Chapter 3. Characterization of Pollution Sources

Overview

Buzzards Bay remains an estuary in transition. The stresses faced by Buzzards Bay are typical of the stresses placed on many estuaries of the northeastern United States from past dumping of wastes, new development, and conflicting uses of natural resources. Along the eastern and northern shores of Buzzards Bay, dramatic coastal development occurred in the 1980s and 1990s. Owners converted small summer vacation homes into year-round residences. Property owners built an even larger number of new homes in some of these summer cottage areas. In the late 1990s and early 2000s, communities on the western shores like Westport, Dartmouth, and Mattapoisett had their own similar growth booms. In contrast, areas like the City of New Bedford, an old industrial and fishing center has had both a severe and continued population and economic decline, in part contributing to the suburban growth patterns in the surrounding communities.

Like many old industrial centers, the greater New Bedford area suffered from decades of pollution. While areas of New Bedford inner and outer harbor and Clarks Cove have seen some dramatic improvements in water quality, this area of Buzzards Bay still faces decades of prescribed cleanup and restoration.

In contrast to the success stories around New Bedford, most growth areas for development around the bay have largely experienced only continued water quality declines during the past two decades. Most of this degradation has been the result of nonpoint source pollution, and regulators have not imposed solutions, nor have towns adopted solutions voluntarily, especially for coastal eutrophication problems.

In the early 2000s, the ability of managers and government to address these problems expanded as DEP began issuing nitrogen TMDLs for some Buzzards Bay embayments, and issued a bacterial TMDL in 2009. Both these actions will have profound environmental, economic, and political impacts in the region for decades to come. Any improvements to water quality, however, will largely depend on the schedule that federal and state government mandates for compliance with these TMDLs. These issues are discussed in other chapters of the Buzzards Bay CCMP.

Management solutions for restoring and protecting Buzzards Bay require an increasingly sophisticated knowledge and understanding of pollution sources, estuarine processes, and the effect of land use on water quality. This chapter is meant to provide a cursory overview of the main pollutant issues facing Buzzards Bay and is not meant to be exhaustive. In each section, we provide footnotes to articles with more thorough discussions, or that contain data that are more specific.

Classification of Pollution Types

To simplify characterizing pollution sources, since the introduction of the Clean Water Act, managers tend to classify pollution sources into point and nonpoint sources. Point sources occur at discrete and identifiable points, usually through pipeline discharges or direct dumping. Obvious point-source discharges into estuarine and coastal waters include sewage treatment plants, industrial discharges, and combined sewer overflows (CSOs). Nonpoint sources are considered diffuse, often intermittent, and sometimes ill-defined inputs to an estuary. These sources include surface runoff, direct atmospheric deposition, underground transport from wastewater and disposal sites, and other pathways that contribute pollutants from agriculture and development to surface waters.

This classification of pollution sources largely reflected the type of discharge permit required from a state or federal agency. However, by 2000, state, and federal discharge permit programs began to treat certain nonpoint sources as permittable pollutant sources. Certain agricultural practices, such as concentrated agricultural feedlots, and water pumped from cranberry bogs also became regulated as point sources of pollution if they caused environmental degradation. In particular, the aggregating of previously considered nonpoint municipal stormwater networks under a regulatory discharge permit program (NPDES) began having profound effects on stormwater is characterized and managed. Someday septic systems could be managed under a programmatic discharge permit, depending upon the outcome of certain legal challenges to nitrogen TMDLs in Massachusetts.

Despite this shift in the regulatory classification of some nonpoint sources, throughout this Buzzards Bay CCMP, we still refer to stormwater discharges and nitrogen discharges from septic systems as nonpoint source pollution.

Wastewater Facilities

Based on 2010 U.S. Census statistics, and estimated sewer coverage in Buzzards Bay, 64,335 units or 55% of the total residential units in the Buzzards Bay watershed are sewered.[34]. Most of these units are tied to one of the six-wastewater treatment facilities shown in Table 11. All sewage treatment facilities cause, or have the

[34] Buzzards Bay NEP analysis; see the detailed explanation of this calculation in Action Plan 1 Managing Nitrogen Sensitive Embayments.

potential to cause, local decline in water quality. Because these facilities collect and treat such a large fraction of residential and commercial wastewater flow and other discharges, and will increasingly do so in the future, they warrant special attention in this chapter. In many instances, sewage treatment facilities have caused regional declines in the health of coastal ecosystems. The type of treatment provided, the location of the discharge, and the types of wastes collected by sewers are critically important to the impacts caused by these systems.

As the population in the Buzzards Bay drainage basin continues to grow, or as sewer systems continue to expand and tie in homes on onsite wastewater facilities, there will be a need to expand the capacity of existing wastewater facilities or to create new ones. Most of these systems are publicly owned wastewater treatment facilities (also called publicly owned treatment works, or POTWs); hence, the operation of these facilities and the siting of future sewage treatment facilities are critically important to the local and regional water quality in Buzzards Bay. Increasingly, with the construction of large new mixed use development projects in the northern Buzzards Bay watershed, and the consolidation of wastewater treatment for some types of commercial development, more privately operated wastewater facilities will also be built. The biggest challenge facing all these wastewater facilities, whatever their scale, is that they must be built or upgraded to comply with new nitrogen TMDLs. When permits for these facilities expire, or are updated to accommodate new flows, state and federal agencies must ensure that they meet nitrogen TMDLs, and that permits are renewed expeditiously.

Facilities discharging to surface waters are issued a National Pollutant Discharge Elimination System (NPDES) permit by the U.S. Environmental Protection Agency (EPA) in consultation with the Massachusetts Department of Environmental Protection (DEP). Massachusetts is the only state that did not delegate this responsibility. Wastewater discharges to groundwater (with system designs over 10,000 gallons per day) are issued a groundwater discharge permit by the DEP.

Table 11. Buzzards Bay major municipal publicly operated treatment facilities (1).

Permit/Municipality	**New Bedford**	**Fairhaven**	**Dartmouth**	**Wareham**	**Marion**	**Falmouth**
Permit Number	MA0100781	MA0100765	MA0101605	MA0101893	MA0100030	SE#3-168
Permit Type	surface	surface	surface	surface	surface	groundwater
Permitted Volume	30.0 MGD	5.0 MGD	4.2 MGD	1.56 MGD	0.5 MGD	1.0 MGD
Percent Sewered(2)	96%	79%	61%	50%	39%	3%
Others served	Acushnet	Mattapoisett	-	Bourne	-	-
Discharge Location	Off Clarks Point in Buzzards Bay	New Bedford Harbor (Acushnet River)	Off Mishaum Point in Buzzards Bay	Agawam River to Wareham River Estuary	Benson Brook to Aucoot Cove	Groundwater to West Falmouth Harbor
Issue date	26-Sep-08	4-Mar-03	18-Jun-09	28-Apr-08	22-May-07	15-Feb-02
Expiration date	26-Sep-13	4-Apr-05	18-Jun-14	27-Apr-13	02-Feb-12	15-Feb-03
Treatment(3)	advanced secondary	secondary	secondary	tertiary	tertiary	tertiary
Pre-treatment Program	yes	no	no	no	no	no
N limit?	no, report only	no, report only	no, report only	yes, 4.0-ppm TN seasonal	no, but seasonal ammonia limit	yes, 3.0-ppm TN seasonal

(1) There are other municipal groundwater discharge systems (Fairhaven West Island facility and Falmouth New Silver Beach facility), and some school (e.g. Mass Maritime Academy) and smaller private discharges not included here. See additional facilities in Table 12.

(2) Data as follows: Falmouth: from town reports (whole town by percent of water accounts), Wareham: Buzzards Bay NEP estimate from built parcels (residential and non residential) coded to sewer and septic (for comparison, 45% from census residential units calculation), Marion, New Bedford Fairhaven and Dartmouth: estimated from analysis of residential units in U.S. Census blocks intersected with estimated sewer maps as outlined in Action Plan 1 Managing Nitrogen Sensitive Embayments. Not shown is Bourne (9% of residential units to Wareham), Acushnet (20% to New Bedford), and Mattapoisett (39% to Fairhaven).

(3) Primary treatment: Wastewater treatment process where solids are removed from raw sewage primarily by physical settling. The process typically removes about 25-35% of solids and related organic matter (BOD). Secondary treatment: Waste treatment process where oxygen-demanding organic materials (BOD) are removed by bacterial oxidation of the waste to carbon dioxide and water. Bacterial synthesis of wastewater is enhanced by injection of oxygen. Tertiary treatment: Waste treatment processes designed to remove or alter the forms of nitrogen or phosphorus compounds contained in domestic sewage.

Figure 27. Town of Falmouth wastewater facility.

There are six major publicly owned municipal treatment works (sewage treatment facilities) in the Buzzards Bay drainage basin (Table 11, Figure 27). All of these discharge to surface waters under a NPDES permit, except the Falmouth wastewater facility, which has a groundwater discharge permit. While the Dartmouth, Marion, and main Falmouth wastewater facilities only serve their communities, the New Bedford facility also serves portions of Acushnet, the Wareham facility also serves part of Bourne (near Buttermilk Bay and the village of Buzzards Bay), and Fairhaven also serves the Town of Mattapoisett (Rt. 6 and Village Center). This sewer service is provided to the respective neighboring towns for a fee.

There are also two smaller municipal community scale facilities operated by Buzzards Bay municipalities, both of which discharge to groundwater. The Town of Fairhaven has a wastewater facility serving approximately 250 residents on West Island (permitted maximum flow of 100,000 gpd), and the Town of Falmouth has a wastewater facility serving 150 residences in the New Silver Beach area of North Falmouth (permitted maximum flow of 60,000 gpd).

The Massachusetts Maritime Academy, a state school, has a wastewater discharge NPDES permit to discharge to Buzzards Bay. The school, which has more than 1,100 students, has a wastewater discharge limit of 77,000 gpd.

A portion of the Mass. Military reservation is sewered, and its wastewater is treated at a facility outside the watershed, in the Town of Sandwich. The treated wastewater (30,000 gpd design limits, permit WE648), is then pumped 8 miles to leaching beds along the Cape Cod Canal, which are inside the Buzzards Bay watershed, so some groundwater borne contaminants from this discharge enter into Buzzards Bay via tidal flows from the Cape Cod Canal. Other groundwater wastewater discharges in the Buzzards Bay watershed over 10,000 gpd are shown in Table 12.

Table 12. Groundwater wastewater discharge groundwater permits in the Buzzards Bay watershed over 10,000 gpd not included in Table 11.

Permit	Town	Facility Name	Design Flow
SE415	Bourne	Brookside Golf Association	60,000
SE670	Bourne	Bourne Middle School	35,400
SE778	Bourne	Pocasset Assisted Living	16,350
SE515	Carver	Mass. Environ. Services	75,000
SE620	Fairhaven	West Island WWTF	100,000
SE49	Falmouth	Seacrest Condo Assoc	85,000
SE720	Plymouth	Plymouth Airport	25,000
SE711	Westport	Edgewater Apartments, LLC	11,000

The NPDES program originated with the federal Water Pollution Control Act of 1972, which required that by 1983 (later adjusted to 1988), sewage treatment facilities that discharge to surface waters must provide a minimum of secondary treatment (biological processes that remove a minimum of 85% of the organic matter). All facilities, except New Bedford, complied with the Act by 1988, and New Bedford finally completed its facility in 1994. There remain special problems faced by New Bedford with respect to their combined sewer overflow systems, and these issues are discussed below.

For the most part, detrimental effects from the discharges of sewage treatment facilities are localized near the sites of discharge, although the New Bedford discharge is of such a magnitude that it has appreciable effects over a broad area. These effects are most acute when the discharge occurs in poorly flushed areas. Both the New Bedford and the Dartmouth plants discharge to well-mixed portions of Buzzards Bay, but the other facilities discharge to coastal embayments with various degrees of tidal flushing.

Permits issued by DEP and EPA are meant to address these impacts by setting allowable concentrations, or sometimes allowable loadings, of pollutants of concern from wastewater facilities. Discharge permits generally have requirements limiting the concentrations of suspended solids, biochemical oxygen demand (BOD), fecal coliform bacteria, and chlorine in the effluent.

During the 1990s, scientists and managers recognized that nutrient levels (nitrogen in saltwater and phosphorus in freshwater systems) in the discharge also caused problems in the receiving waters, and both DEP and EPA began requiring discharge limits for nutrients. In 2006, the Towns of Falmouth and Wareham completed upgrades to their wastewater facilities that enabled tertiary treatment for nitrogen. The Wareham facility was required to limit total nitrogen to 4 ppm during the period May to October. The Falmouth facility, which discharges to West Falmouth Harbor via groundwater flow, has a seasonal discharge limit of 3-ppm total nitrogen. This facility discharges some effluent from the secondary treatment lagoons by spray irrigation. The Falmouth facility achieves a greater amount of nitrogen treatment because the tertiary treated effluent is spray irrigated onto vegetated land.

The Fairhaven treatment facility discharges to New Bedford Inner Harbor and is a significant source of nitrogen to the eutrophic harbor, but the estuary is affected by other sources of pollution, including combined sewer overflows (CSOs) from New Bedford.

The Wareham and Marion facilities discharge to streams or rivers that flow into small embayments (Agawam River branch of the Wareham River estuary and Aucoot Cove, respectively). Nitrogen from these facilities, affects the receiving waters, especially in the poorly flushed estuarine area of the Agawam River.

In contrast to these facilities, the Town of Marion wastewater facility, which discharges to Aucoot Creek, was determined not to affect Aucoot Cove, a well-flushed embayment. Nonetheless, concerns have remained about eutrophic conditions in the tidal creeks in the salt marsh where Aucoot Creek discharges.

The Town of Fairhaven wastewater facility discharges to New Bedford Harbor (Acushnet River) just behind the hurricane barrier. The Buzzards Bay Coalition water quality-monitoring program has identified this harbor as one of the most eutrophic systems in Buzzards Bay. However, because of uncertainties of nitrogen source allocation among the three municipalities surrounding New Bedford Harbor (New Bedford, Acushnet, and Fairhaven), and because of potential costs of upgrading the facility, the EPA has deferred issuing a nitrogen limit within the wastewater permit pending future studies through the DEP Massachusetts Estuaries Project.

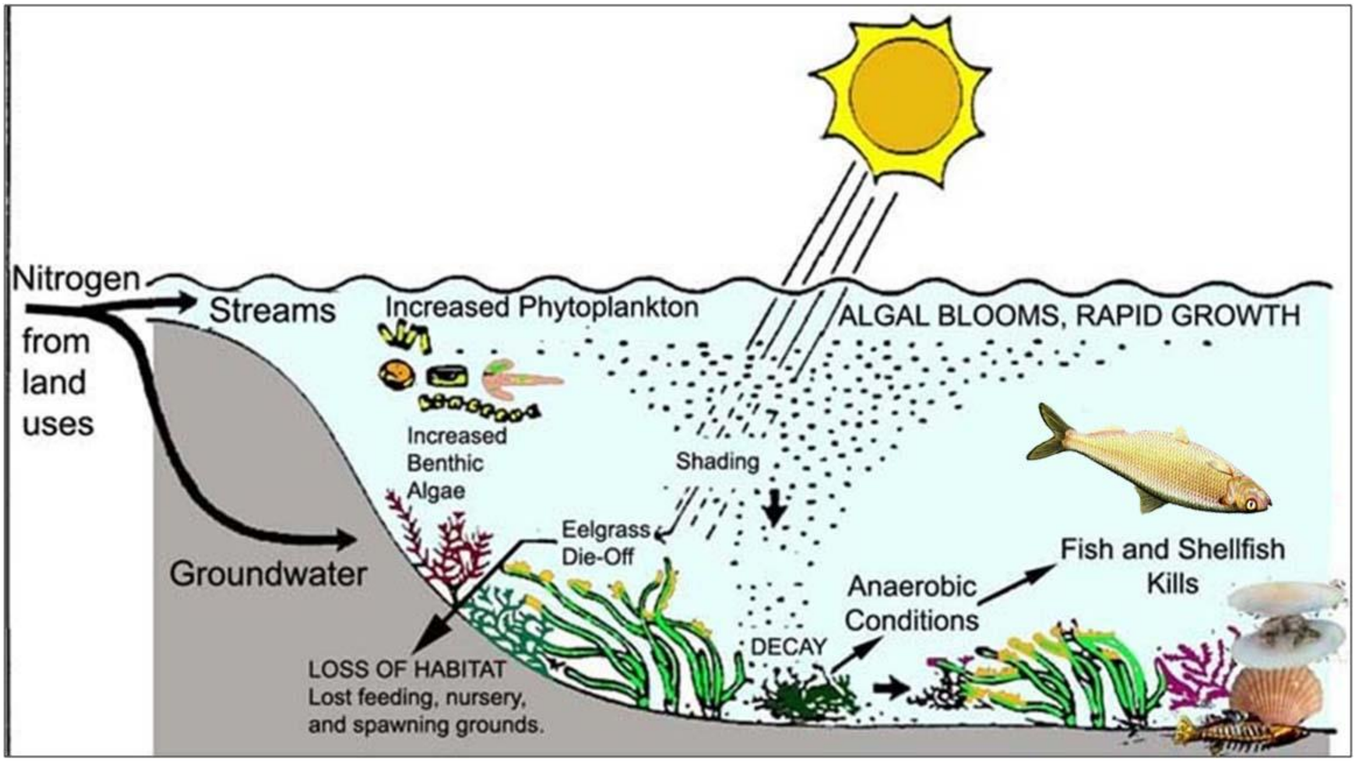
If an industry tied into the system is known to produce toxic materials, or if there has been an identified contaminant problem in the past, the permit may also contain chemical-specific limits, so that special attention can be focused on the contaminants of concern. All permits require self-monitoring by the discharger in order to demonstrate compliance with the specified permit limits. According to federal and state law, municipal plants that treat industrial and commercial contaminants must institute a pretreatment program. This program is designed to identify the sources of toxic compounds and require the contributor to reduce or remove these materials prior to their discharge into the sewer system. Each individual contributor must therefore remove specified pollutants from the flow before it is discharged into the municipal system. In some cases, industries are issued their own permits to discharge directly to the receiving water. The requirements for these permits are always at least as strict as those permit requirements for a municipal discharge.

All of the discharges are sources of bacterial contamination and require closure areas around the outfalls for the protection of public health. These discharges have a significant impact on shellfish resources and sometimes close swimming beaches. This is particularly true for New Bedford and Dartmouth and, to a much lesser extent, for the other communities. All of these treatment plants use chlorine to disinfect the treated wastewater. Although chlorine is an efficient and cost-effective means of disinfection, there is concern that chlorine residuals in wastewater discharged to the bay may have detrimental effects on marine life and the long-term viability of the ecosystem.

Until 2010, the Ocean Sanctuaries Act prohibited any new discharges from wastewater treatment plants directly into Buzzards Bay (part of the Cape and Islands Ocean Sanctuary). This included any increase over the design capacity of the discharge, even if it is of significantly higher quality, or a relocation of the outfall.

However, in 2008, because of the prospect of new industrial scale offshore electrical generating wind facilities, the Massachusetts state legislature passed the Ocean Act requiring the Massachusetts Office of Coastal Zone Management to help resolve conflicts in waters mostly more than 1/3 mile offshore. The new law required that Massachusetts Coastal Zone Management (CZM) develop an Ocean Management Plan that established “goals, siting priorities and standards for ensuring effective stewardship of its ocean waters held in trust for the benefit of the public.” It also resulted in amendments to the Ocean Sanctuaries Act that now allow new ocean outfalls through a not-yet fully defined variance process.

The anti-degradation provision of the Commonwealth’s water quality standards is a potent regulatory tool that protects the beneficial uses of the state’s waters from contamination by municipal treatment plants and other sources. The anti-degradation policy (1) safeguards present water quality conditions necessary to protect existing uses; (2) maintains water quality that exceeds the level necessary to support propagation of fish, shellfish, wildlife, and recreation unless lower water quality is necessary to accommodate economic or social development; and (3) maintains and protects outstanding resource areas designated by the state in an absolute fashion with no qualifications.



Modified from a U.S. Fish and Wildlife circular, Restore Chesapeake Bay (2/90) and the 1991 Buzzards Bay CCMP.

Figure 28. Generalized response of shallow coastal embayments to excessive nitrogen loading.

Major Issues

As populations in the basin grow, there will be a need to increase the capacity of existing wastewater facilities or to build new ones. To protect marine water quality, the preferred option for disposing of sewage appears to be land-based disposal, particularly if it includes tertiary treatment (as is the case in Falmouth). However, in many areas, land-based application is not a feasible option, because of either hydrologic conditions, or a shortage of suitable land. In these cases, other alternatives must be considered that would best protect human health and the environment. In most cases, disposal of effluent to surface waters without nitrogen removal is not desirable, particularly if they are nitrogen sensitive, or have significant living resources or uses.

All treatment plants produce sludge as a by-product. Given the capacity problem at local landfills to receive sludge, the long-term disposal is an issue. Sludge with low concentrations of toxic materials can be composted and used as a soil additive. However, sludge with high concentrations of toxic materials is harder and more costly to dispose of. Toxicants in sludge result largely from materials entering the sewer systems from homes and industry. For this reason, the reduction of toxic contaminants entering the waste must be accomplished through aggressive programs of industrial pollution prevention and if necessary, pretreatment and homeowner toxic use reduction.

Many of the treatment plants in the area have antiquated sewer collection systems. In New Bedford, sanitary sewers are combined with stormwater overflow systems (CSOs). In some towns, flows increase appreciably during storms or periods of high groundwater. The introduction of stormwater and groundwater into sewer collection systems can reduce the effectiveness of wastewater treatment. Although the cost is prohibitive to correct all the sources of groundwater and stormwater entering these sewer networks, correction of the major problem areas can improve plant operation and capacity. Water-conservation measures can also help reduce volume of flow at treatment facilities.

Priority Pollutants

In the 1991 Buzzards Bay CCMP, the Buzzards Bay NEP focused its efforts on three priority pollution problems: pathogen contamination, toxic contamination, and increasing nitrogen inputs and how they affect water quality and living resources in Buzzards Bay. The Buzzards Bay management conference selected these pollution problems because they had the greatest impact on the economic, ecological, and aesthetic values of Buzzards Bay.

These three sources remain the focus of pollution-related recommendations in the Buzzards Bay CCMP 2013 Update, but new emerging contaminants, like pharmaceuticals, also need to be addressed and are discussed in this updated management plan. Below is a thumbnail overview of the pollution sources and impacts to Buzzards Bay and the surrounding watershed.

Nutrients and Eutrophication in Buzzards Bay

Nitrogen, the primary nutrient of concern in marine waters such as Buzzards Bay, is essential for the proper growth and reproduction of individual organisms and, consequently, for the general productivity of the bay. In nature, nitrogen occurs in many forms (e.g., ammonia, nitrates). The addition of excessive amounts of nitrogen (also called “nutrient enrichment” or “nitrogen loading"), to coastal waters results in eutrophication and a general decline in the health of coastal ecosystems (Howarth et al., 2000).[35]

In general, excessive nutrient inputs can result in increased growth of microalgae (such as phytoplankton, for Buzzards Bay see Turner et al. 2009) and macroalgae (seaweeds), which in turn changes the distribution and abundance of species present and in food-web relationships. For example, increased turbidity from phytoplankton growth prevents sunlight from reaching submerged vegetation like eelgrass, and beds of eelgrass begin to disappear (Short et al., 1996). Because eelgrass beds are a valuable habitat and nursery for many organisms, the loss of this community can cause shifts in many populations of animals. Excessive algal growth, coupled with decay of accumulated algae, may result in the depletion of oxygen in the water. Depressed oxygen concentrations (anoxia or hypoxia) can lead to fish kills and death of sensitive benthic organisms. These events are graphically represented in Figure 28 and have been discussed in numerous reviews.

There is also increasing evidence that the effects of high nutrient loading, turbidity and the release of dissolved organic matter from algae, contribute to the prolonged survival and possible growth of coliform bacteria in coastal waters (e.g., Davies et al., 1995; Byappanahalli et al., 2003; Haller et al., 2009). Because coliform levels are used to classify swimming and shellfish areas, nutrient loading may contribute indirectly to the closing of these areas.

Coastal embayments receive nitrogen from a variety of sources including onsite wastewater systems (generally called septic systems), centralized wastewater treatment facilities, atmospheric inputs, and fertilizers used on lawns, golf courses, and agricultural areas. The nitrogen from these sources is conveyed to the bay by effluent outfalls, streams and rivers, overland runoff, and groundwater that drains from the land. The relative importance of these sources depends on the specific land use within each drainage sub-basin.

Elsewhere, atmospheric nitrogen loading is often the focus of management concern, and using the MEP loading model rates, it accounts for a third of the total nitrogen load to Buzzards Bay as a whole (Table 13). However, only about half the dissolved inorganic nitrogen from the atmosphere can be considered pollution from human sources, the other half is part of a natural global nitrogen cycle. Moreover, the central area of Buzzards Bay is not nitrogen impaired; instead, the fringing embayment systems suffer impairments, and in these areas, atmospheric deposition accounts for typically 15% or less of estuary nitrogen loading.

Another important facet of nitrogen inputs from the atmosphere is that they have been declining in the northeastern US for several decades, partly because of Clean Air Act regulatory mandates (Christopher et al., 2005). Despite the decline in atmospheric nitrogen loading, indicators of nitrogen loading such as eelgrass distribution (e.g. Figure 10) support the idea that increases in local watershed loading; not atmospheric loading is the cause of these declines. That is, the dramatic declines of eelgrass around Buzzards Bay during the 1980s and 1990s appeared to follow the rapid population growth and development in the region during the 1970s and 1980s, with water quality and habitat in some estuaries continuing to decline today. More recent water quality data show that trends in declining water quality are continuing in some embayments (Figure 29).

In the 1991 Buzzards Bay CCMP, it was recognized that many areas of the bay were impaired by eutrophication, and that nitrogen sources in the watershed around each embayment were the principal sources of this coastal eutrophication. It was stressed that each watershed had its suite of nitrogen sources, and each watershed needed a management strategy customized to those sources. A concern of many was that the wastewater discharges from New Bedford (the wastewater facility outfall and CSOs) were very large, perhaps accounting for half the watershed loading (exclusive of precipitation to the bay). Nonetheless, the impacts from these discharges were largely confined to within a few miles of the outfalls (Borkman and Turner, 2003; Turner et al., 2000, 2009), and expressed mostly in the form hypoxia with respect to eutrophication impacts.

Twenty years later, nitrogen concentrations and organic loadings from the New Bedford wastewater facility discharge have declined, as has the volume of the CSO discharges. Sewering in other towns has also expanded. Today, at the Buzzards Bay basin level, the New Bedford wastewater facility and CSOs now account for only about 20% of the total non-atmospheric

[35] Andersen et al. (2006) defined eutrophication as ’the enrichment of water by nutrients, especially nitrogen and/or phosphorus and organic matter, causing an increased growth of algae and higher forms of plant life to produce an unacceptable deviation in structure, function and stability of organisms present in the water and to the quality of water concerned, compared to reference conditions.’

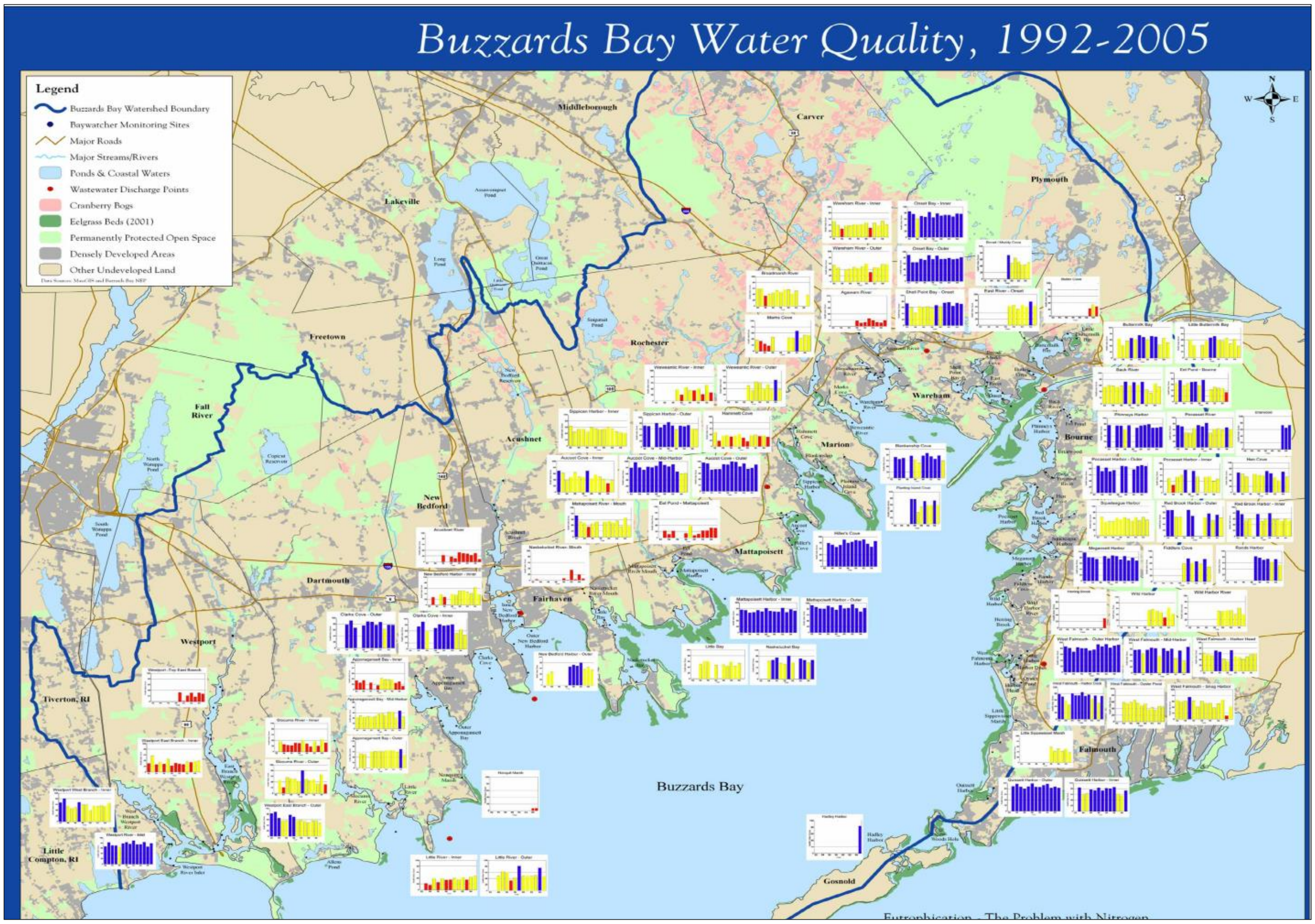


Figure 29. Embayment eutrophication trends from a 2005 Buzzards Bay Coalition bay health index poster.

loading, but the New Bedford outfall is still the single largest non-atmospheric source, and collectively all wastewater outfalls still discharge roughly twice the nitrogen discharged to Buzzards Bay as from septic systems (see Table 13). This is true because more than half the watershed population and most of the industrial businesses in the watershed are connected to these sewer networks.

Despite these statistics, sewage outfalls are generally not the largest source of nitrogen in most embayment watersheds. The more serious effects of nitrogen loading observed in Buzzards Bay occur in the localized network of shallow embayments that border the bay, and the water quality in these systems is the result of inputs from the mostly “non point” sources particular to their surrounding drainage basin. As shown by Table 13, septic systems remain the largest single nitrogen source in most embayments.

Septic systems release large amounts of nitrogen as ammonia, which is rapidly transformed in the groundwater to nitrate in the presence of oxygen. In general, nitrate in groundwater flows great distances without attenuation (or dilution) and with little chance of uptake by plants, although the latest MEP nitrogen models generally assume that about 50% of the nitrogen is lost when it enters ponds, and 30% through the passage of large river systems, but those findings vary among watersheds.

The sources of nitrogen in a watershed can be diverse, and deciphering their contributions can be difficult and complex to resolve. For example, in Phinneys Harbor, septic systems now account for 63% of the nitrogen to the watershed (Figure 30). In rural agricultural areas like Westport, far more nitrogen is contributed to the estuary by fertilizers and animal wastes than by septic systems. In a recent draft TMDL report for the estuary, waste from dairy and beef cows alone, exceeds loading from septic systems in the watershed. In the town of Wareham, loadings from the wastewater facility and cranberry bogs together exceed septic system loadings (Figure 31).

Table 13. Comparison of wastewater and atmospheric nitrogen loading (kg/y) to Buzzards Bay and its subwatersheds.

Embayment	Water area mi^2	Basin Land area mi^2	est. subbasin occupancy	septic system load	wastewater facility and CSO load	atmosphere to embayment	Watershed +atmosph. +outfalls	Comment
Allens Pond	0.30	3.17	2.7	496	0	839	5,707	(1)
Apponagansett Bay	0.52	7.67	3.0	2,718	0	1,461	24,213	(1)
Aucoot Cove	0.50	4.06	2.6	1,970	5,490	1,406	12,787	(1)
Brant Island Cove	0.13	0.64	2.3	419	0	371	1,225	(1)
Buttermilk Bay	0.83	9.91	2.1	16,941	0	2,333	33,175	(1)
Clarks Cove	1.10	2.91	2.5	0	8,845	3,117	30,813	(1)
Hen Cove	0.10	1.67	2.0	2,364	0	283	5,244	(1)
Little Bay	0.29	5.46	3.0	6,821	0	807	31,192	(1)
Little River	0.13	2.05	3.3	773	0	378	4,603	(2)
Mattapoisett Harbor	0.61	26.82	3.0	16,554	0	1,733	51,071	(1)
Megansett / Squeteague Harbor	0.66	4.50	2.5	6,206	0	1,853	31,168	(1)
Little Bay / Nasketucket Bay	0.29	5.46	3.0	6,821	0	807	31,192	(1)
New Bedford Harbor (Acushnet River)	1.49	26.17	2.4	15,503	62,839	4,197	93,830	(3,6,7)
Onset Bay	0.92	4.82	1.9	6,527	0	2,605	18,578	(1)
Phinneys Harbor / Back River	0.84	4.87	2.4	7,934	0	2,365	21,230	(1)
Pocasset Harbor	0.39	1.09	1.4	2,268	0	1,090	5,806	(1)
Pocasset River	0.31	3.33	2.5	4,841	0	872	9,449	(1)
Quisset Harbor	0.18	0.52	1.6	604	0	512	2,234	(1)
Red Brook Harbor	0.24	3.98	2.4	2,582	0	665	9,299	(1)
Sippican Harbor	0.66	3.83	2.7	4,769	0	1,853	18,189	(1)
Slocums River	0.76	36.61	3.0	8,710	0	2,147	34,234	(3)
Wareham River	0.96	43.00	2.3	12,118	9,184	3,950	52,332	(3,4,5)
Weweantic River	0.92	82.77	2.8	43,085	0	2,594	162,264	(1,4)
West Falmouth Harbor	0.31	3.48	2.0	3,665	7,980	910	24,125	(2)
Widows Cove	0.21	2.02	1.8	125	0	589	1,765	(1)
Wild Harbor	0.19	4.04	1.6	4,091	0	534	9,467	(1)
Wings Cove	0.34	1.29	2.7	1,033	0	959	4,319	(1)
Westport Rivers	5.15	68.98	2.9	43,158	0	17,020	192,289	(2)
Non-embayment watersheds						5,799	114,631	(1)
Buzzards Bay, precipitation to bay						716,799	716,799	(5)
New Bedford Wastewater Outfall					368,214		368,214	(6)
Dartmouth Wastewater Outfall					97,892		97,892	(6)
Grand Total				223,097	560,444	780,848	2,219,337	
% of total				10%	25%	35%	100%	

(1) Buzzards Bay NEP approximation from MassGIS land use and MEP loading assumptions.

(2) MEP draft or final report, includes precipitation to estuary areas.

(3) Buzzards Bay NEP estimate from parcel data and other sources.

(4) Calculation using MEP 2000-2010 cranberry bog loading rates.

(5) Atmospheric loading to entire bay surface in the NEP study area (MA waters to RI border), but does not include estuary surface waters in embayment watersheds (total= 162,429 acres), times the MEP loading rate of 4.41 kg per acre.

(6) Outfall loadings as reported to EPA, July 2010 to June 2011, at echo.epa.gov/?redirect=echo.

(7) Total based on Fairhaven Outfall data as per note 6 and CSO estimates in a draft MEP report.

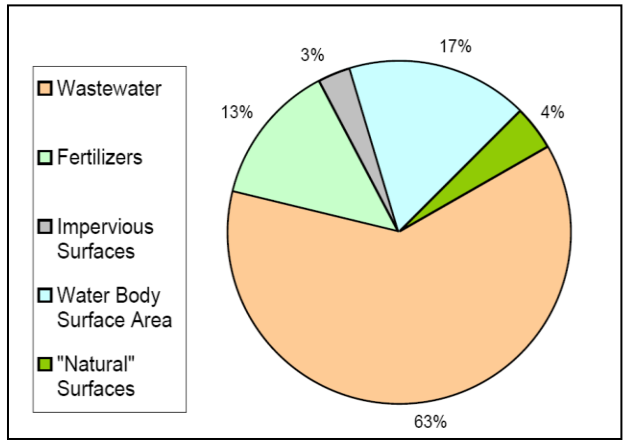
Management Responses to Nitrogen Pollution

Buzzards Bay remains an estuary in transition, and many embayments have shown declining water quality because of nitrogen discharges associated with increased development (Figure 29). In the 1980s, many government officials believed the bay's pollution was largely caused by the legacy of industrial and wastewater pollution from the greater New Bedford area. However, today it is widely understood that each embayment is adversely impacted by land use in its surrounding watershed. With the advent of increasingly sophisticated knowledge and models of estuarine processes in response to nitrogen pollution, local government is now in an excellent position to address coastal eutrophication caused by nitrogen loading. Furthermore, the Massachusetts DEP is now helping develop, and the U.S. EPA is approving, nitrogen TMDLs for impaired coastal embayments, as required by the Clean Water Act. Nitrogen pollution, and the complex political, financial, and regulatory issues and solutions surrounding the problem are the subject of Action Plan 1 Managing Nitrogen Sensitive Embayments.

Pathogen Contamination

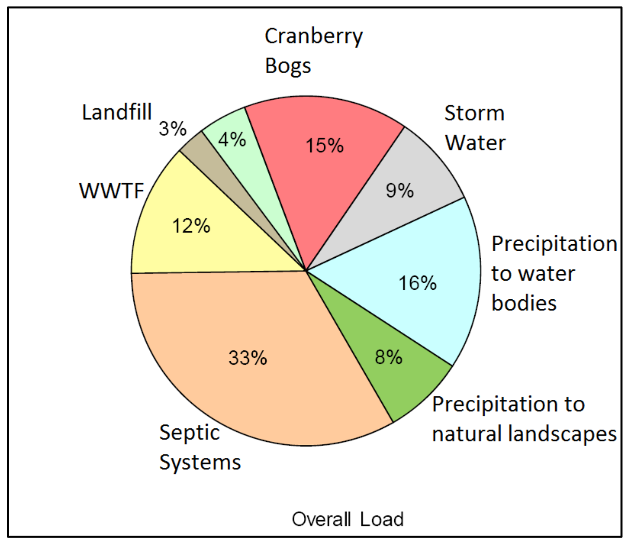
Degradation of water quality due to contamination by pathogens represents a serious health risk and economic loss to many parts of Buzzards Bay. The pathogens associated with sanitary waste disposal that are of primary concern to humans are disease-causing bacteria and viruses. Some bacteria are free-living organisms able to survive on their own and grow in an aquatic habitat; viruses, on the other hand, can grow only inside a suitable host. Of the many different viruses associated with human wastes, most are responsible for causing gastrointestinal illness, but some cause significant illnesses such as hepatitis and polio. Pathogenic bacteria found in waste material are responsible for a variety of diseases.

The presence of certain bacteria (fecal coliforms or Enterococci) in waters overlying shellfish harvesting areas and swimming beaches has historically been the primary index of the "health" of Buzzards Bay. Because public health agencies are not able to measure the entire spectrum of potential human pathogens in the water directly, these "indicator" bacteria are used to assess the probability of the presence of pathogens and human health risks. Enterococci have been the principal indicator used for swimming beaches since about 2001. Managers have used fecal coliforms for evaluating pathogen risks in shellfish since the 1980s. Formerly 'total coliforms' a superset of fecal coliform, was used by health agencies as the basis of regulatory action for both swimming and shellfish areas back to the 1920s.



From Howes et al., 2006.

Figure 30. Sources of nitrogen to Phinneys Harbor-Back River estuary complex in Bourne as reported by the MEP. Because a small percentage of this loading is attenuated, the ratio of sources of nitrogen actually reaching the bay is quite similar.



From Howes et al., 2013.

Figure 31. Sources of "attenuated" nitrogen to Wareham River estuary as reported by the MEP.

Large numbers of fecal coliform bacteria are present in the fecal material of warm-blooded animals. For the most part, most fecal coliforms themselves are not pathogenic, but are often found associated with other organisms that do cause disease in humans. When predetermined concentrations of fecal coliforms are reached, the area is considered unsafe for certain uses. Shellfishing is prohibited when concentrations reach 14 fecal coliforms per 100 milliliters (ml); bathing may be closed by the public health agency overseeing the beach when bacteria concentrations reach 200 fecal coliform per 100 ml.

A number of problems are associated with the use of fecal coliform as an indicator of public-health risk. Although this method may protect human health from bacterial pathogens, the same may not be true for viral pathogens. Under certain circumstances, fecal coliforms bear little, if any, quantifiable association with pathogens of concern, including viruses such as hepatitis A. In addition, the fecal indicator does not differentiate between human and animal wastes. The health risk and implications of the presence of fecal coliform originating from nonhuman sources have not been determined.

Prior to 2001, in Massachusetts, under Chapter 111 of the Massachusetts General Laws, the Massachusetts Department of Public Health regulations (105 CMR Section 445) required that bathing beach samples be taken at least twice monthly during the bathing season. These regulations had also failed to spell out any objective standard requiring beach closure, and instead state, "A [total] coliform count of 1000 per 100 ml shall be considered a guide requiring additional investigation, survey, or special analyses as may be necessary."

All this changed in 2001 when the Massachusetts Department of Public Health issued new regulations requiring weekly testing, and a new bacterial standard for public and semi-public beaches[36]. For marine waters, the Enterococci became the indicator organism[37], and for fresh water, the indicator organisms became either E. coli or Enterococci[38].

Sewage Treatment Plants

The most significant potential point sources of human pathogens into Buzzards Bay are the discharge of sanitary wastes from sewage treatment plants (Figure 32). The combined capacity of all such discharges to the bay exceeds 37 million gallons per day (MGD). Although these plants should be discharging only disinfected wastewater, occasional plant malfunctions and failures do occur. In general, closed "safety zones" around the immediate discharge areas are designed to protect the public from exposure to pathogens and are sized to allow adequate time to close adjacent shellfishing areas in the event of plant failure. However, a growing body of scientific evidence strongly suggests that, in some cases, traditional fecal indicator organisms are not adequately portraying real pathogen risks. For example, following chlorination, many pathogens, as well as fecal coliforms, may enter a temporary state where they may not be detectable using standard assay methods, but may later recover and pose a health risk. Fecal coliforms may also die off more rapidly than some viruses. Because of the high volume of untreated sewage that they release, CSOs in New Bedford are a major source of fecal coliforms to Buzzards Bay. The impacts of bacteria and pathogens from both sewage treatment facilities and CSOs are largely localized near these discharges.

Vessel Sanitary Wastes

Discharge of sanitary wastes from marine craft is a locally significant direct source of pathogens to Buzzards Bay. The more than 4,300 slips and moorings in the bay and the nearly 20,000 vessels passing through the Cape Cod Canal yearly create a considerable potential for waters to become contaminated with untreated sanitary waste from boats. Because of the intermittent and often covert nature of disposal from vessels, the overall impact of sanitary wastes on Buzzards Bay is difficult to assess. Roughly, 60% of the marinas in Buzzards Bay provide pump-out facilities. Marinas that do have these facilities report that they are seldom used.

The impact of sanitary waste pollution from boats tends to be site specific. In poorly flushed areas that have low dilution, the effect may be substantial and unpredictable. Health implications are difficult to evaluate from such unpredictable, and usually undetectable, changes. Nonetheless, direct illegal discharge of human wastes is a potential threat that managers must address because of the large number of boats using Buzzards Bay.

On-Site, Sub-Surface Sewage Disposal

Approximately half of the residents of the Buzzards Bay watershed use on-site, subsurface sewage disposal systems (cesspools or septic systems) to dispose of sanitary wastes. Construction of these systems is regulated by the state's sanitary code, known as Title 5, which sets minimum standards for design and placement. Pathogens are removed from septic-system wastes by two mechanisms: physical retention (or straining) by the receiving soil, and adsorption (or adherence) of pathogens onto soil particles.

Some larger onsite systems collect waste from commercial development and apartments, as well as smaller shared systems. If any of these groundwater discharges exceed 10,000 gallons per day, they must have a state permit issued by the Massachusetts Department of Environmental Protection (Figure 33). Developers often either scale back, or segment projects to create discharges less than 10,000 GPD to avoid state permit requirements.

[36] Semi-public beaches are those operated by trailer parks, campgrounds, motels, condominiums, clubs, and similar entities.

[37] The standard became, "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."

[38] The new standard was either: 1) No single E. coli sample shall exceed 235 colonies per 100 ml and the geometric mean of the most recent five E. coli samples within the same bathing season shall not exceed 126 colonies per 100 ml or (2) No single Enterococci sample shall exceed 61 colonies per 100 ml. and the geometric mean of the most recent five (5) Enterococci samples within the same bathing season shall not exceed 33 colonies per 100 ml.

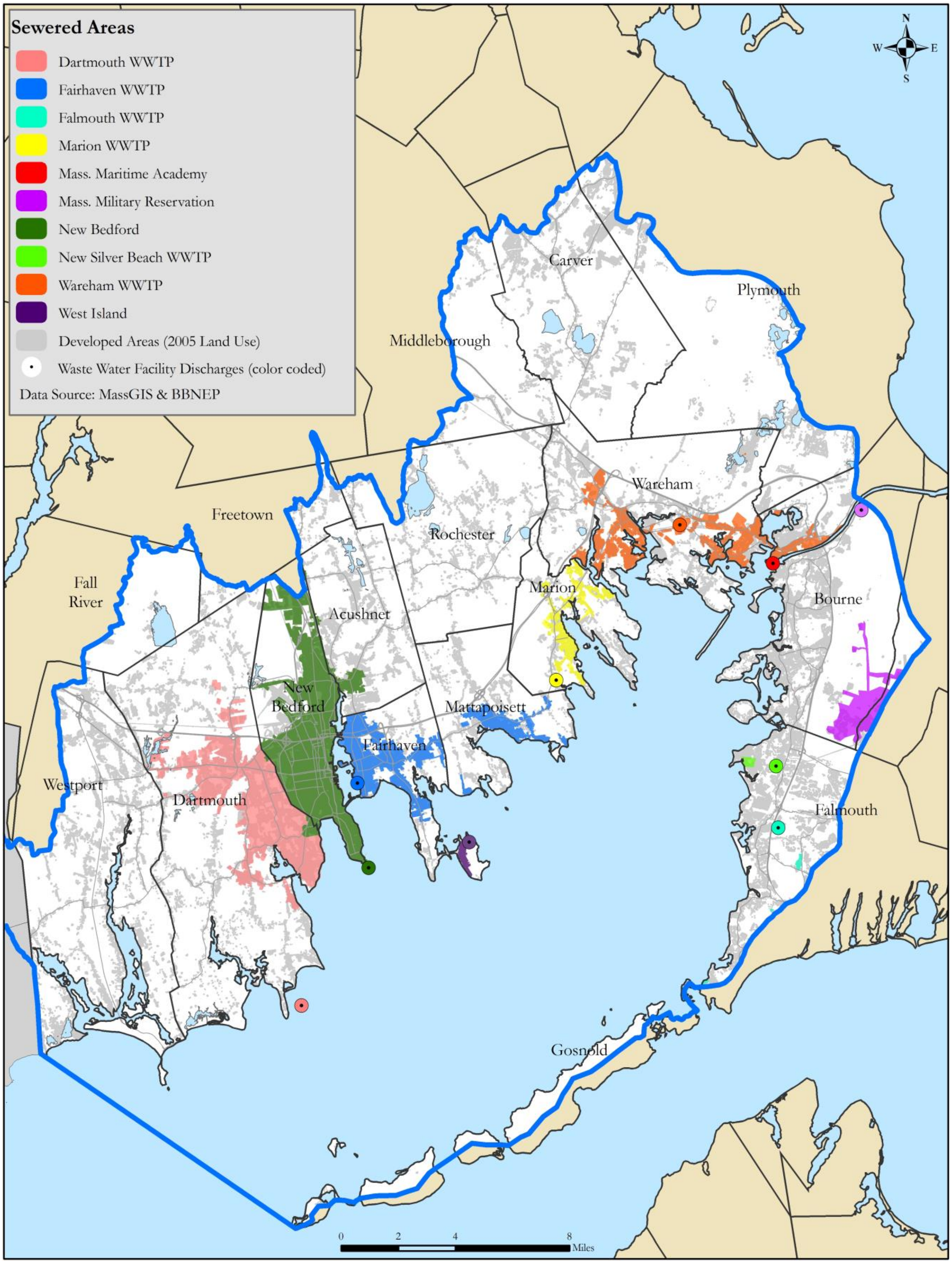


Figure 32. Sewered areas of the Buzzards Bay watershed as of 2010.

Municipal wastewater discharges located color-coded circles.

With the rewrite of the state Title 5 regulations in 1995, the code was amended to include performance standards for nitrogen concentration for nitrogen removal systems. The new code also set total suspended solids (TSS) and biological oxygen demand (BOD) limits for alternative design systems where separation to groundwater, or other design standards cannot be met, or where the system was sited in a nitrogen sensitive area. Title 5 only conferred the nitrogen standard to “nitrogen sensitive areas” (borrowing the term from the 1991 Buzzards Bay CCMP), which by default, only automatically included Zone 2 recharge areas of public wells. Other nitrogen sensitive areas were to be designated under an undefined state designation process that was never implemented. The lack of other types of nitrogen sensitive designations occurred because DEP had decided that the best process for tackling the nitrogen problem was through the more comprehensive efforts under the TMDL process.

Pathogen contamination of Buzzards Bay from onsite wastewater systems can occur in at least three ways. The most obvious threat to public health is an overt system failure. Such a failure occurs when soils can no longer receive septic effluent, and sewage collects on top of the septic system, often breaking out onto the surface of the ground. Sewage may then be transported into the receiving waters by stormwater drainage systems or overland flows. Overt system failure during dry weather probably plays a minor role in the overall pathogen contamination of Buzzards Bay. During heavy rains, many inadequately designed or maintained systems overflow, and this may be a significant source of coliforms in some areas. Many of these failures can be prevented by routine maintenance such as pumping out the solids that collect in the tank.

Closely related to overt failure is the existence of overflow pipes. Such pipes were once connected to the leaching component of septic systems to prevent failure and subsequent surface breakout. Overflow pipes were often designed to empty directly into a major water body or connecting ditch or stream. This practice of connecting overflow pipes is thought to have been quite common in past years, but is now illegal. Past surveys by state and local authorities has documented the locations of many of these overflow pipes around Buzzards Bay, and resulted in their elimination.

Improperly functioning (hydraulically failing) septic systems have long been recognized as a potential contributor of bacterial contamination of the bay. For decades, concerns have been raised about bacterial contamination of groundwater, and these concerns have been the basis of the 100-foot setbacks of septic systems from public and private wells. Still, studies conducted by the Buzzards Bay NEP in the 1980s documented that soils filter pathogenic bacteria out of wastewater over a distance of only a few yards (Heufelder, 1988), and this conclusion has been affirmed in subsequent studies (e.g. Bales et al., 1994). Virus transport remains an ongoing concern (e.g. Nicosia et al., 2001), and these concerns will remain the basis of setbacks of septic systems from water supplies.

Stormwater Runoff

Stormwater refers to that portion of precipitation that is returned to a water body via surface routes from an adjacent land mass. Although precipitation when it falls is generally devoid of fecal indicator organisms, as it flows over the ground, it washes debris and sediments into surface waters. This debris may be composed of, or contaminated with, human or animal wastes.

Historically, stormwater was managed simply to reduce or eliminate local flooding or to drain road surfaces for safety. Roadways and other developments are often designed so that excess water collects in drainage basins, ditches, and pipes, and is then directed to the nearest river, stream, estuary, or other surface water body. Little thought was given to the environmental impacts of these discharges. New development further contributed to the amount of runoff to existing stormwater networks by increasing the amount of paved or impervious surfaces and reducing the surface area available for precipitation to percolate naturally into the ground.

An additional facet of stormwater runoff that is of particular significance in agricultural areas is the sheet flow from landmasses. In this case, instead of being collected and discharged through pipes, the flow is unconsolidated and enters the receiving water in broader, less defined areas.

Numerous investigations have confirmed that stormwater runoff is a major contributor of fecal indicators to surface waters. Agricultural runoff, which dominates the western portion of the bay near Westport, and urban runoff, which dominates New Bedford, and other urbanized areas of the watershed, enters the bay both at discrete points such as pipes and open ditches and in broader, less defined areas of sheet flow.

Two distinct classes of urban runoff enter Buzzards Bay. Many older cities, including New Bedford, built wastewater systems combining stormwater and commercial and residential sewerage in a single pipe, referred to as a combined sewer. During heavy rainstorms, the waste treatment facility in New Bedford is unable to handle the combined volume of sewage and stormwater, and the untreated excess flow is discharged directly into Buzzards Bay through overflow pipes. These pipes are called combined sewer overflows or CSOs. There were 38 such discharges into the Acushnet River Estuary and Clarks Cove when the Buzzards Bay CCMP was completed in 1991. Since that time, 15 have been eliminated by the City of New Bedford (Figure 34). Data show that the highest densities of fecal coliform from all storm pipes investigated generally come from CSOs.

In addition to the CSOs of the New Bedford area, stormwater from other urban or suburban areas around the bay often shows high fecal coliform counts, even where storm and sewer systems are not tied together. The source of elevated coliform concentrations in non-CSO stormwater discharges is the subject of considerable speculation. In some cases, the contamination is believed to originate from pets or wildlife. In other cases, the contamination was due to accidental or illegal septic home hook-ups to stormwater pipes, illegal septic overflow pipes, or from failing septic systems whose sanitary wastes may pool on the top of the ground and find a surface pathway to the receiving water during a rainstorm. Some of these problems can be difficult to identify without upstream testing of stormwater.

Under the Interstate Shellfish Sanitation Program, the Massachusetts Division of Marine Fisheries (DMF) is responsible for conducting shellfish area sanitary surveys in Massachusetts waters every few years to identify existing and potential sources of coliform and pathogens in shellfish resource areas.

These surveys have identified more than 500 discharge pipes in open shellfish resource areas in Buzzards Bay and ranked their potential for contamination. This information is routinely used by the Buzzards Bay NEP and Buzzards Bay municipalities to prioritize stormwater pipes and other sources for remediation, along with other data sources, like the Buzzards Bay stormwater atlas.

The extensive use of the western shore of Buzzards Bay, particularly near Westport, for agricultural purposes makes this area highly susceptible to agricultural runoff. Fecal coliforms from this type of runoff originate primarily in animal feces, resulting from animal husbandry and crop-management practices (i.e., manure spreading).

Wildlife, Waterfowl, and Domestic Animals

Animal wastes enter Buzzards Bay in at least two ways. Stormwater, previously discussed, periodically washes animal wastes from both wildlife and domestic animals into the bay. A more continuous input is from aquatic birds such as Canada Geese and other shore birds. The effects from these inputs vary. Generally, the impact is less in well-flushed areas and greater in poorly flushed areas with organic sediment where the longevity of bacterial species is enhanced. A Buzzards Bay Project study in Buttermilk Bay has indicated that waterfowl waste can accumulate in other protected environments such as beach wrack (the free-floating plant material that washes up with the tide), which appears to

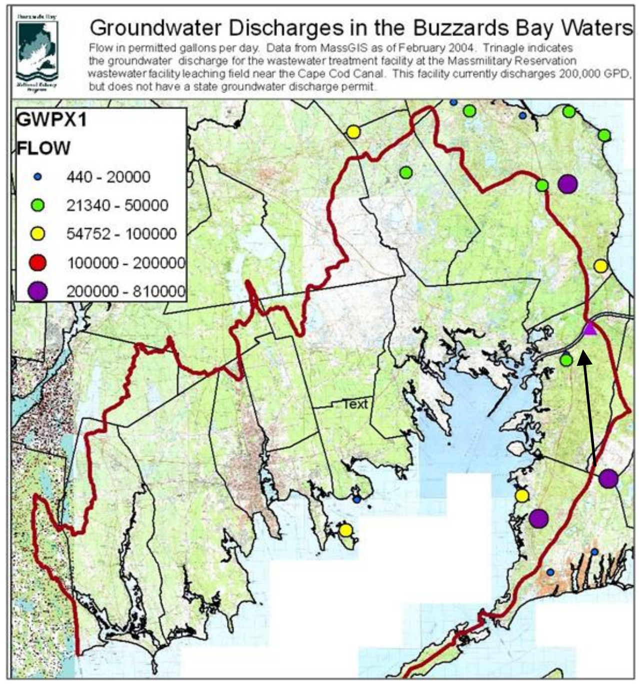


Figure 33. Groundwater discharges in the Buzzards Bay watershed.

Nearly all are wastewater discharges. All have state groundwater discharge permits except a 200,000 gallons per day infiltration bed operated by the federal government for wastewater disposal for the Massachusetts Military facility (outside the watershed), which was relocated in the 1990s to a leach field near the Cape Cod Canal. This discharge is shown as the magenta triangle near the Cape Cod Canal.

prolong bacterial survival (Heufelder, 1988). Thus, it is believed that wildlife, waterfowl, and domestic animals may be locally important sources of coliform contributing to the closure of resource areas.

Other Sources of Coliforms and Pathogens

Although not an original source, certain sediments in Buzzards Bay may act as a protective sink for fecal coliform and pathogens, releasing them back into the water column when the sediment is disrupted during storms or tidal fluxes. It is likely that in areas close to point-source discharges, such as CSOs and stormwater pipes, the sediments provide a protected habitat for settled microorganisms and prolong their survival. Soft organic sediments (e.g., muds) are more able to support bacterial survival and viral stability than are inorganic sediments such as sand and gravel. The introduction of nutrients from septic systems or sewage treatment plants may also play a role in the proliferation of pathogens harbored in sediments (Heufelder, 1988).

In addition to coliforms and pathogens stored in protective sediments, a number of human pathogens have been found to be normal inhabitants of estuaries elsewhere. No attempt has been made to document the presence of these pathogens in Buzzards Bay, but it is presumed they exist.

Toxic Contamination to Buzzards Bay

Buzzards Bay receives a wide range of toxic or carcinogenic chemical contaminants from industrial and municipal wastes, dredged material, atmospheric fallout, river inputs, and other nonpoint pollution sources (Howes and Goehringer, 1996). Chemical contaminants enter Buzzards Bay through accidental oil spills, effluent discharges, river discharges, atmospheric transport and deposition to the bay, or deposition to land and direct runoff to the bay. Chemical pollutants associated with urban and industrial activities enter Buzzards Bay primarily in the western portion near the New Bedford, Fairhaven, and Dartmouth urban areas. Chemicals associated with agricultural activities are more likely to enter the bay from runoff, creeks, and small rivers in the Westport, Dartmouth, Fairhaven, Mattapoisett, Marion, Wareham, Bourne, and Falmouth areas. Chlorine residuals from disinfected sewage discharged from treatment plants may also represent a threat to marine organisms.

The greater New Bedford area is clearly the major contributor of chemical contaminants to Buzzards Bay. The harbor itself is extremely polluted with polycyclic aromatic hydrocarbons (PAHs), trace metals, and polychlorinated biphenyls (PCBs) because of industrial discharges between the 1940s and 1970s and stormwater runoff. On a regional scale, stormwater runoff, particularly from paved surfaces, is also a major source of hydrocarbons to Buzzards Bay.

Evaluation of the fate and effects of chemical contaminants in the marine environment requires an understanding of the temporal and spatial distribution of contaminants; the partitioning of contaminants in the ecosystem among the sediment, the water column, and the living resources; and the level of damage imposed by accumulation of contaminants in the living resources.

Concern about toxic contaminant input to coastal waters is focused on the accumulation and transfer of metals and organic contaminants in marine food webs, including accumulation in seafood species and potential impacts on human health. These concerns are often expressed by regulatory agencies in the form of advisories against the consumption of fish. Figure 35 shows some freshwater ponds in Buzzards Bay so listed. Additional concerns include toxic effects of contaminants on the survival and reproduction of marine organisms and the resulting impact on marine ecosystems. Chemicals of concern are those that have known or potentially deleterious effects on populations of living marine resources and on humans either through mortality, illness, changes in fertility, or other factors that may affect a population's reproductive success.

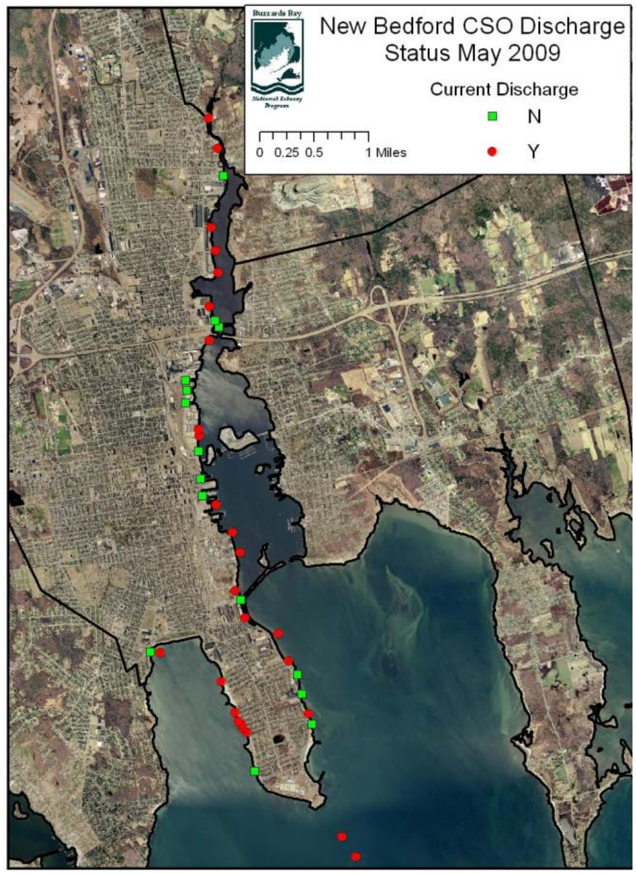


Figure 34. Combined sewer overflows in the City of New Bedford.

Metals and Inorganic Compounds

Certain metals occur naturally at low concentrations in seawater and in marine and estuarine sediments. Additional metals can be added to the marine environment through municipal and industrial wastewater discharges, atmospheric deposition, stormwater runoff, and leaching from boat paints and moorings. Once in the marine environment, metals are generally incorporated into the sediment. Marine invertebrates that live in sediments with high metal contamination may accumulate the metals above natural levels. These toxic metals may then be passed along the marine food web that includes humans.

The U.S. EPA has identified 12 to 15 metals that are of particular concern to humans and ecosystem health due to their toxic effects. Metals of concern include arsenic, antimony, barium, cadmium, chromium, copper, lead, mercury, nickel, selenium, silver, thallium, and zinc. Tin is used in marine anti-fouling paints (e.g., tributyltin) because of its toxic effects on marine fouling organisms, and elevated concentrations in sediment may indicate contamination by such paints. Although it is common and is not toxic in itself (except at very high concentrations), iron is important because many other more toxic metals have an affinity for iron, and thus iron can act as a carrier for more toxic metals.

Metals do not break down in the environment, but can transform from one form to another. Depending on the particular metal and its form, toxicity can vary greatly. Metals frequently become more soluble and mobile when the pH decreases (becomes more acidic). In general, the more soluble a metal becomes, the more bioavailable it becomes to organisms, and thus the more toxic it becomes. This is particularly important in the Northeast where acid precipitation is widespread due to sulfur dioxide emissions from fossil fuel-burning power plants located in the region and in the Midwest. Where acid precipitation is common, fresh water bodies will tend to be acidic and thus may contain more dissolved metals than water of a higher pH (seawater contains buffering compounds that counteract acid precipitation; also, acid precipitation is diluted in the ocean, so the oceans so far do not show the effects of acid precipitation). To reduce metal loadings to coastal waters, it is important to manage the acidity (pH) of public water supplies to minimize the rate of copper and lead leaching from plumbing. (The exception may be areas where the underlying bedrock or soils are rich in calcium carbonate (limestone), which can dissolve in response to acid precipitation, acting as a buffer).

The mobility of metals in sediment or water is also affected by the oxidation potential. The oxidation potential, or redox potential, indicates how much oxygen there is in the environment. Oxidizing conditions are characterized by moderate to high oxygen and the presence of oxidized metals (such as rust), while reducing conditions are characterized by low or no oxygen and the presence of reduced compounds. For example, buried organic-rich sediment is often reducing and contains reduced compounds such as hydrogen sulfide ("rotten-egg gas") or methane, whereas well-oxygenated surface sediments, sediments that lack organic matter, or sand that is being actively transported in the turbulent surf zone will be oxidized. Metals such as iron, arsenic, lead, copper, and others, become more soluble and biologically available in reducing sediments. On land, reducing conditions can exist beneath landfills, in organic-rich soils, wetland soils, and in debris piles. In eutrophic ponds, lakes, or coastal embayments, the combination of organic-rich sediments and low oxygen levels will tend to release any toxic metals that may be present in sediments or water.

There are many potential sources of metal contamination. Metals are used in manufacturing, industrial uses, metal-plating, jewelry-making, textile mills, and leather processing. Metal debris, including municipal and industrial solid waste, is another important source. Metal contamination also occurs due to abrasion and wear of metal parts in vehicles, equipment, and industrial facilities, resulting in metals in stormwater runoff and other discharges. Dissolved metals from metal pipes, metal-containing solutions, acids, wastewater, and other sources end up at wastewater treatment facilities. Metals such as chromium, copper, and arsenic, among others, are used as wood preservatives, which can leach out of wood. In the environment, metal concentrations in sediments and water tend to be highest where there is industrial activity, urban harbors, use of chromated copper arsenate (CCA) treated wood, and untreated stormwater runoff. Decreases in metal inputs are typically related to implementation and enforcement of pollution prevention and pre-treatment controls on industrial users, and elimination of lead in gasoline. Specific metal contaminants are discussed below.

Mercury

Mercury is a naturally occurring metal that can occur as a liquid, gas, or solid. At room temperature, pure mercury is a liquid and can evaporate into the air as a gas. Mercury has been and is still widely used for a wide variety of industrial, medical and research uses. Mercury is used in fluorescent bulbs, thermometers, and electrical switches because of its excellent conducting qualities. Because it is highly toxic to living organisms including pathogenic microorganisms, it was used for centuries as a treatment for venereal disease (e.g., mercuric chloride) and mercury is still used today for antiseptics and medical preservatives (e.g., thimerosol). In the environment, mercury contamination is widespread. Important sources of mercury contamination include emissions from the combustion of fossil fuels, particularly coals and oil shale, which are naturally enriched in mercury; and emissions from landfills and solid-waste incinerators processing items that contain mercury.

Mercury and methylmercury pose particular concerns because of proven links between consumption of mercury-contaminated seafood and severe human health impacts. One of the most dramatic cases of methylmercury poisoning ever occurred in Minamata, Japan, between 1932 and 1968, when a petrochemical plastics-manufacturing factory dumped tons of mercury-containing compounds into Minamata Bay. Over 3,000 people were affected by "Minamata syndrome" which caused severe neurological damage and birth defects. This event helped raise public awareness of the health and ecological dangers of mercury exposure.

Mercury and methylmercury are bioaccumulated by fish and other aquatic organisms, and human consumption of mercury-contaminated fish can result in mercury bioaccumulation in human tissue. Federal and state agencies (FDA, EPA, and DEP) have issued fish consumption advisories warning against consuming ocean fish that bioaccumulate mercury (typically predators such as tuna where mercury can bioaccumulate along the food chain) and fish from fresh water bodies affect-

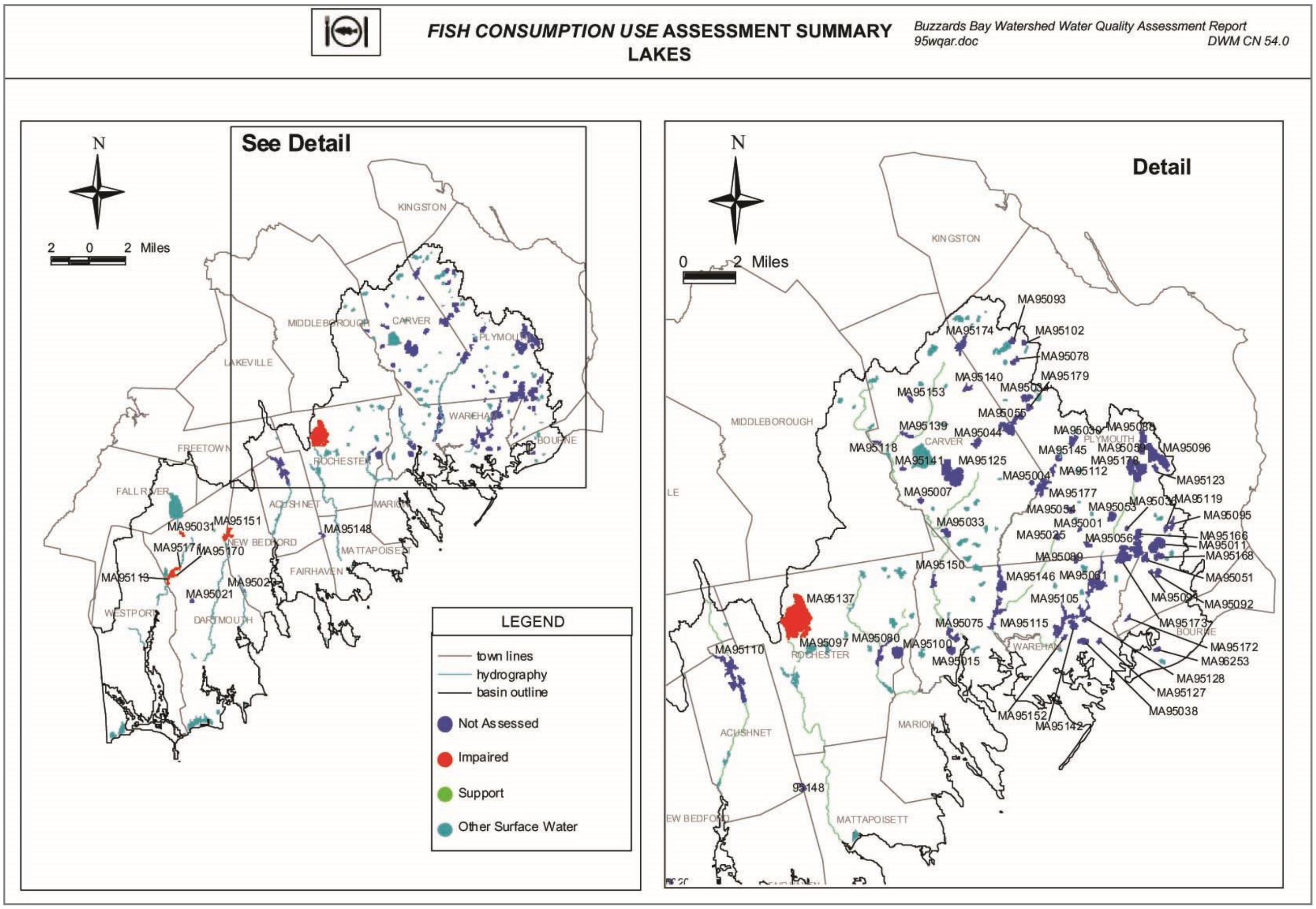


Figure 35. Freshwater fish consumption impairments in the Buzzards Bay watershed.

Most health advisories related to fish consumption are due to elevated mercury concentrations. Figure from DEP 2000 watershed assessment (O'Brien and Langhauser, 2003).

ed by mercury contamination. In 2001, the Massachusetts Department of Public Health (MDPH) issued statewide consumer advisories recommending against consumption of freshwater fish due to mercury contamination, based on widespread testing throughout the state. Fish consumption advisories are issued when elevated levels of a specific contaminant in edible portions of fish poses a health risk for human consumption. For mercury, the FDA's consumption advisory concentration is 1 ppm. In the Buzzards Bay watershed, MDPH also issued site-specific fish consumption advisories[39] for specific fresh water bodies due to elevated mercury contamination in fish (see Table 14).

The suspected source of mercury in this area is atmospheric deposition (i.e., fallout of mercury the air to the earth via rain, snow, gasses, or particles). Most of the water bodies in the Buzzards Bay watershed are not assessed (Figure 35), but it is assumed that they are impacted, and it is the reason why the statewide fish consumption advisory remains in effect.

In the November 2003 Water Quality Assessment of Buzzards Bay[40], DEP estimates that 98% of the rivers (66.22 miles), 56% of estuaries (22.7 square miles) and 79% of lakes (3,563 acres) in the Buzzards Bay watershed have not been assessed for water quality impairments due to contaminants.

Lead

Lead is a dense, soft, malleable metal that is found in metal ore deposits and metal-rich shales, along with

[39] Massachusetts Department of Public Health (MDPH). Fish Consumption Advisories. Retrieved from www.mass.gov/eohhs/gov/departments/dph/programs/environmental-health/exposure-topics/fish-wildlife/fish/. Last accessed October 1, 2013.

[40] O'Brien, K., and A. Langhauser. 2003. Buzzards Bay 2000 water quality assessment report. Department of Environmental Protection Division of Watershed Management Report Number: 95-AC-2 DWM Control Number: 085.0 Massachusetts Department of Environmental Protection Division of Watershed Management. Worcester, Massachusetts. November 2003. www.mass.gov/eea/docs/dep/water/resources/71wqar09/95wqar1.pdf. Last accessed October 11, 2013.

iron, nickel, copper, arsenic, and other metals. Lead's toxic effects on humans and wildlife include neurological, kidney, and liver damage. Examples of extensive use of lead include ammunition, lead pipes, drinking vessels, plates, solder, lead weights, paint, and pesticides (e.g., lead arsenate). Between the mid-1920s and the mid-1980s, tetraethyl-lead was used as an additive in gasoline, which resulted in widespread emissions of lead into the atmosphere, particularly in industrial or heavily traveled areas of the world. The resulting lead fallout has contaminated surface water resources throughout the world. Lead was also used extensively in paints, until it was discovered to cause lead poisoning; removal of such lead paint is now conducted according to state-certified procedures to protect the health of workers and to ensure proper removal and disposal of lead-containing wastes, which are treated as hazardous waste. Like many other metals, it is more soluble in water that has a low pH. The FDA's "action limit" for lead in crustaceans (e.g., crabs, lobsters) is 1.5 ppm and 1.7 ppm for molluscan bivalves (e.g., clams, mussels).

Arsenic and other metals

Other metals like arsenic, antimony, barium, cadmium, chromium, copper, nickel, selenium, silver, thallium, tin, and zinc are also environmental concerns. Silver from home darkrooms and small photographic businesses continues to enter the bay at elevated levels. Chromium and cadmium are associated with automobiles and other vehicles and enter via road runoff.

Organic Compounds and Mixtures

Organic compounds are compounds that contain at least one carbon atom. The major categories of organic compounds and organic mixtures of concern, many of which are synthesized from petroleum and coal, are highlighted in the sections below.

Petroleum and Fossil Fuel Hydrocarbons

Hydrocarbon inputs to Buzzards Bay are the result of accidental oil spills, industrial and municipal wastes, stormwater runoff, small boats and other marine craft, and creosote-treated wood pilings. Buzzards Bay and the Cape Cod Canal serve as a major transportation route for small tankers and barges carrying petroleum products to the Boston market. It is estimated that over 370,000 gallons of fossil fuel hydrocarbons have been accidentally spilled into the bay between 1973 and 2001. However, the everyday, more insidious inputs of hydrocarbons to the bay from stormwater and wastewater from industry and sewage treatment facilities have been calculated to be equal to or greater than the inputs from accidental spills.

PAHs

PAHs are pervasive compounds that represent a significant threat to humans and the ecosystem. Both combusted and non-combusted fossil fuels contribute to the pollution of the environment via the atmosphere, road runoff, oil spills, and point sources of discharge. Some PAHs cause cancers and birth defects and others are accumulated in tissues, causing physiological damage[41]. Greatest accumulations are found in busy harbors, near old creosote pilings, and in areas with industrial discharges.

Pesticides

The use of older, non-organic pesticides such as lead arsenate has largely been discontinued, but their long-term residual impacts are uncertain. Similarly, most chlorinated pesticides have been banned and replaced by shorter-lived, target-specific chemicals, but residual legacy amounts can be found in bay and marsh sediments. However, most existing pesticide related impairments are probably the result of commercial and residential applications and misapplications, including use of pesticides before heavy rains.

Pesticides enter Buzzards Bay largely from nonpoint sources, e.g., agricultural runoff, golf courses, lawn care, and gardens. Cranberry growers have lowered pesticide input by reducing applications and adopting integrated pest-management practices, yet water testing in Wareham shows that low levels of some agricultural biocides (below action thresholds) enter the recharge zones of public wells at detectable levels (SEA Consultants Inc., 2010). In addition, however, other users of pesticides and lawn care products, such as golf courses, institutions, municipalities, and residential owners, need to be informed about the risks posed by the use of pesticides and lawn care products. Such uses are typically not regulated, and therefore the potential contribution from these non-agricultural pesticide sources needs to be considered.

PCBs

PCBs are a family of organic compounds used since 1926 in electrical transformers as insulation, and in liquid coolants, flame-retardants, lubricants, carbonless paper, adhesives, caulking compounds, and marine paints. They are extremely persistent in the environment because they do not readily break down into less harmful chemicals.

PCBs in the Buzzards Bay watershed were principally derived from several industries in the New Bedford area that manufactured capacitors and generators. The manufacturers discharged PCB-containing effluent and

[41] A good summary of PAH threats is found at www.mass.gov/eea/agencies/massdep/toxics/reports/polycylic-aromatic-hydrocarbons-pahs.html.

materials through outfalls, the sewage treatment plant, and direct dumping principally between the 1940s and 1970s. High PCB levels in the New Bedford area resulted in designation of the Upper Acushnet River as a Superfund site. Feasibility studies to remove and destroy the PCBs, and remediate the affected areas of New Bedford Harbor were developed in the 1990s, and are still being implemented today. Although the manufacture of PCBs ceased in 1979, they remained in many types of older electrical transformers in use. Leaks from these and other types of equipment, along with illegal dumping contributed to nonpoint pollution sources of PCBs in the environment.

PCBs are persistent compounds in the environment and bioaccumulate in sediments and some seafood species. Because of this contamination, over 18,000 acres (encompassing all of New Bedford Harbor and areas into Buzzards Bay) were closed to fishing and shellfishing (lobsters), and remain so[42] (see Figure 36). PCBs persist in sediments to levels that violate water quality standards, posing a risk to humans and the ecosystem. Enforcement of the closure has proven to be difficult because of work force shortages, and in 2009, the Division of Marine Fisheries proposed suspending the permits of lobster fisherman who placed pots in these areas, but this rule was not enacted.

Sediments in the harbor continue to act as a major source of PCB contamination to Buzzards Bay. Other past sources include atmospheric transport from New Bedford and other industrial areas in the northeast, and the disposal of New Bedford Harbor dredged materials into the bay.

The extent of PCB contamination in marine resources taken from areas outside of New Bedford has been studied. Results show that although edible tissues of the three species tested (lobster, flounder, and quahog) generally have PCB levels below the FDA Action Level of 2.0 ppm (parts per million), some samples are dangerously close to the FDA limit, especially lobster hepatopancreas, or tomalley (Schwartz, 1987).

In some sections of Buzzards Bay, shellfishing, fishing, and lobster trapping is prohibited due to high concentrations of contaminants such as PCBs in sediments. Consumption advisories for these areas, warning against consumption of any shellfish or fish, are posted permanently until cleanup activities have been completed. These areas include New Bedford Harbor and the Acushnet River estuary (see Action Plan 16 Reducing Toxic Pollution).

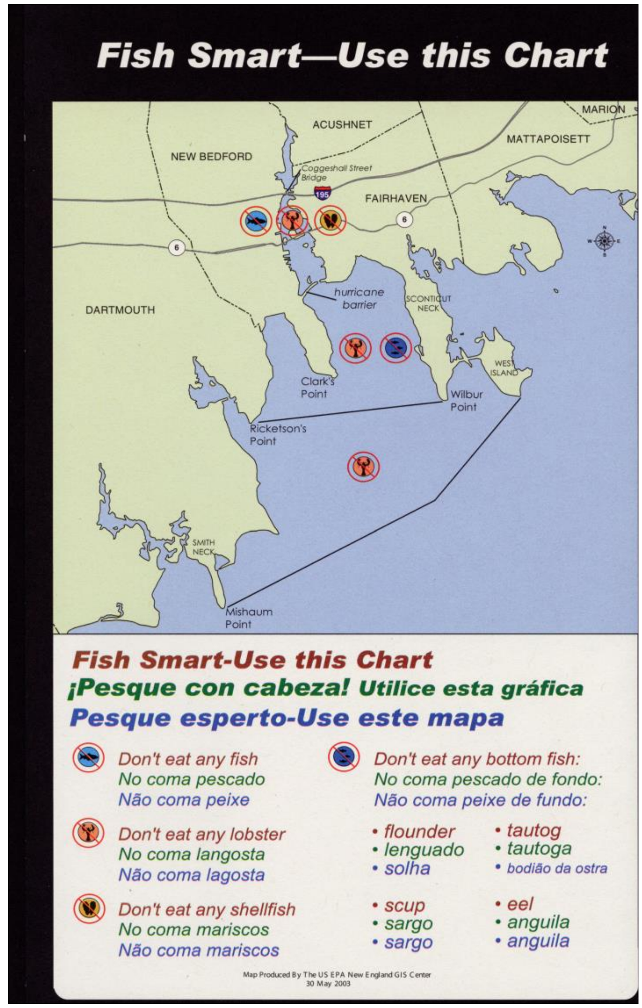


Figure 36. New Bedford area fisheries closures as shown on an outreach poster produced by the U.S. EPA in 2003.

Included in a mailer titled "New Bedford Harbor & PCB Contamination - A Fisherman's Guide, August 2003." Retrieved from www.epa.gov/region1/superfund/sites/newbedford/213062.pdf. Last accessed November 7, 2013, part of EPA's Fish Smart Campaign.

In addition to these marine areas, several watershed freshwater ponds have health advisories of the consumption of fish because of elevated PCB levels (these areas are shown in Table 14).

Dioxins and Furans

Dioxins are a family of toxic chemicals that share a similar chemical structure and include certain polychlorinated dibenzo dioxins (PCDDs), polychlorinated dibenzo furans (PCDFs) and twelve of the polychlorinated biphenyls (PCBs). These compounds are unintentional byproducts of certain industrial chemical processes, and the combustion of certain chemicals. Generally, dioxins and furans are found in trace amounts, but because of their toxicity and strong carcinogenicity and their persistence and tendency to bioaccumulate, they

[42] The Massachusetts Department of Public Health (MDPH) regulation "Prohibition against certain fishing in New Bedford Harbor" (105 CMR 260) was implemented on September 25, 1979 to protect seafood consumers from PCB (polychlorinated biphenyl)-contaminated fish and shellfish in 3 areas of the Acushnet River estuary.

Table 14. Freshwater fish consumption advisories in the Buzzards Bay watershed.

Location	Water body	Fish Species	Advisory	Hazard
Acushnet	New Bedford Reservoir	Largemouth Bass; American Eel	Yes	Mercury, DDT
Bourne	Great Herring Pond	Smallmouth Bass	Yes	Mercury
Carver	Sampsons Pond	Brown Bullhead, Yellow Perch	Yes	Mercury, DDT
Dartmouth	Copicut River	All fish; American Eel; Largemouth Bass	Yes	PCBs, Mercury
Dartmouth	Cornell Pond	All fish; American Eel; Largemouth Bass	Yes	PCBs, Mercury
Dartmouth	Noquochoke Lake	All fish; Largemouth Bass; American Eel	Yes	Mercury, PCBs
Dartmouth/ New Bedford	Turner Pond	All fish	Yes	Mercury
Rochester	Long Pond	Largemouth Bass; Black Crappie	Yes	Mercury
Rochester	Snipatuit Pond	Largemouth Bass; Black Crappie	Yes	Mercury

Data from MDPH Freshwater Fish Consumption Advisory List Massachusetts Department of Public Health Bureau of Environmental Health August 2013. Retrieved from www.mass.gov/eohhs/gov/departments/dph/programs/environmental-health/exposure-topics/fish-wildlife/fish/. Last accessed October 1, 2013.

represent an important human health and environmental risk.

In the Buzzards Bay watershed, New Bedford Harbor and the surrounding landscape is the area of the greatest known concentrations of dioxins and furans. This contamination is principally related to the manufacture and disposal of PCBs[43]. The threat posed by these compounds should be greatly diminished with the completion of the Superfund efforts in New Bedford Harbor.

Other Organic Pollutants

Analysis of the effluent from the New Bedford sewage treatment plant has shown that several of the synthetic organic compounds listed by EPA as priority pollutants are present in measurable quantities. These compounds are typical of what is found in sewage from urban industrialized areas.

Historically, a variety of industrial wastes containing chemicals of concern, were discharged into New Bedford Harbor. More recently, research has shown that tributyltin (TBT), which is sometimes added to marine paint as an antifoulant, is toxic and harmful to marine organisms in coastal ecosystems, even at the extremely low concentrations observed when TBT leaches from boats. Federal legislation and regulations have been phasing out the use of TBT as an additive. In April 1988, Massachusetts banned the use of TBT-containing paints on all non-aluminum vessels under 25 meters in length. Paints with low TBT release rates (micrograms per day) can be used on larger vessels.

Contaminants of Emerging Concern

Contaminants of emerging concern (CECs) is a broad catch-all category of novel, or previously unstudied, or previously presumed harmless compounds now found with increasing frequency in the streams, lakes, and groundwater. Awareness of these compounds stems in part from the fact that laboratory methods have improved where parts per billion and parts per trillion detection limits are now possible. In addition, studies have shown that certain persistent compounds may exert important non-toxic effects that may affect the health, ecological fitness, and fecundity of various aquatic and terrestrial species.

CECs include pharmaceuticals, flame retardants (polybrominated diphenyl ethers), endocrine-disrupting chemicals (EDCs), carbon nanoparticles, and pharmaceutical and personal care products (PPCPs) that enter groundwater and surface waters, most often from wastewater disposal discharges (septic systems or wastewater facilities). Some of these compounds in drinking water have been correlated with human disease or development problems, and other compounds, particularly endocrine disruptors, may affect sexual development and sex ratios in fish and invertebrates.

In 1985, the EPA established guidelines to determine ambient water quality criteria for aquatic life. The guidelines addressed acute risk (short-term effects on survival and growth of adults and juveniles) and chronic risk (longer-term effects on reproduction) for traditional pollutants. However, these tests do not evaluate the more subtle impacts of CEC and PPCPs on populations of aquatic species, and new tests must be developed.

For these and other reasons, CECs remain unregulated. In 2008, the U.S. EPA developed a white paper highlighting the problem, and including recommenda-

[43] See summary by Wang, S. T. 1989. Relative Risks posed by Polychlorinated Biphenyls, Polychlorinated Dibenzodioxins and Dibenzofurans in New Bedford Harbor sediments. Retrieved from www.epa.gov/region1/superfund/sites/newbedford/225118.pdf. Last accessed October 31, 2013.

tions for future action[44]. The principal actions recommended in the white paper focus on the development of aquatic life criteria tests based on sound science to evaluate CECs. This effort will require EPA to establish panels to develop criteria and tests for compounds with similar environmental modes of action. Until these criteria are developed, CECs will remain largely unregulated. Because it may take many years and millions of dollars to answer these questions, EPA will need to establish priorities on which CECs must be first evaluated.

Until the regulatory strategies are worked out, the principal focus of CEC management in the Buzzards Bay watershed should be to reduce the amount of unwanted CECs and toxics being flushed down toilets and other wastewater streams. For example, it is estimated that roughly 10% of the pharmaceuticals entering the environment originate from consumers disposing of unwanted prescription and non-prescription medicines in toilets. Because most Buzzards Bay communities have their solid waste incinerated at the SEMASS waste to energy facility, or disposed of at lined landfill facilities, the recommended disposal strategy for those communities is to throw away their medicine in the household trash. For those still disposing of waste in landfills, because these landfills are lined, this is still a preferable disposal mechanism, although these municipalities can also consider waste disposal collection days, and most pharmacies are increasingly accepting unused and outdated prescriptions. Municipal sewer operators should also work proactively with hospitals, doctors' offices, nursing homes, laboratories, and pharmaceutical or chemical manufacturers to encourage non-wastewater disposal of a variety of these not yet regulated CECs

Sources of Toxic Contaminants

Industrial or Commercial Uses

Urban centers such as New Bedford and Fairhaven contribute substantially to mass loadings of toxicants largely via point sources of discharge through sewage treatment facilities, industrial discharges, combined sewer overflows, stormwater outfalls, and surface runoff. Because of the intensive sampling for the Superfund site, wastewater treatment facilities, and compliance monitoring requirements for NPDES permits, more data are available on types and levels of contaminants in the New Bedford area than elsewhere. Both organic compounds (PAHs and PCBs) and metals make this area one of the most contaminated in the nation. With respect to metals, the New Bedford Inner Harbor is noted for elevated concentrations of copper, nickel, zinc, and chromium. Dredging and sediment suspension from storms probably contributed to past export of these contaminants to areas outside the harbor.

Marinas, Docks, and Boats

Less well known are the cumulative impacts of chronic pollution from nonpoint sources that enter small embayments and harbors from marinas, docks, and boats. Nonpoint sources of contaminants include boat antifouling paints, oil spills, creosoted and chemically treated pilings, and overland runoff carrying metals, organic compounds, and pesticides into receiving waters. These contaminants are often associated with particles and accumulate in sediments; but without an adequate monitoring program, the extent of contamination remains undocumented.

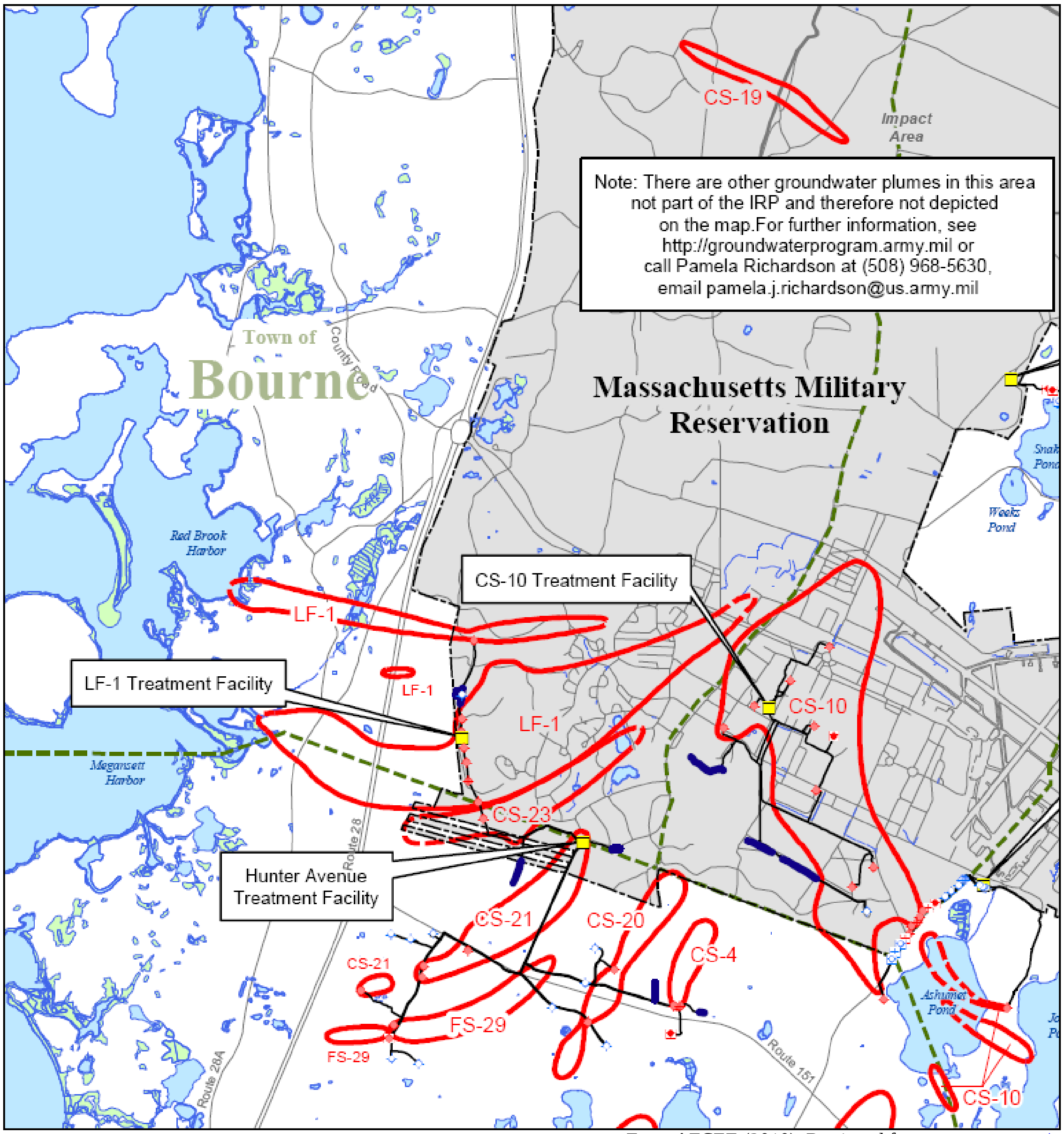
Residences

Homes are responsible for 25% of the hazardous waste disposal in the Commonwealth and discharge a wide variety of toxic materials into the wastewater stream and landfills. Contaminants from this source include everyday household products such as paint, paint removal products, used oil, batteries, fuel, fluorescent lamps, mercury thermometers, solvents, cleaning products (ammonia, chlorine bleach), insecticides, pesticides, herbicides, fungicides, antifreeze, rat poison, shampoos (which may contain high levels of selenium), oven cleaners, metal polishes, spot removers, and many other products. Empty and partially empty containers are disposed of in landfills or the contents are poured directly into drains to enter sewers and septic systems. Degreasing agents used in some septic systems may be toxic; one of these cleaners contains trichloroethylene (TCE), which is a common contaminant of drinking water and is difficult or impossible to eliminate once it reaches water supplies. Disposal of household chemicals into septic systems may cause contamination of groundwater, which may be an important nonpoint source of toxic inputs into embayments throughout Buzzards Bay.

Landfills

Although newer landfills are required to have non-permeable liners beneath them to prevent toxic liquids from infiltrating into groundwater or seeping out into adjacent water resources, liners can leak, allowing pollutants to contaminate water resources (U.S. EPA, 1987). Older landfills that do not have liners have generally been closed and are being monitored to ensure that contaminated groundwater plumes do not reach

[44] White Paper, Aquatic life criteria for contaminants of emerging concern. Part I - General challenges and recommendations. Prepared by the OW/ORD Emerging Contaminants Workgroup. June 3, 2008 Draft, Response document, EPA-SAB-09-007. Retrieved from water.epa.gov/scitech/swguidance/standards/upload/2008_06_03_criteria_sab-emergingconcerns.pdf. Last accessed October 11, 2013. See also December 18, 2008 draft.



From AFCEE (2010). Retrieved from www.epa.gov/region1/mmr/pdfs/454664.pdf.

Figure 37. MMR Superfund groundwater plumes on Cape Cod.

drinking water supplies. Some landfill plumes are being actively remediated, such as the LF-1 plume originating on the Massachusetts Military Reservation that discharges to Red Brook Harbor in Bourne (AFCEE, 2010). The Carver-Marion-Wareham landfill is located within the 100-foot buffer zone to the Wankinco River, and there is observable seepage from the base of the landfill into the river itself, near a monitoring station specified by the Department of Environmental Protection.

Agricultural Sources

Agricultural chemicals that may be toxic or harmful to fish, wildlife and/or plants include herbicides, fungicides, insecticides, and others that are grouped together and commonly called pesticides. By their very nature, they are designed to inactivate or kill specific target organisms. The USDA's NRCS has developed a pesticide evaluation approach (Windows Pesticide Screening Tool, or WIN-PST) that utilizes information on soils, water resources, and pesticide toxicity to evaluate whether the use of a specific pesticide could result in a risk to aquatic life due to leaching and runoff of the pesticide. According to NRCS Technical Notes NM WQ Technical Note 9, pesticide-soil combinations which result in a hazard rating of 'Intermediate', 'High', or Extra High' should be mitigated (Scheffe and Sporcic, 2001).

Groundwater Plumes from Contaminated Sites

Contaminated groundwater plumes originate from sites where contaminants have leached into the groundwater from soil and/or surface water. Contaminated groundwater plumes are typically associated with sites on land such as automotive repair stations that have experienced fuel spills, dry cleaning facilities, or other commercial facilities that have experienced solvent spills, or other commercial, industrial, medical, institutional, or household facilities where contaminant spills have occurred. For example, there are several groundwater plumes entering or heading toward Buzzards Bay from the Massachusetts Military Reservation (see

Figure 37; AFCEE, 2010). These are located in Bourne and Falmouth. Plumes are now reaching Buzzards Bay near Squeteague Harbor (Bourne and Falmouth) and Red Brook Harbor (Bourne). These represent two branches a plume emanating from the landfill (LF-1) on the Massachusetts Military Reservation. Other notable plumes include one from the Falmouth wastewater treatment facility. It is likely that other occurrences of groundwater contamination in the Buzzards Bay watershed have not been identified because they are not in the zone of contribution to a municipal water supply or otherwise investigated.

Wastewater

Wastewater can contain many contaminants other than heavy metals, PAHs, PCBs, dioxin, and pesticides. Examples include estrogen compounds and endocrine-disrupting compounds (found in pharmaceuticals, personal care products, pesticides, plastics and many other industrial materials), surfactants, caffeine, optical brighteners (used in detergents as a substitute for bleach), and chlorination by-products (e.g., trihalomethanes and others[45]). Chlorination of drinking water supplies and wastewater is widely used for basic disinfection, and the by-products of the reaction between chlorine and organic matter present in wastewater are organochlorine compounds such as trihalomethanes that are toxic in themselves. Unless dechlorination is done, such by-products can persist in drinking water and wastewater and may occur in the environment.

Estrogen and endocrine-disrupting compounds are commonly present in wastewater and are not removed by present methods of secondary or tertiary wastewater treatment. Such compounds can cause developmental and/or reproductive changes in aquatic organisms such as fish and crustaceans. Some scientists believe these compounds have contributed to skewed sex ratios in Buzzards Bay lobster populations[46].

Transport, Fate and Effects of Toxic Compounds

In order for a toxic chemical to affect an organism, there must be an exposure. The factors that determine toxicity of a particular compound include physical and chemical characteristics of the compound, how it affects an organism, the exposure pathway, the duration of exposure, and the concentration of the toxic compound. Exposure to toxic chemicals can occur through ingestion of contaminated sediments, water or tissue; dermal contact with contaminants; or inhalation of dust, gases or aerosols containing toxic chemicals. The duration of exposure is also important, as well as the concentration.

Where possible exposure pathways exist, toxic chemicals can adversely affect aquatic and terrestrial organisms, ecosystems, and humans. Human consumption of contaminated seafood or human exposure to other sources of toxic compounds poses the greatest concern. Exposure of aquatic organisms to toxic compounds can result in bioaccumulation of toxic chemicals in tissues, biomagnification (increasing concentration of tissue contaminants moving up the food chain) and/or food web effects.

The fate and effect of contaminants in Buzzards Bay depends on several factors. Most contaminants are associated with particles and accumulate in sediments, usually near the source of the input or in depositional areas. The greatest concentrations are found closest inshore where there is the greatest human activity and productive shellfishing. Metals do not degrade, but usually accumulate in sediments. Some organic compounds (e.g., low molecular weight PAHs) may be degraded or broken down by organisms into compounds that are more or less toxic. Other organic compounds (e.g., PCBs and high molecular weight PAHs) are persistent, bioaccumulate in tissues, and are transferred in the food chain to higher organisms. PAHs are known carcinogens. PCBs have deleterious effects on nervous systems; and both PAHs and PCBs negatively affect reproduction, survival, and growth.

The numerous pathways by which contaminants enter, accumulate, and move in marine ecosystems make them difficult to regulate. In general, it is easier to regulate point sources of discharge than nonpoint sources. Regulations are designed to protect the ecosystem and human health, and criteria have been established for chemicals in the water, in sediments, and in tissues (of seafood). Even if new discharges of toxic chemicals

[45] The U.S. EPA is considering regulating the amounts and kinds of chlorination by-products in drinking water, based on their toxicity to living organisms.

[46] "Human hormones hurt lobsters." www.southcoasttoday.com/apps/pbcs.dll/article?AID=/20070114/NEWS/701140339&cid=sitesearch. Last accessed October 11, 2013.

could be eliminated immediately, it could take many years for previous discharges of even biodegradable contaminants to dissipate, or for some ecosystems or populations to return to their original state.

There remain many unknowns about the pathways and impacts of toxic contaminants. For this reason, scientists and managers must continue to collect field data and document biological responses so that managers can continue to set realistic and cost-effective goals to reduce their impact on the environment.

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