The 'Head of the Bay' Stormwater Monitoring Project:
Identifying and Reducing Sources of Stormwater Bacteria

By The Coalition for Buzzards Bay
July 10, 2007

funding provided by a grant from the Buzzards Bay National Estuary Program

The Bacteria Problem

Shellfishing provides significant recreational and economic benefits for residents of Buzzards Bay. Increasing human populations and its associated developments brings with it wastewater, impervious surfaces, and an increased need for efficiently conveying stormwater out to our waterways. Unfortunately, the consequence of this is that stormwater often carries a variety of pollutants, including disease causing bacteria and viruses, that reduce coastal water quality and trigger shellfish bed and swimming beach closures.

Stormwater contaminated with fecal coliform bacteria is one of the principle causes of shellfish bed closures in Buzzards Bay. Closures of shellfishing areas create hardships for coastal communities because they restrict the public from the recreational and commercial activities that make these communities such desirable places to live. State agencies and municipal boards typically devote substantial effort to determine if shellfish are safe for consumption and if our beaches are safe for bathing. These efforts play an important role in protecting public safety, but often the additional resources necessary to identify and remediate significant sources of bacteria are not available.

The Head of the Bay towns of Bourne, Wareham and Marion have all been leaders in efforts to remediate stormwater discharges in Buzzards Bay and, with funding provided by the Buzzards Bay National Estuary Program, have partnered with the nonprofit organization The Coalition for Buzzards Bay to collect needed data on bacteria conditions at some of the worst stormwater discharges in their towns. The Head of the Bay Stormwater Monitoring Project (HOB project) was conceived as a means to bring local experts together to identify the 'worst' stormwater discharges (those likely to carry high bacteria loads to nearby sensitive shellfish beds and bathing beaches) and to test and prioritize these sources in order to provide a scientific basis for remediating and reducing bacteria in sensitive coastal areas.

This report provides a summary of results from stormwater "first flush" samples taken from stormwater discharges likely to contribute to coastal fecal coliform bacteria contamination in the towns of Bourne, Marion and Wareham. This data will allow local communities to focus their limited resources on the correction of those discharges that are most likely to improve water quality and public safety and reopen shellfish beds.

Using Fecal Coliform Bacteria to Assess Water Quality

Fecal coliform bacteria are present in the intestines of warm blooded animals such as humans and, although they can cause disease directly, serve as useful indicators for the presence of wastewater contamination. Sources of fecal coliform bacteria include malfunctioning title 5 septic systems, leaks in an existing wastewater treatment infrastructure, pet and other animal waste and illegal wastewater discharges from boats. The primary pathway of fecal coliform contamination into Buzzards Bay waters is through the discharge of stormwater runoff.

Fecal coliform bacteria provide the basis for the Massachusetts standard to assess the safety of shellfishing areas and swimming beaches. Fecal coliform bacteria are measured because they are indicators of wastewater contamination within the watershed or upstream drainage area. Contact with contaminated water (consumption of shellfish, swimming, etc.) increases the likelihood of contracting a disease that can vary from mild upset stomach (gastro-enteritis) to severe and sometimes fatal dysentery, cholera, or typhoid.

Disease causing bacteria and viruses in wastewater are believed to survive for only a limited time after they leave their host person or other animal and can be removed, for example, by slowing down the flow so bacteria can settle out or die, or by filtering wastewater through the ground, as happens with a properly functioning title 5 septic system. Fecal coliform bacteria may accumulate during dry periods and be washed into waterways during the initial flush of a rainfall. As is typical of most of Buzzards Bay embayments, higher bacteria counts after rainfall events provides evidence that stormwater is a major source of fecal coliform bacteria to our waterways.

Project Background

During the fall of 2007 staff from the Coalition for Buzzards Bay met with representatives from the Buzzards Bay National Estuary Program, the Massachusetts Division of Marine Fisheries, and municipal officials from the towns of Bourne, Marion and Wareham to select sites for inclusion in the HOB sampling project. Town municipal officials included Boards of Health, Conservation Commissions, and Public Works Directors. The principle goal was to identify stormwater discharges that were likely to contribute disproportionately high bacteria loads, resulting shellfish bed closures as well as the closure of bathing beaches.

One of the catalysts for the HOB project was the “Atlas of Stormwater Discharges in the Buzzards Bay Watershed” produced by the Buzzards Bay National Estuary Program in 2003 (updated 2007). This report delineated the stormwater infrastructure and identified more than 2600 pipes that discharge into Buzzards Bay. Of these, 988 discharge from the towns of Bourne (169 pipes), Wareham (592 pipes) and Marion (227 pipes). The atlas provided detailed maps to locate existing stormwater discharges and provided ‘first cut’ priority ranking of stormwater discharges to Buzzards Bay.

Project Details

Areas for sampling were initially based upon proximity to shellfish beds as shown upon the 2006 Massachusetts Division of Marine Fisheries Shellfish Bed Closures maps. Often several stormwater discharges within a sampling area were selected for monitoring to enhance the probability of identifying the main bacteria contributors. Chosen sample stations are listed in Table 1 and shown in figures 1 – 11.

Once the monitoring sites were selected, the Coalition and the BBNEP developed a series of agreed-to monitoring protocols:

1) Sampling should take place following 72 hours of dry weather
2) Sampling should occur during ‘first flush’, here defined as up to 1 inch of rain from the start of the rainfall event, but preferably less than 0.5 inch total
3) Sampling during the fall months can continue until night temperature drop below 5°C and daytime temperatures rise above 10°C during the preceding 72 hours (based upon approval by Bernie Taber, BBNEP).
4) Spring sampling will generally resume in May, but can begin earlier when night temperatures do not drop below 5°C and temperatures rise above 10°C during the day during the preceding 72 hours (based upon approval by Bernie Taber, BBNEP).
5) During a rainfall, efforts should be focused on sampling all the chosen stormwater sites within a drainage area (watershed) or town in order to provide information about the relative bacteria contribution for stormwater sources within each town.
6) For some sites, tides cause the outflow pipes to become inaccessible or create backflow problems within the stormdrain system. In these locations alternative sampling sites could be utilized upstream but within the same stormwater flow. These alternative sites were sampled when the most downstream location was not accessible.

Water samples were taken from the stormwater source according to the protocols outlined in the Quality Assurance Project Plan (QAPP) developed for The Coalition for Buzzards Bay’s water quality monitoring programs (Williams and Howes 2006). Water samples for bacteria testing were taken by hand, filling a sterile 100 ml container in a moving stream of water, most preferentially at the outfall of a pipe or as stormwater overflowed from the road or seawall edge. When end point outfall or overflow locations were not available, samples were taken from within the catch basin at outflow or inflow pipes using a sampling pole to position the collecting bottle. When a catch basin was filled with stormwater above the in- and outflow pipes (common in tidal areas), the grate was removed, the runoff water was allowed to flow 2 minutes prior to sampling below the lip of the catch basin. All samples were taken from moving (not stagnant) water and great care was taken to not let the sampling bottle contact anything other than the water source to be sampled.

An additional 250 ml water sample was taken for measuring turbidity (the amount of suspended particulate matter in the water, here measured in Nephelometric Turbidity Units or NTUs). Temperature and specific gravity were also measured and used to calculate salinity. In some cases elevated salinity provides an indication of the dilution of stormwater with tidal (higher salinity) waters. For all samples, a simple estimate of flow was made either based on the time it takes to fill a measured container or, when it was not possible to capture the flow within a container, a 'rough' best estimate was made.

Fecal coliform and turbidity samples were delivered to the Barnstable County Laboratory within 24 hours (in most cases within 8 hours) for analysis. The laboratory protocol for fecal coliform testing was 3 dilutions using Method # MF-SM 9222D and for turbidity analysis method # EPA 180.1.

Rainfall data are accessible for stations in the surrounding watershed using weather station data posted on www.weatherunderground.com (Wareham stations KMAWAREH1 and KXIMAWAR2 and Marion Station KMAMARIO1) provided rainfall data over the sampling period. This data was available to estimate the amount of rainfall that had occurred in the previous 24 hours from the time each sample was taken. The previous 24-hour rainfall data were computed from KMAMARIO1 (Jun 15, 2008 only) and KXIMAWAR2 (all other dates) to the nearest time prior to sampling time and not corrected for storm paths or distances from source. Fecal coliform results and flow data were examined in relation to see how flushing rates and bacteria counts were affected by cumulative rainfall.

Analysis

The principle goal of this project is to identify and prioritize the sources of fecal coliform bacteria from stormwater according to their relative contribution to shellfish bed closures.

For a general assessment of the bacteria condition, the Massachusetts Fecal Coliform Standards for shellfish harvesting waters (Class SA) is the basis for shellfish bed closures. This is based upon calculations of geometric means for regular samples and sets the limit of a geometric mean of 14 CFUs per 100 ml (a CFU and with a second standard that no more than 10% of the samples can exceed a 28 per 100 ml).

Bacteria samples typically are highly variable. As such, the computation of the geometric mean is a standard technique for reducing the effects of extreme values. The geometric mean provides a 'smoothed' measure of the typical bacteria condition, and is used to interpret the bacteria levels when more than 1 sample is taken from a stormwater source or location.

For analysis, results were $\log_e$ transformed and plotted against measured variables. Data were fit by simple linear or quadratic least squares regression. Quadratic terms were retained only if t-values were significant for the quadratic term. Significant regression fits were interpreted as evidence of correlation between the variables. A significant quadratic term is seen as evidence of a non-linear relationship with the dependent variable and the shape of fitted regression lines are interpreted accordingly.

Results

Details of each sample site location are listed in Table 1 and the locations of the sites are shown on maps in figs. 1 - 11. Fecal coliform bacteria results are listed from each site by town, station, and date in Table 2. The summary of results including the number of samples, average flow and the geometric mean and maximum fecal coliform values for Bourne, Marion, and Wareham are listed in tables 3, 4 and 5, respectively (also see figs. 12 – 14). In the case of non-detects and exceedances, values were converted to the detection limit. That is, a value of <10 was assigned 10, and >200,000 was assigned 200,000 for the purposes of calculating geometric mean and displaying data in figures 12-17. The geometric means substantially exceeded the state geometric mean and maximum standards fecal coliform bacteria at most sites.

The specific results for each town are reviewed below.

Bourne

Three areas of Bourne were included in stormwater sampling: Bennets Neck, Pocasset River, and Hen Cove.

Geometric mean fecal coliform bacteria counts from Bennets Neck (Table 3, Figs. 3 and 12) were below 1,000 CFUs per 100 ml and average flow rates were below 10 liters per minute. Although these results are well above state fecal coliform standards, these counts are relatively low. As such, Bennets Neck is not likely to be a priority site for remediation.

Pocasset River sites had fecal coliform geometric mean below 1,000 CFUs per 100 ml, but the maximum value of 8,800 CFUs per 100 ml at BPR2 showed that stormwater at this source can carry high bacteria loads (also see Table 3, Figs. 4 and 12). The flow at this location continues through a drainage ditch that may remove some of the bacteria before it enters Pocasset River. A necessary step would be determine if this source is reduced within the wetland by sampling at a point where this source flows into the Pocasset River.

Geometric means of data from Hen Cove generally show that a large amount of fecal coliform bacteria are coming from the residential area south of Conservation Pond (BHC2b, BHC3, and BHC4; also see Table 3 and Figs. 5 and 12). Although the average flows were variable, based upon bacteria concentration and estimated flow, BHC3 (just south of the town dock and launch) contributes the highest fecal coliform load to the sub-watershed and would be a suitable target for remediation efforts. BHC4 was also a large source of bacteria. A seep at this location had a relatively low bacteria count and low flow volume. Despite frequent use of Conservation Pond by waterfowl, the pond appears to act as a sink for bacteria. Samples from the outlet (BHC2) had relatively low concentrations of fecal coliform bacteria, but the high and more persistent flows still indicated it as a potential problem source. Bacteria counts from a street overflow just south of the Conservation Pond (BHC2b), which receives most of its flow from Park Street and Wamsutta Avenue, were relatively high. This is evidence that there is a significant source of bacteria within the land drainage area south of Conservation Pond.

Marion

The watershed for these locations includes residential housing, a school (Tabor Academy), marinas, large parking lots and roads, boat launches, and docks (Fig. 6). MAR1 is a consistent source of high bacteria loads (Table 4, Fig 13). MAR2, an intertidal outfall pipe, was sampled on one occasion. The result of 30,000 CFUs per 100 ml together with a high flow (400 liters per minute) identifies that this site is an important bacteria source. Samples from an upstream catchbasin, MAR2alt, were from the inflow pipe within the catchbasin and may not have captured the combined sources that contribute at the pipe outflow (MAR2). Bacteria sources within this drainage area should be investigated further. MAR5 occasionally carried high bacteria loads together with high flows. MAR1, MAR2, and MAR5 are sites most worthy of consideration for remediation projects. The large outflow pipe at MAR3 conveyed high amounts of stormwater with a low concentration of bacteria. Other sources in Marion were below 1,000 CFU per 100 ml on all samples.

It was not clear whether MAR4alt was upstream from MAR4, but this site was the only location that met the minimum state standards for fecal coliform geometric mean of no more than 14 CFUs per 100 ml (based upon 1 sample).

Wareham

Sampling locations in the Town of Wareham are shown in Fig. 7. Adjacent to the town center of Wareham (Fig. 8), WAR1 had high levels of bacteria and had a high flow volume (Table 5). Persistent oil residues and orange flocculent (particulates) were typically also present at this site. The outflow pipe receives runoff from a large area, including an oil storage facility and a shopping plaza. This site should be a good candidate for a possible remediation project. WAR2, an outfall pipe just east of an open railroad building, also contributed a large bacteria load with high volumes of stormwater flow. Other locations near Wareham town center (Fig. 9: WAR3, WAR4, WAR5, and WAR6) had comparatively lower bacteria levels and flow volumes (Table 5).

Within the Pinehurst Beach neighborhood, WPH2 and WPH3 (Fig. 10) were the largest fecal coliform contributors when flow was taken into account (Table 5). However, WPH2 and WPH4 were both concentrated sources of fecal coliform bacteria. Results from other locations within this neighborhood were often high (maximum counts > 900 CFUs per

100 ml) but had lower flow volumes. WPH2, WPH3 and WPH4, because of the combined relative high bacteria counts and flow volumes, should be considered as the most effective targets for remediation.

The boat launch site (WWR1, Fig. 10) was a high volume site with occasional high bacteria counts. There is a reservoir on the beach that may have formerly provided some bacteria settlement, but cracks in the concrete now allow stormwater to flow directly onto the beach. This location could be considered as a candidate for remediation.

Both locations in the Parkwood Beach neighborhood (Fig. 10) had high concentrations of fecal coliform bacteria. Both of these outflow pipes must have at least one reservoir within the stormwater drainage systems, as there was a substantial delay after the beginning of a rainfall before flow was evident. The bacteria load from WPW2, based upon the high concentration and flow, make it a priority for remediation.

Geometric means for fecal coliform bacteria were generally above 1000 CFUs per 100 ml at most sampling locations in the Swifts and Hamilton Beach area (see Table 5, Fig. 11). WSB1 had the highest concentration of fecal coliform bacteria (geometric mean of 17,329 CFUs per 100 ml based upon 2 samples, Fig. 14) but had an estimated average flow of 56 liters per minute. WSB4 and WSB7, due to relatively high flows and high bacteria concentrations, had the highest expected bacteria loads. Remediating these three sources could provide significant reductions of bacteria to the adjacent receiving waters.

Drainage Area

Many things contribute to fecal coliform bacteria contamination at a particular source. The most important is the location of the source, or sources, of bacteria and concentration of bacteria at the source. Sources can include any human or animal waste contamination. It could be a broken septic system which may intermittently break out (leak) into surface water with high rains or heavy usage, it could be a popular dog walk location, or rest stop for local birds. When it rains, the way it rains can influence how much bacteria get carried to the nearest waterbody. For example, a downpour can wash bacteria over the land in a ‘first flush’ surge, whereas a slow sprinkling ran (with total rainfall the same) may completely percolate into the ground and carry few bacteria.

Characteristics of the drainage area, such as the amount of roads, parking lots, or other impervious surfaces, can influence how many bacteria are carried from the sources. This is partly because the speed and the amount of stormwater increase with the amount of impervious surface. With large vegetated areas, including forests and wetlands, bacteria are reduced because stormwater is slowed and allowed to percolate into the ground.

Temperature or Seasonal Effects

A sharp decline in fecal coliform CFUs occurred over the 2 sampling dates in the fall of 2007. The first, October 27, 2007 followed a long period of relatively little rain and 2 out of 3 sites sampled in Bourne on this date exceeded 30,000 CFUs per 100 ml. The next sampling event on November 6, 2007 followed a 1.48 inch rainfall (occurred on November 3) and was much lower. It is important to note that this rainfall event overlapped with the 72-hour dry period criteria, but was sampled because this rainfall was likely to be the last of the season within the required temperature criteria. In spring 2008, fecal coliform CFU counts generally increased over subsequent sampling events; the sampling date with the highest temperature had the highest geometric mean fecal coliform count (Table 6).

Temperature is known to have an important influence on the amount of bacteria found in stormwater samples. Fecal bacteria significantly increased with temperature over the range of temperatures sampled here (range 10.6 to18.9 ^{o}C, $\log_e$ transformed fecal coliform CFUs~temp. in degrees ^{o}C, $P<0.001$, $R^2 = 0.20$, see Fig. 15).

Although increasing temperatures were significantly correlated with increasing fecal bacteria CFUs (Fig. 15, $R^2=0.20$) this may be due to changes in the drainage area that occur at the same time as changes in temperature. For example, some of the shoreline communities investigated in this report are seasonal and experience fewer residents and fewer domestic animals closer to winter. Similarly, people may walk their animals further from home (or not clean up after them) more during warmer weather.

Cumulative Rainfall and Turbidity

The plot of the relationship between fecal coliform counts and 24-hour cumulative rainfall shows evidence that the relationship is not linear (based upon a significant quadratic term in the regression, Fig. 16) and trends upward at the commencement of rain and peaks at approximately 0.40 inches of 24-hour cumulative rainfall.

There is considerable evidence that fecal coliform bacteria can attach to soil and other particles. In other studies it has been shown that as stormwater flushing speeds increase there will be an increase in turbulence that will suspend soil particles and increase bacteria loads. At one site (WSB5 in Wareham on 11/6/07) NTUs were greater than 4,000 likely due to a construction project just upstream. When this data point was removed our data still showed great variation in fecal coliform results with increasing turbidity. In general, there was evidence of a non linear relationship between fecal coliform counts and NTUs based upon a significant quadratic term in the marginally significant regression fit (Fig. 17). Based upon this regression line, there was indication that fecal coliform CFUs peaked near 66 NTUs (Fig. 17). Given that relatively low fecal coliform bacteria (380 CFUs) accompanied the extreme high NTU value of greater than 4,000, it is likely that higher NTUs measurements were confounded by erosion that did not carry high bacteria loads.

Discussion

We have identified sources with high levels of fecal coliform bacteria from stormwater in the towns of Bourne, Marion, and Wareham. These data will help prioritize sites for stormwater treatment. By identifying the appropriate best management practices for stormwater remediation at these sites, it will be possible to significantly reduce bacteria loads to improve water quality, increase public safety and reopen important shellfishing areas. For priority stormwater bacteria sources identified in this report, investigating the drainage area and forming plans to reduce loads at the source or slowing and improving filtration should be the next steps of remediation efforts.

When high bacteria loads are present, practical approaches to reducing bacteria include: identifying and reducing the source or sources in the watershed, reduce the amount of impervious surfaces, and channeling stormwater from rooftops, roads and parking lots into vegetated areas, infiltration basins, or retention basins to slow its flow and help it absorb into the ground.

Animal waste may be an important fecal coliform source in many of the drainage systems we investigated in this report. ‘Clean up your pet-waste’ education programs and collection sites should be considered as a component for bacterial reduction in all of the towns included in this report and could be a cost effective part of community wide plans to reduce bacteria contamination.

Best management practices for remediation of bacteria loads from stormwater often include types of infiltration devices that promote percolation of stormwater into the soil. These practices filter out harmful bacteria, reduce the peak flow volumes that carry harmful bacteria and transport soil and cause erosion, and reduce other harmful pollutants by filtering, and allowing settling and natural breakdown. Some of these practices include porous pavement, dry detention basins (basins created to allow diverted stormwater to soak into the ground) or infiltration pits or trenches. Wet detention basins are created ponds or pools that reduce bacteria by helping stormwater to seep into the ground, allowing bacteria to settle out, or die, but also may reduce nitrogen through natural attenuation. Maintenance of the stormwater infrastructure by the cleaning of catchbasins and maintenance of existing stormwater pipes to prevent clogging can also play a role in reducing bacteria contamination.

Summary

The Head of the Bay Stormwater monitoring project brought together local experts and available information on stormwater infrastructure to identify high priority stormwater sources likely to contribute to shellfish beds and swimming beach closures in the towns of Bourne, Marion and Wareham. Staff from The Coalition for Buzzards Bay conducted fecal coliform tests and other measurements during rain events to provide a scientific and cost effective basis for towns to prioritize their stormwater remediation projects. Implementing the appropriate remediation projects can reduce or eliminate some of the largest sources of bacteria pollution, improve public safety, and potentially reopen productive shellfishing areas.

Table 1. List and description of sites included in the Head of the Bay Stormwater Monitoring Project.

No.	Town	Code	Site Name	Latitude	Longitude	Site Description
1	Bourne	BBN1	Bennets Neck 1	41.7018	-70.6141	An outfall pipe east of Shore Road about 30' north of intersection with Bennets Neck Drive. Two pipes enter within about 10' and drain into waterbody. This is the north pipe and it receives stormwater from down slope and catchbasins to the north along Shore Road.
2	Bourne	BBN2	Bennets Neck 2	41.7018	-70.6141	An outfall pipe east of Shore Road about 20' north of intersection with Bennets Neck Drive. Two pipes enter within about 10' and drain into waterbody. This is the south pipe and it receives stormwater from down slope and catchbasins along Bennets Neck Drive and to the east.
3	Bourne	BPR1	Pocasset River 1	41.6974	-70.6176	A pipe outfall located at the edge of a field east of Shore Road only had flow on one occasion, and it was not clear whether this was just concentrated flow over the grass area. In June there was much evidence of dog use.
4	Bourne	BPR1alt	Pocasset River 1 alternate	41.6978	-70.6178	A catchbasin that receives a surface flow from the north along Shore Road and from the parallel catchbasin across the street to the west.
5	Bourne	BPR2	Pocasset River 2	41.6932	-70.6182	An outflow pipe located in the southeast corner of the Catholic Church parking lot. Samples were taken about 10' down from the pipe scour pool near the road.
6	Bourne	BHC1	Hen Cove 1	41.6867	-70.6223	An overflow at the edge of the road as stormwater overflows onto the public beach. The drainage area includes 3 catchbasins in the road adjacent to the beach and drains Circuit Avenue from just south of Wabash Avenue and to about 25 m west of the intersection with Island Drive.

Table 1. Continued.

No.	Town	Code	Site Name	Latitude	Longitude	Site Description
7	Bourne	BHC2a	Hen Cove 2a pond outlet	41.6867	-70.6196	An outfall pipe to the southeast of Circuit Avenue receives flow from Conservation Pond and includes a large drainage area bounded by Island Drive, Shore Road, and houses to the west of Park Street.
8	Bourne	BHC2b	Hen Cove 2b street overflow	41.6867	-70.6195	A road cut that receives flow primarily down slope along Park Street just above Wamsutta Ave, along Wamsutta to the southeast almost to Saco Ave. A small area of the lower Island Drive and about 25 m west of this intersection along Circuit Avenue also drains along the road to this road cut.
9	Bourne	BHC3	Hen Cove 3	41.6860	-70.6186	A catchbasin that discharges to an intertidal pipe. Only at low tide is the outfall pipe accessible and this is the preferred sampling location. In heavy rainfall the stormwater discharges over the road edge to Hen Cove but in moderate rain the catchbasin was partially filled and sampling was overflow into the catchbasin.
10	Bourne	BHC4 BHC4w	Hen Cove 4 overflow	41.6847	-70.6179	A road cut that receives flow primarily down slope along Bell Buoy Road to the southeast and some drainage from lower Hill Street. This discharge is about 40' north of the prominent beach pipe (that did not discharge during any visit). Sampling was in flow at road edge. A consistent seep (BHC4w) below the seawall was evident in wet and dry weather and this was sampled on one occasion.
11	Marion	MAR1	Marion 1 park landing	41.7128	-70.7662	An outfall pipe at the northeast corner of the dock at Veterans' Memorial Park at Old Landing, Front Street. It is covered at moderate and high tides and its catchbasin is filled and thus not suitable for sampling at moderate and high tides.

Table 1. Continued.

No.	Town	Code	Site Name	Latitude	Longitude	Site Description
12	Marion	MAR2	Marion 2	41.7111	-70.7662	An outfall pipe located to the southeast of Tabor Academy's 'Daggett House' in the intertidal zone.
13	Marion	MAR2alt	Marion 2 alternate	41.7111	-70.7668	Sample location within catchbasin at the inflow pipe entering from the east across Front Street.
14	Marion	MAR3	Marion 3 intertidal outfall	41.7089	-70.7645	A 76 cm intertidal concrete outfall pipe accessible only at low tides.
15	Marion	MAR4	Marion 4	41.7089	-70.7645	A strong flow seep, presumably from an outfall pipe located behind the seawall just south of the dock and edge of parking lot.
16	Marion	MAR4alt	Marion 4 alternate	41.7089	-70.7646	Sampled from within catchbasin on driveway west of MAR4, sampled from inflow pipe coming from southwest.
17	Marion	MAR5	Marion 5	41.7074	-70.7638	Outfall pipe from seawall just south of property boundary with Tabor Academy's 'U' shaped building
18	Wareham	WAR1	Wareham 1	41.7627	-70.7195	Outfall pipe east of shopping plaza. Can follow path from SE plaza to the east over the RR tracks to the water. This pipe gets combined runoff from the southwest and from a ditch that runs to the northwest behind the plaza and receives runoff from the plaza and residential parcels to the northwest.
19	Wareham	WAR1alt	Wareham 1 alternate	41.7626	-70.7196	This location is in an uncovered circular opening of a basin to the southeast of WAR1. This location received more direct runoff from the property to the south and included a high proportion of oil.
20	Wareham	WAR2	Wareham 2	41.7585	-70.7147	A 24" intertidal outfall accessible in most tide states. On one occasion the sample was taken from the Merchants Way upstream catchbasin outflow pipe.
21	Wareham	WAR3	Wareham 3 grate overflow	41.7572	-70.7133	Samples were taken from the overflow into the catchbasin on the south side of Merchants Way 2 meters NW of the private driveway.

Table 1. Continued.

No.	Town	Code	Site Name	Latitude	Longitude	Site Description
22	Wareham	WAR4	Wareham 4	41.7564	-70.7111	Outfall pipe at the southeast cornet of the restaurant parking lot.
23	Wareham	WAR5	Wareham 5	41.7559	-70.7121	Outfall pipe apparently broken and empties behind the seawall, sample taken in outflow pipe within catchbasin
24	Wareham	WAR6	Wareham 6	41.7558	-70.7119	Outfall pipe accessible from the southern end of the floating dock during most tide states.
25	Wareham	WPH1	Pinehurst 1 beach overflow	41.7490	-70.7090	Beach overflow at the southeast corner end of Nimrod Way. Sampled at flow over steps.
26	Wareham	WPH2	Pinehurst 2 beach pipe	41.7486	-70.7101	Intertidal outfall pipe at the end of Warr Avenue.
27	Wareham	WPH3	Pinehurst 3 beach	41.7485	-70.7109	Intertidal outfall pipe at the end of Sea Street in marsh grass about 25 m from seawall.
28	Wareham	WPH4	Pinehurst 4	41.7477	-70.7110	Outfall pipe at the end of Cottage Street.
29	Wareham	WPH5	Pinehurst 5 grate	41.7471	-70.7098	1st catchbasin southeast of Blue Jay Terrace. Sampled at outflow pipe within catchbasin or overflow into catchbasin
30	Wareham	WPH6	Pinehurst 6 street grate	41.7469	-70.7094	2nd catchbasin southeast of Blue Jay Terrace. Sampled at outflow pipe within catchbasin or overflow into catchbasin
31	Wareham	WWR1	Wareham River 1	41.7504	-70.7005	This is a cracked concrete stormwater basin on the beach just north of the town boat launch. Samples were from outfalling water.
32	Wareham	WPW1	Parkwood 1	41.7474	-70.6995	Outfall between houses at the end of Chestnut Street. Only flow during after large rain indicating large reservoir in catchbasin
33	Wareham	WPW2	Parkwood 2	41.7463	-70.7041	Large beach outfall pipe to the west of the intersection of Teakwood Avenue with Parkwood Drive. Flow volume was large but only occurred after significant rainfall (indicated large reservoir).
34	Wareham	WSB1	Swifts 1	41.7441	-70.7194	This is the northern outfall pipe east of Broadmarsh Avenue emptying into a small cove/marsh just north of Pilgrim Avenue. Lots of leaf litter disposed in the area.

Table 1. Continued.

No.	Town	Code	Site Name	Latitude	Longitude	Site Description
35	Wareham	WSB2	Swifts 2	41.7441	-70.7193	This is the south outfall pipe east of Broadmarsh Avenue emptying into a small cove/marsh just north of Pilgrim Avenue. Lots of leaf litter in the area. This pipe is broken and the land owner is concerned about the erosion caused when flows are high. In the spring of 2008 a family of raccoons appeared to be resident.
36	Wareham	WSB3a	Swifts 3a	41.7438	-70.7154	This is broken outfall pipe on the beach north of the Smith Avenue intersection with Pilgrim Avenue.
37	Wareham	WSB3b	Swifts 3b	41.7418	-70.7126	A catchbasin in the middle of Worrall Avenue just south of the intersection with Pilgrim Avenue. Sampling was in the outflow pipe to the southwest.
38	Wareham	WSB4	Swifts 4	41.7386	-70.7185	An outflow from a cracked reservoir at the edge of a drainage ditch. The cracked reservoir is located to the southwest of the end of Beach Street (follow the angle of the street to the water.
39	Wareham	WSB5	Swifts 5	41.7386	-70.7185	Intertidal outflow pipe east of end of Ruggles Avenue.
40	Wareham	WSB6	Swifts 6	41.7382	-70.7181	Intertidal outflow pipe to the west of the west corner of the beach parking lot.
41	Wareham	WSB7	Swifts 7	41.7363	-70.7213	Beach outfall pipe in the intertidal zone but usually accessible.

Table 2. Fecal coliform results and associated measurements from Head of the Bay sites by town, sub-watershed, site and date.

#	Date	Town	Location	Site	Time	Sample Depth (cm)	Temp °C	Specific Gravity	Salinity (PPT)	Est. flow (liter per min	NTU turbidity	Fecal Coliform
1	04/28/08	Bourne	Bennets Neck	BBN1	17:12	15	13.9	1.001	1	8	23	14
2	05/08/08	Bourne	Bennets Neck	BBN1	12:40	5	15.6	1.000	0	8	22	210
3	04/28/08	Bourne	Bennets Neck	BBN2	17:10	12	13.9	1.001	1	8	21	130
4	05/08/08	Bourne	Bennets Neck	BBN2	12:45	5	15	1.000	0	8	20	90
5	04/28/08	Bourne	Hen Cove	BHC1	15:00	1	13.3	1.000	0	4	36	63
6	05/08/08	Bourne	Hen Cove	BHC1	12:05	2	15.6	1.000	0	8	26	<10
7	06/15/08	Bourne	Hen Cove	BHC1	11:45	5	16.1	1.000	0	200	17	640
8	10/25/07	Bourne	Hen Cove	BHC2a	9:15	20	14	1.009	11	2	1.8	520
9	04/28/08	Bourne	Hen Cove	BHC2a	11:45	10	10.6	1.001	1	800	1.6	<10
10	05/08/08	Bourne	Hen Cove	BHC2a	11:35	25	13.9	1.01	13	800	1.8	9
11	06/15/08	Bourne	Hen Cove	BHC2a	11:55	25	17.2	1.000	0	1000	7.1	200
12	04/28/08	Bourne	Hen Cove	BHC2b	11:45	1	11.7	1.001	1	8	48	81
13	05/08/08	Bourne	Hen Cove	BHC2b	11:40	10	15.6	1.000	0	8	17	4,400
14	06/15/08	Bourne	Hen Cove	BHC2b	11:50	5	16.1	1.000	0	40	13	11,000
15	10/25/07	Bourne	Hen Cove	BHC3	8:40	1	14	1.001	1	2	33	45,000
16	04/28/08	Bourne	Hen Cove	BHC3	11:30	1	11.7	1.000	0	8	82	27
17	05/08/08	Bourne	Hen Cove	BHC3	11:50	1	16.1	1.000	0	20	20	1,100
18	06/15/08	Bourne	Hen Cove	BHC3	11:37	20	16.7	1.000	0	600	35	4,400
19	10/25/07	Bourne	Hen Cove	BHC4	9:05	1.5	13.75	1.001	1	200	64	32,000
20	04/28/08	Bourne	Hen Cove	BHC4	14:10	1	12.8	1.000	0	4	110	9
21	05/08/08	Bourne	Hen Cove	BHC4	11:25	1	15	1.000	0	8	42	72
22	06/15/08	Bourne	Hen Cove	BHC4	11:30	10	18.9	1.000	0	400	60	19,000
23	06/15/08	Bourne	Hen Cove	BHC4w	12:40	1	15	1.001	1	2	4.3	400

Table 2. Fecal coliform results and associated measurements (continued).

#	Date	Town	Location	Site	Time	Sample Depth (cm)	Temp °C	Specific Gravity	Salinity (PPT)	Est. flow (liter per min)	NTU turbidity	Fecal Coliform
24	05/08/08	Bourne	Pocasset R.	BPR1	12:30	1	15.6	1.000	0	8	46	510
25	06/15/08	Bourne	Pocasset R.	BPR1	12:05	10	16.1	1.000	0	40	28	290
26	04/28/08	Bourne	Pocasset R.	BPR2	16:50	20	13.9	1.001	1	20	43	88
27	05/08/08	Bourne	Pocasset R.	BPR2	12:20	5	15.6	1.000	0	20	46	290
28	06/15/08	Bourne	Pocasset R.	BPR2	12:10	10	16.1	1.000	0	80	23	8,800
29	11/06/07	Marion	Tabor	MAR1	11:33	1.5	13.5	1.006	8	8	31	460
30	05/20/08	Marion	Tabor	MAR1	18:30	5	14.4	1.000	0	40	50	5,500
31	06/04/08	Marion	Tabor	MAR1	13:50	3	17.2	1.001	1	80	56	55,000
32	06/04/08	Marion	Tabor	MAR2	13:40	15	15.6	1.001	1	400	35	30,000
33	11/06/07	Marion	Tabor	MAR3	12:10	38	12.5	1.022	27	500	12	63
34	06/04/08	Marion	Tabor	MAR3	13:30	5	17.2	1.001	1	200	9	9
35	11/06/07	Marion	Tabor	MAR4	12:25	3	14.5	1.006	7	20	4.6	140
36	06/04/08	Marion	Tabor	MAR4	13:35	5	17.2	1.001	1	40	9	480
37	11/06/07	Marion	Tabor	MAR5	12:37	5	13	1.000	0	200	36	4,000
38	05/20/08	Marion	Tabor	MAR5	19:00	20	12.8	1.01	12	120	170	99
39	06/04/08	Marion	Tabor	MAR5	13:55	5	16.7	1.001	1	80	36	720
40	11/06/07	Marion	Tabor	MAR2alt	11:55	1.5	14	1.009	11	10	4.5	2,800
41	05/20/08	Marion	Tabor	MAR2alt	19:45	10	10.6	1.000	0	20	6.2	63
42	05/20/08	Marion	Tabor	MAR4alt	19:15	2	12.8	1.000	0	40	15	9

Table 2. Fecal coliform results and associated measurements (continued).

#	Date	Town	Location	Site	Time	Sample Depth (cm)	Temp °C	Specific Gravity	Salinity (PPT)	Est. flow (liter per min)	NTU turbidity	Fecal Coliform
43	04/28/08	Wareham	Wareham, Town	WAR1	18:10	12	13.9	1.000	0	600	11	3,900
44	06/04/08	Wareham	Wareham, Town	WAR1	9:40	20	17.8	1.011	15	80	4.9	4,500
45	04/28/08	Wareham	Wareham, Town	WAR2	18:00	4	13.9	1.001	1	600	9.1	200
46	05/20/08	Wareham	Wareham, Town	WAR2	20:00	15	13.3	1.000	0	800	16	640
47	06/04/08	Wareham	Wareham, Town	WAR2	9:20	20	17.8	1.000	0	80	87	1,500
48	04/28/08	Wareham	Wareham, Town	WAR3	17:50	1	14.4	1.000	0	8	28	17
49	06/04/08	Wareham	Wareham, Town	WAR3	9:05	1	18.9	1.000	0	4	100	2,300
50	04/28/08	Wareham	Wareham, Town	WAR4	18:30	4	14.4	1.000	0	400	22	38
51	06/04/08	Wareham	Wareham, Town	WAR4	10:30	3	17.8	1.000	0	80	120	910
52	06/04/08	Wareham	Wareham, Town	WAR5	10:45	30	16.1	1.006	8	80	93	910
53	04/28/08	Wareham	Wareham, Town	WAR6	18:25	4	13.3	1.000	0	20	16	290
54	06/04/08	Wareham	Wareham, Town	WAR6	10:35	3	16.1	1.016	21	80	56	1,200
55	04/28/08	Wareham	Pinehurst Beach	WPH1	19:45	2	12.2	1.000	0	8	10	110
56	06/04/08	Wareham	Pinehurst Beach	WPH1	11:25	2	16.1	1.000	0	40	32	820
57	04/28/08	Wareham	Pinehurst Beach	WPH2	19:15	4	13.9	1.001	1	4	21	1,000
58	06/04/08	Wareham	Pinehurst Beach	WPH2	11:35	2	17.2	1.000	0	8	36	28,000
59	04/28/08	Wareham	Pinehurst Beach	WPH3	19:30	15	12.8	1.001	1	80	32	100
60	06/04/08	Wareham	Pinehurst Beach	WPH3	11:45	6	17.8	1.000	0	20	29	6,100
61	04/28/08	Wareham	Pinehurst Beach	WPH4	20:15	2	12.8	1.001	1	8	11	2,000
62	06/04/08	Wareham	Pinehurst Beach	WPH4	12:00	3	18.9	1.000	0	20	15	2,200
63	04/28/08	Wareham	Pinehurst Beach	WPH5	19:55	2	12.8	1.000	0	40	58	120
64	06/04/08	Wareham	Pinehurst Beach	WPH5	11:47	10	18.3	1.000	0	8	21	1,500
65	04/28/08	Wareham	Pinehurst Beach	WPH6	20:00	1	12.8	1.000	0	8	19	330
66	06/04/08	Wareham	Pinehurst Beach	WPH6	11:52	30	16.7	1.000	0	8	24	970

Table 2. Fecal coliform results and associated measurements (continued).

#	Date	Town	Location	Site	Time	Sample Depth (cm)	Temp °C	Specific Gravity	Salinity (PPT)	Est. flow (liter per min)	NTU turbidity	Fecal Coliform
67	04/28/08	Wareham	Parkwood Beach	WPW1	18:40	4	13.3	1.000	0	400	77	44
68	06/04/08	Wareham	Parkwood Beach	WPW1	14:25	5	15.6	1.000	0	8	58	30,000
69	04/28/08	Wareham	Parkwood Beach	WPW2	18:50	10	13.3	1.000	0	800	17	15
70	06/04/08	Wareham	Parkwood Beach	WPW2	11:05	5	17.2	1.000	0	160	70	>200,000
71	11/06/07	Wareham	Swifts	WSB1	12:50	5	12	1.000	0	100	10	2,100
72	06/04/08	Wareham	Swifts	WSB1	12:25	4	17.8	1.000	0	12	25	143,000
73	11/06/07	Wareham	Swifts	WSB2	12:55	3	12	1.000	0	100	9.3	2,900
74	06/04/08	Wareham	Swifts	WSB2	12:20	2	16.1	1.000	0	12	25	12,000
75	11/06/07	Wareham	Swifts	WSB3a	13:05	5	12.5	1.001	1	100	6.8	590
76	06/04/08	Wareham	Swifts	WSB3b	12:35	20	17.2	1.000	0	40	18	4,000
77	11/06/07	Wareham	Swifts	WSB4	13:15	15	13	1.005	5	300	23	9,800
78	06/04/08	Wareham	Swifts	WSB4	12:50	25	16.1	1.010	13	400	20	4,400
79	11/06/07	Wareham	Swifts	WSB5	13:40	15	13.5	1.003	3	200	>4000	380
80	06/04/08	Wareham	Swifts	WSB5	13:00	20	16.1	1.001	1	80	18	3,000
81	11/06/07	Wareham	Swifts	WSB6	13:25	20	13	1.001	1	100	11	3,800
82	11/06/07	Wareham	Swifts	WSB7	13:50	12	12.5	1.000	0	500	38	28,000
83	06/04/08	Wareham	Swifts	WSB7	13:10	5	16.7	1.000	0	400	27	3,200
84	04/28/08	Wareham	Wareham River (Launch)	WWR1	19:00	4	13.9	1.000	0	1200	80	83
85	06/04/08	Wareham	Wareham River (Launch)	WWR1	10:55	5	16.1	1.006	8	160	39	3,000

Table 3. Summary of the geometric mean and maximum of fecal coliform CFU counts and the number of samples from each site within the Town of Bourne.

Town	Location	Site	Number of Samples	Average Flow (liters per min)	Geometric Mean	Maximum Sample Value
Bourne	Bennets Neck	BBN1	2	8	54	210
Bourne	Bennets Neck	BBN2	2	8	108	130
Bourne	Hen Cove	BHC1	3	71	74	640
Bourne	Hen Cove	BHC2a	4	651	55	520
Bourne	Hen Cove	BHC2b	3	19	1,577	11,000
Bourne	Hen Cove	BHC3	4	158	1,557	45,000
Bourne	Hen Cove	BHC4	4	153	792	32,000
Bourne	Hen Cove	BHC4W	1	2	400	400
Bourne	Pocasset River	BPR1	2	24	385	510
Bourne	Pocasset River	BPR2	3	40	608	8,800

Table 4. Summary of the geometric mean and maximum of fecal coliform CFU counts and the number of samples from each site within the Town of Marion.

Town	Location	Site	Number of Samples	Average Flow (liters per min)	Geometric Mean	Maximum Sample Value
Marion	Tabor	MAR1	3	43	5,182	55,000
Marion	Tabor	MAR2	1	400	30,000	30,000
Marion	Tabor	MAR2alt	2	15	420	2,800
Marion	Tabor	MAR3	2	350	24	63
Marion	Tabor	MAR4	2	30	259	480
Marion	Tabor	MAR4alt	1	40	9	9
Marion	Tabor	MAR5	3	133	658	4,000

Table 5. Summary of the geometric mean and maximum of fecal coliform CFU counts and the number of samples from each site within the Town of Wareham.

Town	Location	Site	Number of Samples	Average Flow (liters per min)	Geometric Mean	Maximum Sample Value
Wareham	Town Center	WAR1	2	340	4,189	4,500
Wareham	Town Center	WAR2	3	493	577	1,500
Wareham	Town Center	WAR3	2	6	198	2,300
Wareham	Town Center	WAR4	2	240	186	910
Wareham	Town Center	WAR5	1	80	910	910
Wareham	Town Center	WAR6	2	50	590	1,200
Wareham	Pinehurst Beach	WPH1	2	24	300	820
Wareham	Pinehurst Beach	WPH2	2	6	5,292	28,000
Wareham	Pinehurst Beach	WPH3	2	50	781	6,100
Wareham	Pinehurst Beach	WPH4	2	14	2,098	2,200
Wareham	Pinehurst Beach	WPH5	2	24	424	1,500
Wareham	Pinehurst Beach	WPH6	2	8	566	970
Wareham	Boat Launch	WWR1	2	680	499	3,000
Wareham	Parkwood Beach	WPW1	2	204	1,149	30,000
Wareham	Parkwood Beach	WPW2	2	480	1,732	200,000
Wareham	Swifts	WSB1	2	56	17,329	143,000
Wareham	Swifts	WSB2	2	56	5,899	12,000
Wareham	Swifts	WSB3a	1	100	590	590
Wareham	Swifts	WSB3b	1	40	4,000	4,000
Wareham	Swifts	WSB4	2	350	6,567	9,800
Wareham	Swifts	WSB5	2	140	1,068	3,000
Wareham	Swifts	WSB6	1	100	3,800	3,800
Wareham	Swifts	WSB7	2	450	9,466	28,000

Table 6. Summary of the geometric means for all samples by date. Average water sample temperatures and the average and variance of $\log_e$ transformed fecal coliform counts are provided for reference. Different sets of locations were sampled on each date.

Date	Samples (N)	Temp (°C)	Geometric mean	Average Log_e Fecal Coliform Count (CFUs)	Variance Log_e Fecal Coliform Count (CFUs)
10/25/07	3	13.9	9081	9.11	6.16
11/06/07	12	13	1415	7.26	3.15
04/28/08	22	13.2	91	4.52	2.67
05/08/08	9	15.3	164	5.1	4.18
05/20/08	5	12.8	182	5.2	5.93
06/04/08	26	17	3538	8.17	4.23
06/15/08	8	16.5	1820	7.51	3.38