource.

As discussed in Section VI (*Circulation and Nitrogen Attenuation in Muddy Creek*) potential modification of tidal exchange between Upper Muddy Creek (up-gradient of the historic location of the dike) and lower Muddy Creek, such that upper basin residence time is increased, could have positive effects on both increasing nutrient attenuation in the upper portion of the system and decreasing bacterial contamination to Lower Muddy Creek. As described in the Massachusetts Estuaries Project Nutrient Threshold Report for the Town of Chatham Embayment Systems, one of the modeled nutrient management alternatives describes converting Upper Muddy Creek to a permanent freshwater pond by placing a fish ladder in the existing dike. In so doing, it is possible that the higher water residence time resulting from the proposed impoundment could promote die off of bacteria prior to discharge to Lower Muddy Creek. This potential reduction in bacteria contamination coming from the proposed freshwater pond (Upper Muddy Creek) may result in lower overall bacterial concentrations at sampling Station 3 and further downstream towards the mouth.

VIII.1 TMDL Implementation Plan

The objective of this TMDL is to specify reductions in bacterial pollutant loads so that the water quality standards for aquatic life and shellfish harvesting can eventually be met. It is recognized by the DMF observations that Muddy Creek and the fringing wetlands in the upper basin are a haven for wild animals and waterfowl. Concentrations of wild animals are a natural source of bacteria that cannot be regulated. That being said, management would be necessary for any human activity that could be causing wildlife to congregate such as feeding waterfowl. Existing impervious areas and any increase in impervious cover will be targeted for runoff controls so that wet weather loads do not exceed current contributions from this source. MassDEP specifically encourages the following measures.

- ✓ Town of Chatham should evaluate and construct possible improvements to the Town Landing (at Station 1) to control roadway runoff such as paving and installing storm water infrastructure (Germano, 2001).

- ✓ Identify and notify the owner of Duck Marsh Lane, a private way, that the 3 catch basins exposed on an eroding bank of Muddy Creek are no longer functional and need to be replaced (Sherwood, 1995 and Germano, 2001).

- ✓ Town of Harwich should take appropriate corrective measures to remediate the discharge from the storm drain at the end of Sugar Hill Drive and the adjacent roads that terminate near the shores of Muddy Creek. This may include additional water quality sampling to determine potential sources of bacteria pollution.

- ✓ The Massachusetts Highway Department should determine the Route 28 roadway drainage area discharging to Muddy Creek and install best management structures and/or operational practices to the maximum extent practicable. At a minimum, drainage must be improved to meet the water quality standard for bacteria in SA waters. Given this is a waterway with an approved TMDL, the MHD must meet the requirements of EPA's NPDES General Permit for Stormwater Discharges from Small MS4s (Phase II), Part I D(1-4), as it pertains to approved TMDLs.

- ✓ Investigate, design and construct the most appropriate measure(s) to improve tidal flushing that may include removing the sand bar that has accumulated downstream of the Route 28 culvert.

- ✓ Further water quality monitoring is needed near Station 3 in the upper basin to determine the bacteria input from the stream at the head of Muddy Creek, and the adjacent residential areas and wildlife inputs from both the Harwich and Chatham banks.

- ✓ Bacterial testing that targets waterfowl as a potential source of contamination should consider analytical tests to differentiate anthropogenic from non-anthropogenic sources of bacterial contamination for definitive proof that waterfowl are the source.

VIII.2 TMDL Monitoring

Long term monitoring at established ambient sampling stations will be important to assess the effectiveness of BMPs and whether or not standards are attained. The Massachusetts Division of Marine Fisheries has a well established and effective shellfish monitoring program that provides quality assured data for the inlet of Muddy Creek up to Route 28 (Area 58.1). Each growing area must have a complete sanitary survey every twelve years, a triennial evaluation every three years and an annual review in order to maintain a shellfish harvesting classification with the exception of those areas already classified as Prohibited (such as Muddy Creek Area 58.2). The National Shellfish Sanitation Program establishes minimum requirements for sanitary surveys, triennial evaluations, annual reviews and annual fecal coliform water quality monitoring and includes identification of specific sources and assessment of the effectiveness of controls and attainment of standards.

The regular monitoring of the DMF does not preclude efforts by other groups to monitor on a more frequent basis, as was exemplified by the Town of Chatham Water Quality Department sampling between 1996 through 1998. MassDEP will work with such groups to ensure all data are compatible and comparable. The DMF data in combination with other qualified group's data will be used to evaluate progress, and will serve as a baseline to evaluate future controls resulting from the implementation of a comprehensive storm water management, further source identification efforts, and other implementation activities identified in this TMDL.

As part of the Storm Water Phase II Rule, Chatham and Harwich are required to identify any illicit discharges from their storm drains and eliminate them. Wet weather data of discharges from storm drains is also necessary to further identify wet weather sources of bacteria within the drainage systems (e.g., in-system overflows between the sanitary sewer and the storm drains).

VIII.3 Reasonable Assurances

Reasonable assurances that the TMDL will be implemented include: a history of voluntary actions taken by local officials, citizen organizations and the general public; the availability of financial incentives; the existing, competitive grant and loan programs; as well as enforcement of current regulations for pollution control at the local, state and federal level. Storm water NPDES permit coverage will address discharges from municipal owned storm water drainage systems. Enforcement of regulations controlling non-point discharges include local enforcement of the states Wetlands Protection Act and Rivers Protection Act; Title 5 regulations for septic systems and various local regulations including zoning regulations. Financial incentives include Federal monies available under the 319 NPS program and the 604 and 104b programs, which are provided as part of the Performance Partnership Agreement between MassDEP and the USEPA. Additional financial incentives include state income tax credits for Title 5 upgrades, and low interest loans for Title 5 septic system upgrades through municipalities participating in this portion of the state revolving fund program.

IX. Public Participation

A public meeting was held at the Chatham Town Offices on November 29, 2004 to present the findings and receive comments on the draft Bacteria TMDLs for Frost Fish and Muddy Creeks. Approximately 23 people were in attendance, including representatives from USEPA, MassDEP-SERO and the Town of Chatham. A copy of the attendance list for the meeting is attached. Additionally, the meeting was telecast on the local public access television cable channel for Chatham.

The following is a summary of the meeting, the questions asked, and responses to the comments raised.

Presentations:
Bob Duncanson, Town of Chatham Health & Environment, began the meeting by introducing the presenters and describing the purpose of the public meeting.
Steve Halterman, MassDEP, presented a brief overview of the project.
Russell Isaac, MassDEP, presented an overview of the TMDL process and background information on bacteria.
Alice Rojko, MassDEP, presented the results of the Frost Fish Creek TMDL report including a summary and analysis of the data with recommendations for future action.
Andrea Langhauser, MassDEP, presented the results of the Muddy Creek TMDL report that also included a summary and analysis of the data with recommendations for future action.
Information on grants and technical assistance available at the state level to assist with implementation efforts was also presented.

Handouts provided at the meeting:
Printout of power point presentation for Frost Fish and Muddy Creeks
Report - Draft Bacteria Total Maximum Daily Load for Frost Fish Creek Chatham, Massachusetts
Report - Draft Bacteria TMDL for Muddy Creek
Information Sheet – TMDLs Another Step to Cleaner Waters; 604(b) grant announcement

Questions and Responses:
The questions that arose during the public meeting are subsumed in the following responses .

Question – Since there are high bacteria counts in areas near wildlife and there are also storm drains in those areas, how can we differentiate the impact of waterfowl, from other sources, on bacteria counts?

> **Response –** In order to determine the impact of these different sources, there needs to be a way to differentiate the sources of bacteria. One technique that can be used as a screening tool is analyzing for Fluorescent Whitening Agents/Optical Brighteners. This testing is a way of determining whether or not laundry detergents (which potentially indicate the presence of other human wastes e.g. fecal bacteria) are entering a waterbody either through a direct discharge or after traveling through the ground via a septic system. Ciba-Geigy Specialty Chemicals Corp., the principal chemical manufacturer of these

substances, named its products as FWA-1, FWA-2, FWA-4, OB-1, and OB-2. All are fluorescent and are added to laundry detergents and papers to make these materials look whiter and brighter. In areas of elevated bacterial counts, the presence of optical brighteners/fluorescent whitening agents helps establish the link to humans rather than to domestic or wildlife animals. The chemical analysis of water samples for FWAs/OBs by high-performance liquid chromatography with a fluorescent detector definitively establishes the presence of these individual compounds and thus the likely presence of human wastewater. However, simple measurement of gross fluorescence alone may produce false positive for human wastewater since there are naturally occurring substances in watersheds not related to human wastewater that fluoresce (e.g., certain aquatic organisms). The best approach would be to first screen samples in the field for gross fluorescence, and if detected, then collect samples for laboratory HPLC-FL analysis to confirm the presence of individual FWAs/OBs.

Other methods under development to differentiate the sources of bacteria are genetic fingerprinting including DNA sequencing and ribotyping. However, these microbial source tracking (MST) methods are not as definitive as had been anticipated and their accuracy in field-study situations has been questioned because of various problems associated with the target organisms, level of complexity and stability of markers used. Recent research has demonstrated that fecal source library-dependent whole genome DNA fingerprinting methods for E. coli (e.g., ribotyping, rep-PCR, etc.) are unable to accurately determine the animal source of fecal waste. On the other hand, there is growing evidence that library-independent methods relying on the detection of individual source-specific genetic markers in fecal bacteria can accurately determine the source of fecal waste. The Wall Experiment Station is currently validating two human-marker polymerase-chain-reaction (PCR) assays for the detection of fecal bacteria from human sources using human and non-human fecal samples from Massachusetts sources. One of the PCR assays is a library-independent method involving the detection of human-specific rDNA markers in fecal Bacteroidetes. Fecal Bacteroidetes is a group of anaerobic bacteria present in high concentrations in human and other animal feces that has shown promise as a source-tracking indicator of human fecal contamination. The other PCR assay, also a library-independent method, involves the detection of a human-specific genetic marker (i.e., genes encoding for the enterococcal surface protein, esp, a putative virulence factor) in Enterococcus faecium, a current fecal contamination indicator. Once validated with Massachusetts fecal samples, these two human-marker PCR assays will allow us to identify the presence of human fecal pollution and associated risks from human enteric pathogens in Massachusetts watersheds.

A joint government-academic researcher meeting sponsored by USEPA and USGS was organized to validate the use of current microbial source tracking (MST) methods. As a result the U.S. EPA National Exposure Research Laboratory in Cincinnati is actively working on a comprehensive microbial source tracking (MST) guidance document that addresses the strengths and weaknesses of all MST methods currently in use. The best analytical approach for microbial source tracking will likely involve several validated testing methods combined to demonstrate the presence or absence of human wastewater (e.g., detection of human-specific genetic markers in fecal bacteria as well as detection of

FWAs/OBs, caffeine, and/or pharmaceutical substances used exclusively in human medicine). Until the science is further developed and guidance is provided, caution should be exercised in the use of these methods.

Question - The data that were collected on Muddy Creek indicate that there is a spike in the level of bacteria at Route 28 which may be caused by runoff. Is it possible to measure this?

Response – The level of fecal coliform triples after a rain event at Route 28 and this has not been observed at the other stations on Muddy Creek. The next steps are to define the contributing area of the storm drain and collect additional stormwater samples with the ultimate goal of identifying and eliminating potential bacterial sources that may be contributing to the problem.

Question – The Division of Marine Fisheries (DMF) uses Most Probable Number (MPN) while other samplers have used Membrane Filtration (MF). Can the results of these different techniques be compared?

Response – Shellfish closures are based on MPN, however, the shellfish program does accept data based on the MF technique. In the SMAST Technical Reports, the data from the two methods were kept separate in the statistical analysis. The synthesis bar graphs contain separately identified values so it is possible to easily identify the source of the data. These synthesis graphs illustrate the spatial trends and wet/dry weather effects on fecal coliform levels. This is important, since the difference in methods should not change the general bacterial distribution and trends, but rather can result in different absolute numbers. In addition, the individual data sets are also discussed in the report as to what they alone show and how they fit into the overall pattern.

Question – What happens if it is determined that wildlife is the cause of the bacteria problem?

Response –Since the presence of wildlife is naturally occurring in Frost Fish and Muddy Creeks, the TMDL reports are not recommending any implementation measures be taken to reduce the elevated bacteria levels from wildlife. Shellfishing areas would have to remain closed, however, until the bacteria levels meet water quality standards for harvesting shellfish.

Question – Will this type of TMDL process be applied to other waterbodies that may have bacteria problems? In particular, are there any plans for Cockle Cove Creek?

Response – Currently, MassDEP is focusing on waterbodies that are on the Integrated List of Impaired Waters. Cockle Cove Creek is not on the Integrated List at this time but this does not preclude the town from taking action to locate and correct sources of bacteria that may be present.

Questions presented to MassDEP in letter dated October 15, 2004 from Robert Duncanson, Director of Health and Environment, Town of Chatham

Question – It is unclear what the expectation is in doing testing (i.e. Bacterial Source Tracking) to differentiate anthropogenic (human induced) versus non-anthropogenic sources (naturally occurring, i.e. waterfowl/wildlife). The current standards, for both shellfish harvesting and swimming, do not make any distinction from a regulatory perspective. This has been a source of debate for a number of years, i.e. is the risk any different based on the source of the fecal coliform and can it be quantified? While this type of testing can help target remediation efforts, if the source is "natural" and cannot be remediated the water quality goal may never be achievable.

> **Response –** From a practical standpoint differentiating human from natural sources will not in and of itself change any decision on whether or not the shellfish beds can be opened. The information provided from this type of bacterial source tracking will, however, be useful in identifying what measures, if any, would be appropriate to remediate the bacterial contamination, particularly those that are human induced. Although there is no regulatory significance as it may relate to shellfishing there is some regulatory difference under the state Water Quality Standards and TMDL programs. The state Water Quality Standards set goals for the uses of the waters of the Commonwealth and are intended to protect those uses from degradation caused by point and non-point anthropogenic sources. The Standards however at 314 CMR 4.03 (5) state "Excursions from criteria due to solely natural conditions shall not be interpreted as violations of standards and shall not affect the water use classifications adopted by the Department". In addition, a TMDL must be developed for impaired waters where those impairments are caused by anthropogenic sources but not if the sole source is a natural condition. The point of the above is to illustrate that there is some regulatory significance to demonstrating if the sources are of anthropogenic origin or not. It is possible that if the anthropogenic sources are eliminated the water in question may meet some or all of their designated uses.

Question – It is unclear why the swimming standard is being applied to either Frost Fish Creek or Muddy Creek. Neither presently have any swimming beaches nor are they used for swimming purposes due to lack of access, fringing marsh, etc. Neither area would seem to meet the definition of "Bathing Water" in 310 CMR 445.010.

> **Response –** Although there is no swimming actually taking place under current conditions, the MA Water Quality Standards define both Creeks as Class SA waters and have designated the water quality goals as excellent habitat for fish, other aquatic life and wildlife and for primary and secondary contact recreation. Given this they must be protected for those uses. Data on *Enterococci* was collected by SMAST because it is thought to be a better indicator of human health risk from pathogens than fecal coliform bacteria. Currently there is no standard for *Enterococci* for shellfishing areas thus the DPH swimming standard of 104 *Enterococci*/100 mL was utilized in analyzing the data. In order to safe guard the quality and value of a water resource and protect public health, it is imperative that the water resource meet surface water quality standards. At the very minimum, Frost Fish Creek and Muddy Creek should be meeting the swimming standard even though there are no swimming beaches. The ultimate goal is to protect human health and return these waters to their most beneficial use as a shellfish resource.

Question – Discuss the rationale for using 0.25 inches as the cutoff between wet and dry weather.

> **Response –** This is a commonly used standard since it has been determined that the potential for runoff is generally relatively low for anything less than 0.25 inches.

Question – The use of geometric means for single samples is inappropriate. It may also be useful to provide the range of the data.

> **Response –** It has been noted in the tables where the value represented is only one data point and where too few data were available to calculate an accurate geometric mean. Data tables are included in appendices to the final reports.

Question - The role of tide and its affect on bacterial levels at the various stations is not adequately addressed.

> **Response –**The affects of changing water circulation patterns in the Frost Fish Creek and Muddy Creek systems on nutrient attenuation and migration of bacterial contamination are briefly summarized in the bacteria TMDL reports under the Evaluation of Freshwater Flow and Nitrogen Attenuation section. It was found that the tidal inlets (culverts/weir) significantly restrict the tidal exchange in these systems and hold water in the basin during low tide. Increasing the tidal exchange would have the affect of transferring bacterial contamination more readily to receiving waters such as Ryder Cove. The most effective way to manage bacterial contamination is by reducing the inputs to Frost Fish Creek and Muddy Creek rather than by increasing the outputs through tidal exchange. Hydrodynamic and water quality modeling was completed for Frost Fish and Muddy Creek as part of a comprehensive nutrient analysis and threshold development effort undertaken by the Massachusetts Estuaries Project (MEP) and detailed information on this issue is presented in the MEP Chatham Nutrient TMDL Technical Report.

Transmitted Via E-mail from Michael Hill – EPA New England, Office of Ecosystem Protection

Question – MassDEP should consider adding the water quality standard for swimming to these TMDLs and making recommendations in the TMDL Implementation section regarding swimming and recreational activities.

> **Response –** The reports include the water quality standard for swimming in the Water Quality Standards Section. Neither Frost Fish Creek nor Muddy Creek have swimming beaches and are not used for swimming purposes because there is relatively little access due to fringing marsh, etc. Both creeks are navigable, so it is reasonable to assume there could be direct human contact with the water. As pointed out in the response above, at the very minimum, Frost Fish Creek and Muddy Creek should be meeting the swimming standard in order to protect human health.

Question - EPA agrees with MassDEP that the role of wildlife needs to be further investigated. However, are there other actions related to controlling wildlife that can be recommended right now? For example, is there anyway to discourage the birds from congregating on the power lines -- such as installing fishing line above the lines to prevent roosting?

> **Response –** The technical reports for Frost Fish and Muddy Creeks did not present detailed information on the species of wildlife that were present. In order to account for the bacteria load from these sources an evaluation of the wildlife present in the area must be made. This will provide for a better understanding of bacteria sources and in turn a better assessment of water quality management alternatives. Once this has been accomplished, the Department of Fish and Game should be consulted for control methods.
>
> Cormorants and other seabirds have been observed on the transmission lines crossing Muddy Creek by the water quality monitors and authors of the technical and TMDL reports. The 2001 Shellfish Survey by MA Division of Marine Fisheries noted large flocks of sea ducks (200+) offshore during the winter months but concluded that water sampling did not indicate any adverse impact on water quality from the presence of these animals during the open harvest season.

Transmitted electronically from Henry Barbaro - MassHighway on December 15, 2004

Question Both reports have comments that pertain to MassHighway operations. Unfortunately, MassHighway has not been provided the opportunity to coordinate with MassDEP in developing these TMDL requirements. As sister State agencies, coordination is absolutely necessary in order to develop requirements that MassHighway can comply with. For example, requiring stand-alone drainage upgrades to roadways that are not programmed for improvements simply is not practicable considering MassHighway's construction schedule and budget.

> **Response –**Meetings have been held between MassHighway and MassDEP over the last several years for the purpose of coordinating the objectives of both agencies. The purpose of the draft TMDL reports is to elicit comments and it also presents an excellent opportunity for coordination.

Question – Muddy Creek TMDL Implementation Plan (p.51) – "The Massachusetts Highway Department should determine the Route 28 roadway drainage area discharging to Muddy Creek and install appropriate best management structures or operational practices" should read:
"As part of the next Route 28 reconstruction project, the Massachusetts Highway Department should determine the Route 28 roadway drainage area discharging to Muddy Creek and install practicable best management structures, or operational practices, as warranted by the magnitude of contaminant loading to Muddy Creek."

> **Response –** Wording has been changed in the Muddy Creek report in the following manner: "The Massachusetts Highway Department should determine the Route 28 roadway drainage area discharging to Muddy Creek and install best management

structures and/or operational practices to the maximum extent practicable with a goal of meeting the water quality standard for bacteria in SA waters. Given this is a waterway with an approved TMDL, the MHD must meet the requirements of EPA's NPDES General Permit for Stormwater Discharges from Small MS4s (Phase II), Part I D(1-4), as it pertains to approved TMDLs." MassDEP has not deferred to the Route 28 reconstruction project since we do not have any information about the extent or the time schedule for it. MassDEP also suggests that the Massachusetts Highway Department work with the town of Chatham to work out a reasonable schedule for these activities.

Question – Frost Fish Creek TMDL Implementation (p.49) – "The Massachusetts Highway Department should work with the Town to mitigate the Route 28 roadway drainage in the immediate area by determining any sources and identifying appropriate Best Management structures and operational practices that should be implemented." should read:
"As part of the next Route 28 reconstruction project, the Massachusetts Highway Department should work with the Town to mitigate the Route 28 roadway drainage in the immediate area by installing practicable best management structures, or operational practices, as warranted by the magnitude of contaminant loading to Frost Fish Creek."

Response – Wording has been changed in the Frost Fish Creek report in the following manner: "The Massachusetts Highway Department should determine the Route 28 roadway drainage area discharging to Frost Fish Creek and install best management structures and/or operational practices to the maximum extent practicable with a goal of meeting the water quality standard for bacteria in SA waters. Given this is a waterway with an approved TMDL, the MHD must meet the requirements of EPA's NPDES General Permit for Stormwater Discharges from Small MS4s (Phase II), Part I D(1-4), as it pertains to approved TMDLs." MassDEP has not deferred to the Route 28 reconstruction project since we do not have any information about the extent or the time schedule for it. MassDEP also suggests that the Massachusetts Highway Department work with the town of Chatham to work out a reasonable schedule for these activities.

Participants at the Frost Fish Creek and Muddy Creek TMDL meeting at the Chatham Town Offices.

Commonwealth of Massachusetts
Executive Office of Environmental Affairs
Department of Environmental Protection
Division of Watershed Management, 627 Main Street, Worcester, MA 01608

MEETING ATTENDANCE

Meeting: Bacteria TMDL - Muddy & Frost Fish Creeks
Presenters: A Roiko A Langhauser
Date: 11/29/04 Location: Chatham Town Offices

Name	Affiliation/Address	Phone/Email
Terry Campbell	Stearns & Wheler LLC	tcampbell@stearnswheler.com
Ron Bergman	44 Parliament	[illegible] @ hotmail.c
Fred Jensen	Wastewater CAC	fredjensen@comcast.net
Lynne Pleffner	Planning Board - Chatham	lpleffner@comcast.net
Tim [illegible]	Cape Cod [illegible]	[illegible]
Robert Duncanson	Town of Chatham	508-945-5165
Brian Howes	SMAST	508-999-6316
Brian Dudley	DEP-SERO	508-946-2753
Russ Isaac	DEP-DWM	508-767-2876
Steve Halterman	DEP-DWM	508-849-4012
Andrea Langhauser	DEP-DWM	617-348-4084
Alice Rojko	DEP-DWM	508-849-4001

Commonwealth of Massachusetts
Executive Office of Environmental Affairs
Department of Environmental Protection
Division of Watershed Management, 627 Main Street, Worcester, MA 01608

MEETING ATTENDANCE

Meeting: Nov 29th 2007 Bacteria TMDL Muddy + Frost Fish

Presenters: A. Rojko, A. Langhauser

Date: 11-29-07 Location: Chatham Town Hall

Name	Affiliation/Address	Phone/Email
William G. Redfield	Town of Chatham Water & Sewer	508-945-5150
[illegible]	Stearns and Wheler	508-778-1707
Frank Sampson	Harwich WQTF	508 430 1915
Paul P. [illegible]	Chatham BOH	508-945-5575
[illegible]	BOH	508-945-2611
Mike Hill	USEPA	617 918 1398
Martha Stone	Friends of Chatham Waterways	508-945-2716
Chuck Pollard	CAC	508 945 4665
Bob [illegible]	CAC	508 945-7746
John [illegible]	CAC	508-945-7475
Walter Butler	FCW, Chatham	508-945-0936

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APPENDIX A

Raw Data from Stations within Muddy Creek 1985 – 2003

Date	Station	Location	Collected By	fc/100 ml
4/29/1985	1		DMF	1.5
11/20/1985	1		DMF	33
3/31/1986	1		DMF	3.6
7/17/1986	1		DMF	5.8
12/22/1986	1		DMF	128
4/9/1987	1		DMF	1.7
7/6/1987	1		DMF	14
9/30/1987	1		DMF	41
11/9/1987	1		DMF	8.2
4/20/1988	1		DMF	3.6
8/3/1988	1		DMF	11
9/21/1988	1		DMF	8.2
11/15/1988	1		DMF	14
1/30/1989	1		DMF	0.85
2/15/1989	1		DMF	0.85
3/30/1989	1		DMF	30
4/20/1993	1		DMF	5.8
4/28/1993	1		DMF	5.8
5/26/1993	1		DMF	1.6
7/14/1993	1		DMF	5.8
8/11/1993	1		DMF	8.2
9/23/1993	1		DMF	64
11/8/1993	1		DMF	1.6
12/20/1993	1		DMF	3.6
3/21/1994	1		DMF	1.6
4/19/1994	1		DMF	1.6
5/17/1994	1		DMF	3.6
6/14/1994	1		DMF	1.7
7/26/1994	1		DMF	65
9/19/1994	1		DMF	65
9/26/1994	1		DMF	3.6
10/18/1994	1		DMF	18
11/21/1994	1		DMF	23
12/28/1994	1		DMF	1.7
3/20/1995	1		DMF	4
4/25/1995	1		DMF	18
5/23/1995	1		DMF	1.9
9/27/1995	1		DMF	51
12/11/1995	1		DMF	18
1/29/1996	1		DMF	2
1/29/96	1	RTE 28 BRIDGE	DMF	2
3/20/96	1	RTE 28 BRIDGE	DMF	14
3/27/1996	1	Mouth, Town Landing	R. Duncanson	<2
4/22/96	1	RTE 28 BRIDGE	DMF	1.9
4/24/1996	1	Mouth, Town Landing	R. Duncanson	4
5/23/96	1	RTE 28 BRIDGE	DMF	1.9
6/6/1996	1	Mouth, Town Landing	R. Duncanson	2

Date	Station	Location	Collected By	fc/100 ml
6/18/1996	1	Mouth, Town Landing	R. Duncanson	22
6/19/96	1	RTE 28 BRIDGE	DMF	14
7/2/1996	1	Mouth, Town Landing	R. Duncanson	71
7/16/1996	1	Mouth, Town Landing	R. Duncanson	90
9/23/96	1	RTE 28 BRIDGE	DMF	36
10/1/96	1	RTE 28 BRIDGE	DMF	14
10/23/96	1	RTE 28 BRIDGE	DMF	8
2/24/97	1	RTE 28 BRIDGE	DMF	1.9
3/19/97	1	RTE 28 BRIDGE	DMF	1.9
4/30/97	1	RTE 28 BRIDGE	DMF	4
9/23/97	1	RTE 28 BRIDGE	DMF	4
10/13/97	1	RTE 28 BRIDGE	DMF	1.9
12/10/97	1	RTE 28 BRIDGE	DMF	2
1/7/98	1	RTE 28 BRIDGE	DMF	50
2/23/98	1	RTE 28 BRIDGE	DMF	1.9
3/26/98	1	RTE 28 BRIDGE	DMF	1.9
4/29/98	1	RTE 28 BRIDGE	DMF	1.9
6/16/1998	1	Mouth, Town Landing	Duncanson	>50
6/17/1998	1	Mouth, Town Landing	Duncanson	50
6/18/1998	1	Mouth, Town Landing	Duncanson	22
9/29/98	1	RTE 28 BRIDGE	DMF	8
10/27/98	1	RTE 28 BRIDGE	DMF	22
12/28/98	1	RTE 28 BRIDGE	DMF	1.9
1/26/99	1	RTE 28 BRIDGE	DMF	14
2/9/99	1	RTE 28 BRIDGE	DMF	1.9
3/8/99	1	RTE 28 BRIDGE	DMF	11
4/7/99	1	RTE 28 BRIDGE	DMF	1.9
5/20/99	1	RTE 28 BRIDGE	DMF	28
6/3/99	1	RTE 28 BRIDGE	DMF	28
11/22/99	1	RTE 28 BRIDGE	DMF	1.9
12/13/99	1	RTE 28 BRIDGE	DMF	2
3/27/00	1	RTE 28 BRIDGE	DMF	1.9
4/25/00	1	RTE 28 BRIDGE	DMF	1.9
5/10/00	1	RTE 28 BRIDGE	DMF	51
6/19/00	1	RTE 28 BRIDGE	DMF	6
9/6/00	1	RTE 28 BRIDGE	DMF	28
10/2/00	1	RTE 28 BRIDGE	DMF	1.9
10/17/00	1	RTE 28 BRIDGE	DMF	14
10/31/00	1	RTE 28 BRIDGE	DMF	51
11/16/00	1	RTE 28 BRIDGE	DMF	50
12/4/00	1	RTE 28 BRIDGE	DMF	4
1/9/01	1	RTE 28 BRIDGE	DMF	1.9
2/7/01	1	RTE 28 BRIDGE	DMF	4
5/1/01	1	RTE 28 BRIDGE	DMF	1.9
5/16/01	1	RTE 28 BRIDGE	DMF	22
8/7/01	1	RTE 28 BRIDGE	DMF	51
11/27/2001	1			8
1/9/2002	1			1.9
2/19/2002	1			1.9
4/3/2002	1			2

Date	Station	Location	Collected By	fc/100 ml
5/8/2002	1			36
11/19/2002	1			1.9
1/15/2003	1			1.9
3/13/2003	1			1.9

Date	Station	Location	Collected By	fc/100 ml
4/29/1985	2		DMF	9.1
11/20/1985	2		DMF	7.8
3/31/1986	2		DMF	18
7/17/1986	2		DMF	5.8
4/9/1987	2		DMF	5.8
4/20/1993	2		DMF	3.6
4/28/1993	2		DMF	8.2
5/26/1993	2		DMF	11
7/14/1993	2		DMF	8.2
8/11/1993	2		DMF	18
9/23/1993	2		DMF	64
11/8/1993	2		DMF	5.8
12/20/1993	2		DMF	1.7
3/21/1994	2		DMF	1.6
4/19/1994	2		DMF	14
5/17/1994	2		DMF	14
6/14/1994	2		DMF	5.8
7/26/1994	2		DMF	14
9/19/1994	2		DMF	65
9/26/1994	2		DMF	3.6
10/18/1994	2		DMF	65
11/21/1994	2		DMF	65
12/28/1994	2		DMF	30
3/20/1995	2		DMF	2
4/25/1995	2		DMF	2
5/23/1995	2		DMF	2
12/11/1995	2		DMF	18
3/20/96	2	ARBUTUS TRAIL	DMF	4
3/27/1996	2	end of Arbutus Trail	R. Duncanson	<2
4/22/96	2	ARBUTUS TRAIL	DMF	1.9
4/24/1996	2	end of Arbutus Trail	R. Duncanson	14
5/23/96	2	ARBUTUS TRAIL	DMF	2
6/6/1996	2	end of Arbutus Trail	R. Duncanson	2
6/18/1996	2	end of Arbutus Trail	R. Duncanson	50
7/2/1996	2	end of Arbutus Trail	R. Duncanson	29
7/16/1996	2	end of Arbutus Trail	R. Duncanson	<90
9/23/97	2	ARBUTUS TRAIL	DMF	50
10/13/97	2	ARBUTUS TRAIL	DMF	2
12/10/97	2	ARBUTUS TRAIL	DMF	1.9
1/7/98	2	ARBUTUS TRAIL	DMF	14
2/23/98	2	ARBUTUS TRAIL	DMF	1.9
3/26/98	2	ARBUTUS TRAIL	DMF	11
4/29/98	2	ARBUTUS TRAIL	DMF	11
12/28/98	2	ARBUTUS TRAIL	DMF	2
2/9/99	2	ARBUTUS TRAIL	DMF	1.9
3/8/99	2	ARBUTUS TRAIL	DMF	6
4/7/99	2	ARBUTUS TRAIL	DMF	11
5/20/99	2	ARBUTUS TRAIL	DMF	50

Date	Station	Location	Collected By	fc/100 ml
7/17/1986	3		DMF	30
4/9/1987	3		DMF	3.6
7/6/1987	3		DMF	18
9/30/1987	3		DMF	41
4/20/1988	3		DMF	5.8
8/3/1988	3		DMF	30
9/21/1988	3		DMF	64
11/15/1988	3		DMF	30
1/30/1989	3		DMF	3.6
2/15/1989	3		DMF	0.85
3/30/1989	3		DMF	23
4/28/1993	3		DMF	65
5/26/1993	3		DMF	64
7/14/1993	3		DMF	23
8/11/1993	3		DMF	65
9/23/1993	3		DMF	65
11/8/1993	3		DMF	5.8
12/20/1993	3		DMF	3.6
3/21/1994	3		DMF	1.6
4/19/1994	3		DMF	11
5/17/1994	3		DMF	65
3/27/1996	3	end of Sugar Hill Drive	R. Duncanson	<2
4/24/1996	3	end of Sugar Hill Drive	R. Duncanson	28
6/6/1996	3	end of Sugar Hill Dr.	R. Duncanson	22
6/18/1996	3	end of Sugar Hill Drive	R. Duncanson	28
7/2/1996	3	end of Sugar Hill Drive	R. Duncanson	>246
7/16/1996	3	end of Sugar Hill Drive	R. Duncanson	180

Date	Station	Location	Collected By	fc/100 ml
9/23/1993	3A		DMF	65
11/8/1993	3A		DMF	8.2
12/20/1993	3A		DMF	3.6
3/21/1994	3A		DMF	1.6
4/19/1994	3A		DMF	14
5/17/1994	3A		DMF	64
6/14/1994	3A		DMF	18
7/26/1994	3A		DMF	18
9/19/1994	3A		DMF	65
9/26/1994	3A		DMF	18
10/18/1994	3A		DMF	41
11/21/1994	3A		DMF	8.2
12/28/1994	3A		DMF	1.7
3/20/1995	3A		DMF	1.9
4/25/1995	3A		DMF	4
5/23/1995	3A		DMF	8
12/11/1995	3A		DMF	2
3/20/96	3A	#549 RIVERVIEW	DMF	1.9
3/27/1996	3A	#549 Riverview Drive	R. Duncanson	<2
4/22/96	3A	#549 RIVERVIEW	DMF	2
4/24/1996	3A	#549 Riverview Drive	R. Duncanson	4
5/23/96	3A	#549 RIVERVIEW	DMF	28
6/6/1996	3A	#549 Riverview Dr.	R. Duncanson	2
6/18/1996	3A	#549 Riverview Dr.	R. Duncanson	50
7/2/1996	3A	#549 Riverview Drive	R. Duncanson	55
7/16/1996	3A	#549 Riverview Drive	R. Duncanson	<90
9/23/97	3A	#549 RIVERVIEW	DMF	18
3/26/98	3A	#549 RIVERVIEW	DMF	4
4/29/98	3A	#549 RIVERVIEW	DMF	4
12/28/98	3A	#549 RIVERVIEW	DMF	11

Date	Station	Location	Collected By	fc/100 ml	E. Coli CFU/100mL	Enterococcus CFU/100mL
11/7/2002	SM	muddy crk	SMAST	<10	12	72
11/17/2002	SM	muddy crk	SMAST	200	100	206
11/20/2002	SM	muddy crk	SMAST	<100	<10	10
12/5/2002	SM	muddy crk	SMAST	10	8	14
12/10/2002	SM	muddy crk	SMAST	<10	<4	2
12/17/2002	SM	muddy crk	SMAST	<10	4	10
12/23/2002	SM	muddy crk	SMAST	20	4	4
1/6/2003	SM	muddy crk	SMAST	160	92	68
1/15/2003	SM	muddy crk	SMAST	<10	<4	<2
1/23/2003	SM	muddy crk	SMAST	10	4	2
1/29/2003	SM	muddy crk	SMAST	<10	<4	2
2/6/2003	SM	muddy crk	SMAST	10	16	<2
2/10/2003	SM	muddy crk	SMAST	160	120	<2
2/25/2003	SM	muddy crk	SMAST	<10	<4	2
3/6/2003	SM	muddy crk	SMAST	<10	20	<2
3/10/2003	SM	muddy crk	SMAST	<10	<4	<2
3/20/2003	SM	muddy crk	SMAST	<10	<4	6
3/24/2003	SM	muddy crk	SMAST	<10	<4	2
4/3/2003	SM	muddy crk	SMAST	<10	<4	4
4/7/2003	SM	muddy crk	SMAST	<10	<4	<2
4/17/2003	SM	muddy crk	SMAST	10	12	12
4/23/2003	SM	muddy crk	SMAST	60	32	26
5/1/2003	SM	muddy crk	SMAST	30	52	16
5/5/2003	SM	muddy crk	SMAST	10	<4	<2
5/19/2003	SM	muddy crk	SMAST	<10	8	20
5/29/2003	SM	muddy crk	SMAST	90	60	18
6/2/2003	SM	muddy crk	SMAST	860	412	182
6/12/2003	SM	muddy crk	SMAST	100	72	14
6/16/2003	SM	muddy crk	SMAST	320	372	>400
6/26/2003	SM	muddy crk	SMAST	40	36	20
6/30/2003	SM	muddy crk	SMAST	40	52	14
7/10/2003	SM	muddy crk	SMAST	110	80	254
7/14/2003	SM	muddy crk	SMAST	220	144	170
7/21/2003	SM	muddy crk	SMAST	40	32	20
7/28/2003	SM	muddy crk	SMAST	530	316	230
8/6/2003	SM	muddy crk	SMAST	80	4	16
8/12/2003	SM	muddy crk	SMAST	370	116	136
8/20/2003	SM	muddy crk	SMAST	<10	12	<2
8/26/2003	SM	muddy crk	SMAST	54	272	248