PHOSPHORUS IN MASSACHUSETTS WATERS

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EXECUTIVE SUMMARY

This report summarizes information on the role of phosphorus as a contributing factor to water quality problems in Massachusetts waters. In addition, the potential water quality impacts associated with a detergent phosphorus ban are examined. The findings of this investigation are based solely upon the compilation, analysis, and interpretation of existing data. To a large extent, these data have been derived from various state agency conducted monitoring efforts or state funded studies conducted by outside contractors.

An overview of water quality conditions in the state is provided in Section 2.0. Regional data on water quality conditions are presented in Section 3.0: more detailed analyses of phosphorus balances for three selected river basins (Assabet, Millers, and Deerfield River Basins), and on a state-wide basis are provided in Section 4.0. Section 5.0 addresses the potential water quality impacts on lakes, rivers, and harbors associated with a state-wide detergent ban. Section 6.0 summarizes principal conclusions.

Summary of State-wide Water Quality Conditions

Approximately 57% of the river miles in the State of Massachusetts do not or only partially support their designated uses. In 19% of the total river miles, failure to support designated uses is attributed primarily to excessive nutrient levels. Baseline survey data on 360 waterbodies throughout the state, have revealed that about 12% of the states' lakes are classified as eutrophic or nutrient enriched. The sources of these nutrients to both lakes and rivers include industrial discharges, municipal wastewater treatment plants (WWTPs), combined sewer overflows (CSOs), and nonpoint sources such as urban and agricultural runoff, septic systems, lake and river sediments, as well as others.

Summary of Data Compilation

Rivers: Information in the Massachusetts Division of Water Pollution Control (MDWPC) 1988 Biennial Water Quality (305b) Report was reviewed and summarized with respect the the number of river miles in each of the 32 river basins reporting water quality problems associated with excessive nutrient concentrations. The Assabet River was examined more closely, as an example of a basin with water quality impairment due to nutrients originating primarily from point sources. Phosphorus load allocation studies conducted by the MDWPC in 1980 revealed that due to the Assabet's low dilution capacity, the <0.1 ppm instream phosphorus concentration desired for control of nuisance algal growth (USEPA, 1976) could not be achieved even with a WWTP effluent limitation of 1 ppm. The Assabet River illustrated the difficulties associated with controlling plant growth and resulting water quality impairment in river systems with low dilution capacity, point source discharges, and suitable habitat for plant growth. Despite a reduction in instream phosphorus concentrations associated with an effluent phosphorus limitation, proportional benefits, as measured by reductions in plant growth would not be expected.

Harbors: Existing water quality and sediment data indicated limited compliance with water quality standards. Of the 47.3 mi^2 of Boston Harbor assessed, 39.2 mi^2 partially support designated uses and 8.1 mi^2 support designated uses. Water quality problems are associated predominantly with heavy metals, fecal coliform bacteria, oil and grease, and dissolved oxygen. Excessive nutrient loadings are not considered a significant problem (MDWPC,1988). Phosphorus, in particular, is not likely to be problematic because algal growth in marine environments is usually limited by nitrogen rather than phosphorus.

Lakes: The MDWPC has completed one day baseline surveys of 523 waterbodies within the state. Of these, data for 360 lakes are stored in a the Pond and Lakes Information Systems (PALIS). An analysis of these data, revealed that about 12% of the states lakes are classified as eutrophic (or nutrient enriched). Primary phosphorus sources are nonpoint sources, failing septic systems, atmospheric deposition, and internal recycling from bottom sediments. Only one lake was reported impacted by a municipal WWTP (Quabog Pond in the Chicopee River Basin). Improvements to the facility were completed in 1988, and a seasonal phosphorus limit of 1.0 ppm was set for April to September. Information regarding the lakes response to these improvements has not been compiled.

Advanced Treatment Plants: Of the approximately 125 major WWTPs (>.05 mgd) in Massachusetts, 34 have advanced treatment processes. Of these 34, 20 have special phosphorus removal facilities, and associated phosphorus limits (typically 1.0 ppm). The MDWPC has continued to assess water quality conditions in the receiving waterbodies, but no conclusive evidence of water quality improvement (as measured by reductions in stream phytoplankton growth) has been developed.

Summary of Phosphorus Balance Analyses

Mass-balance calculations were performed to quantify phosphorus sources and to evaluate potential impacts of a phosphate detergent ban and other control measures on phosphorus concentrations in three Massachusetts River basins (Assabet, Millers, and Deerfield). The calculations are based upon flows and nutrient concentrations at river monitoring stations and wastewater discharges monitored by the Massachusetts DEP in each basin.

Assabet River Basin: Although a phosphate detergent ban would reduce total phosphorus loading to the river by approximately 31%, projected river phosphorus concentrations (>0.5 ppm under average monitored flows and >0.7 ppm under 7-Q-10 flows) would remain well above the 0.1 ppm EPA guideline for avoiding nuisance algal growth in streams. Because of high phosphorus concentration and low N/P ratios, biological responses to a phosphate detergent ban are not expected in the Assabet River.

Millers River Basin: Phosphorus concentrations ranging from 0.14 ppm to 0.22 ppm downstream of wastewater discharges are projected for the Millers River under existing conditions. With a phosphate detergent ban, this range would be 0.12 to 0.18 ppm. The response is largely attributed to reductions from the Gardner wastewater treatment plant, which accounts for 63% of the total point-source phosphorus load to the basin under existing conditions. Stream phosphorus levels less than 0.1 ppm would be achieved at some locations with wastewater treatment to 1 ppm, and at all locations with diversion of wastewaters from the basin (nonpoint sources only). Biological responses to reductions in phosphorus may be muted by possible nitrogen limitation. A phosphate detergent ban alone, would not be expected to influence compliance with the EPA guideline (<0.1 ppm) in this basin.

Deerfield River Basin: Phosphorus-balance calculations indicate that detergent phosphorus accounted for 14.6% of the total phosphorus discharged to the Deerfield River during the survey periods. Nonpoint sources accounted for 55.8% and other point sources accounted for 29.6%. Phosphorus profiles under average monitored flows are below 0.08 ppm for each scenario evaluated. These low concentrations are consistent with the lack of reported nutrient problems on the mainstem. Under 7-Q-10 flows, a section of the river below the Kendall County discharge is projected to exceed 0.1 ppm. A phosphate detergent ban would reduce the fraction of this 4-mile segment exceeding 0.1 ppm under 7-Q-10 flows, but significant impacts on beneficial uses are unlikely, based upon the fact that nutrient-related water-quality problems have not been reported in this segment.

State-wide Mass-Balance: Additional calculations were performed to estimate total phosphorus loads to each river basin in Massachusetts. Loads are partitioned into nonpoint and point source components. These calculations were based largely upon basin watershed areas, population, and wastewater effluent volumes compiled by the Massachusetts Audubon Society (Coburn and Hubley, 1989).

Total phosphorus loads to inland basins consist of nonpoint sources (19.8%), effluents from advanced wastewater treatment plants (3.6%), effluents from other wastewater treatment plants (73.1%) and effluents from on-site disposal systems (3.5%). Detergent-derived phosphorus accounts for a total of 25.3% (24.1% discharged in municipal wastewaters and 1.2% discharged in effluents from on-site disposal systems). The total load 14,792 lbs/day) is nearly 15 times that which would occur under pristine conditions (completely forested watershed without wastewater discharges).

Summary of Impacts of a Phosphate Detergent Ban

Review of available documents indicated that efforts have been made to address the problem of nutrient enrichment via reductions in point-source loads, as well as the control of nonpoint sources in some watersheds. A state-wide phosphate detergent ban has been proposed as another technique for reducing phosphorus loads to receiving waters, with the ultimate goal of improving water quality. Such bans have been implemented in twelve states, and have generally been linked to the restoration/protection of major waterbodies which are phosphorus-limited, and "downstream" of the states' wastewater discharges (i.e., Lake Erie, Lake Champlain, and the upper reaches of the Chesapeake Bay). However, no such waterbody exists in Massachusetts. Therefore, the justifications for a phosphate detergent ban in Massachusetts would have to be directed at reducing phosphorus-related water quality problems in specific inland river systems or lakes.

Based upon monitoring data from municipal WWTPs before and after phosphate detergent bans in other states, detergents account for 22-35% of the total phosphorus in domestic sewage. An examination of the river miles which reportedly experience water quality problems associated with nutrients originating from WWTPs, suggests that from 6.7% to 11% of the total river miles in the state might benefit from a phosphate detergent ban. In these river segments, reductions in phosphorus concentrations resulting from a phosphate detergent ban would not necessarily cause proportionate reductions in the growth of nuisance aquatic plants and algae because such growth is often limited or controlled by other factors, such as nitrogen, light, substrate, and/or flushing rate.

Documentation of voluntary use of low-phosphate detergent was examined. No information exists regarding the voluntary use of low-phosphate detergents on a regional or statewide basis. However, information was available and examined for shoreline residents of four lakes in Massachusetts. The results of questionnaires regarding detergent use among these residents revealed that 25 - 38% of the shoreline residents voluntarily or incidentally use low-phosphate detergents. Therefore, the actual percent reduction in phosphorus loads associated with a state-wide ban could fall in the lower end of the reported 22-35% range of contribution. Information on the number of voluntary or incidental low-phosphate detergent users prior to the bans in other states is not available.

The percent contribution of septic systems to lake phosphorus budgets was examined. The results of this analysis revealed that, in general, a load factor on the order of 3 lbs/system-yr was assumed by the engineers or consultants completing the studies. This value exceeds values typically reported in the literature. Due to limited documentation of methodologies and assumptions used to estimate septic system phosphorus loads in the study reports, it was not possible to determine the appropriateness or justification for this high load factor. Assuming that the estimated septic system loads provided in the diagnostic/feasibility study reports are realistic, the average reduction in lake phosphorus loads attributed to a phosphate detergent ban would be less than 5.3%.

Conclusions

Based upon mass-balance calculations (Section 4.2), implementation of a phosphate detergent ban would reduce total phosphorus loads to inland river basins by approximately 25%. Because of the effects of other limiting factors, equivalent reductions in algal growth are not expected. Mass-balance calculations conducted in four river basins indicate that a phosphate detergent ban would not significantly reduce the extent of water-use impairment currently attributed to eutrophication because of the importance of non-detergent phosphorus sources (point and nonpoint) and other growth-limiting factors in those segments where eutrophication-related water quality problems have been reported.

Detergent phosphorus accounted for an average of 5.3% of lake total phosphorus loads, and for more than 20% of the loads in 13% of the studied lakes. For a variety of reasons stated in Section 5.3, these percentages likely overstate the importance of detergent-derived phosphorus as a factor contributing to lake problems. Nonpoint sources, which account for an average of 70.3% of lake phosphorus loads are the most important factor contributing to deterioration of lake water quality on a statewide scale.

1.0 INTRODUCTION

Phosphorus is an essential nutrient for aquatic plant growth in inland waters. When present in excessive concentrations under the proper environmental conditions, phosphorus can stimulate nuisance algal growth, reduce water transparency, and cause a loss of oxygen from lake bottom waters. Such conditions can impair aesthetic qualities, impair recreational uses, and destroy habitat for fish and desirable aquatic vegetation. Phosphorus often limits or regulates algal growth in freshwaters (Cooke et al., 1986). Other factors, such as nitrogen, light, temperature, depth, bottom sediment characteristics, velocity, and flow, also regulate biological response to nutrients.

Phosphorus enters lakes and rivers from domestic wastes, industrial wastes, wastewater treatment facilities, fertilizers, urban runoff, agricultural runoff, and natural sources (e.g., precipitation, dustfall, pollen, waterfowl, weathering of soils and rocks). Its impact on water quality depends upon resulting ambient phosphorus concentration levels and upon the combination of physical and chemical factors which regulate biological responses in each stream or lake environment.

This report summarizes information on the role of phosphorus as a factor contributing to water quality problems in Massachusetts waters. An overview of water quality conditions is presented in Section 2. Regional data on water quality conditions in Massachusetts's rivers and lakes are compiled and discussed in Section 3. Efforts to reduce phosphorus loads to specific water bodies via advanced wastewater treatment are also described in Section 3. Section 4 describes mass balance calculations which have been performed to quantify phosphorus sources in specific river basins and on a statewide basis. Based upon the compiled data, Section 5 discusses the potential water quality impacts of a statewide phosphate detergent ban, as one of a number of methods for improving nutrient-related water quality. Conclusions are summarized in Section 6.

Primary data sources include studies conducted for or by the Massachusetts Department of Environmental Protection, Division of Water Pollution Control (MDWPC):

1. MDWPC. 1988. Commonwealth of Mass. Summary of Water Quality.
   Appendix I - Massachusetts Surface Water Quality Standards
   Appendix II - Massachusetts Lake Classification Program
   Appendix III - Basin/Segment Information
   Appendix IV - Nonpoint Source Assessment Report

2. MDWPC, 1986, 1988. Water Quality Data for 1984-85 & 1986-87 Surveys of the Assabet River Basin.

3. Massachusetts Clean Lakes Program. Diagnostic/Feasibility Studies conducted between 1981 and 1988 by private consulting firms and MDWPC.

4. Data Retrieved from the Ponds and Lakes Information System for Massachusetts (PALIS, Godfrey et al., 1979) for 360 Massachusetts lakes inventoried through 1986.

5. DEP. 1989. Pollutant Reductions from Wastewater Treatment Plant Upgrading in Massachusetts 1978-1988.

Data on nutrients, related water quality conditions, limnological characteristics, and inventories of pollution sources are summarized and discussed below.

2.0 OVERVIEW OF WATER QUALITY CONDITIONS

Massachusetts rivers and streams are classified according to "the uses for which the waters shall be enhanced, maintained, and protected". Each class is defined by the most sensitive uses it is intended to protect. Of the 1646 river miles assessed through 1988, uses are designated as follows (MDWPC,1988):

Class	Designated Use	River Miles
Inland Waters:		
A	public water supply	44.3
B	protection of aquatic life; primary and secondary contact recreation	1436.7
C	protection of aquatic life; secondary contact recreation	14.0
Coastal and Marine Waters:		
SA	protection of aquatic life; primary and secondary contact recreation; shellfish harvesting in approved areas	64.4
SB	protection of aquatic life; primary and secondary contact recreation, shellfish harvesting in restricted areas	86.7

Of 10,704 total river miles in Massachusetts, 1646 miles (15%) have been monitored by MDWPC. Based upon data collected through 1988, 43% of river miles fully support, 37% partially support, and 20% do not support their use classifications. Partial or non-support of uses in 57% of the river miles is attributed to pollutant loadings from point sources (19%), from nonpoint sources (21%), or from combinations of point and nonpoint sources (27%).

Point sources of pollution include industrial discharges, municipal wastewater treatment plants (WWTPs) and combined sewer overflows (CSOs). Municipal WWTPs are considered to be primarily responsible for biochemical oxygen demand (BOD) and nutrient problems in rivers, while CSOs are the leading causes of coliform bacteria problems. As a result of construction and upgrading of WWTPs, 1988 data indicate that the water quality impacts of point sources are declining.

Nonpoint sources of pollution are more numerous, diverse, and can be difficult to control. These include urban and agricultural runoff, failing septic systems, illegal discharges, marinas, lake and river bottom sediments, landfills, and natural sources (waterfowl, wetlands, atmospheric deposition) (MDWPC,1988). Leading nonpoint sources contributing to water quality violations are urban runoff and failing septic systems. The most common water quality problem is coliform bacteria; other problems include dissolved oxygen (biochemical oxygen demand), nutrients, oil and grease, solids and metals. Table 1 classifies river basins by pollutant and source.

Massachusetts lakes and ponds are classified by MDWPC according to trophic status, not designated uses. Of the 2,859 lakes and ponds in the state, 523 (18%) have been surveyed. Based upon data available through 1988 for 478 lakes, the trophic status of the surveyed lakes is as follows:

Trophic Status	Acres	# of Lakes	% of Total Surveyed
Eutrophic	4,220	56	12%
Mesotrophic	29,269	289	60%
Oligotrophic	16,136	133	28%

Nonpoint sources of pollution (principally surface runoff) and failing septic systems are identified as the leading causes of high nutrient loads and siltation in lakes and ponds (MDWPC, 1988). Siltation, resulting from land erosion, is a particular problem because it reduces lake depths and provides substrate for nuisance aquatic vegetation. Point sources are generally unimportant; only one lake with a point source in its watershed has been identified (see Section 3.3). MDWPC (1988) considered combined sewer overflows to be the principal point source of water quality impairment, followed by wastewater treatment plants, and industrial discharges.

TABLE 1

NUMBER OF BASINS REPORTING POLLUTANT AND SOURCE

Category Nonpoint Source	Oil & Grease	Bacteria/ Pathogens	Nutrients	Turbidity/ Solids	D.O. BOD	Metals	PCB's	Organics	Color	Total
Agriculture	-	6	2	1	1	-	-	-	-	10
Birds/Waterfowl	-	3	-	-	-		-	-	-	3
Failing Septic Systems	-	16	4	-	-	-	-	-	-	20
Hazardous Waste Sites	-	-	-	-	-	2	1	-	-	3
Illegal Discharges	-	9	2	-	1	-	-	-	-	12
In-place Sediments	1	-	3	-	4	7	5	1	-	21
Landfills/Leachate	-	-	2	1	-	2	-	-	-	5
Natural Conditions	-	5	1	-	10	-	-	-	2	18
Urban Runoff	2	24	5	2	12	2	-	-	-	47
Vessels/Marinas	1	5	1	-	1	-	-	-	-	8
TOTAL	4	68	20	4	29	13	6	1	2	
Point Source										
Industrial	1	4	8	2	3	4	2	3	1	28
Municipal	-	14	16	5	12	4	-	-	-	51
CSO's	1	18	8	1	10	3	2	-	-	43
TOTAL	2	36	32	8	25	11	4	3	1	

Source: DWPC. 1988. Summary of Water Quality

3.0 DATA COMPILATION

3.1 River Basins

Appendix III of MDWPC (1988) summarizes water quality conditions by river segment in each of the 32 drainage basins. The data are based upon river basin surveys conducted by MDWPC approximately every five years to update water quality data bases, monitor upgraded wastewater treatment plants, and detect new sources of pollution. Some basins have not been monitored in over ten years and the information is based upon historical data and MDWPC professional judgment. An example of basin/segment data is provided in Appendix A.

The information in MDWPC (1988) has been reviewed and summarized with respect to the number of river miles reporting water quality problems due to excessive nutrient concentrations. The primary sources of nutrient loads in each segment have also been identified. Results are given in Table 2. Figure 1 shows river basin locations. Results indicate that 57% of the total river miles in the state do not or only partially support their designated uses. In 19% of the total river miles, failure to support designated uses is attributed primarily to excessive nutrient levels. The primary sources of nutrients identified by the MDWPC are wastewater treatment plant discharges and urban runoff, and in some cases combined sewer overflows (CSOs). Mass-balance calculations have been performed to quantify phosphorus sources, and to evaluate the potential impacts of a detergent ban in three river basins (Assabet, Millers, and Deerfield). The results of these analyses are discussed in Section 4.0 of this report.

The Assabet River is an example of a basin with water quality impairment due to nutrients originating primarily from point sources. From its headwaters in the Town of Westborough, the Assabet River flows northeasterly for 31 miles through the Towns of Westborough, Marlborough, Maynard, Hudson and Concord. Several shallow impoundments provide physical conditions (bottom siltation, low velocity) which are conducive to algal and plant growth. The Assabet joins with the Sudbury River in Concord to form the Concord River, which flows north to the Merrimack.

The Assabet drains an area of 175 square miles and receives discharges from four municipal WWTPs and the Concord MCI (state prison) WWTP. Due to WWTP discharges and numerous impoundments, the river does not meet the Class B water quality standards. As a result of upgrades to municipal WWTPs in 1987, however, water quality conditions have begun to show improvement. The length of river not supporting designated uses has decreased from 30 miles (96.8%) to 11.4 miles (36.8%); however, 18.6 miles (60%) still

TABLE 2

INVENTORY OF MASSACHUSETTS RIVER BASINS IMPACTED BY NUTRIENTS

RIVER MILE CATEGORY

- TOTAL Total River Miles
- A Miles Supporting Uses - No Water Quality Problems
- B Miles Not Supporting Uses Because of Factors Other Than Nutrients
- C Miles Not Supporting Uses Because of Nutrients
- D Miles Partially Not Supporting Uses Because of Nutrients
- E = C + D
- E% = E / TOTAL x 100%

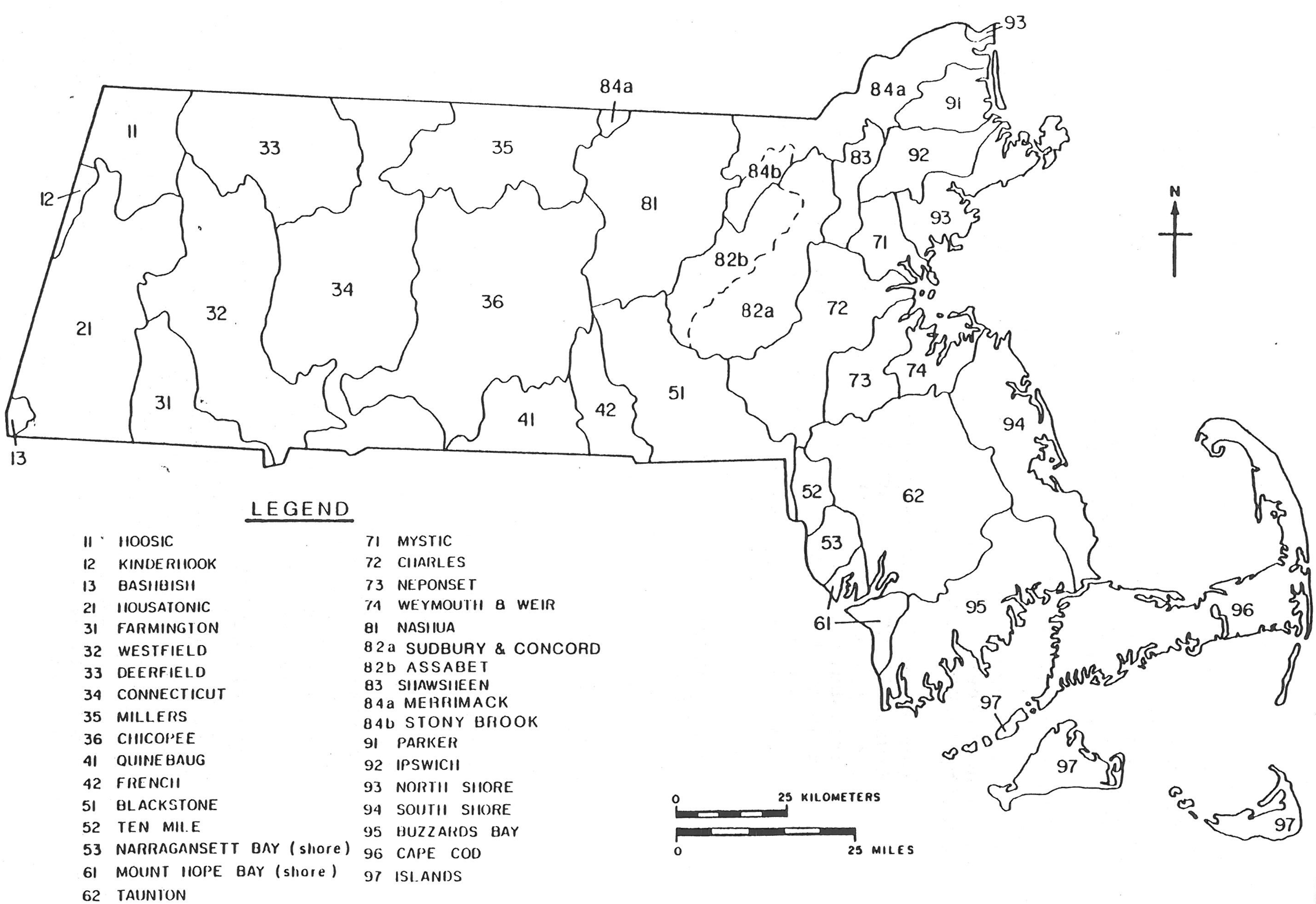
POLLUTION SOURCE CATEGORY

1 wastewater discharges
2 septic effluents
3 combined sewer overflows
4 stream sediments
5 urban runoff
6 industrial discharges
7 wetlands
8 landfill leachate

		------------- RIVER MILES -------------							...WWTP's.. With P		----PRIMARY SOURCES----							
CODE	RIVER BASIN	TOTAL	A	B	C	D	E	E%	Limits	All	1	2	3	4	5	6	7	8
82B	Assabet	31.0	0.0	1.0	11.4	18.6	30.0	96.8%	0	4	x	x		x	x			
51	Blackstone	84.9	36.0	13.5	31.7	3.7	35.4	41.7%	1	8	x				x			
95	Buzzards Bay	63.4	14.4	47.0	0.0	2.0	2.0	3.2%	0	5		x			x			
72	Charles	91.9	44.4	44.1	3.4	0.0	3.4	3.7%	2	3	x							
36	Chicopee	134.5	62.8	57.8	0.0	13.9	13.9	10.3%	4	8	x				x			
34	Connecticut	79.9	54.2	22.4	0.0	3.3	3.3	4.1%	0	14	x							
33	Deerfield	79.2	76.8	0.0	1.9	0.5	2.4	3.0%	0	4	x							
31	Farmington	25.6	25.6	0.0	0.0	0.0	0.0	0.0%	0	0								
42	French	35.5	21.2	4.8	4.0	5.5	9.5	26.8%	2	3	x	x		x				
11	Hoosic	37.9	8.5	29.4	0.0	0.0	0.0	0.0%	0	0								
12	Housatonic	79.5	20.2	3.9	10.3	45.1	55.4	69.7%	1	6	x				x	x		
92	Ipswich	36.6	32.1	4.5	0.0	0.0	0.0	0.0%	0	0								
84A	Merrimack	72.8	0.0	66.4	6.4	0.0	6.4	8.8%	0	9	x					x		
35	Millers	51.0	28.5	8.4	0.0	14.1	14.1	27.6%	0	8	x				x	x		
61	Mount Hope Bay	7.2	0.0	7.2	0.0	0.0	0.0	0.0%	0	1								
71	Mystic	16.4	0.0	9.6	6.8	0.0	6.8	41.5%	0	0			x		x			
81	Nashua	101.3	34.1	45.6	17.9	3.7	21.6	21.3%	3	6	x							x
73	Neponset	32.6	0.0	0.0	32.6	0.0	32.6	100.0%	0	0		x	x		x			
93	North Coastal	43.0	0.0	37.0	6.0	0.0	6.0	14.0%	0	9				x		x		x
91	Parker	22.0	22.0	0.0	0.0	0.0	0.0	0.0%	0	0								
41	Quinebaug	38.1	31.0	0.0	5.1	2.0	7.1	18.6%	0	4	x			x	x			
83	Shawsheen	25.0	0.0	25.0	0.0	0.0	0.0	0.0%	0	0								
94	South Shore	51.7	18.4	26.0	0.0	7.3	7.3	14.1%	1	5		x			x		x	
84B	Stony Brook	17.5	0.0	10.3	1.9	5.3	7.2	41.1%	0	0					x	x	x	
82A	Sudbury/Concord	63.9	9.3	44.9	4.2	5.5	9.7	15.2%	1	4	x				x		x	
62	Taunton	172.7	70.7	70.9	0.0	31.1	31.1	18.0%	3	8	x				x	x	x	
52	Ten Mile	31.6	7.9	14.4	0.0	9.3	9.3	29.4%	2	3	x			x	x	x		
32	Westfield	106.0	89.0	17.0	0.0	0.0	0.0	0.0%	0	3								
74	Weymouth	13.4	2.9	10.5	0.0	0.0	0.0	0.0%	0	0								
TOTAL		1646.1	710.0	621.6	143.6	170.9	314.5	19.1%	20	115	15	5	2	5	14	7	4	2
PERCENT OF TOTAL		100.0%	43.1%	37.8%	8.7%	10.4%	19.1%											

Sources: MDWPC. 1988. Commonwealth of Massachusetts.
Summary of Water. Appendix III - Basin/Segment Information
Coburn (1989)

Figure 1 RIVER BASINS and COASTAL DRAINAGE AREAS



only partially support designated uses and none of the river miles have improved enough to meet water quality standards. The susceptibility of the Assabet to water quality problems basically reflects its low natural dilution capacity for wastewater discharges and the presence of numerous impoundments, which facilitate biological responses to nutrients and other substances contained in the wastewater discharges.

Four municipal WWTPs (Westborough, Shrewsbury, Hudson and Maynard) were upgraded in 1987. Improvements to Marlborough West are in progress. Upgrades to the Concord MCI facility are in the planning stages. Following is a brief description of each facility (MDWPC, 1988):

Westborough/Shrewsbury WWTP: A new Westborough Regional WWTP was constructed in Spring 1987 to replace the Shrewsbury and older Westborough WWTPs. Shrewsbury flows were tied into the regional facility in June 1987. The WWTP provides advanced secondary treatment with nitrification for a flow capacity of 7.68 mgd. The discharge is into the upper reaches of the Assabet, near the headwaters.

Hudson WWTP: The upgraded plant provides advanced secondary treatment with nitrification and post-aeration. The design flow is 2.63 mgd and enters the river at mile point 16.0.

Maynard WWTP: This plant provides secondary treatment with rotating biological contactors (RBC) and post-aeration. The design flow is 1.43 mgd and enters the river at mile point 6.8.

Marlborough West WWTP: This plant provides secondary treatment and is currently under enforcement action by the USEPA due to violations of NPDES effluent limits for BOD, ammonia, and total suspended solids. The plant is being upgraded to advanced secondary treatment with nitrification (completion date ~Fall 1990 to Spring 1991). The design flow is 1.9 mgd and discharges to the Assabet River six miles downstream from the Westborough Regional WWTP.

Concord MCI WWTP: This WWTP has a relatively small discharge (design capacity of 0.162 mgd) to the Assabet River at mile point 2.4. An upgrade is needed to handle increased flows. Although the discharge frequently violates its NPDES permit limits, MDWPC considers the impact on the river to be small because the ratio of WWTP flow to river flow is small and the discharge is relatively close to the Concord River junction.

None of the improvements to the municipal WWTPs included phosphorus removal capabilities, nor are phosphorus limits specified in the NPDES permits.

Phosphorus removal was not required at the upgraded Assabet River WWTP's based upon waste load and phosphorus load allocation studies conducted in 1980. Copies of these studies are contained in Appendix B. The studies concluded that stream eutrophication was limited by nitrogen and that changes in phosphorus concentrations would not significantly improve the trophic state of the river. Because of the low dilution capacity of the river, the desired instream phosphorus concentration of 0.1 ppm (a typical criterion for avoiding nuisance algal growths in streams, USEPA, 1976) could not be attained even with a WWTP effluent limitation of 1 ppm. Both studies recommended that facility designs be capable of adding phosphorus removal, if so justified in the future. Effluent phosphorus limits well below 1 ppmiter (feasible, but expensive) would be required to reduce stream phosphorus concentrations sufficiently to control algal growth.

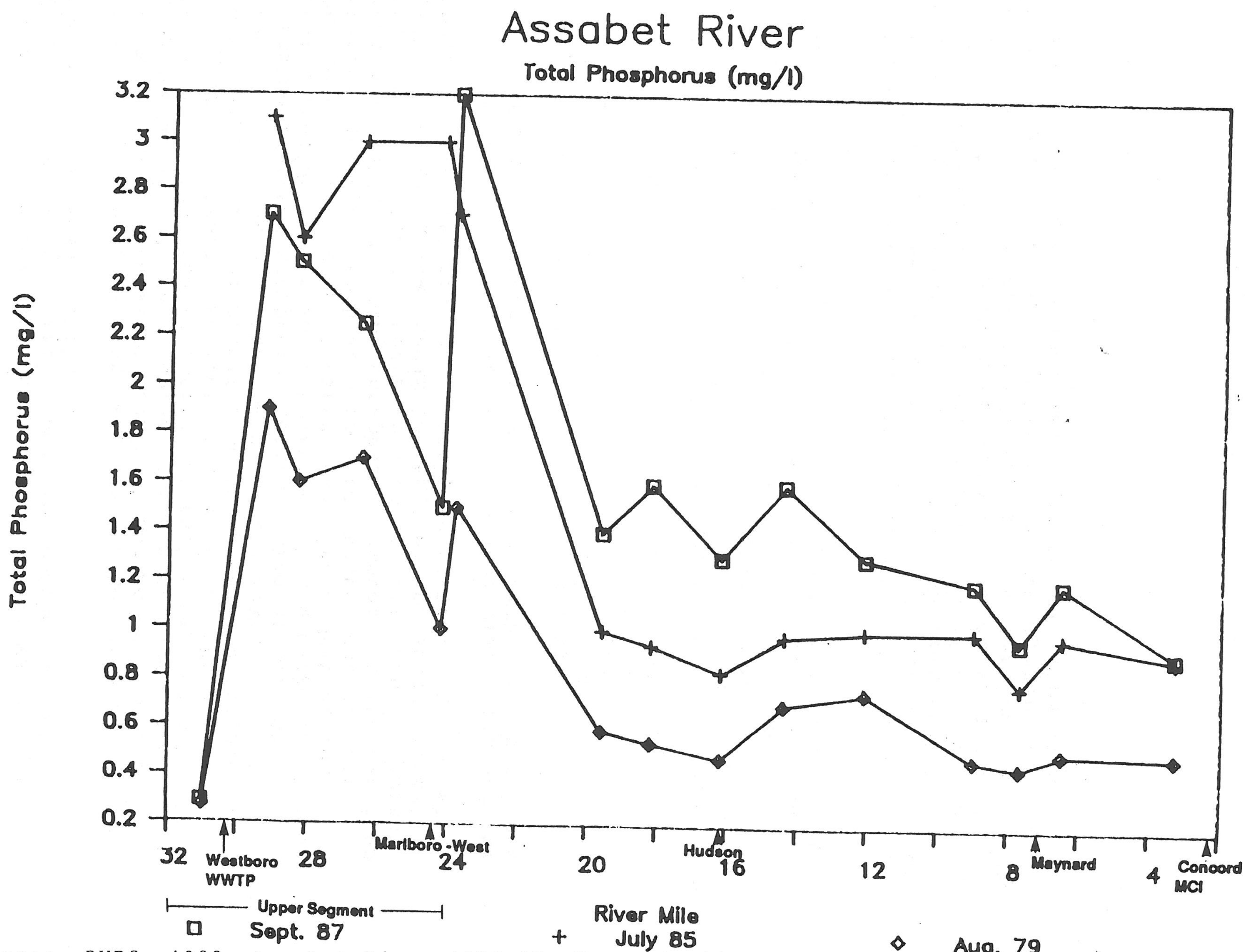
In 1987, the MDWPC sampled the wastewater discharges and the effluent phosphorus concentrations for each WWTP were as follows:

Westborough Regional:	3.3 - 5.6 ppm
Marlborough West:	7.0 - 25.0 ppm
Hudson:	5.2 - 6.8 ppm
Maynard:	4.4 - 7.9 ppm
Concord MCI:	5.7 - 10.0 ppm

The MDWPC evaluated phosphorus concentrations in the upper and lower Assabet River based on the monitoring data collected in 1987. Figure 2 shows downstream trends in phosphorus concentrations from August 1979 to September 1987. Table 3 presents a compilation of the phosphorus concentrations measured in 1984-85 and 1987. Figure 3 shows the approximate location of the sampling stations.

In the upper segment, instream phosphorus levels have not declined since the WWTP upgrades. This is attributed to the fact that phosphorus loadings from the upgraded Westborough Regional WWTP have not decreased. Bottom sediments are also recycling nutrients to the overlying water. Additional analysis would be required to determine whether variations in streamflow between the two monitoring periods also contribute to the apparent lack of improvement. Phosphorus loads may increase over time with

FIGURE 2



Source: DWPC. 1988. Assabet River 1986-87, Water Quality Survey Data

TABLE 3

ASSABET RIVER BASIN PHOSPHORUS CONCENTRATIONS (1984-1987)

STAT	RM	Date 841204	850123	850226	850416	850627	850717	850822	850910	851017	870218	870317	870416	870513	870722	870723	870805	870827	870901	870902	870923	N	Average
AS01	31.8	0.14	0.06	0.12	0.12	0.10	0.19	0.14	0.09	0.10	0.05	0.04	0.08	0.06	0.05	0.08	0.28				0.08	17	0.12
AS02	31.0	0.11	0.06	0.16		0.09									0.04	0.07	0.26	0.04	0.5	0.07	0.09	11	0.11
AS04	30.1	1.40	0.94	0.34	2.20	1.40	2.40	1.20	1.10	1.70	0.43	0.22	0.13	0.54								13	1.08
AS05	29.2	1.60	1.80	0.86	1.50	1.90	3.10	1.40	1.10	2.20	2	0.8	0.27	0.75	3.8	3.3	2.3	3.5	3.3	2.1	0.57	20	1.91
AS06	28.3	1.00	1.00	0.72	1.90	1.40	2.60		0.70	1.70	2.5	0.58	0.3	0.44	3.8	3.2	2.6	4.6	3.1	1.9	0.79	19	1.83
AS07	26.5	1.40	1.10	0.76	1.40	1.90	3.00	1.40	0.69	2.50	3	0.49	0.32	3.04	3	3.2	2.5	3.4	2.9	1.6	0.8	20	1.92
AS08	25.4	1.20	0.82	0.58	1.00	1.10			0.72	1.60												7	1.00
AS09	24.2	1.00	0.64	0.54		0.99	3.00		0.72	1.10	0.83	0.36	0.22	0.44	1	2	1.8	2.5	1.5	1.5	0.5	18	1.15
AS10	23.8						2.70				1.5	0.34	0.25	2.29	2.2	2.7	2.8	2.1	4.4	2	0.58	12	1.99
AS11	22.0						0.98															1	0.98
AS12	20.6						1.10															1	1.10
AS13	19.6						1.00															1	1.00
AS14	18.2						0.94															1	0.94
AS15	17.6						0.99															1	0.9
AS16	16.2						0.83															1	0.83
AS17	14.4						0.98															1	0.98
AS18	12.1						1.00															1	1.00
AS19	9.0						1.00															1	1.00
AS20	7.7						0.78															1	0.78
AS21	6.5						0.98															1	0.98
AS22	6.1						0.90															1	0.90
AS23	4.6						0.92															1	0.92
AS24	3.3						0.90															1	0.90
AS25	2.6						0.69															1	0.69
AS26	0.4						0.60															1	0.60
AST03	30.5					0.06	0.10		0.06													3	0.07
AST06	26.9		0.09																			1	0.09
AST07	26.2	0.23		0.11		0.10	0.25		0.08													5	0.15
TPWB	30.2	6.80	2.40	1.80	21.00	3.60	6.50	4.20	5.20	5.20		0.88	4.5	4								19	3.48
TPSB	29.8	20.00	4.20	6.90	6.70	7.10	9.00	7.50	6.50	5.00	9.6	4.9	3.5	4.5								15	6.36
TPWR															5.6	5.5			5.3	5.5	3.3	5	5.04
TPMB	24.1						1.30								12	7			25	9.2		5	10.90
TPH	16.0						7.00								5.2	5.2			5.7	6.8		5	5.98
TPM	6.8						6.20								6.3	7.9			4.4	7.1		5	6.38
TPC	2.4						3.10												5.7	10		3	6.27

NOTES:

STAT = Station
RM = River Mile
N = Number of samples
AS = Designates station location on main stem of the Assabet River
AST = Designates station location a tributary to the main stem of the Assabet River

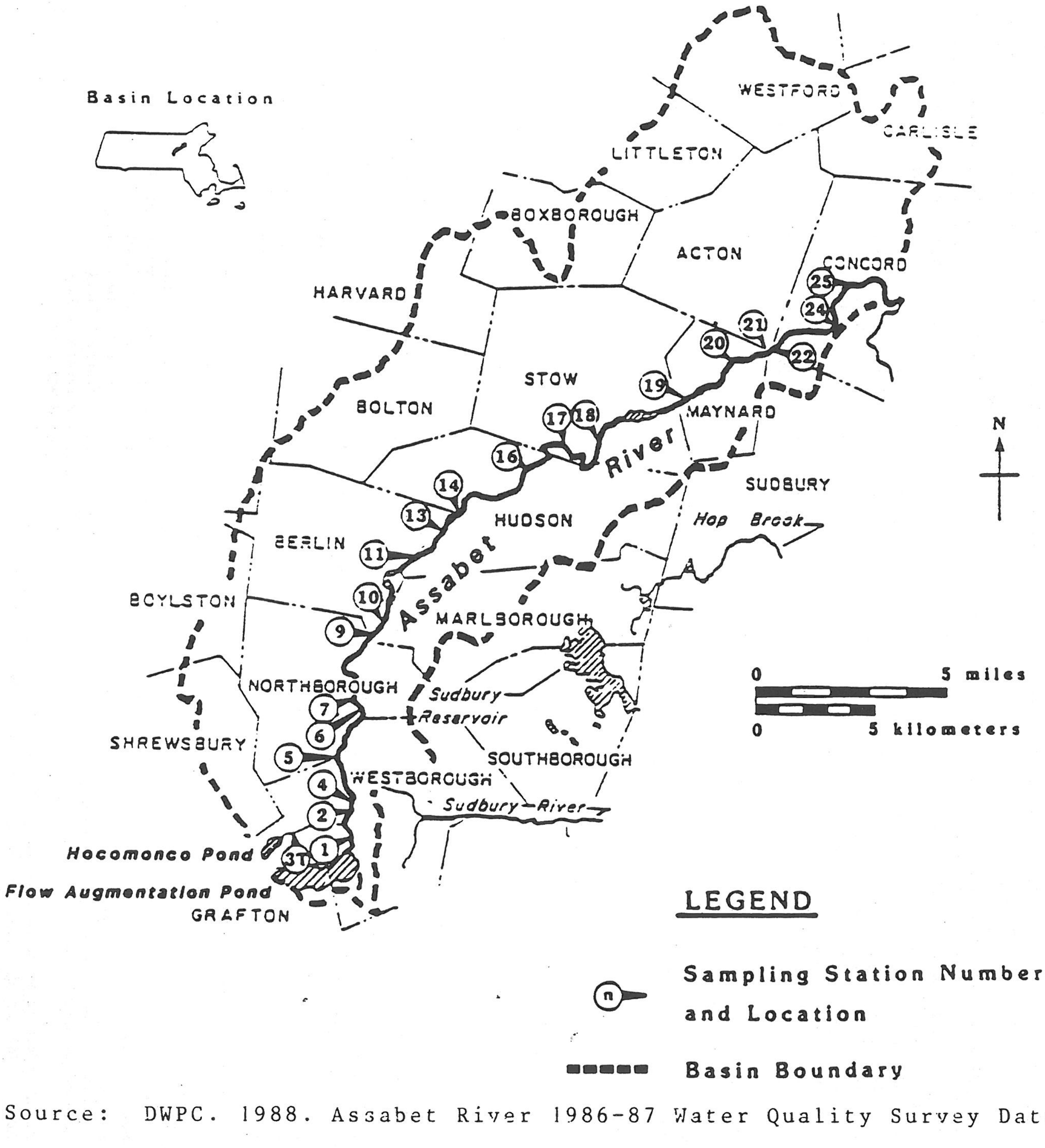
TPWB = Westboro Treatment Plant
TPWR = Westboro Regional Treatment Plant
TPSB = Shrewsbury Treatment Plant
TPMB = Marlboro West Treatment Plant
TPH = Hudson Treatment Plant
TPM = Maynard Treatment Plant
TPC = Concord MCI Plant

Refer to Figure 3 for location of sampling stations
SOURCE: MDWPC. 1988. Assabet River Water Quality Survey Data. 1986-1987.
MDWPC. 1986. Assabet River Water Quality Survey Data. 1984-1985.

Figure 3

LOCATION of SAMPLING STATIONS

ASSABET RIVER BASIN



Source: DWPC. 1988. Assabet River 1986-87 Water Quality Survey Data increased WWTP flows. Concentrations are very high (well above the 0.1 ppmiter instream criterion) and contribute to nuisance algal and weed growth in impounded and other slow-moving sections of the river, including the mouth.

The Assabet River illustrates the difficulties associated with controlling plant growth and resulting water quality impairment in river systems with low dilution capacity, point-source discharges, and suitable habitat for plant growth. Although instream phosphorus concentrations would decrease if a 1.0 ppmiter effluent limit were set, proportionate benefits, as measured by reductions in plant growth, would not be expected. Extraordinary treatment measures (effluent limits well below 1.0 ppmiter) would be require to achieve such benefits.

3.2 Boston Harbor

Data collection under this project has focused on inland waterways. Considering the attention currently directed at the clean-up of Boston Harbor, however, a brief description of water quality conditions and controlling factors in the Harbor is appropriate.

Boston Harbor receives runoff and wastewater discharges from four major coastal rivers (Mystic, Charles, Neponset, and Weymouth Fore), as well as minor tributaries. Water quality is influenced by urban runoff and combined sewer overflows from Boston and adjacent cities. Approximately 500 mgd of wastewater is discharged into the Harbor through the Nut Island and Deer Island primary treatment facilities operated by the Massachusetts Water Resources Authority. Upgrading of the treatment plants, construction of an additional secondary treatment facility, and separation/treatment of combined sewer overflows are among the numerous pollution abatement efforts currently underway. Other pollution sources include industrial discharges, watercraft wastes, refuse dumping, and contaminated bottom sediments.

Existing water quality and sediment data indicate limited compliance with water quality standards. Of the 47.3 mi^2 of Boston Harbor assessed, 39.2 mi^2 partially support designated uses and 8.1 mi^2 support designated uses. Predominant water quality problems are associated with fecal coliform bacteria, heavy metals, oil and grease, and dissolved oxygen. Excessive nutrient loading is not considered a significant problem (MDWPC, 1988). Phosphorus, in particular, is not likely to be a significant pollution factor in the Harbor because algal growth in marine environments is usually limited by nitrogen rather than phosphorus (Parsons et al., 1977). Toxic compounds originating in wastewater discharges and combined sewer overflows may also limit plant productivity.

3.3 Lakes and Ponds

The Division of Water Pollution Control has developed a classification system to determine the trophic status of the State's lakes and ponds. A baseline limnological survey of each waterbody is conducted, generally in one day. It consists of bathymetric mapping, physical, chemical, and biological sampling, and mapping of the aquatic macrophyte communities. As of 1988, MDWPC has conducted 523 baseline surveys on waterbodies throughout the state. The lake data collected through 1986 on 360 lakes are stored in a computer system called Ponds and Lakes Information System (PALIS). Appendix C is a partial listing of the PALIS data base (as available through 1986) arranged by river basin. Table 4 shows a cross-tabulation of the lake trophic state by county and river basin. These data are consistent with the 1988 data summary presented in Section 2.0; approximately 12% of the state's lakes are eutrophic or "excessively enriched".

The lake classification system is used for ranking lakes to be studied under the Massachusetts Clean Lakes Program. The first phase is a diagnostic/feasibility (D/F) study designed to determine the lake's current condition and to develop a restoration/protection program. The diagnostic portion of each study involves basic data gathering and analysis. Detailed information is collected on the watershed and the lake's physical, chemical and biological characteristics. The lake's trophic state is assessed and pollutant sources are quantified. Fifty-five D/F studies have been completed for MDWPC. Each of these reports has been reviewed to extract basic lake data, such as size, nutrient concentrations, phosphorus loads and trophic status. Table 5 summarizes the results.

The majority of the lakes (60% of those reported) are classified as eutrophic, with phosphorus being the limiting nutrient in all but one (Lake Quannapowitt). Primary phosphorus sources are nonpoint sources, failing septic systems, atmospheric deposition, and internal sources (recycling from bottom sediments). There are no reported industrial point sources to any of the lakes or tributaries, and only one lake (Quaboag Pond) is impacted by a municipal wastewater treatment plant (WWTP).

Quaboag Pond, located in the Chicopee River Basin, receives discharge from the Spencer WWTP. The facility is located 4.5 miles upstream of the pond. It discharges to Cranberry Brook, just upstream of its confluence with the Sevenmile River, which joins East Brookfield River to become the major tributary to Quaboag Pond. A D/F study provides background information on the WWTP (BEC, 1986).

TABLE 4

LAKE TROPHIC STATE BY COUNTY AND RIVER BASIN

TROPHIC STATE CODES
1 Oligotrophic
2 Oligo-Mesotrophic
3 Mesotrophic
4 Meso-Eutrophic
5 Eutrophic

PALIS DATA BASE
thru 1986

TROPHIC STATE VS. COUNTY

COUNTY	TROPHIC STATE CODE 1	2	3	4	5	ALL
1 Barnstable	14	4	13	3	2	36
3 Berkshire	16	0	6	4	2	28
5 Bristol	3	0	7	2	5	17
7 Dukes	0	0	0	0	0	0
9 Essex	0	1	8	1	2	12
11 Franklin	2	1	9	0	1	13
13 Hampden	6	2	20	0	7	35
15 Hampshire	5	1	7	4	2	19
17 Middlesex	6	2	27	7	7	49
19 Nantucket	0	0	0	0	0	0
21 Norfolk	0	0	14	3	3	20
23 Plymouth	7	2	11	2	4	26
25 Suffolk	0	0	2	1	1	4
27 Worcester	23	10	57	6	4	100
ALL	82	23	182	33	40	360

TROPHIC STATE VS. RIVER BASIN

RIVER BASIN	TROPHIC STATE CODE 1	2	3	4	5	ALL
11 Hoosic	0	0	1	0	0	1
21 Housatonic	10	0	2	4	2	18
31 Farmington	4	0	2	0	0	6
32 Westfield	5	0	9	0	2	16
33 Deerfield	0	0	0	0	0	0
34 Conneciticut	4	3	7	4	5	23
35 Millers	2	3	20	1	2	28
36 Chicopee	7	1	16	0	3	27
41 Quinebaug	4	0	6	1	0	11
42 French	6	1	7	0	0	14
51 Blackstone	5	5	13	3	1	27
52 Ten Mile	2	0	2	1	0	5
53 Narragansett Ba	0	0	0	0	0	0
61 Mount Hope Bay	0	0	1	0	0	1
62 Taunton	2	0	9	1	4	16
71 Mystic	0	0	2	0	2	4
72 Charles	2	0	9	6	6	23
73 Neponset	0	0	2	0	1	3
74 Weymouth & Weir	0	0	4	0	0	4
81 Nashua	4	2	23	3	3	35
82 Sudbury/Concord	4	0	6	1	1	12
83 Shawsheen	0	0	1	1	0	2
84 Merrimack	1	1	10	2	0	14
91 Parker	0	0	1	0	0	1
92 Ipswich	0	1	3	0	0	4
93 North Shore	0	0	4	0	2	6
94 South Shore	3	2	5	1	0	11
95 Buzzards Bay	3	0	4	1	4	12
96 Cape Cod	14	4	13	3	2	36
97 Islands	0	0	0	0	0	0
ALL	82	23	182	33	40	360

TABLE 5

LAKE DATA DERIVED FROM DIAGNOSTIC/FEASIBILITY STUDIES

MASS. D/F/ STUDY DATA BASE

PALIS	LAKE NAME	BASIN	TOWN	CITATION	DATE	WA	SA	DEPTH
82011	Boon	Assabet	Hudson	CDM' 1987	1985	1440.0	163.0	10.7
82007	Bartlett Pond	Assabet	Northboro	IEP, 1986	1984	1690.0	44.0	4.6
82017	Chauncy	Assabet	Westboro	W+H, 1986	1985	1094.4	175.0	11.9
82042	Fort Meadow Res.	Assabet	Marlboro	IEP, 1987	1986	2180.0	263.0	11.0
72096	Populatic Pond	Blackstone	Franklin	BSC, 1988	1987	300.0	45.9	6.5
51142	Salisbury	Blackstone	Worcester	CDM, 1987	1985	1820.0	15.1	3.1
51112	North Pond	Blackstone	Hopkinton	M+E, 1987	1986	1813.0	238.6	8.0
51135	Ripple	Blackstone	Grafton	A-N, 1986	1985	7131.3	64.2	4.1
51073	Indian Lake	Blackstone	Worcester	Lycott, 89	1987	200.0	193.0	10.7
95020	Buttonwood Pond	Buzzards Bay	New Bedford	BEC, 1988	1987	495.0	5.9	3.0
96157	John's Pond	Cape Cod	Mashpee	Dwpc, 82	1980	1216.0	323.0	19.4
96257	Red Lilly Pond	Cape Cod	Barnstable	K-V, 1980	1980	190.5	13.3	2.6
96182	Long Pond	Cape Cod	Yarmouth	M+E, 1986	1985	152.0	59.0	10.0
96115	Great Pond	Cape Cod	Eastham	BEC, 1987	1985	326.5	110.5	11.8
72053	Jennings Pond	Charles	Natick	W+H, 1986	1985	1640.0	9.4	4.3
82029	Dudley	Charles	Wayland	IEP, 1983	1981	336.1	90.8	9.2
72140	Winthrop	Charles	Holliston	W+H, 1985	1984	902.0	102.0	5.0
72045	Hardys Pond	Charles	Waltham	M+E, 1985	1984	907.0	42.0	2.0
72043	Hall's Pond	Charles	Brookline	M+E, 1986	1985	107.0	1.0	2.8
36130	Quaboag	Chicopee	Brookfield	BEC, 1896	1985	49063.0	537.0	6.7
36131	Quacumquasit	Chicopee	Brookfield	BEC, 1986	1985	870.0	218.0	32.5
82043	Fort Pond	Concord	Littleton	DWPC, 81	1979	1887.0	108.0	12.7
34005	Arcadia	Conn	Belchertown	Lycott, 85	1984	1600.0	40.0	11.5
84015	Forge Pond	Conn	Granby	BEC, 1989	1987	9323.0	75.0	3.0
34021	Puffer's Pond	Conn	Amherst	T+B, 1985	1984	9920.0	11.0	7.0
34051	Metacomet	Conn	Belchertown	Lycott, 85	1984	1600.0	70.0	16.0
34099	Massasoit	Farmington	Springfield	BEC, 1986	1985	20350.0	200.0	10.0
21014	Buel	Housatonic	Monterey	IEP, 1982	1981	2668.0	59.0	
92059	Silver Lake	Ipswich	Wilmington	BEC, 1988	1986	132.2	28.5	12.8
92038	Martins	Ipswich	N.Reading	A-N, 1985	1984	5057.0	92.0	5.0
80020	Cochituate	Merrimac	Framingham	DWPC, 82	1976	10726.4	233.0	19.9
84039	Mill Pond	Merrimack	W. Newbury	IEP, 1988	1986	929.0	16.0	4.1
35023	Lake Ellis	Millers	Athol	BEC, 1987	1986	1783.0	68.9	3.9
81161	Wyman Pond	Millers	Westminster	A-N, 1983	1981	4483.0	200.0	5.0
71018	Hill's Pond	Mystic	Arlington	M+E, 1986	1985	15.0	2.0	3.0
71005	Black Nook	Mystic	Cambridge	W+H, 1987	1986	24.0	2.5	1.5
81054	Harbor Pond	Nashua	Townsend	W+H, 1988	1986	37632.0	46.0	4.3
81122	Lake Shirley	Nashua	Lunenberg	M+E, 1988	1987	9154.0	354.0	5.6
81034	Eagle	Nashua	Holden	DWPC, 1981	1979	10240.0	84.0	0.7
81035	E. Waushakum	Nashua	Sterling	DEQE, 1984	1981	1702.0	184.0	4.0
81007	Bare Hill Pond	Nashua	Harvard	W+H, 1987	1986	2675.0	321.0	10.0
73030	Massapoag	Neponset	Sharon	IEP, 1984	1982	1842.4	397.0	14.5
71014	Ell Pond	N.Coastal	Melrose	Lycott, 85	1984	1100.0	22.0	5.6
93008	Brown's Pond	N.Coastal	Peabody	CDM, 1989	1987	359.0	25.0	10.8
93014	Chebacco	N.Coastal	Hamilton	Lycott, 85	1984	3657.0	123.5	13.1
93024	Floating Bridge	N.Coastal	Lynn	CDM, 1986	1985	289.0	10.1	7.2
93023	Flax	N.Coastal	Lynn	CDM, 1986	1984	1640.0	48.9	16.0
93071	Sluice	N.Coastal	Lynn	CDM, 1986	1984	1333.0	39.0	21.0
93060	Quannapowitt	N.Coastal	Wakefield	CDM, 1986	1984	747.0	250.0	6.3
41052	Walker	Quinebaug	Sturbridge	BEC, 1985	1984	2278.0	103.0	6.7
83004	Fawn Lake	Shawsheen	Bedford	Allian, 89	1988	67.5	11.5	2.4
82112	Waushakum	Sudbury	Framingham	IEP, 1988	1986	1360.0	82.0	15.9
62119	W. Monponsett	Taunton	Halifax	Lycott, 87	1985	1907.0	276.0	7.0
62218	E. Monponsett	Taunton	Halifax	Lycott, 87	1985	2060.0	246.0	7.0
32055	Pequot Pond	Westfield	Westfield	Lycott, 86	1985	1663.0	166.4	15.0
MEAN						4110.5	122.0	8.7

DATE	Date of Diagnostic/Feasibility Study	
WA	Watershed Area	Acres
SA	Surface Area	Acres
DEPTH	Mean Depth	Feet

TABLE 5 (Continued)

MASS. D/F/ STUDY DATA BASE

PALIS LAKE NAME	BASIN	-----Average Water Quality----- CHL	TP	TKN	SD	CLR	LN	%MAC	TROPHIC
82011 Boon	Assabet	15.0	0.01	0.41	1.7		P		M/E
82007 Bartlett Pond	Assabet	17.6	0.04	0.70	1.6		P	75	
82017 Chauncy	Assabet	7.7	0.05	0.30	1.2		P		E
82042 Fort Meadow Res.	Assabet	5.9	0.01	0.28	3.6		P	50	M/E
72096 Populatic Pond	Blackstone	15.7	0.29	2.28	0.9			25	E
51142 Salisbury	Blackstone	18.7	0.07	0.52			P	50	E
51112 North Pond	Blackstone	57.0	0.01	0.59	6.0		P	75	E
51135 Ripple	Blackstone	9.8	0.03	1.14	0.9		P	100	E
51073 Indian Lake	Blackstone	20.7	0.06	0.25			P	25	E
95020 Buttonwood Pond	Buzzards Bay	40.0	0.10	0.96	1.0		P	100	E
96157 John's Pond	Cape Cod		0.04	0.85	4.3	5	P	50	M
96257 Red Lilly Pond	Cape Cod	5.1	0.02	0.52			P	75	M/E
96182 Long Pond	Cape Cod	8.9	0.23	0.59	3.0			50	E
96115 Great Pond	Cape Cod	8.3	0.03	0.47	3.2		P	75	
72053 Jennings Pond	Charles	34.0	0.08	0.39	1.2			75	E
82029 Dudley	Charles	3.7	0.02	0.38	7.5		P	50	E
72140 Winthrop	Charles	4.0	0.04	1.30	2.3		P		E
72045 Hardys Pond	Charles	33.5	0.23	1.60	0.5			25	E
72043 Hall's Pond	Charles	8.2	0.10	0.10	0.8				E
36130 Quaboag	Chicopee	12.3	0.05	0.44	1.5		P	50	E
36131 Quacumquasit	Chicopee	10.8	0.02	0.24	3.7		P	25	E
82043 Fort Pond	Concord	9.8	0.08	1.01	1.5	53	P	25	M
34005 Arcadia	Conn	7.5	0.01	0.78	2.4		P	75	E
84015 Forge Pond	Conn	77.0	0.12	1.20	0.9		P	75	E
34021 Puffer's Pond	Conn	10.0	0.03	0.52	2.3			25	M/E
34051 Metacomet	Conn	27.5	0.04	0.95	1.9		P	50	M/E
34099 Massasoit	Farmington	11.8	0.04	0.52	1.7		P	100	M
21014 Buel	Housatonic		0.28	0.34		10		75	E
92059 Silver Lake	Ipswich	1.6	0.03	0.45	4.5		P	50	E
92038 Martins	Ipswich	16.2	0.20	1.08	0.8		P	25	E
80020 Cochituate	Merrimac	9.0	0.03	0.73	1.9	30	P	50	M
84039 Mill Pond	Merrimack	11.9	0.32	0.43	1.6		P	100	E
35023 Lake Ellis	Millers	5.9	0.01	0.35	2.8			75	M
81161 Wyman Pond	Millers	1.2	0.03	0.54	2.2		P		E
71018 Hill's Pond	Mystic	11.0	0.28	1.60			P	75	M/E
71005 Black Nook	Mystic	5.4	0.12	0.50	1.0			25	E
81054 Harbor Pond	Nashua	4.0	0.05	0.34	1.7		P	100	E
81122 Lake Shirley	Nashua	4.1	0.02	0.10			P	50	
81034 Eagle	Nashua	2.2	0.07	0.70	3.0		P	100	M/E
81035 E. Waushakum	Nashua	1.6	0.06	0.47	4.4		P		M/E
81007 Bare Hill Pond	Nashua	3.9	0.04	0.22	3.6		P	50	E
73030 Massapoag	Neponset	3.2	0.04	0.51	6.9		P	25	M
71014 Ell Pond	N.Coastal	84.3	0.14	1.70	1.0		P	50	M/E
93008 Brown's Pond	N.Coastal	13.6	0.02	0.38	3.4		P	25	E
93014 Chebacco	N.Coastal	7.8	0.02	1.08	1.5		P		
93024 Floating Bridge	N.Coastal	6.8	0.05	0.60	1.6		P		M/E
93023 Flax	N.Coastal	6.7	0.03	0.84	1.1		P	25	
93071 Sluice	N.Coastal	5.6	0.02	0.37	2.7		P	50	
93060 Quannapowitt	N.Coastal	30.0	1.89	1.36	1.2		N	25	E
41052 Walker	Quinebaug	5.6	0.02	0.38	2.6		P	75	
83004 Fawn Lake	Shawsheen	13.1	0.02	2.50	1.1		P	25	M
82112 Waushakum	Sudbury	5.7	0.01	0.32	3.3		P	25	M
62119 W. Monponsett	Taunton	7.5	0.04	0.68	1.4		P	25	E
62218 E. Monponsett	Taunton	3.4	0.01	0.37	1.8		P	25	E
32055 Pequot Pond	Westfield	7.1	0.03	1.17	2.1		P	50	M/E
MEAN		14.3	0.10	0.72	2.3			54	

CHL	Mean Chlorophyll-a	ug/liter
TP	Mean Total P	mg/liter
TKN	Total Kjeldahl N	mg/liter
SD	Mean Secchi Depth	Meters
CLR	Mean Color	Pt-Co Units
LN	Limiting Nutrient (P,N)	
%MAC	Macrophyte Coverage	%
TROPHIC	Trophic State	

MASS. D/F/ STUDY DATA BASE

PALIS	LAKE NAME	BASIN	POINT	NONPT	SEPTIC	ATMOS	INTERN	TOTAL	RESID#
			----- Phosphorus Loads (lbs/yr) -----						
82011	Boon	Assabet	0	410	827	73	14	1324	
82007	Bartlett Pond	Assabet	0	586	265		40	891	150
82017	Chauncy	Assabet	0	1074	453	114		1641	43
82042	Fort Meadow Res.	Assabet	0	1204	57	117		1378	
72096	Populatic Pond	Blackstone	0	37626	871	13	57	38567	123
51142	Salisbury	Blackstone	0	10243	0			10243	
51112	North Pond	Blackstone	0	675	666	84		1425	450
51135	Ripple	Blackstone	0	1851	0	20		1871	
51073	Indian Lake	Blackstone	0	844	0	77	75	996	
95020	Buttonwood Pond	Buzzards Bay	0	1018	0	2		1020	
96157	John's Pond	Cape Cod	0	1219	13	106		1338	
96257	Red Lilly Pond	Cape Cod	0	10432	0	136		10568	
96182	Long Pond	Cape Cod	0	93	0	18		110	
96115	Great Pond	Cape Cod	0	26	0	29	96	151	
72053	Jennings Pond	Charles	0	823	4	13	99	939	
82029	Dudley	Charles	0	184	103	22		309	26
72140	Winthrop	Charles	0	131	550	40		721	
72045	Hardys Pond	Charles	0	106	0	22		128	
72043	Hall's Pond	Charles	0	84	0	0		84	
36130	Quaboag	Chicopee	6157	6466	547	392		13562	
36131	Quacumquasit	Chicopee	0	57	242	42	66	407	108
82043	Fort Pond	Concord	0	540	0	18		558	
34005	Arcadia	Conn	0	39	84	14		137	
84015	Forge Pond	Conn	0	4676	56	31		4763	24
34021	Puffer's Pond	Conn	0	760	0			760	
34051	Metacomet	Conn	0	38	123	22	7	190	
34099	Massasoit	Farmington	0	21618	0	181	163	21962	
21014	Buel	Housatonic	0	787	57	44		888	
92059	Silver Lake	Ipswich	0	109	0	13		122	
92038	Martins	Ipswich	0	721	321	33		1075	
80020	Cochituate	Merrimac	0	7940	0			7940	
84039	Mill Pond	Merrimack	0	304	0	7		311	
35023	Lake Ellis	Millers	0	785	0	13		798	
81161	Wyman Pond	Millers	0	302	558	117		977	
71018	Hill's Pond	Mystic	0	2	0	1		3	
71005	Black Nook	Mystic	0	59	0	4	286	349	
81054	Harbor Pond	Nashua	0	11370	0	14	569	11953	
81122	Lake Shirley	Nashua	0	1098	207	159		1464	
81034	Eagle	Nashua	0	73	0	25		98	
81035	E. Waushakum	Nashua	0	89	302	40		431	
81007	Bare Hill Pond	Nashua	0	2408	333	139	1682	4562	90
73030	Massapoag	Neponset	0	1085	103	88		1276	13
71014	Ell Pond	N.Coastal	0	412	0	7	127	546	
93008	Brown's Pond	N.Coastal	0	264	0	14	2	280	
93014	Chebacco	N.Coastal	0	140	350	40	44	574	
93024	Floating Bridge	N.Coastal	0	802	0			802	
93023	Flax	N.Coastal	0	1947	0			1947	
93071	Sluice	N.Coastal	0	452	0			452	
93060	Quannapowitt	N.Coastal	0	5395	0			5395	
41052	Walker	Quinebaug	0	747	0	18	22	787	
83004	Fawn Lake	Shawsheen	0	23	0	2	96	121	
82112	Waushakum	Sudbury	0	269	154	37	104	564	67
62119	W. Monponsett	Taunton	0	807	412	117		1336	116
62218	E. Monponsett	Taunton	0	807	390	117		1314	114
32055	Pequot Pond	Westfield	0	50	317	53	63	483	
MEAN			112	2583	152	49	190	2962	110

Phosphorus Load Components (lbs/yr)

POINT	Municipal Point Source
NONPOIN	Nonpoint Load
SEPTIC	Shoreline Septic Systems
ATMOS	Atmospheric Load
INTERN	Internal Load (Bottom Sediments)
TOTAL	Total Load
RESID#	No. Shoreline Residences (<250 ft)

The Spencer WWTP has existed since the early 1900's and is considered to be a major source of nutrients to the system. The plant was upgraded to secondary treatment in 1971. The effluent had a mean phosphorus concentration of 3.3 ppm and a rated capacity of 0.98 mgd. Considering overflow events, a phosphorus load "on the order of 4,400 kg/yr [9,702 lbs/yr] is considered an accurate appraisal of the Spencer WWTP input to the aquatic system under study, although the potential for great temporal variability of the load is recognized" (BEC 1986, p. 186). The D/F study took into account the proposed upgrade to tertiary treatment, including addition of a clarifier/flocculation basin for phosphorus removal, an aeration tank for nitrification, improved sand filter beds, and wetland treatment. Assuming a seasonal (April-October) phosphorus effluent limitation of 1.0 ppm and a flow capacity of 5 mgd, the future annual load would be 6,350 lbs/yr, or 65% of the pre-upgrade load. The load cited in the D/F phosphorus budget was 6,157 lb/yr.

Improvements to the facility were completed in 1988. Alum and lime are added to precipitate phosphorus. The NPDES effluent limitation for phosphorus is set as 1.0 ppm from April to September. According to the engineer who assisted with the design of the improvements, the facility is currently discharging 0.6 to 0.74 mgd with a phosphorus concentration of 0.25 to 1.2 ppm. The flow design capacity is approximately 2.7 mgd. Information on lake responses to this treatment has not been compiled.

3.4 Treatment Plants with Phosphorus Removal

Among the approximately 125 major municipal WWTP's in Massachusetts, 34 (27%) have advanced treatment processes (Table 6). Major discharges are defined as plants with flows exceeding 0.05 mgd and/or containing potentially toxic pollutants (DEP, 1989). Of these 34 plants, 20 have special phosphorus removal facilities.

According the Technical Services Branch of MDWPC, the Commonwealth began imposing phosphorus limitation on certain WWTPs approximately 15 years ago in cases where the effluent was known to discharge into eutrophic or low-flow waters susceptible to algal growth. The applied effluent limit was 1.0 ppm Total P. As noted above in the case of the Assabet, treatment to this level would not necessarily result in decreased stream algal growth. In subsequent years, the MDWPC has continued to assess water quality conditions (i.e., algal growth, instream phosphorus levels) in the receiving waterbodies, but no conclusive evidence of water quality

TABLE 6

LIST OF ALL MAJOR ADVANCED WWTP'S IN MASSACHUSETTS 1988

WWTP	RECEIVING WATER	7Q10 (cfs)	DATE ADV.	TRMT	WWTP FLOW cfs	Eff. limits mg/l BOD	NH3	TP	DO
Pittsfield	Housatonic	25.45	1977	SAST	25.5	10	1.0	1.0	6.0
Gardner	Millers	2.72	UC	SAST	6.56	10	1.0	—	6.0
Winchendon	Millers	6.9	1975	SAST	0.75	15	—	—	—
N. Brookfield	Dunn Bk.	0.5	UC	SAST	0.78	15	1.0	1.0	6.0
Spencer	Cranberry	0.16	UC	SAST	0.93	10	1.0	1.0	6.0
Ware	Ware	19.86	1985	SAST	3.1	25	1.0	1.0	—
Southbridge	Quinebaug	12.92	1987	SAST	3.74	15	2.0	—	6.0
Leicester	French	0.2	UC	SAST	0.54	12	2.0	1.0	6.0
Webster-Dudley	French	12.95	UC	SAST	9.30	10	2.0	1.5	6.0
Hopedale	Blackstone	0.7	1981	SAST	0.91	15	2.0	1.0	—
Northbridge	Blackstone	115.0	1974	SAST	2.79	10	—	—	—
UBWPAD	Blackstone	7.9	1988	SAST	86.8	10	2.0	—	6.0
West Upton	West River	0.5	1972	SAST	0.47	15	—	—	—
Attleboro	Ten Mile	5.6	1980	SAST	13.3	5.0	1.5	1.0	6.0
N. Attleborough	Ten Mile	0.47	1980	SAST	7.13	5.0	1.0	1.0	6.0
Bridgewater	Town River	2.65	1989	AST	2.23	20	3.0	—	6.0
Brockton	Salisbury	0.6	1984	SAWT	27.9	5.0	1.0	1.0	6.0
Mansfield	Threemile	4.2	1985	SAST	4.85	10	1.0	1.0	6.0
Middleborough	Nemasket	2.95	1978	AWT	3.88	7.0	1.0	1.0	7.0
Taunton	Taunton	40.4*	1978	SAST	13.0	15	1.0	—	6.0
CRPCD	Charles	6.0	1979	SAST	7.04	15	—	—	6.0
Medfield	Charles	7.99	1975	AST	2.36	15	—	1.0	6.0
Milford	Charles	0.73	1986	SAWT	6.67	7.0	1.0	1.0	6.0
Fitchburg East	Nashua	17.3	1976	SAWT	19.2	8.0	1.0	1.0	5.0
Fitchburg West	Nashua	8.8	1975	SAWT	23.7	8.0	1.0	1.0	8.0
Leominster	Nashua	31.8	1984	SAST	14.4	15	1.3	1.0	5.0
Hudson	Assabet	14.0	1986	SAST	4.03	15	3.0	—	6.0
Marlborough East	Hop Bk.	0.16	1974	SAWT	8.53	7.0	0.5	0.75	—
Marlborough West	Assabet	9.88	UC	SAST	4.48	15	2.0	—	5.0
Westborough	Assabet	3.51	1987	SAST	11.9	10	1.0	—	6.0
Rockland	French Stm	0.8	1982	SAWT	3.88	6.0	1.0	1.0	7.4
Marion	Aucoot Cove	*	1971	AST	0.78	10	—	—	—
Wareham	Agawam	*	1972	AST	2.79	10	—	—	—
Ware	Ware	19.86	1985	SAST	3.1	25	1.0	1.0	—

UC - Under Construction
SAST - Seasonal Advanced Secondary Treatment (BOD<30 mg/l)
AST - Advanced Secondary Treatment (year round BOD limits, BOD<30 mg/l)
SAWT - Seasonal Advanced Wastewater Treatment (BOD<10 mg/l)
AWT - Advanced Wastewater Treatment (year round BOD limits, BOD<10 mg/l)
— - No Limit
* - Tidal

NOTE: WWTP Flow Reported As Design or Permitted Maximum Discharge - Average Actual Flows Are Approximately 57% of Design Flow.

Source: DWPC. 1989. Pollutant Reductions from WWTP Upgradings in Massachusetts 1978-1988 improvement (as measured by reductions in stream phytoplankton growth) has been developed. Eutrophic conditions still exist in many receiving waters, such as Hop Brook. This stream receives treated effluent from the Marlborough-East WWTP, which has had an effluent P limit of 0.75 ppmiter since 1974.

4.0 PHOSPHORUS BALANCE ANALYSIS

4.1 River Basin Phosphorus Balance

4.1.1 Data Sources

Available water quality and discharge rate data were collected from the most recent MDWPC River Basin Studies for the Assabet, Millers, and Deerfield River Basins. The specific data sources for each Wastewater Treatment Plant (WWTP) are provided in Appendix D. Because of inconsistencies in the information provided in the respective river basin studies, the data sources vary considerably for each WWTP, and in many cases it was necessary to approximate key input parameters using the best available information. The data collected for each WWTP discharging in these basins included:

- Average river phosphorus concentration (at upstream river monitoring station)
- Average effluent phosphorus concentration
- Drainage area upstream of the discharge point
- Average observed effluent discharge rate
- Design effluent discharge rate
- Average observed river discharge rate at upstream monitoring station
- River 7-Q-10 low flow at the point of discharge or other available locations in the river basin

Eight to nine samples were typically collected at each river monitoring station during the River Basin Studies. Effluent monitoring was, however, typically limited to two to four samples collected on two sampling occasions. In most cases, river flow for the period of study was only reported for USGS gauge stations within the basin. Therefore, river flow for this analysis was frequently extrapolated from the available flow data based on the flow per square mile for the gauge station. Similarly, 7-Q-10 flow for WWTP discharges were only reported in the River Basin Studies for the Millers River. Therefore, 7-Q-10 flows were approximated in a similar manner. The upstream drainage areas for each WWTP were estimated based upon river mile location, and drainage area reported in the Gazetteer of Stream Characteristics (USGS, 1984a; USGS, 1984b).

4.1.2 Mass-Balance Calculations

Mass-balance calculations have been performed to quantify phosphorus sources and to evaluate potential impacts of a detergent ban and other control measures on phosphorus concentrations in three Massachusetts River basins (Assabet, Millers, and Deerfield). The calculations are based upon flows and nutrient concentrations at river monitoring stations and wastewater discharges monitored by the Mass DEP in each basin.

Each basin is divided into segments bounded by wastewater discharges. Information compiled for each segment includes river mile, drainage area, streamflow, and monitored stream concentration upstream of the wastewater discharge. A mass-balance is performed to predict the phosphorus load leaving each river segment, based upon the following equation:

Downstream Load = Upstream Load + Effluent Load + Nonpoint Load - Retention

Loads are calculated in units of pounds per day (lbs/day) and refer to stream and effluent flow conditions present during river survey periods. Nonpoint (runoff) load is estimated by multiplying the local drainage area (mi^2) by the nonpoint export factor ($lbs/mi^2 \cdot day$), calculated from monitored streamflow and concentration at the inflow to the first segment (above all wastewater discharges). This procedure may under-estimate nonpoint loads because land use intensities typically increase moving downstream in each river basin. Nonpoint phosphorus export is generally higher in watersheds with greater percentages of urban and agricultural land uses, as compared with forested and other undeveloped land uses (Omernik, 1977; NALMS, 1990). Regional monitoring data from streams not impacted by wastewater discharges indicate average total phosphorus concentrations of .015, .06 and .14 ppmiter in streams draining forested, agricultural, and urban areas, respectively (Walker, 1982).

Retention accounts for phosphorus removal within the stream and is calculated by difference from the other terms. This reflects several mechanisms (sedimentation, adsorption to stream sediments, biological uptake, etc.). These mechanisms are generally more important in impoundments or other river segments with long water residence times. A negative retention term calculated for any segment is assumed to reflect under-estimation of nonpoint load; in this situation, the nonpoint load is increased accordingly and the retention term is set to zero. The effects of retention are represented by a "calibration factor", which is defined as the ratio of the measured load leaving the segment to sum of the loads entering the segment (upstream + effluent + nonpoint). In projecting stream loads for alternative phosphorus control schemes, the calibration factor is assumed to be constant. This is consistent with modeling procedures generally used for lakes and impoundments (NALMS, 1990).

A corresponding water balance is performed to predict downstream flows. The procedure provides a basis for projecting the cumulative effects of changes in effluent phosphorus loads on stream phosphorus concentrations and loads leaving each basin segment. Four phosphorus-control scenarios are evaluated.

(1) Existing. This reflects average conditions during the period of river monitoring by the DEP.

(2) Phosphate Detergent Ban. Wastewater phosphorus loads entering each river segment from wastewater treatment facilities not practicing phosphorus removal are reduced by 33%, the average reduction in effluent phosphorus loads observed following a phosphorus detergent ban in Maryland (Walker, 1987).

(3) Effluent P = 1 ppm. Wastewater phosphorus concentrations are reduced to a maximum of 1 ppmiter, which is achievable via physical/chemical treatment. This reflects changes likely to result from investment in phosphorus removal facilities and application of effluent phosphorus limits for all wastewater discharges in the basin.

(4) Nonpoint Only. Wastewater phosphorus loads are eliminated. Stream phosphorus profiles reflect nonpoint sources (runoff from forested, agricultural and urban land areas).

These calculations are performed for the average streamflow and effluent conditions which were present during the river basin surveys. Calculations are tabulated in Appendix D.

A second set of calculations estimates total phosphorus concentrations and total nitrogen to phosphorus ratios upstream and downstream of each wastewater discharge in each basin under low-flow conditions for Scenarios (1) and (2) above. The low-flow condition is defined as the 7-day-average low flow experienced at 10-year frequency (7-Q-10). This condition is typically used as a "worst case" for evaluating impacts of point source discharges on river systems and for setting effluent permit limits. These calculations are based upon average measured nitrogen and phosphorus concentrations in the river upstream of each discharge and upon average effluent flows and concentrations.

Potential biological responses to decreases in stream phosphorus concentration would include decreases in phytoplankton (algae suspended in the water) and periphyton (algae attached to the stream bed). Biological responses would be expected only when the supply of phosphorus limits or controls algal growth. Other factors, such as nitrogen, light, or flow velocity, may regulate algal growth and reduce sensitivity to changes in phosphorus concentrations. The ratio of total nitrogen to total phosphorus is used as an indicator of the potential for growth limitation by phosphorus vs. nitrogen according to the following classification:

(A) N/P < 7 - Nitrogen-Limited; Biological responses to changes in phosphorus are unlikely;

(B) N/P > 15 - Phosphorus-Limited; Biological responses to changes in phosphorus are possible if other factors, such as light or flow velocity, are not controlling;

(C) 7 < N/P < 15 - Transition (Both N and P Limited); Biological responses to changes in phosphorus are possible, but modified by effects of nitrogen limitation.

These ranges are consistent with empirical relationships between algae and nutrient concentrations in impoundments (Walker, 1984; 1985). Predictions of N/P ratio upstream and downstream of each wastewater discharge provide a basis for assessing the likelihood of biological responses to reductions in stream phosphorus concentration resulting from a phosphate detergent ban. Predicted stream total phosphorus concentrations are also compared with the USEPA (1976) guideline for avoiding nuisance algal growth in streams (<0.1 ppm).

4.1.3 Results - Assabet River Basin

Phosphorus-balance calculations indicate that detergent phosphorus accounted for 31.2% of the total phosphorus discharged to the Assabet River during the survey period. Other sources included point sources (63.4%, exclusive of detergent component) and nonpoint sources (5.4%). Nutrient-related water quality problems have been identified along the entire monitored length of the Assabet River (River Miles 30 to 0). Figure 4 shows predicted total phosphorus profiles for Scenarios 1-4 under average monitored flows. Figure 5 shows predicted total phosphorus concentrations and total N/P ratios upstream and downstream of each wastewater discharge under 7-Q-10 flows.

Assabet River phosphorus concentrations are generally high because of the predominance of point sources. Although a phosphate detergent ban would reduce total phosphorus loading to the river by approximately 31%, river phosphorus concentrations are projected to remain well above the 0.1 ppm EPA guideline for avoiding nuisance algal growth in streams. With a detergent ban in effect, predicted

FIGURE 4

Assabet River Basin

Predicted Total Phosphorus Concentrations

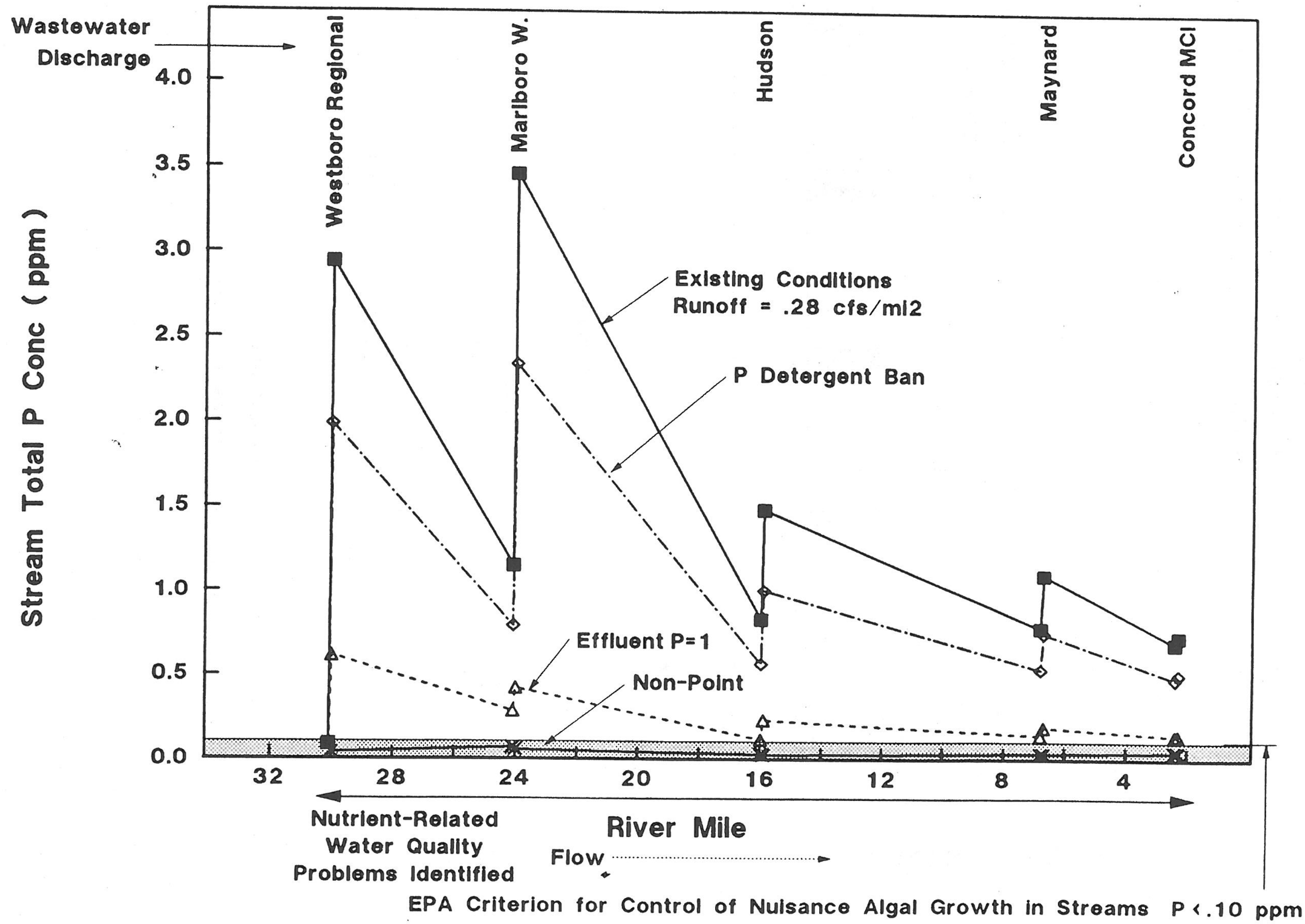
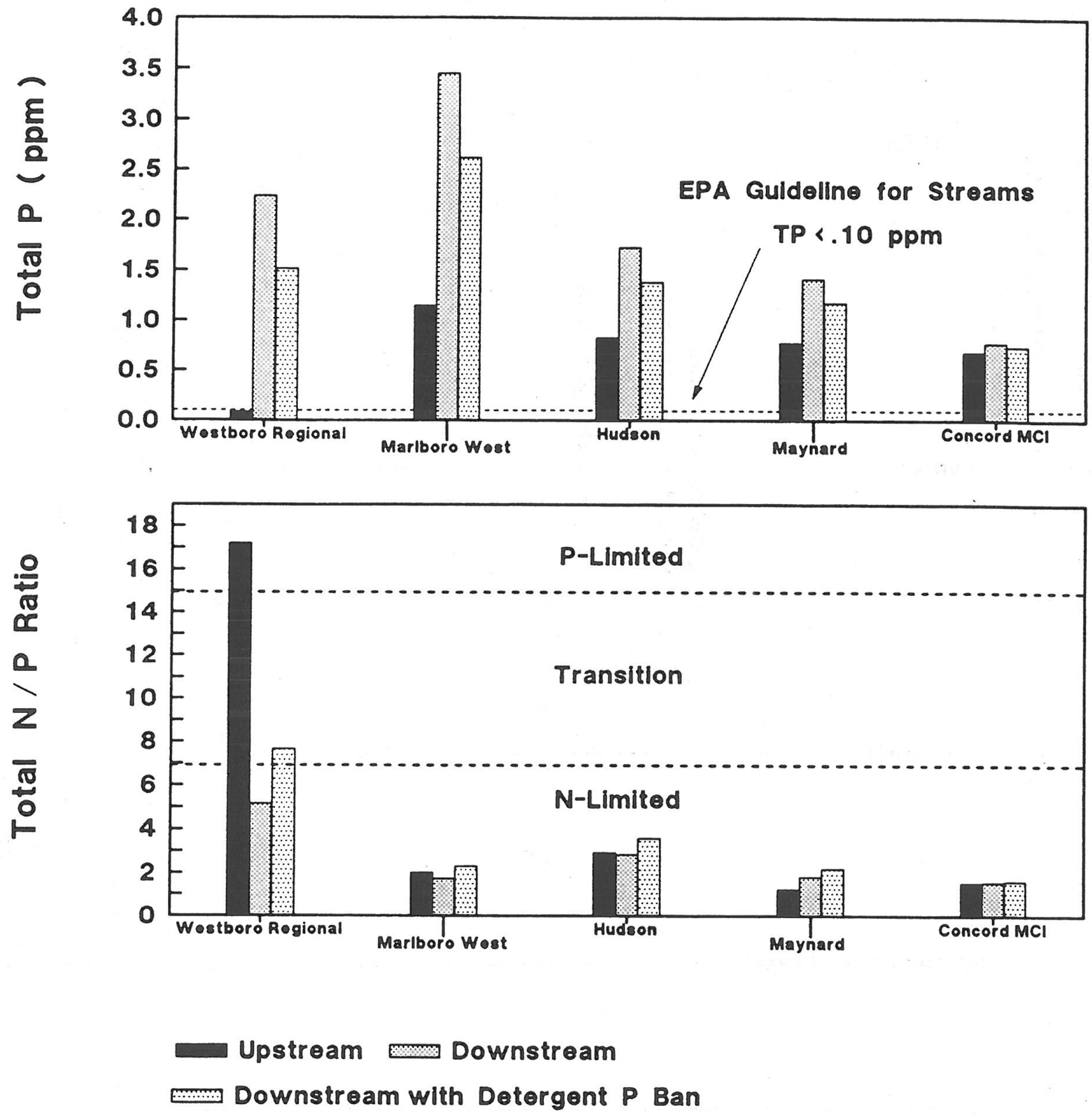


FIGURE 5

Assabet River Basin

Predicted Stream Responses Under 7-Q-10 Flows



concentrations downstream of wastewater discharges would exceed 0.5 ppm under average monitored flows and exceed 0.7 ppm under 7-Q-10 flows. N/P ratios downstream of wastewater discharges would remain in the nitrogen-limited range. Because of high phosphorus concentration and low N/P ratios, biological responses to a detergent ban are not expected in the Assabet River.

As discussed above (Section 3.1), a similar conclusion was reached by the Mass DEP in evaluating the potential benefits of equipping wastewater treatment facilities in this basin for phosphorus removal. As shown in Figure 4, stream phosphorus concentrations would exceed 0.1 ppm, even with treatment of all effluents to 1 ppm. The susceptibility of the Assabet River to nutrient enrichment problems reflects a low dilution capacity for the relatively high density of wastewater discharges in the basin. Based upon this analysis, it is unlikely that significant improvements in eutrophication-related water quality conditions could be achieved without extraordinary treatment measures (e.g., land treatment) or diversion of wastewater effluents from the basin. Nonpoint sources (urban runoff) are also important contributing factors, particularly in the lower portion of the basin.

4.1.4 Results - Millers River Basin

Phosphorus-balance calculations indicate that detergent phosphorus accounted for 13.4% of the total phosphorus discharged to the Millers River during survey periods. Nonpoint sources accounted for 59.4% and other point sources accounted for 27.2% under 7-Q-10 low flows. Nutrient-related water quality problems have been identified in the Otter River and in the Millers River between River Miles 30.4 and 25.6, immediately downstream of the Otter River confluence. Figure 6 shows predicted total phosphorus profiles for Scenarios 1-4 above under average monitored flows. Figure 7 shows predicted total phosphorus concentrations and total N/P ratios upstream and downstream of each wastewater discharge under 7-Q-10 flows.

Model projections (Figure 6) show phosphorus concentrations ranging from 0.14 ppm to 0.22 ppm downstream of wastewater discharges in the Millers River under existing conditions. With a phosphate detergent ban, this range would be 0.12 to 0.18 ppm. The response is attributed largely to reductions in phosphorus loads from the Gardner wastewater treatment plant, which discharges to Otter River and accounts for 63% of the total point-source phosphorus load to the basin under existing conditions. Stream phosphorus levels less than 0.1 ppm would be achieved at some locations with wastewater treatment to 1 ppm and at all locations with diversion of wastewaters from the basin (nonpoint sources only). Total N/P ratios (Figure 7) are generally in the transition

FIGURE 6

Millers River Basin

Predicted Total Phosphorus Concentrations

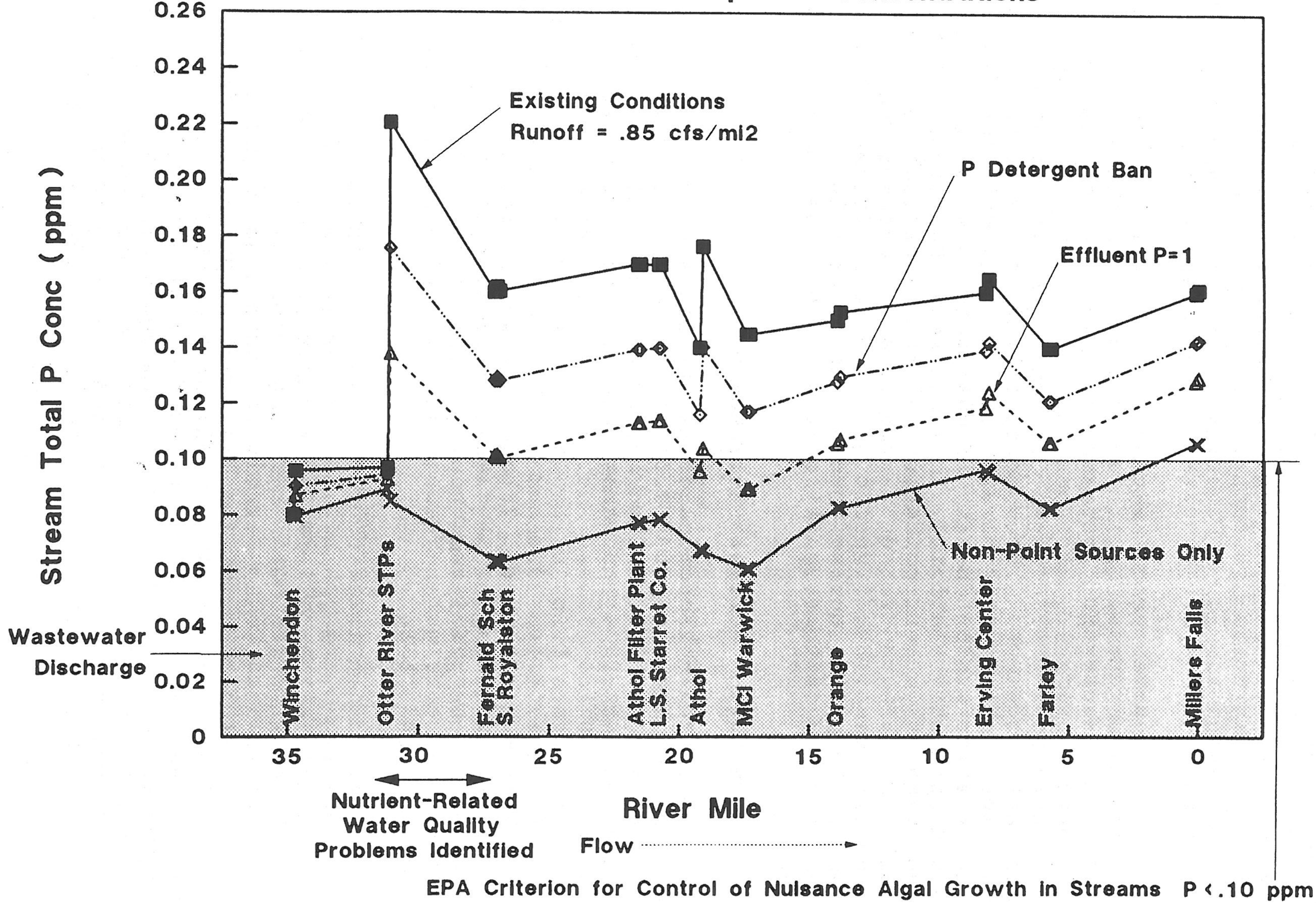
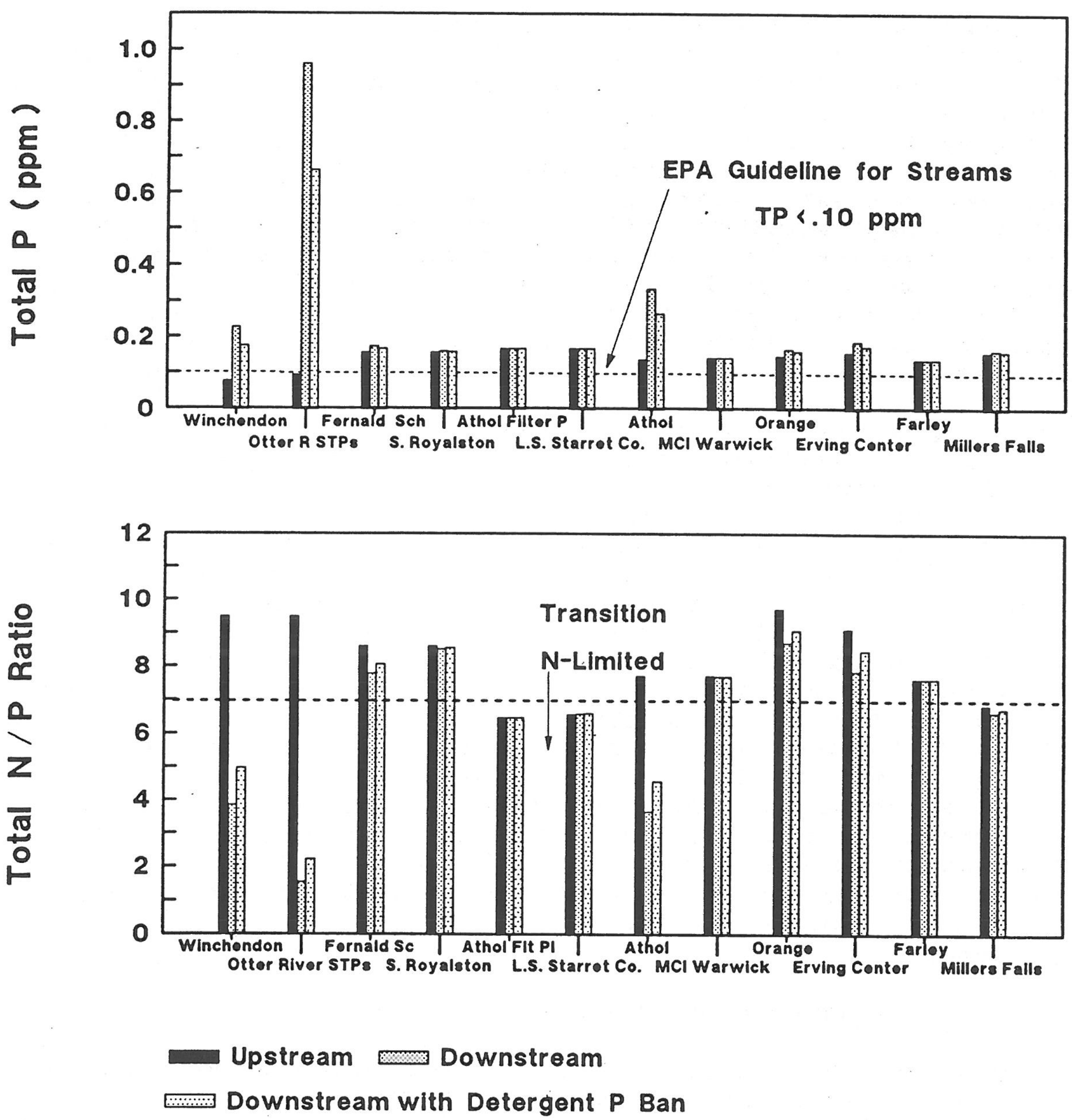


Figure 7

Millers River Basin
Predicted Stream Responses Under 7-Q-10 Flows



range (between 7 and 15). The calculations indicate that a phosphate detergent ban alone would not be expected to influence compliance with the EPA guideline (<0.1 ppm) for control of nuisance algal growth. Nitrogen limitation may also control biological responses.

4.1.5 Results - Deerfield River Basin

Phosphorus-balance calculations indicate that detergent phosphorus accounted for 14.6% of the total phosphorus discharged to the Deerfield River during the survey periods. Nonpoint sources accounted for 55.8% and other point sources accounted for 29.6%. The detergent contribution increased to 27.6% under 7-Q-10 low flows. While nutrient-related water quality problems have been identified on a small tributary of the Deerfield (small tributaries receiving Greenfield WWTP effluent and untreated discharges from Ashfield), problems have not been identified on the mainstem. Figure 8 shows predicted total phosphorus profiles for Scenarios 1-4 under average monitored flows. Figure 9 shows predicted total phosphorus concentrations and total N/P ratios upstream and downstream of each wastewater discharge under 7-Q-10 flows.

Major point sources in the Deerfield River basin include the Kendall County discharge at River Mile 18.7 and Greenfield at River Mile 1.9. Phosphorus profiles under average monitored flows are below 0.08 ppm for each scenario evaluated (Figure 8). These low concentrations are consistent with the lack of reported nutrient problems on the mainstem. At 7-Q-10 flows (Figure 9), phosphorus concentration in the 4-mile river segment between the Kendall County and Greenfield discharges is projected to vary from 0.2 to 0.08 ppm under existing conditions. A phosphate detergent ban would reduce the maximum concentration below the Kendall County discharge from 0.2 to 0.15 ppm. This, in turn, would decrease the fraction of the 4-mile segment exceeding the 0.1 ppm guideline under 7-Q-10 flows. Biological response would be limited by low N/P ratios. More detailed projections of biological response in this segment would require use of coupled water-quality and phytoplankton models, such as QUAL-2E (Brown and Barnwell, 1985). Beneficial impacts on water uses are unlikely, however, based upon the fact that nutrient-related problems have not been reported in this segment.

4.2 State-Wide Phosphorus Balance

Additional calculations have been performed to estimate total phosphorus loads to each river basin in Massachusetts (Appendix E). Loads are partitioned into nonpoint and point source components. These calculations are based largely upon basin watershed areas, population, and wastewater effluent volumes compiled by the Massachusetts Audubon Society (Colburn and Hubley, 1989). Wastewater effluent loads are adjusted to reflect facilities with phosphorus effluent limits (Table 6). Nonpoint source loads are estimated by relating population density to impervious area and

FIGURE 8

Deerfield River Basin

Predicted Total Phosphorus Concentrations

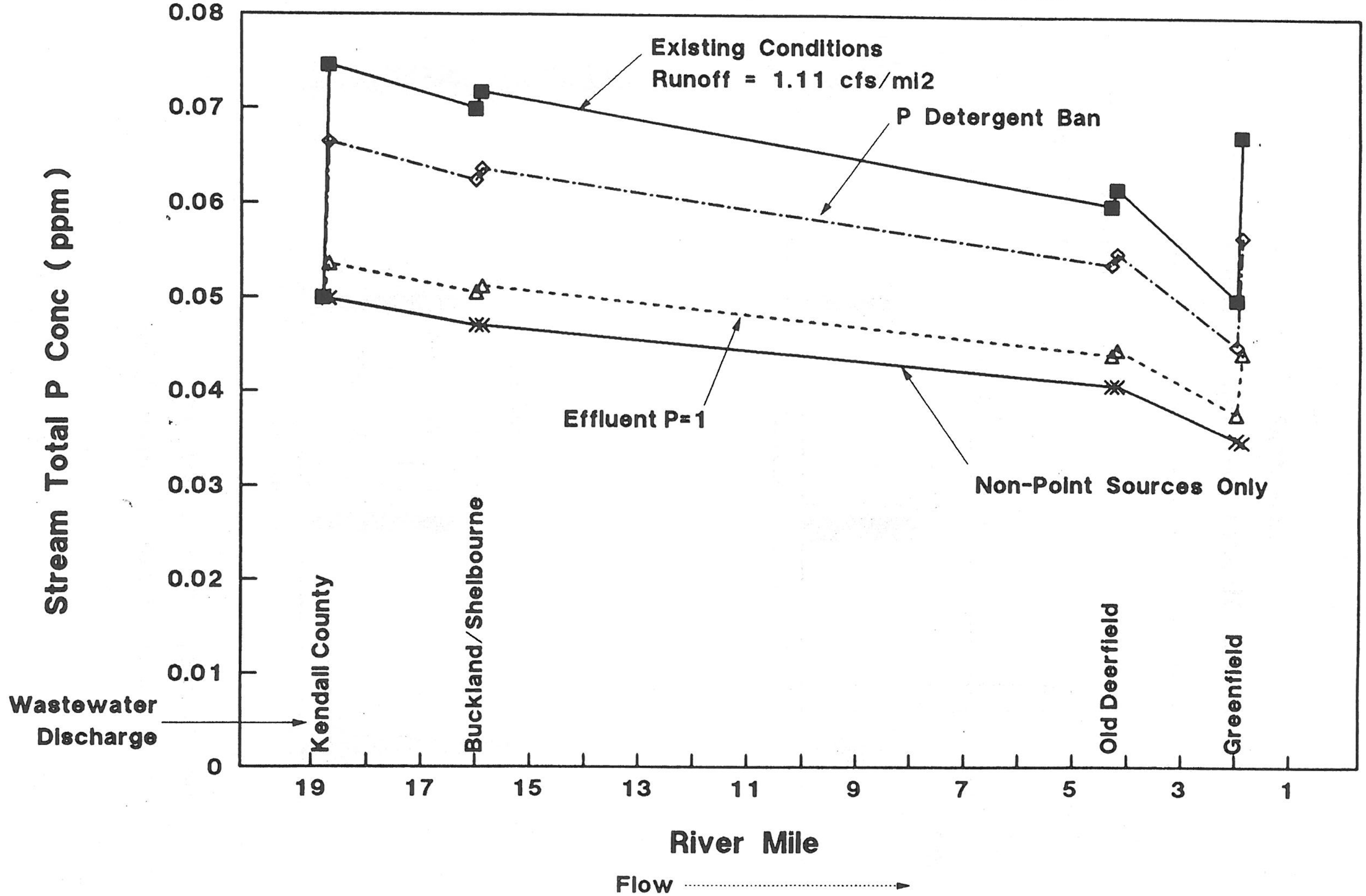
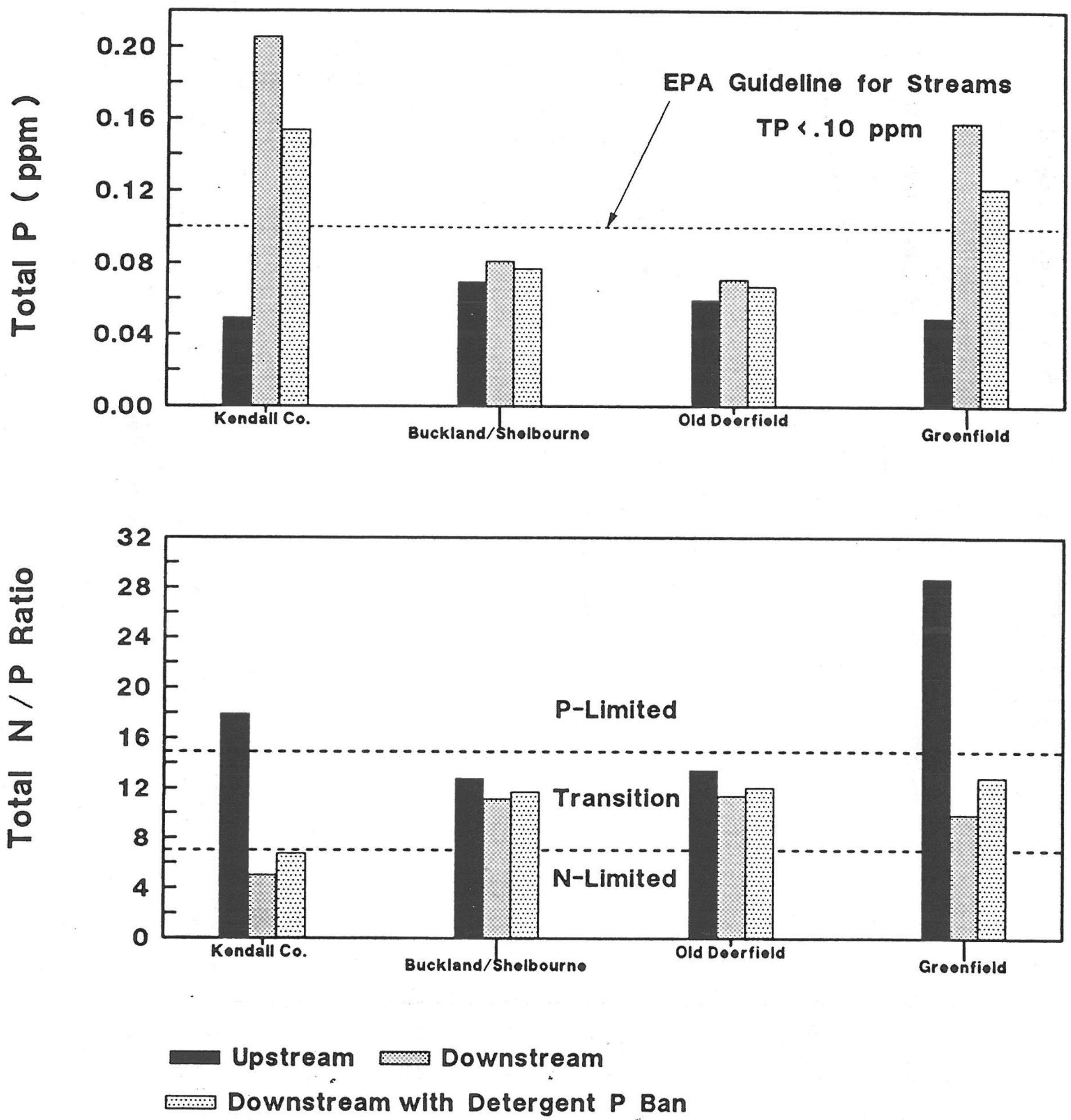


Figure 9

Deerfield River Basin

Predicted Stream Responses Under 7-Q-10 Flows



applying export coefficients typical of the Northeast (Omernik, 1977; Walker, 1978, 1982, 1982b). Phosphorus loads from on-site wastewater disposal systems are estimated based upon population density (30% using on-site systems; Coburn and Hubley, 1989) and assuming 95% phosphorus removal. Actual removal efficiency is probably higher on a statewide basis, since systems located further than 300 feet from watercourses are normally assumed to remove 100% of the influent phosphorus load (USEPA, 1985; Maine DEP, 1989). Because of regional variations in agricultural land uses, use of on-site disposal systems, and interbasin transfers of wastewater, results of the calculations are probably less accurate for the individual basins than for the state as a whole. Model inputs and results are summarized in Appendix E.

Phosphorus discharged to coastal waters would not be expected to impact water quality because phosphorus does not limit plant growth in marine environments. Interbasin transfers of wastewater, industrial discharges, and inflow/ infiltration of seawater into wastewater systems in the metropolitan Boston area (MWRA system) also complicate the formulation of phosphorus balances in this region. It is probable that phosphorus loads to the Boston Harbor are over-estimated by this methodology. Results for inland river basins (as identified in Appendix E) are more accurate and provide general perspective on the relative importance of various phosphorus sources in Massachusetts. These are summarized in Table 7 and discussed below.

Total phosphorus loads to inland basins consist of nonpoint sources (19.8%), effluents from advanced wastewater treatment plants (3.6%), effluents from other wastewater treatment plants (73.1%) and effluents from on-site disposal systems (3.5%). Detergent-derived phosphorus accounts for a total of 25.3% (24.1% discharged in municipal wastewaters and 1.2% discharged in effluents from on-site disposal systems). The total load (14,792 lbs/day) is nearly 15 times that which would occur under pristine conditions (completely forested watershed without wastewater discharges).

5.0 POTENTIAL IMPACTS OF A PHOSPHATE DETERGENT BAN

The previous sections describe the status of Massachusetts water bodies with respect to nutrient enrichment and describe efforts that have been made to control the problem by reducing point-source loads. Efforts are also underway, particularly in several lake watersheds, to control nonpoint sources of phosphorus. This is a more difficult task because nonpoint sources are of greater magnitude, intimately linked to land uses, and difficult to regulate.

A statewide phosphate detergent ban has been proposed as another technique for reducing phosphorus loads to receiving waters and improving water quality. Such bans have been implemented in twelve states (Soap and Detergent Assoc., pers. comm., 1990). Bans have generally been linked to restoration/protection efforts directed at major water bodies which are phosphorus-limited

Table 7

Total Phosphorus Discharged to Inland River Basins of Massachusetts

SOURCE	LBS/ DAY	LBS/ DAY	%	CONC PPM	LBS/ CAP-YR	LBS/ AC-YR
NonPoint Sources	2925		19.8%	.046	.28	.26
Pervious Areas		808	5.5%	.013	.08	.07
Impervious Areas		1652	11.2%	.026	.16	.15
Agriculture		465	3.1%	.007	.04	.04
AWT Effluents	533		3.6%	.008	.05	.05
WWTP Effluents	10818		73.1%	.172	1.04	.97
Detergent-Derived		3570	24.1%	.057	.34	.32
Other		7248	49.0%	.115	.70	.65
Onsite Disposal Systems	516		3.5%	.008	.05	.05
Detergent-Derived		170	1.2%	.003	.02	.02
Other		346	2.3%	.005	.03	.03
Total	14792		100.0%	.235	1.42	1.33
Total Detergent-Derived		3740	25.3%	.060	.36	.34
Pristine Conditions	990		6.7%	.016	-	.09

Total Basins = 19

Total Area = 4,055,920 acres (Coburn, 1989)

1988 Population = 3,791,700 (Coburn, 1989)

AWT = Advanced Wastewater Treatment Plants with Phosphorus Removal

Pristine Conditions = Load for Forested Watershed without Point Sources

CONC = Average Concentration of Load Diluted in Total Basin Runoff of 11,672 cfs

LBS/CAP-YR = Phosphorus Load per Capita per Year

LBS/AC-YR = Phosphorus Load per Acre of Total Land Surface per Year and "downstream" of the state's wastewater discharges. Examples are the Great Lakes, Lake Champlain, and the upper reaches of Chesapeake Bay. However, no such waterbody exists in Massachusetts. Therefore, the justification for a phosphate detergent ban in Massachusetts would have to be directed at reducing phosphorus-related problems in specific inland river segments or lakes.

Based upon monitoring data from municipal wastewater treatment plants before and after phosphate detergent bans, detergents account for 22-35% of the total phosphorus in domestic sewage (Hartig, 1982; Walker, 1987; Booman and Sedlak, 1989; MWCOG, 1989). For the purposes of estimating the potential impact of a phosphate detergent ban on phosphorus loads from municipal point sources and septic systems in Massachusetts, a 33% detergent contribution is assumed; this is based upon effluent data from 65 Maryland sewage treatment plans in 1985 and 1986 (Walker, 1987). This estimate may overstate the percentage contribution in Massachusetts, depending upon the level of voluntary and incidental low-phosphate detergent use.

Documentation of the extent of voluntary use of low-phosphate detergent on a state-wide or basin-wide basis is not available. This information has been documented, however, for shoreline residents of four lakes in Massachusetts as part of Diagnostic/Feasibility studies (Dudley Pond, Fort Meadow Reservoir, Lake Cochichewick, and Mill Pond). Shoreline residents were surveyed, by means of a questionnaire, and asked to provide information regarding the brands of laundry and dishwashing detergents used. The responses of these surveys are summarized in Table 8. About 25 to 38 percent of those responding to the surveys were voluntarily using low- or no-phosphate detergents, while 62 to 75 percent used high-phosphate detergents for laundry and dishwashing.

Dudley Pond, Fort Meadow Reservoir, and Mill Pond are recreational lakes located in urbanized sections of northeastern and central Massachusetts. Lake Cochichewick is also located in a developed region, and serves as the drinking water supply for the Town of North Andover, Massachusetts. Shoreline residents had likely received limited or no formal public education regarding the use of low-phosphate detergents prior to the conduct of these surveys. In general, the survey responses for these lakes are likely representative of detergent use in Massachusetts. However, the use of low-phosphate detergents may be greater in environmentally sensitive areas with heightened environmental awareness, such as Cape Cod. In other regions, the percentages of residents voluntarily using low phosphate detergents maybe somewhat lower.

These survey results, though limited, suggest that prior to public education efforts promoting the use of low-phosphate detergents, some residents are voluntarily or incidentally using low-phosphate

Table 8. Estimates of Voluntary Use of Low-Phosphate Detergents Among Lake Shore Residents

Lake Name	Study Year	Location	Number of Respondents	% Using High-P Detergents	% Using Low-P Detergents
Lake Cochichewick	1987	N. Andover, MA	36	75%	25%
Dudley Pond	1985	Wayland, MA	69	62%	38%
Mill Pond	1988	W. Newbury, MA	16	75%	25%
Fort Meadow Reservoir	1986	Marlborough, MA	14	71%	29%

detergents. One might expect that the use of low-phosphate detergents would increase following the implementation of public education programs, particularly in cases where phosphate detergents are shown to have a measurable impact on the trophic condition of the lake.

The following sections describe potential water quality impacts of a phosphate detergent ban on rivers, harbors, and lakes, in Massachusetts. Secondary impacts unrelated to water quality (e.g., consumer inconvenience, increased energy costs; Viscusi, 1984) are not discussed.

5.1 Impacts on Rivers

Based upon mass-balance calculations (Section 4.2), implementation of a phosphate detergent ban would reduce total phosphorus loads to inland river basins by approximately 25% (Table 7). As indicated in Table 2, water uses in 315 Massachusetts river miles (19% of the total) are limited by nutrients, based upon the "Not supporting" and "Partially not supporting" categories. Phosphorus loads from wastewater treatment facilities with phosphorus effluent limits would not change as a result of a phosphate detergent ban, although reductions in chemical doses required for phosphorus removal would be expected (Sonzogni and Heidtke, 1986; MWCOG, 1989). Of the 315 miles with nutrient problems, 133 miles would not be expected to benefit from a phosphate detergent ban because they are either (1) located immediately below wastewater discharges which already have phosphorus effluent limits (Table 6) or (2) have nutrient sources that are unrelated to domestic wastewaters (nonpoint runoff, wetlands, etc.), based upon descriptions provided by the MDWPC Biennial Water Quality (305b) report (MDWPC, 1988). The remaining 182 river miles constitute 11.0% of the total stream length and are distributed among 13 out of 29 river basins. this represents an upper bound estimate of the number of river miles which might benefit from a detergent ban.

These 182 river miles include at least 71 river miles where biological responses to changes in phosphorus concentrations are expected to be minimal. For example, as described above in Section 3.1), the Assabet River (30 miles) is not expected to respond because plant and algae growth are limited by nitrogen in this basin. Coastal basins (Neponset, Mystic, Buzzards Bay) account for another 41 miles with low sensitivity because of a lack of point source discharges and probable nitrogen limitation. This leaves 111 river miles (or 6.7% of the total) as a lower bound estimate of the river miles which might benefit from phosphate detergent ban.

Between 6.7% and 11.0% of the states river miles might benefit from a phosphate detergent ban, as measured by increased support of designated uses. Decreases in stream phosphorus concentration will not necessarily lead to reductions in algae or plant growth or in visible improvements, however, as demonstrated in the case of the Assabet. If a reduction in effluent concentration to 1 ppmiter (via advanced wastewater treatment) would not result in visible improvements in the stream, then neither would a reduction to ~3.7 ppmiter (via a detergent ban). More detailed analyses, such as application of coupled water quality and phytoplankton models (Brown and Barnwell, 1985) would be required to quantify benefits in each river basin. Such analyses should consider the total nutrient budgets and effects of factors other than phosphorus (nitrogen, light, depth, velocity) as factors regulating plant productivity in each river segment.

5.2 Impacts on Harbors

In marine environments, such as Boston Harbor, algal growth is generally limited by nitrogen, rather than phosphorus. It is unlikely that reductions in phosphorus loads to Boston Harbor or to other coastal areas attributed to a phosphate detergent ban would cause reductions in plant growth or other improvements in water quality.

5.3 Impacts on Lakes

As indicated in Table 9, shoreline septic systems accounted for more than 50% of the lake total phosphorus budgets in 9 out of 50 lakes studied under the MDWPC Clean Lakes Program. As shown in Figure 10, septic systems account for an average of 16% of the phosphorus load to D/F study lakes. This would correspond to an average reduction of 5.3% (33% x 16%) in lake phosphorus load attributed to a phosphate detergent ban. Based upon the reported voluntary use of low phosphate detergents in lake watersheds (25 - 38%), the effective reduction in phosphorus loading would be on the order of 3.2 to 3.9%. Phosphorus load reductions on the order of 20% or more are generally required to cause noticeable improvements in lake clarity and related water quality conditions (Jones and Lee, 1986). It is unlikely that a detergent ban would cause visible improvements in the population of lakes as a whole. Limitations in the estimates of septic tank contributions must be considered in evaluating potential benefits to specific lakes.

Direct measurement of contributions from on-site wastewater disposal systems to lakes is extremely difficult. The estimates generally reflect assumptions on the part of the study investigators. Septic contributions are often estimated by a applying a "load factor" (lbs/system-year) to the number of septic systems within a certain distance (e.g., 250-300 ft) of the lake shore. Figure 11 plots the estimated septic P load against the number of shoreline residences for 12 lakes with reported data. Estimates are generally consistent with

TABLE 9

POTENTIAL IMPACT OF PHOSPHATE DETERGENT BAN ON LAKE PHOSPHORUS BUDGETS

MASS. D/F/ STUDY DATA BASE		--WITHOUT DETERGENT BAN--			----WITH DETERGENT BAN----		
PALIS LAKE NAME	BASIN	SEPTIC	TOTAL	SEPTIC/ TOTAL	SEPTIC	TOTAL	%DECREASE
82011 Boon	Assabet	827	1324	62.5%	554	1051	20.6%
82007 Bartlett Pond	Assabet	265	891	29.7%	178	804	9.8%
82017 Chauncy	Assabet	453	1641	27.6%	304	1492	9.1%
82042 Fort Meadow Res.	Assabet	57	1378	4.1%	38	1359	1.4%
72096 Populatic Pond	Blackstone	871	38567	2.3%	584	38280	0.7%
51142 Salisbury	Blackstone	0	10243	0.0%	0	10243	0.0%
51112 North Pond	Blackstone	666	1425	46.7%	446	1205	15.4%
51135 Ripple	Blackstone	0	1871	0.0%	0	1871	0.0%
51073 Indian Lake	Blackstone	0	996	0.0%	0	996	0.0%
95020 Buttonwood Pond	Buzzards Bay	0	1020	0.0%	0	1020	0.0%
96157 John's Pond	Cape Cod	13	1338	1.0%	9	1334	0.3%
96257 Red Lilly Pond	Cape Cod	0	10568	0.0%	0	10568	0.0%
96182 Long Pond	Cape Cod	0	110.2	0.0%	0	110	0.0%
96115 Great Pond	Cape Cod	0	151	0.0%	0	151	0.0%
72053 Jennings Pond	Charles	4	939	0.4%	3	938	0.1%
82029 Dudley	Charles	103	309	33.3%	69	275	11.0%
72140 Winthrop	Charles	550	721	76.3%	369	540	25.2%
72045 Hardys Pond	Charles	0	128	0.0%	0	128	0.0%
72043 Hall's Pond	Charles	0	84.44	0.0%	0	84	0.0%
36130 Quaboag	Chicopee	547	13562	4.0%	366	13381	1.3%
36131 Quacumquasit	Chicopee	242	407	59.5%	162	327	19.6%
82043 Fort Pond	Concord	0	558	0.0%	0	558	0.0%
34005 Arcadia	Conn	84	137	61.3%	56	109	20.2%
84015 Forge Pond	Conn	56	4763	1.2%	38	4745	0.4%
34021 Puffer's Pond	Conn	0	760	0.0%	0	760	0.0%
34051 Metacomet	Conn	123	190	64.7%	82	149	21.4%
34099 Massasoit	Farmington	0	21962	0.0%	0	21962	0.0%
21014 Buel	Housatonic	57	888	6.4%	38	869	2.1%
92059 Silver Lake	Ipswich	0	122	0.0%	0	122	0.0%
92038 Martins	Ipswich	321	1075	29.9%	215	969	9.9%
80020 Cochituate	Merrimac	0	7940	0.0%	0	7940	0.0%
84039 Mill Pond	Merrimack	0	311	0.0%	0	311	0.0%
35023 Lake Ellis	Millers	0	798	0.0%	0	798	0.0%
81161 Wyman Pond	Millers	558	977	57.1%	374	793	18.8%
71018 Hill's Pond	Mystic	0	3	0.0%	0	3	0.0%
71005 Black Nook	Mystic	0	349	0.0%	0	349	0.0%
81054 Harbor Pond	Nashua	0	11953	0.0%	0	11953	0.0%
81122 Lake Shirley	Nashua	207	1464	14.1%	139	1396	4.7%
81034 Eagle	Nashua	0	98.02	0.0%	0	98	0.0%
81035 E. Waushakum	Nashua	302	431	70.1%	202	331	23.1%
81007 Bare Hill Pond	Nashua	333	4562	7.3%	223	4452	2.4%
73030 Massapoag	Neponset	103	1276	8.1%	69	1242	2.7%
71014 Ell Pond	N.Coastal	0	545.99	0.0%	0	546	0.0%
93008 Brown's Pond	N.Coastal	0	280.2	0.0%	0	280	0.0%
93014 Chebacco	N.Coastal	350	574	61.0%	235	459	20.1%
93024 Floating Bridge	N.Coastal	0	801.6	0.0%	0	802	0.0%
93023 Flax	N.Coastal	0	1947	0.0%	0	1947	0.0%
93071 Sluice	N.Coastal	0	452	0.0%	0	452	0.0%
93060 Quannapowitt	N.Coastal	0	5395	0.0%	0	5395	0.0%
41052 Walker	Quinebaug	0	787	0.0%	0	787	0.0%
83004 Fawn Lake	Shawsheen	0	120.9	0.0%	0	121	0.0%
82112 Waushakum	Sudbury	154	564	27.3%	103	513	9.0%
62119 W. Monponsett	Taunton	412	1336	30.8%	276	1200	10.2%
62218 E. Monponsett	Taunton	390	1314	29.7%	261	1185	9.8%
32055 Pequot Pond	Westfield	317	483	65.6%	212	378	21.7%
MEAN		152	2962	16.0%	101.9	2911.5	5.3%

SEPTIC P Load from Shoreline Septic Systems (lbs/yr)
TOTAL P Load from All Sources (lbs/yr)

%DECREASE % Decrease in P Load with Detergent Ban
Assumes Detergent P / Septic P = 33%

FIGURE 10

AVERAGE PHOSPHORUS BUDGET FOR D/F STUDY LAKES

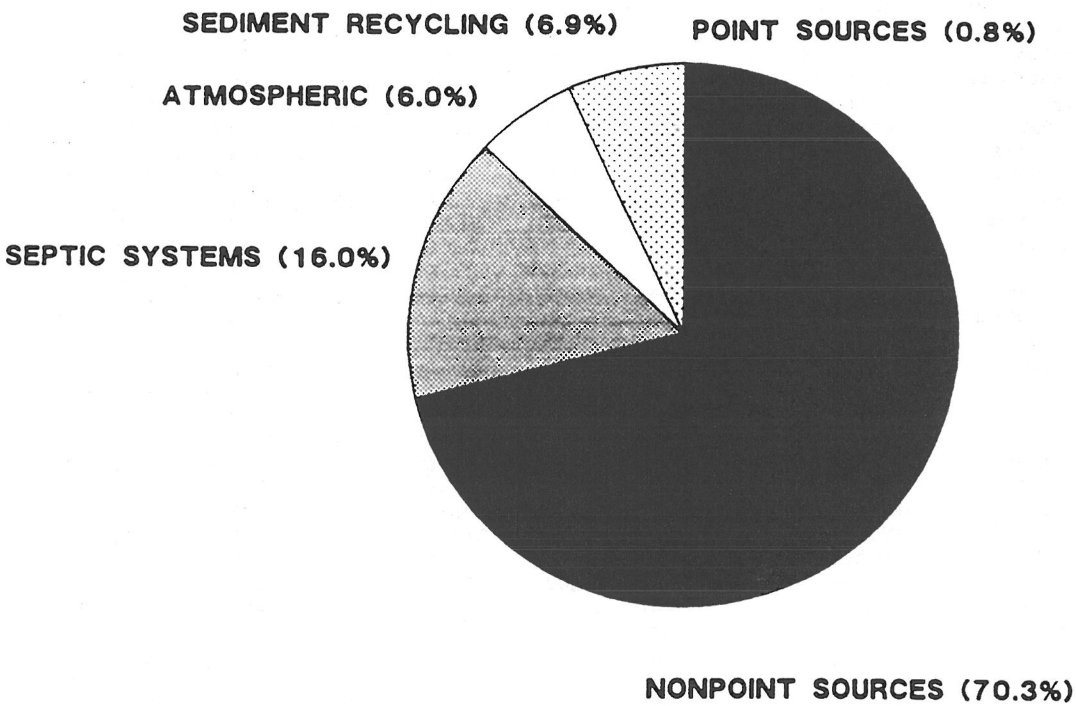
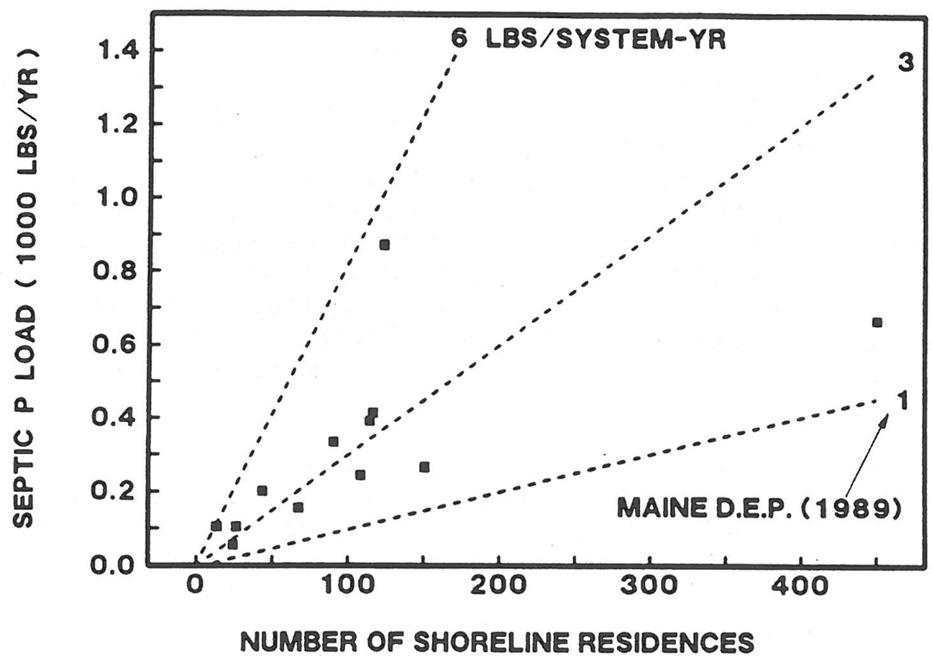


FIGURE 11

LAKE PHOSPHORUS LOADS ATTRIBUTED TO SEPTIC SYSTEMS VS. NUMBER OF SHORELINE RESIDENCES



an average load factor of 3 lbs/system-yr (range ~1.5 to 6 lbs/system-year) discharged from on-site treatment systems to the lakes.

A load factor of 3 lbs/system-year exceeds values typically reported in the literature. In developing phosphorus budgets for lakes studied under the National Eutrophication Survey, the USEPA (1975) assumed an average load factor of 0.63 lbs/residence per year for septic systems within 328 feet (100 meters) of the shoreline (0.25 lbs/capita-yr x average of 2.5 people/residence). The Maine DEP recently developed a procedure for use in lake watershed planning (Maine DEP, 1989). The procedure states that a load factor of 1 lb/system-year should be assumed for systems which are (1) within 250 feet of lakeshore or tributary, (2) in sand and gravel soils; and (3) do not have loam liners. If any of these criteria are not met, a load factor of 0 lbs/system-year is assumed. Reasons for the high septic system load factors assumed in Massachusetts lake studies are unknown. They may reflect high percentages of failing systems, which compelled lake investigators to assume atypical values.

In order to examine the possible reasons for the atypical values, diagnostic/feasibility study reports for 17 lakes, with reported septic systems load contributions in excess of 25%, were reviewed to determine the methodologies and corresponding assumptions used to calculate septic systems loads for these lakes. A number of methodologies were cited in these reports, including NES (1974), Reckhow and Simpson (1980), USEPA (1980), Dillon and Kirschner (1975), and others. In most cases, these methodologies involve multiplying a per-capita or per-residence loading rate by the number of capita years or residences, and multiplying by an attenuation coefficient to account for various removal processes. Several of these methods require the user to select phosphorus loading rates and attenuation factors based upon best professional judgment, and knowledge of watershed geology and hydrogeology, and septic system characteristics (use, maintenance, age, failures, etc.). However, in many cases this basic information utilized in the load calculations (e.g., number of residences, number of individuals per residence, phosphorus load, and attenuation coefficients) were not documented in these reports. Without this documentation and specific knowledge pertinent site-specific factors, it is not possible to calculate loads using a consistent methodology.

Estimates of maximum percentage load reductions attributed to a phosphate detergent ban range from 0% to 25.2% for the D/F study lakes in Table 9. Maximum reductions exceed 20% (the level indicated by Jones and Lee (1986) as associated with perceptible changes in lake quality) in 7 out of 55 lakes. These percentage reductions likely overstate the beneficial impacts of a phosphate detergent ban on lake conditions, for the following reasons:

(1) The D/F load estimates appear to be based upon septic load factors which are 3 to 5 times higher than values typically

assumed in other lake studies. If this reflects a high percentage of failing septic systems, the appropriate step would be to repair or replace such systems. With properly functioning systems, the percentage impacts of detergents would be much lower. A statewide phosphate detergent ban is not an acceptable solution to failing septic tanks.

(2) The percentage reductions assume that detergent phosphorus accounts for 33% of the phosphorus discharged from the septic systems, based upon data from municipal sewage treatment facilities. This percentage would be lower for septic systems serving seasonal residences without laundry facilities or automatic dishwashers. Detailed breakdowns of seasonal vs. permanent residences around the study lakes are not available.

(3) Use of low-phosphate detergents is generally recommended by D/F study consultants as part of lake restoration/protection plans. Some reductions in detergent phosphorus loads may have already been achieved through voluntary efforts (estimated at 25 - 38%) on the part of lakeshore residents, as promoted by lakeshore associations, state lake associations (COLAP), and public education programs. A statewide phosphate detergent ban may be unnecessary to achieve detergent phosphorus load reductions in specific lakes.

(4) The D/F study data base is comprised primarily of "problem" lakes; 29 out of 44 (66%) of those classified were eutrophic. On a statewide basis, 12% of the lakes are classified as eutrophic. The relative importance of detergents as a component of the total phosphorus budgets would tend to be lower in entire population of lakes, the nutrient budgets of which are dominated by surface runoff and other nonpoint sources.

(5) Many of the lakes are troubled more by aquatic weeds than by algae or phytoplankton. Changes in phosphorus load have been associated with changes in algal growth and related water quality conditions in many lakes. A causal linkage between phosphorus load and weed growth has not been established, however. It is generally accepted that most rooted aquatic plants are able to satisfy nutrient requirements via uptake from sediment. In a study of the impacts of phosphorus on streams, the Wisconsin DNR (1984) observed that in streams with silt substrates, macrophyte biomass were related to sediment nutrient concentrations. For this reason, a 20% reduction in phosphorus load would not cause a proportionate reduction (or any reduction) in rooted aquatic plant growth.

Based upon the above analysis, the average reduction in lake phosphorus loads attributed to a phosphate detergent ban would be less than 5.3%, and possibly as low as 3.2%. Localized, voluntary reductions in use of high-phosphate detergents may be effective in specific lakes where such sources are important. A continued focus on nonpoint sources (Figure 10) is needed if noticeable improvements in water quality are to be achieved on a statewide basis.

6.0 CONCLUSIONS

The report describes the status of Massachusetts water bodies with respect to nutrient enrichment and efforts that have been made to control the problem by reducing point-source loads. Phosphorus from point and nonpoint sources contributes to water quality problems in lakes and some river segments. Approximately 12% of the state's lakes are classified as "eutrophic" or excessively enriched. Approximately 19% of the monitored river miles in the state do not support their designated uses (i.e., meet water quality standards) primarily because of nutrient-related water quality problems.

Phosphorus effluent limits (generally, 1 ppmiter) have been established at 20 major municipal wastewater treatment facilities. Reductions in stream algal growth directly attributed to reductions in point-source phosphorus concentrations have not been demonstrated. Much more stringent effluent limits may be required to achieve significant reductions in stream algal growth and resulting water quality impairment, as in the case of the Assabet River. More detailed analyses would be required to evaluate benefits of phosphorus controls on a site-by-site basis.

A phosphate detergent ban would reduce the average phosphorus concentration in effluents from secondary treatment plants without phosphorus effluent limits by approximately 33% (from ~5.5 ppmiter to ~3.7 ppmiter). Total phosphorus loads to inland river basins would be reduced by approximately 25%. Between 6.7% and 11.0% of the monitored river miles in Massachusetts might benefit from a phosphate detergent ban, as measured by increased support of designated uses. Water quality benefits, as measured by reduction in stream algal and periphyton growth, would generally not be proportionate to reduction in phosphorus loading because of the effects of other growth-limiting factors. Rooted aquatic plants are not expected to respond to changes in effluent or stream phosphorus concentrations, because of the availability of sediment nutrient sources.

Based upon phosphorus budgets developed for 55 lakes studied under the Massachusetts Clean Lakes program, detergent phosphorus accounts for an average of 5.3% of lake total phosphorus loads and accounts for more than 20% of the loads in 13% of the studied lakes. For a variety of reasons stated in Section 5.3, these percentages likely overstate the importance of detergent-derived phosphorus as a factor contributing to lake problems. A focus on nonpoint sources, which contribute an average of 70.3% of lake phosphorus loads) is needed if significant improvements in lake water quality are to be achieved.

REFERENCES

Athayede, D.N., P.E. Shelley, E.D. Driscoll, D.Gaboury, G. Boyd, "Results of the Nationwide Urban Runoff Program, Volume I - Final Report", U.S. Environmental Protection Agency, Water

Brown, L.C. and J.O. Barnwell. "Computer Program Documentation for the Enhanced Stream Water Quality Model QUAL2E." USEPA, Office of Research and Development, Athens, GA. EPA/600/3-85/005, August 1985.

Coburn, B. and R. Hubley. 1989. "Watershed Decisions", Conference on Watershed Futures, Massachusetts Audubon Society, November 1989.

Cooke, G.D., E. B. Welch, S.A. Peterson, P.R. Newroth, Lake and Reservoir Restoration, Butterworths, Boston, 1986.

DEP. Pollutant Reductions From WWTP Upgradings In Massachusetts 1978-1988. Massachusetts Department of Environmental Protection, Division of Water Pollution Control, Prepared by Margaret T. Webber. April 1989

Fetter, C.W., "Attenuation of Waste Water Elutriated through Glacial Outwash", Groundwater, Vol. 15, pp. 365-371, 1977.

Godfrey, P.J., S.A. Joyner, E.L. Goldstein, L. Ross, "The Development of PALIS: A Ponds and Lakes Information System for Massachusetts", Water Resources Research Center, University of Massachusetts, Amherst, Publication No. 108, December 1979.

Huber, W.C. and R.E. Dickinson, "Storm Water Management Model, Version 4: User's Manual", U.S. Environmental Protection Agency, Environmental Research Laboratory, Athens, Georgia, August 1988.

Lee, G.F. and R.A. Jones, "Evaluation of Detergent Phosphate Bans on Water Quality", Lakeline, North American Lake Management Society, pp. 8-11, January 1986.

Metropolitan Washington Council of Governments, "Effects of Phosphate Ban in DC, Maryland, and Virginia", Waterline, Vol. 1, Issue 1, Summer 1989.

Maine Department of Environmental Protection, "Phosphorus Control in Lake Watersheds: A Technical Guide to Evaluating New Development", September 1989.

REFERENCES (Cont.)

MDWPC. 1986. Assabet River Basin, 1986-1987, Water Quality Survey Data. Massachusetts Division of Water Pollution Control, (MDWPC), April 1988.

MDWPC. 1986. Assabet River Basin, 1984-1985; Water Quality Survey Data. Massachusetts Division of Water Pollution Control, (MDWPC), May 1986.

MDWPC. 1988. Commonwealth of Massachusetts 1988 Summary of Water Quality. Massachusetts Division of Water Pollution Control, (MDWPC), March 1988.

MDWPC. 1990. Millers River Basin, 1987; Wastewater Discharge Data. Massachusetts Division of Water Pollution Control, (MDWPC), June 1990.

MDWPC. 1990. Millers River Basin, 1987; Water Quality Survey Data. Massachusetts Division of Water Pollution Control, (MDWPC), June 1990.

MDWPC. 1989. Deerfield River Basin, 1988; Water Quality Survey and Wastewater Discharge Data. Massachusetts Division of Water Pollution Control, (MDWPC), September 1989.

North American Lake Management Society, "The Lake and Reservoir Restoration Guidance Manual," U.S. Environmental Protection Agency, Office of Water, Washington, D.C., EPA 440/4-90-006, August 1990.

North American Lake Management Society, "Monitoring Lake and Reservoir Restoration", Technical Supplement to "The Lake and Reservoir Restoration Guidance Manual", U.S. Environmental Protection Agency, Office of Water, Washington, D.C., EPA 440/4-90-007, August 1990.

Omernik, J.M., "Nonpoint Source-Stream Nutrient Level Relationships: A Nationwide Study," U.S. Environmental Protection Agency, Corvallis Environmental Research Laboratory, EPA-600/3-77-105, September 1977.

Parsons, R.S., Takahashi, B. Hargrave, Biological Oceanographic Processes, Permagon Press, Second Edition, 1977.

Reckhow, K.H., M.N. Beaulac, J.T. Simpson, "Modeling Phosphorus Loading and Lake Response Under Uncertainty: A Manual and Compilation of Export Coefficients", U.S. Environmental Protection Agency, Clean Lakes Section, Washington, June 1980.

REFERENCES (Cont.)

Sawhney, B.L. and D.E. Hill, "Phosphate Sorption Characteristics of Soils Treated with Domestic Waste Water", Journal of Environmental Quality, Vol. 4, pp. 342-346, 1975.

Sonzogni, W.C. and T.M. Heidtke, "Effect of Influent Phosphorus Reductions on Great Lakes Sewage Treatment Costs", Water Resources Bulletin, Vol. 22, No. 4, pp. 623-627, August 1986.

Tofflemire, T.J. and M. Chen, "Phosphate Removal by Sands and Soils", Groundwater, Vol. 15, pp. 377-387, 1977.

U.S. Environmental Protection Agency, "Nitrogen and Phosphorus in Wastewater Effluents", Working Paper No. 22, National Eutrophication Survey, July 1974.

U.S. Environmental Protection Agency, "National Eutrophication Survey Methods 1973-1976", National Eutrophication Survey, Working Paper No. 175, June 1975.

U.S. Environmental Protection Agency, "Quality Criteria for Water", Office of Water Planning and Standards, Washington, 1976.

U.S. Geologic Survey. 1984. Gazatteer of Hydrologic Characteristics of Streams in Massachusetts -- Merrimack River Basin. water-resouces Investigations Report 84-4284. U.S. Department of the Interior, Boston, MA.

U.S. Geologic Survey. 1984. Gazatteer of Hydrologic Characteristics of Streams in Massachusetts -- Connecticut River Basin. Water-Resources Investigations Report 84-4282. U.S. Department of the Interior, Boston, MA.

Viscusi, W.K., "Phosphates and the Environmental Free Lunch", Regulation, pp. 53-55, December 1984.

Walker, W.W., "Land-Use/Nutrient Export Relationships in the Northeast", prepared for Meta Systems, Inc. and New Haven Water Company, 1978.

Walker, W.W., "A Sensitivity and Error Analysis Framework for Lake Eutrophication Modeling," Water Resources Bulletin, Vol. 18, No. 1, pp. 53-61, February 1982.

Walker, W.W., "Calibration and Testing of a Eutrophication Analysis Procedure for Vermont

Walker, W.W., "Empirical Prediction of Chlorophyll in Reservoirs," in "Lake and Reservoir Management," Proceedings of the Third Annual Conference, North American Lake Management Society, Knoxville, Tennesee, pp. 292-298, 1984.

Walker, W.W., "Empirical Methods for Predicting Eutrophication in Impoundments - Report 3: Model Refinements," prepared for Office, Chief of Engineers, U.S. Army Corps of Engineers, Waterways Experiment Station, Vicksburg, Mississippi, March 1985.

Wisconsin DNR. 1984. Impacts of Phosphorus on Streams. Water Resources Management. Wisconsin Dept. of Natural Resources, Milwaukee, Wisconsin.

ASSABET RIVER BASIN (82b)

Description of the Watershed

The Assabet River has its beginnings in the town of Westborough. It flows northeasterly for 31 miles through the towns of Westborough, Marlborough, Maynard, Hudson, and Concord. The Assabet drains an area of 175 square miles. It receives the discharges of four municipal wastewater treatment plants and a state prison wastewater treatment plant. Because of the number of wastewater discharges and the numerous impoundments along its course, the Assabet River does not meet class B water quality standard conditions.

The United States Geological Survey (USGS) maintains a flow gaging station in Maynard with records dating back to 1941. The average discharge at this gage over 42 years of record is 185 cubic feet per second (cfs) while the seven-day ten-year low flow is 15.1 cfs.

Water Quality Conditions and Trends

The Assabet River is slowly recovering from the impacts of years of inadequate sewage treatment. All of the river's wastewater treatment plants have either been recently upgraded, or are in the planning process for upgrading.

The former Westborough and Shrewsbury discharges are now combined through the new Westborough Regional WWTP which provides advanced secondary treatment (ammonia oxidation). Since this plant's opening in the late spring of 1987, remarkable changes have occurred in the upper Assabet. Dissolved oxygen values have improved to nearly the water quality standard, and fecal coliform bacteria and suspended solids levels have markedly decreased.

The Marlborough West WWTP will soon be upgraded to advanced secondary treatment (ammonia oxidation) and should be on-line by 1989-1990.

The Hudson WWTP has been upgraded to advanced secondary (ammonia oxidation) and operated as such for the first time during the spring of 1987. Improvements in dissolved oxygen downstream are expected.

The Maynard WWTP has been upgraded to improve its operation. It has remained a secondary plant, but has incorporated innovative technology-rotating biological contactors. This upgraded plant went on-line early in 1987.

Finally, the small discharge from the state prison, Concord MCI WWTP, will be upgraded in the next few years to accommodate expansion at the facility.

Nonpoint sources of pollutant loadings to the Assabet River include in-place sediments, urban and storm runoff. The in-place sediments are of particular interest in the upper Assabet up to the town of Marlborough, and in the Acton/Maynard area, but heavy sediment deposits are actually present throughout most of the river. These sediments can create an oxygen demand, and absorb and

Source: MDWPC. 1988. Commonwealth of Massachusetts Summary of Water Quality Appendix III.

release nutrients and metals, depending on such factors as river flow and pH. Since three of the Assabet's newly upgraded WWTP's just began operating during 1987, continued monitoring of the Assabet for changes in dissolved oxyg and nutrients will be important to ascertain how and if the in-place sediments will stabilize with time. Urban and stormwater runoff affect the Assabet to a small degree, apparent mainly in slightly elevated fecal coliform bacterial counts in some areas. Best management practices will be addressed in the stat Nonpoint Sources Management Plan, which is due to be published in late 1988.

The Assabet River's remaining problems, especially high nutrient concentrations, should not be minimized. During summer months the river supports profuse aquatic weed and algae population, and this situation is expected to continue. In addition, since the Assabet is impounded and slow moving in many places, sediment oxygen demand and nutrient recycling may be a problem in area for many more years.

Thus, recent progress toward improved water quality has occurred and further progress is expected on the Assabet River; however, continued vigilance and planning will be necessary before the Assabet River can meet all of its water quality goals.

REFERENCES

Hanley, Nora. Assabet River 1984-85 Water Quality Survey Data, Wastewater Discharge Data and Analysis. Massachusetts Division of Water Pollution Control. Westborough, Massachusetts. 1986. 76 pp.

Massachusetts Division of Water Pollution Control. 1976. Baseline Water Quality Surveys of Selected Lakes and Ponds in the Assabet River Basin 1974. Westborough, Massachusetts. 64 pp.

_______________. 1979. Assabet River 1979 Water Quality Survey Data. Westborough, Massachusetts. 97 pp.

_______________. 1981. The Sudbury Concord and Assabet Basin Water Quality Management Plan. Westborough, Massachusetts. 52 pp.

_______________. Unpublished data. 1987

Figure 3

ASSABET RIVER BASIN (82b)

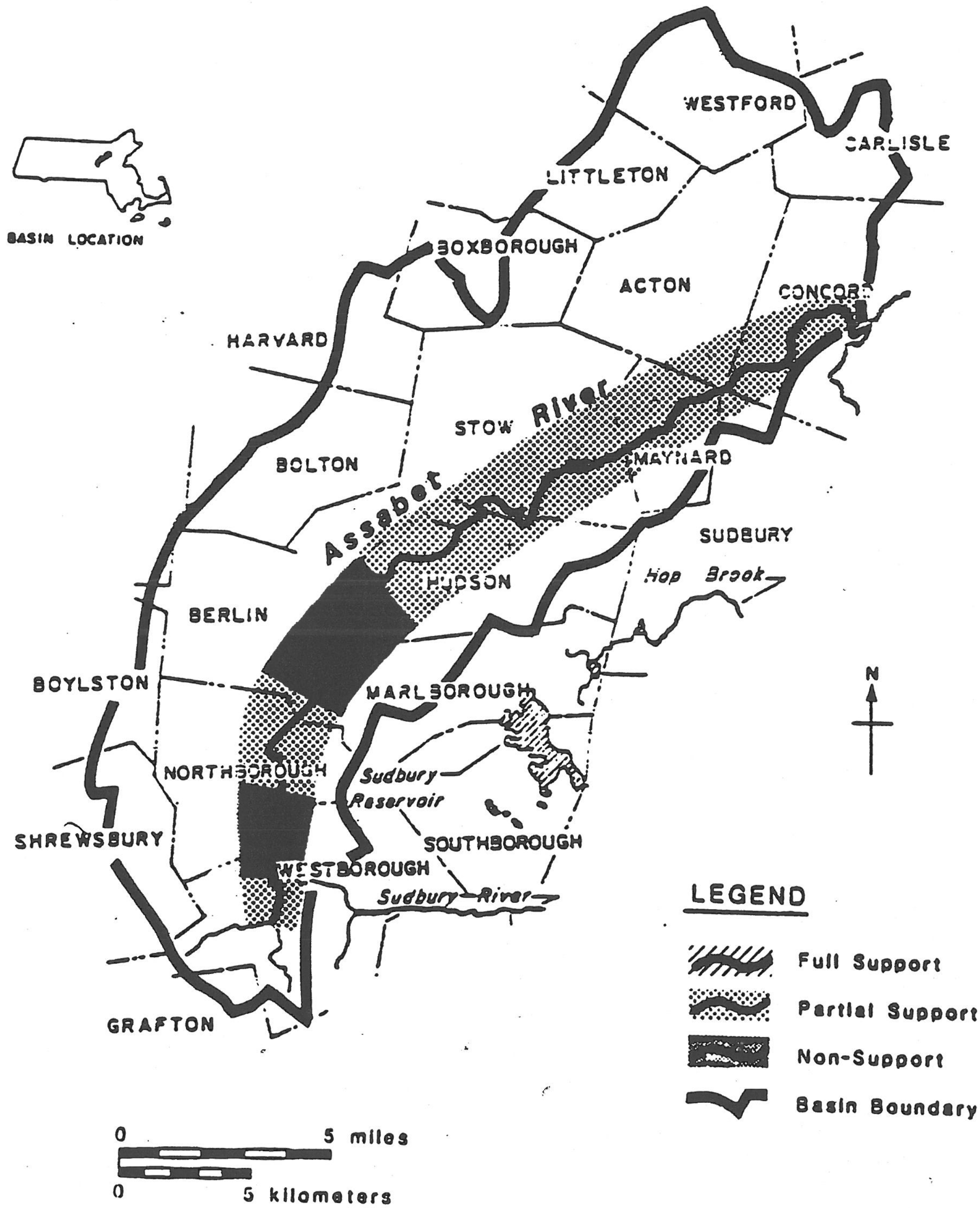


TABLE 1
ASSABET RIVER BASIN

SEGMENT DESCRIPTION	RIVER MILES	WATER USE CLASSIFICATION	SUPPORT STATUS	WATER QUALITY PROBLEMS	SOURCE OF PROBLEMS	ABATEMENT NEEDS TO MEET CLASSIFICATION
Outlet of flow Augmentation Pond, Westborough to Westborough WWTP, Westborough	31.0-30.0	B/AL/AD	PS	Fecal coliform bacteria	-Nonpoint sources	-Best management practices (BMP) for nonpoint sources.
Westborough WWTP to Rt. 20 dam, Northborough	30.0-26.5	B/AL	NS	D.O. Nutrients Fecal coliform bacteria	-Westborough WWTP -In-place sediments -Westborough WWTP -Urban runoff	-The new Westborough WWTP must continue to operate satisfactorily. -Sediments and water column should continue to be monitored for sediment stabilization. -BMP for nonpoint sources.
Route 20 dam to Marlborough Westerly WWTP, Marlborough	26.5-24.2	B/AL	PS	D.O. Nutrients	-Westborough WWTP -In-place sediments	-The new Westborough advanced WWTP must continue to operate satisfactorily.
Marlborough Westerly WWTP to Hudson WWTP, Hudson	24.2-16.3	B/AL	NS	D.O., Nutrients, Nickel Fecal coliform bacteria	-Marlborough Westerly WWTP. -In-place sediments -Marlborough Westerly WWTP -Urban runoff	-Upgrading of Marlborough West WWTP for increased flows and ammonia oxidation. Expected completion is in 1989. -Sediments and water column should continue to be monitored for sediment stabilization. -BMP for nonpoint sources.

TABLE 1 (CONTINUED)

SEGMENT DESCRIPTION	RIVER MILES	WATER USE CLASSIFICATION	SUPPORT STATUS	WATER QUALITY PROBLEMS	SOURCE OF PROBLEMS	ABATEMENT NEEDS TO MEET CLASSIFICATION
Hudson WWTP to outlet of Boons Pond, Stow	16.3-12.3	B/AL	PS	D.O., Nutrients Fecal coliform bacteria	-Hudson WWTP -In-place sediments -Hudson WWTP -Surface runoff	-The newly upgraded Hudson advanced WWTP must continue to operate satisfactorily. -BMP for nonpoint sources.
Outlet of Boons Pond to before Maynard WWTP, Maynard	12.3-6.5	B/WWF	PS	Nutrients, Fecal coliform bacteria	-Upstream WWTP	-Continued proper operation of upstream WWTP.
Maynard WWTP to before Concord MCI WWTP, Concord	6.5-2.5	B/WWF	PS	D.O., Nutrients Fecal coliform bacteria, Lead Mercury	-Maynard WWTP -In-place sediments -Maynard WWTP -Urban runoff -Unknown	-The newly upgraded Maynard WWTP must continue to operate satisfactorily. -BMP for in-place sediments and runoff. -Continued water column and sediment monitoring to aid in informed decision-making.
Concord MCI WWTP to confluence with Sudbury River, Concord	2.5-0.0	B/WWF	PS	Nutrients Lead, Mercury	-Concord MCI WWTP -Upstream WWTP -Urban runoff -Unknown	-Upgrading of Concord MCI WWTP. -Continued good operation of other upstream WWTP. -BMP for nonpoint sources.

Miles Assessed: 31.0 mi
Miles Supporting Classification: 0.0 mi
Miles Partially Supporting Classification: 19.6 mi

MEMORANDUM

TO: Paul Hogan

FROM: Deb McKechnie

DATE: April 17, 1980

SUBJECT: Assabet River Phosphorus Load Allocations

Introduction

EPA requires a justification showing phosphorus removal "will definitely result in significant water quality improvement" when phosphorus removal capabilities are recommended (PRM#79-7,p.4). This policy is defined in the critique of the Gardner load allocation. EPA points out that there is no existing or potential eutrophication problem in the Otter River, and thereby disallows phosphorus removal requirements at the Gardner treatment plant. The need exists to examine eutrophic potential in the Upper Assabet River.

Point Source Loadings

Presently, there are three point dischargers of phosphorus on the Upper Assabet: Westborough STP, Shrewsbury STP and Marlborough West STP. the treatment plants contributed 20, 36 and 65 kg/day during the June survey, and 17, 27 and 38 kg/day during the August survey, respectively. If a phosphorus effluent limit of 1.0 mg/l were imposed, the proposed Westborough/Shrewsbury plant (at design flow) would contribute 25 kg/day, and the Marlborough West plant (at design flow) would contribute 8 kg/day.

If one considers the total input of phosphorus in the Upper Assabet system, one finds 120 kg/day entered the system during the June survey and 82 kg/day during August. Under effluent limitation, the input would be 33 kg/day. The percent change between survey measurements and phosphorus-limited effluents is -73 percent for June and -60 percent for August.

The flow required to dilute the effluent to an instream level of 0.1 mg/l is found accordingly:

$$\frac{(Q_p)\ (1\ \text{mg/l}) + (Q_x)(P_b)}{Q_p + Q_x} = 0.1\ \text{mg/l}$$

where Q_p = plant discharge in cfs

Q_x = upstream flow required for this dilution

P_b = background concentration of phosphorus in mg/l

The dilution flow for the Westborough/Shrewsbury plant is 116 cfs. Flow this high is not expected because the Flow Augmentation Pond largely controls the flow in this segment. The dilution flow for the Marlborough West plant is 56 cfs, a flow that can be expected approximately 35 percent of the time (Higgins, p.148).

When kg/day of phosphorus (instream) are graphed versus river mile, one notices little (if any) non-point contributions of phosphorus in the Upper Assabet. The peaks resulting from the treatment plant effluents are well defined. The only segment where there is an unexpected increase is AS02-AS03.

Nutrient Limitation

The EPA National Eutrophication Survey (Working Paper #219) concludes the Woodside and Hudson Center impoundments are nitrogen-limited. The assay alga used was *Selenastrum capricornutum* which requires an N:P ratio = 11. The samples contained N:P ratios of 2 and 3 for the Woodside and Hudson Center impoundments, respectively. Spikes of phosphorus did not affect the Hudson impoundment sample, while nitrogen spikes increased the maximum dry weight yield of the alga (p.17).

The 1979 survey also indicates that the Upper Assabet is nitrogen-limited. The N:P ratios for this data set are nitrate-nitrogen:total phosphorus. The June N:P ratios varied from 0.5 at AS03 to 1.6 at AS01 and AS06. The August N:P ratios range from 0.2 at AS03 to 2.4 at AS09, AS10 and AS11.

In order to change the nutrient limitation in the Upper Assabet, instream phosphorus would have to decrease five-fold at the least, and more likely ten-fold. It is at this point in the nutrient balance that the aquatic community would respond to the phosphorus level by increasing or decreasing its biomass with the phosphorus concentration. To reduce or retard the eutrophic rate, the phosphorus concentrations instream would need to be lowered below the critical N:P ratio of 10-15, thereby raising the ratio to 20-30.

The complicating factor in the analysis presented above appears when nitrification capabilities are considered for the treatment plants. If nitrification is imposed on the treatment plants, and the total nitrogen input is reduced, the N:P ratio will decrease, taking us further from phosphorus limitation. Nitrogen-fixers (eg. *Cyanophyta*) could play a larger role in the ecosystem than present, and thus counteract the effect.

Present Primary Productivity

Using dissolved oxygen data (The Assabet River, 1979: Water Quality Data), DICURV2 was run to determine gross photosynthesis and respiration values in the Upper Assabet. The photosynthesis and respiration values are found from the following equation:

$$\frac{DC}{Dt} = K_2(Cs-C) + P-R$$

Cumulative gross respiration values were graphed versus cumulative gross photosynthesis, and the following relationships resulted:

P = ~~0.27 R + 11~~ 0.26R + 2 (June)

P = ~~0.24 R + 11~~ 0.24R - 10 (Aug)

Erdmann discusses the P:R ratio as it relates to the ecosystem (Journal WPCF 51). When $P>R$, the system can be classified as autotrophic. Conversely, when $P<R$, it can be classified as heterotrophic. When P equals R, the system's energy is balanced, which indicates a mature ecosystem (Kimball and Pare, March 1979, p.16).

The graph of P versus R shows an overall heterotrophic condition; P:R = 0.26, 0.24. ~~The segment AS01-AS03 shows a localized autotrophic state.~~ The heterotrophy is likely due to the organic loading in the river. "...some streams may be fertile in having high total respiratory metabolism and yet possess little primary productivity." (Odum, Limnology and Oceanography 1: 116)

Chlorophyll a data collected in 1979 shows moderate levels for the period of survey. June data range from 1 to 8 mg/l at stations AS02 through AS13. August data varied from 0.8 to 9 mg/l, except stations AS02 and AS12, which showed values of 27 and 18 mg/l, respectively.

Rooted macrophytes are a problem in the Woodside and Hudson impoundments. The Woodside impoundment often has a cover of duckweed (*Lemna*). The contribution of the macrophyte community to the system is difficult to evaluate because its magnitude is not reflected in chlorophyll a data or algae counts. The constraints of the macrophyte community are similar to those of the algal community. Nutrient and light limitations are the same for both plant groups. The rooted macrophytes, unlike the algae, are able to store nutrients in their root systems from one season to another.

Sediment Phosphorus Content

Sediment sampling conducted in May 1977 give the following results:

Station	Total P (mg/l)
AS02	340
AS06	360
AS09	600
AS12	2200

(MAPC, 1977 Data Report, p.173.) The sediment release rate depends on the concentration and oxygen conditions (Snow and DiGiano, 1976, p.166-167). The opportunity exists for the phosphorus-laden sediments to recharge the overlying water until an equilibrium concentration is reached instream. Depending on sediment transport, (particularly, spring flush) the recharge capability could exist for several years with phosphorus limitations imposed. Seasonal phosphorus loading could annually renew the sediments, which, in turn, may recharge the water column.

Conclusions

1. Phosphorus loadings in the Upper Assabet are almost entirely attributable to the municipal discharges.

2. With phosphorus limitations imposed, reductions in instream levels will only be 60 to 70 percent.

3. The target limitation for instream phosphorus of 0.1 mg/l cannot be attained at the Westborough/Shrewsbury plant, and will only be reached downstream of the Marlborough West plant 35 percent of the time.

4. The Upper Assabet, and particularly the Woodside and Hudson Center impoundments, is nitrogen-limited.

5. Requirements of 1.0 mg/l at the treatment plant effluents will not phosphorus limit the stream.

6. The Upper Assabet is in a state of heterotrophy, not autotrophy.

7. Sediments are rich in phosphorus, and capable of recharging to the water column.

Recommendations

As the benefit of phosphorus removal at the Westborough/Shrewsbury and Marlborough West treatment plants is uncertain, effluent phosphorus limits should not be required at these two facilities. Eutrophication, at present, is limited by nitrogen (and light, at many stations); changes in phosphorus concentrations will not significantly affect the trophic state.

The complexity of the Upper Assabet's trophic condition dictates we continue to monitor its situation. Should the stream's chemical characteristics change, and become phosphorus-limited, phosphorus effluent limits may be necessitated. For this reason, the facility plans should include the "flexibility to add phosphorus removal capabilities if justified at a later date" (EPA, Summary of Findings (Gardner), 19 February 1980, p.8). The instream phosphorus levels can be traced to the point sources; if phosphorus is found to be a problem in the future, it will be easily controlled through effluent limitations.

DM/lg
cc: Brian Friedmann

Phosphorus Loadings

Although much of the upper Assabet River supports significant instream plant growth, the requirement for limiting WWTP effluent phosphorus concentrations is problematic. Results from the National Eutrophication Survey (1974) indicate that the Woodside (reach 6) and Hudson (reach 10) impoundment are nitrogen-limited. Field data from the 1979 survey also indicates a nitrogen-limited condition for all reaches. Finally, phosphorus concentrations emanating from the Augmentation Pond are generally >0.1 mg/l and when combined with a theoretical WWTP effluent concentration of 1.0 mg/l, it is obvious that a phosphorus concentration $\leq$0.1 mg/l is unachievable. Even in the event that the Augmentation Pond phosphorus concentration is reduced to 0.0 mg/l, a dilution flow of approximately 90 cfs would be needed at the Westboro outfall to achieve a 0.1 mg/l instream phosphorus concentration. At this time, therefore, the requirement for phosphorus removal does not seem justifiable. However, in the event future analysis can justify removal, it is suggested that the forthcoming facility design consider phosphorus removal as an add-on process.

Ammonia Toxicity

Ammonia concentration, pH, and temperature data from the 1979 survey do not indicate that ammonia toxicity is a problem according to criteria set forth in Quality Criteria for Water (p. 10, July 1976, USEPA).

Source: DWPC. 1980. Waste Load Allocation - Westborough and Marlborough Westerly.

PALIS DATA BASE - THROUGH 1986 SORTED BY RIVER BASIN

CTY = MASS COUNTY CODE
LAT = LATITUDE (HHMMSS)
LONG = LONGITUDE (HHMMSS)
BASIN = RIVER BASIN CODE
AREA = LAKE SURFACE AREA (ACRES)
VOLUME = LAKE VOLUME (ACRE-FT)
DMAX = MAXIMUM DEPTH (FEET)
SHORE = SHORELINE LENGTH (FEET)
DAREA = DRAINAGE AREA (MI2)

STR = THERMAL STRATIFICATION CODE
0 = UNSTRATIFIED
1 = STRATIFIED

SEVER = SEVERITY POINTS
00 = GOOD QUALITY
18 = POOR QUALITY

MASS. COUNTY CODES

01 = BARNSTABLE
03 = BERKSHIRE
05 = BRISTOL
07 = DUKES
09 = ESSEX
11 = FRANKLIN
13 = HAMPDEN
15 = HAMPSHIRE
17 = MIDDLESEX
19 = NANTUCKET
21 = NORFOLK
23 = PLYMOUTH
25 = SUFFOLK
27 = WORCESTER

TROPHIC STATE CODES

1 = OLIGOTROPHIC
2 = OLIGO-MESOTROPHIC
3 = MESOTROPHIC
4 = MESO-EUTROPHIC
5 = EUTROPHIC

MASS. RIVER BASIN CODES

11 = HOOSIC
21 = HOUSATONIC
31 = FARMINGTON
32 = WESTFIELD
33 = DEERFIELD
34 = CONNECTICUT
35 = MILLERS
36 = CHICOPEE
41 = QUINEBAUG
42 = FRENCH
51 = BLACKSTONE
52 = TEN MILE
53 = NARRAGANSETT B
61 = MOUNT HOPE BAY
62 = TAUNTON
71 = MYSTIC
72 = CHARLES
73 = NEPONSET
74 = WEYMOUTH & WEIR
81 = NASHUA
82 = SUDBURY/CONCORD
83 = SHAWSHEEN
84 = MERRIMACK
91 = PARKER
92 = IPSWICH
93 = NORTH SHORE
94 = SOUTH SHORE
95 = BUZZARDS BAY
96 = CAPE COD
97 = ISLANDS

LAKEID NAME	COUNTY	BASIN	LAT	LONG	AREA	VOLUME	DMAX	SHORE	DAREA	STR	SEVER	TROPHIC
RIVER BASIN CODE = 11												
11001 BERKSHIRE POND	3	11	423020	731146						0	11	3
11002 CHESHIRE RESERVOIR	3	11	423200	731130	272	2077	10	20		0	7	
RIVER BASIN CODE = 21												
21005 ASHMERE LAKE	3	21	422045	730500	217					0	5	1
21014 LAKE BUEL	3	21	421015	731645	194	3284	43	17500				4
21015 CARD POND	3	21	421935	732200			6			0	4	1
21016 CENTER POND	3	21	422840	730920	30					0	5	1
21029 EAST INDIES POND	3	21	420350	731135						0	3	1
21040 LAKE GARFIELD	3	21	421106	731150	262	4150	31	24000		1	9	4
21042 GOODRICH POND	3	21	422652	731315			18			1	14	5
21043 GOOSE POND	3	21	421650	731145	225	5593	48	20000		1	2	3
21044 GREENWATER POND	3	21	421700	730900	88		55			1	3	1
21057 LAUREL LAKE	3	21	421936	731615	165	4310	53	16040		1	8	4
21078 ONOTA LAKE	3	21	422815	731700	617					1	4	1
21082 PLUNKETT RESERVOIR	3	21	422530	730745	73					1	3	1
21083 PONTOOSUC LAKE	3	21	422952	731455	467	6532	35	25400	21.35	1	11	5
21084 PROSPECT LAKE	3	21	421140	732710			12			0	3	1
21088 RICHMOND POND	3	21	422450	731915	218					1	5	1
21094 SHAKER MILL POND	3	21	422022	732215			5.5			0	4	1
21105 STOCKBRIDGE BOWL	3	21	422020	731830	374	8914	48	18100		1	9	4
21110 UPPER GOOSE POND	3	21	421705	731040	45	727	32	9400		1	4	3
21120 WOODS POND	3	21	422119	731424	122				161	1	17	
21121 RISINGDALE IMPOUNDMENT	3	21	421455	732127								
RIVER BASIN CODE = 31												
31003 BENTON POND	3	31	421102	730250	52	397	25	8000		0	2	1
31004 BIG POND	3	31	421137	730232	273	3618	27	17300		1	10	3
31008 CRANBERRY POND	13	31	420352	730017	68	687	20	8700		1	8	3
31026 NOYES POND	13	31	420622	730136	162	1554	15	1400		0	3	1
31027 OTIS RESERVOIR	3	31	420905	730222	1200	16074	40	72		1	5	1
31036 SHAW POND	3	31	421520	730731	100	372	15	9800		1	5	1

LAKEID	NAME	COUNTY	BASIN	LAT	LONG	AREA	VOLUME	DMAX	SHORE	DAREA	STR	SEVER	TROPHIC
RIVER BASIN CODE = 32													
32012	BUCK POND	13	32	421015	724212	32	177	25	4500		1	11	3
32013	BUCKLEY-DUNTON LAKE	3	32	421830	730515	138	874	11	5500		0	7	3
32015	CENTER POND	3	32	421755	730410	105	611	17	14000		1	5	3
32021	CONGAMOND LAKES MIDDLE	13	32	420135	724524	259	4715	35	2700		1	13	5
32022	CONGAMOND LAKES NORTH	13	32	420240	724508	41	648	40	6000		1	12	5
32023	CONGAMOND LAKES SOUTH	13	32	420153	724552	134	1853	25	1700		1	13	3
32026	COOLEY LAKE	13	32	420322	725105	91	249	8	9875		0	8	3
32029	DAMON POND	15	32	422504	725000	86	319	10	11500		0	9	3
32040	HAMMOND POND	15	32	422442	724800	44	269	12	8000		0	10	3
32043	HORSE POND	13	32	421034	724152	27	116	9	4500		0	5	1
32054	NORWICH POND	15	32	421823	724957	115	1736	48	1000		1	9	3
32055	PEQUOT POND	13	32	421105	724140	64	738	31	17000		1	4	1
32060	RUDD POND	3	32	421745	730453	73	572	20	9500		1	6	1
32061	RUSSELL POND	13	32	420919	725158	85	1365	35	8000		1	8	3
32076	WINDSOR POND	3	32	422915	730626	98	2013	53	5500		1	8	1
32079	YOKUM POND	3	32	421815	730730	95	529	12	9000		0	3	1
RIVER BASIN CODE = 33													
33001	ASHFIELD POND	11	33	423154	724803						1	8	
33016	PELHAM LAKE	11	33	424200	725322						0	10	
33017	PLAINFIELD POND	15	33	423230	725730						0	3	
33018	SHERMAN RESERVOIR	15	33	424400	725540						1	4	
RIVER BASIN CODE = 34													
34002	ALDRICH LAKE BASIN 1	15	34	421655	723300	14	104	17	5500		1	12	4
34005	ARCADIA LAKE	15	34	421818	722540	40	273	13	4465		0	6	2
34024	FORGE POND	15	34	421622	722807	68	125	7	20253		0	12	4
34025	FULLER POND	15	34	422335	724030								
34035	LAKE HOLLAND	15	34	421850	722555	12	163	30	2784		1	8	1
34042	LEVERETT POND	11	34	422725	723053	65	431	19	11420		0	6	2
34045	LOON POND	13	34	420837	723000	30	310	25	4600		0	6	2
34047	LOWER HIGHLAND LAKE	15	34	422652	724755	88	764	16	10500		0	4	1
34048	LOWER MILL POND	15	34	421620	723930	32	122	15	12300		0	10	3
34049	LOWER POND	15	34	421515	723423			15					1
34051	METACOMET LAKE	15	34	421822	722555	49	373	18	7620		0	7	3
34057	NASHAWANNUCK POND	15	34	421540	724000	22	126	12	12111		1	11	3
34066	OXBOW POND BASIN 1	15	34	421730	723800	168	822	18	39522		0	16	5
34067	OXBOW POND BASIN 2	15	34	421750	723730	41	162	11	9410		0	16	5
34073	PORTER LAKE	13	34	420622	723352	28		10			0	15	5
34084	SILVER LAKE	13	34	420352	723807			8					5
34093	UPPER HIGHLAND LAKE	15	34	422737	724755	41	345	16	10000		0	4	1
34096	VENTURE POND	13	34	420653	723024	7		9	2195		0	15	5
34098	LAKE WARNER	15	34	422322	723430	68		9	17920		0	12	4
34099	WATERSHOPS POND	13	34	420615	723300	157		20	37719		1	10	3
34103	LAKE WYOLA	11	34	423000	722545	129		33	11993		1	9	3
34104	WILLOW LAKE	15	34	422052	724130						0	6	3
34105	RUBBER THREAD POND	15	34	421552	724022						0	11	
34106	ALDRICH LAKE BASIN 2	15	34	421650	723135	23	64	7	8000		1	12	4
RIVER BASIN CODE = 35													
35007	BENTS POND	27	35	423328	715907	8	13	4	3000		0	11	3
35008	BOURN-HADLEY POND	27	35	423322	720522	8	14	6	2600				2
35015	DAVENPORT POND	27	35	423237	721207						0	9	3
35017	LAKE DENISON	27	35	423837	720520	61	387	15	8000		1	9	3
35021	DUNN POND	27	35	423430	715817	15	43	7	4666		0	7	3
35023	ELLIS POND	27	35	423430	721222	54	187	9	11300		0	9	3
35034	KENDALL POND	27	35	423345	720107	21		27	5666		1	5	1
35035	LAUREL LAKE	11	35	423715	722215	65	726	32	9300		1	7	3
35041	LOWER NAUKEAG LAKE	27	35	424000	715230	251	42	5	28400		0	6	2
35047	LAKE MONOMONAC	27	35	424250	720030						0	7	3
35048	MOORES POND	11	35	423922	722052	30	295	24	4400		0	4	1
35052	NORTH SPECTACLE POND	11	35	423115	721610	43		10	4400	0.04	1	9	3
35053	PACKARD POND	11	35	423800	721400	38	756	43	7400		1	7	3
35056	PARKER POND	27	35	423445	720043			2	6000		0	7	3
35057	PARTRIDGEVILLE POND	27	35	423245	720245	37	224	12	7000		0	6	2
35070	LAKE ROHUNTA	27	35	423300	721622								3
35072	RUGGLES POND	11	35	423253	722653			15			0	9	3

LAKEID	NAME	COUNTY	BASIN	LAT	LONG	AREA	VOLUME	DMAX	SHORE	DAREA	STR	SEVER	TROPHIC
35078	SOUTH ATHOL LAKE	27	35	423215	721530	82		5	13000		0	8	3
35081	SOUTH SPECTACLE POND	11	35	423052	721607	45	259	18	5330		1	11	3
35082	SPORTSMANS POND	27	35	423632	721352	93	358	5	12500		0	10	3
35086	SUNSET LAKE	27	35	424100	715830	278	2317	15	2233		1	12	4
35089	TULLY POND	11	35	423815	721430	77	203	12	8096		1	7	3
35094	WARD POND	27	35	424050	715300	51	454	23	11500		1	13	5
35095	WATATIC POND	27	35	424115	715615	111	712	12	16000		0	11	3
35097	WHEELERS POND	11	35	423720	721935			45			0	7	3
35098	WHITE POND	11	35	423300	721530	64	429	20	11000		1	10	3
35101	WHITNEY POND	27	35	424050	720200	110	836	19	12500		1	10	3
35109	ORANGE IMPOUNDMENT	11	35	423522	721822			14			0	14	5

RIVER BASIN CODE = 36

LAKEID	NAME	COUNTY	BASIN	LAT	LONG	AREA	VOLUME	DMAX	SHORE	DAREA	STR	SEVER	TROPHIC
36010	BEAVER LAKE	15	36	421530	721820						0	5	1
36012	BEMIS ROAD POND	13	36	422822	715715	21.5	28.7	4	4070		0	10	3
36020	BRIGHAM POND	13	36	422822	720000	47	230	9	8100		0	13	5
36023	BROOKS POND	27	36	421800	720230						1	7	
36032	CHICOPEE FALLS IMPD	13	36	420938	723407						0	11	
36040	CRANBERRY MEADOW POND	27	36	421113	720010			15			0	4	1
36049	DEAN POND	13	36	420605	721610			31			1	9	3
36052	DIAMOND INTERNATIONAL	13	36	421136	721933						0	13	
36053	DIMMOCK POND	13	36	420855	722928	11	68	10	2760		0	8	3
36056	EAMES POND	27	36	421845	715720			15			1	8	3
36061	FIVE MILE POND	13	36	420830	723040	41	620	35	5700		1	6	2
36066	HARDWICK POND	27	36	421845	721425	99		20			1	13	5
36067	HARRIS POND	13	36	421040	722935	12	16	4	8500		0	11	3
36069	HAVILAND POND	13	36	421022	722830	26	420	35	5200		1	7	3
36073	HOWE POND	27	36	421247	715957			20			1	8	3
36079	LAKE LASHAWAY	27	36	421410	720250	270	2303	20		0.09000	1	8	3
36083	LONG POND	13	36	420915	723037	13	19	4	3290				3
36084	LAKE LORRAINE	13	36	420845	723050	28	430	35	5300		1	7	3
36086	VAN HORN POND LOWER	13	36	420730	723550						1	13	
36092	LAKE MATTAWA	11	36	423400	721922	144	1896	35	1250		1	5	1
36093	MINECHOAG POND	13	36	420945	722735	22	76	13	4900		0	9	3
36094	MONA LAKE	13	36	420835	723115	22	697	10	3900		0	13	5
36103	MURPHY POND	13	36	421017	722937			4			0	10	3
36107	NINE MILE POND	13	36	420852	722607	28	336	20	5758		1	10	3
36115	GRAVES BROOK RES	13	36	420943	721840			43			1	4	1
36130	QUABOAG POND	27	36	421148	720410	531	3145	12	2640		0	8	
36131	QUACUMQUASIT POND	27	36	421021	720422	218	7077	72	1875		1	6	
36132	QUEEN LAKE	27	36	423200	720700	134	2014	22	16250	0.68	0	1	1
36150	SUGDEN RESERVOIR	27	36	421615	715807	83		21			0	4	1
36155	THOMPSONS POND	27	36	421810	715825			50			1	7	3
36158	VAN HORN POND UPPER	13	36					21	5818		1	13	5
36162	WARE IMPOUNDMENT	15	36	421549	721344						1	11	
36163	WESTERN MASS ELECTRIC	13	36	420915	722850						1	8	
36166	WICKABOAG POND	27	36	421430	720915			12			0	7	3
36171	RED BRIDGE IMPOUNDMENT	13	36	421052	722408	83	1750	45	12672	664	1	15	3
36172	CAMP PUTNAM POND	27	36	421922	720412						0	4	1

RIVER BASIN CODE = 41

LAKEID	NAME	COUNTY	BASIN	LAT	LONG	AREA	VOLUME	DMAX	SHORE	DAREA	STR	SEVER	TROPHIC
41001	ALUM POND	27	41	420834	720714	195		45					3
41008	CEDAR POND	27	41	420730	720525	153	741	16	23616		0	8	3
41011	COMMINS POND	27	41	421212	721147						0	5	
41014	EAST BRIMFIELD RESERV	13	41	420627	720840			15			0	7	3
41016	LAKE GEORGE	13	41	420330	721252	93		13			1	8	3
41017	GLEN ECHO LAKE	27	41	420949	715933	112		22			1	11	3
41022	HOLLAND POND	13	41	420445	720955	65		21			1	5	1
41027	LEADMINE POND	27	41	420348	720730	62		46			1	2	1
41029	LITTLE ALUM POND	13	41	420750	720908	73		42			1	3	1
41043	PRINDLE LAKE	27	41	420645	715945								
41046	SHERMAN POND	13	41	420806	721140	86		10			0	7	3
41048	LOWER ASHWORTH POND	27	41	420900	720040			25			1	12	4
41052	WALKER POND	27	41	420819	720339	94		16			0	5	1

RIVER BASIN CODE = 42

LAKEID	NAME	COUNTY	BASIN	LAT	LONG	AREA	VOLUME	DMAX	SHORE	DAREA	STR	SEVER	TROPHIC
42005	BUFFUMVILLE LAKE	27	42	420708	715439	186		17			1	8	3
42018	GORE POND	27	42	420451	715649	175		20			1	12	3
42019	GRANITE RESERVOIR	27	42	420600	715600	198		16			0	4	1
42023	GREENVILLE POND	27	42	421223	715522	30		13			1	10	3

LAKEID	NAME	COUNTY	BASIN	LAT	LONG	AREA	VOLUME	DMAX	SHORE	DAREA	STR	SEVER	TROPHIC
42024	HAYDEN POND	27	42	420433	715509	41		33			1	1	1
42036	MERINO POND	27	42	420302	715406	70		15			0	2	1
42043	PIERPOINT MEADOW POND	27	42	420505	715459	90		12			0	7	1
42047	ROBINSON POND	27	42	420620	714948	100		5			0	4	1
42049	SARGENT POND	27	42	421455	715500						0	10	2
42053	SLATERS POND	27	42	420700	714922	101		18			1	4	1
42055	STILES RESERVOIR	27	42	421242	715655	353		18			1	9	3
42058	TEXAS POND	27	42	421017	715338	27		6			0	9	3
42059	THAYERS POND	27	42	420930	715305						0	13	
42064	WEBSTER LAKE	27	42	420230	715045	1209	13998	41	0		1	6	3
42067	CLARA BARTON POND	27	42	420913	715343			12			1	9	3

RIVER BASIN CODE = 51

51009	BELL POND	27	51	421618	714700			17	2542		0	6	2
51010	BRIERLY POND	27	51	421037	714635			7	4333		0	9	3
51024	COES RESERVOIR	27	51	421515	715034	86	167	14	10800	1.66	0	10	3
51027	COOK POND	27	51	421707	715130	20	96	10	5400	1.62	0	9	3
51031	CRYSTAL LAKE	27	51	420250	714607	93	556	11	10900	1.28	0	8	3
51035	DARK BROOK RES - LOWER	27	51	421115	715200						0	10	3
51036	DARK BROOK RES - UPPER	27	51	421137	715145						0	10	3
51039	DOROTHY POND	27	51	421257	714504	141	1488	17	22000	3.42	0	9	3
51043	EDDY POND	27	51	421038	715037	156	553	16	22200	0.6	0	8	3
51050	FLINTS POND-NORTH BASIN	27	51	421500	714413	84		12	12000	2.38	0	9	2
51056	GREEN HILL POND	27	51	421700	714652	26	141	9	5500	0.21	0	7	3
51073	INDIAN LAKE	27	51	421752	714845	193	2066	20	20000	3.13	1	9	
51078	JORDAN POND	27	51	421605	714448	20	73	12	3800	0.1	0	11	4
51083	LACKEY POND	27	51	420543	714125	128	642	8	20000	31.42	0	12	5
51091	MANCHAUG POND	27	51	420600	714637	344	4213	30	26500	5.79	1	3	1
51109	MUMFORD R IMPOUNDMENT	27	51	420430	713712			15			0	6	2
51111	NIPMUCK POND	27	51	420545	713415	85	1087	22	10600	1	1	6	2
51117	PATCH POND	27	51	421552	715100			5	1647		0	8	3
51120	PONDVILLE POND	27	51	421127	714900	37	224	8	15100	5.02	0	13	4
51125	QUINSIGAMOND	27	51	421626	714522	475	15611	85	56000	20.84	1	11	3
51126	RAMSHORN POND	27	51	420915	714830	116	1279	30	2500	2.27	1	3	1
51142	SALISBURY POND	27	51	421636	714823	13	58	7	5000	3.82	0	16	4
51150	SILVER LAKE	27	51	420345	712755	42	142	9	9100		0	10	3
51152	SINGLETARY POND	27	51	420939	714645	327	8259	30	26800	2.67	1	10	1
51161	STONEVILLE RESERVOIR	27	51	421230	715136	55	261	10	10400	2.89	0	5	2
51170	WAITE POND	27	51	421500	715330	70	160	8	9000	1.24	0	5	1
51172	WALLUM LAKE	27	51	420006	714608	322	10836	75	27000	1.78	1	2	1
51188	FLINTS POND SOUTH BASIN	27	51	421437	714348	170		15	25000	0.98	0	9	3

RIVER BASIN CODE = 52

52006	CENTRAL POND	5	52	415130	712025						0	13	
52011	DODGEVILLE POND	5	52	415535	711726			5			0	11	
52013	FALLS POND (CORAL LAKE)	5	52	415810	711925						1	14	3
52015	FARMERS POND	5	52	415709	711807			5			0	14	
52016	FULLER POND	21	52	420047	712058			10			0	10	3
52020	HEBRONVILLE POND	5	52	415438	711911			5			0	12	
52022	JAMES V TURNER	5	52	414100	705835			30					4
52027	MECHANICS POND	5	52	415654	711743			5			0	14	
52041	WETHERELL POND	21	52	420000	712015			5			0	14	
52043	RESERVATION POND	5	52	415230	712030								
52044	ATTLEBORO GRAVEL PIT #1	5	52	415750	711846						0	4	1
52045	ATTLEBORO GRAVEL PIT #2	5	52	415450	711852						0	3	1

RIVER BASIN CODE = 53

53001	BURRS POND	5	53	414920	712015						1	15	

RIVER BASIN CODE = 61

61001	COOK POND	5	61	414030	711030						1	12	
61005	SAWDY POND	5	61	413700	710815						0	3	
61006	SOUTH WATUPPA POND	5	61	413937	710745	1446	22246	22		147.6	0	9	3

RIVER BASIN CODE = 62

62007	BARROWSVILLE POND	5	62	415705	711210						0	13	
62011	BIG BEARHOLE POND	5	62	415150	705900						0	8	
62023	BROCKTON RESERVOIR	21	62	420658	710318	83	964	20	900	28.3	1	8	3

LAKEID	NAME	COUNTY	BASIN	LAT	LONG	AREA	VOLUME	DMAX	SHORE	DAREA	STR	SEVER	TROPHIC
62038	CHARTLEY POND	5	62	415651	711400	59	113	7	14000	38.4	0	13	5
62039	CHASE POND	5	62	414130	710830						0	13	
62042	CLEVELAND POND	23	62	420715	705855	88	176	6	1700	28.4	0	12	4
62090	HOBART POND	23	62	420507	705545						0	14	5
62094	ISLAND GROVE POND	23	62	420638	705628	33	154	10	920	30.3	0	13	3
62103	LEACH POND	5	62	420355	710920			12			0	7	3
62114	MEMORIAL PARK POND	5	62	415325	710535						0	13	
62119	MONPONSETT POND WEST	23	62	420030	705045						0	13	5
62131	LAKE NIPPENICKET	23	62	415815	710230	354	751	6	2600	24	0	7	3
62134	NORTON RESERVOIR	5	62	415906	711204	519	1664	10	2600	8.4	0	10	5
62162	ROBBINS POND	23	62	420015	705428	124	495	5	9000	2.7	0	5	1
62166	LAKE SABBATIA	5	62	415640	710627	251	1890	30	27840		1	11	3
62187	TERRY BROOK POND	5	62	414640	710455						1	10	
62190	THIRTYACRE POND	23	62	420543	710245	24	74	7	6000	3.3	0	4	1
62198	TURNPIKE LAKE	21	62	420100	711620	115	170	4	19800		0	6	3
62201	WALDO LAKE	21	62	420634	710253	70	300	9	11100	3.6	0	7	3
62213	WINNECUNNET POND	5	62	415815	710752	148	740	11	10	312.4	0	8	3
62218	MONPONSETT POND EAST	23	62	420015	705015						0	7	3

RIVER BASIN CODE = 71

LAKEID	NAME	COUNTY	BASIN	LAT	LONG	AREA	VOLUME	DMAX	SHORE	DAREA	STR	SEVER	TROPHIC
71005	BLACKS NOOK	9	71	422320	710910						0	12	
71010	CHANDLERS POND	25	71	422040	711000						0	14	
71014	ELL POND	17	71	422737	710355						1	10	3
71018	HILLS POND	17	71	422440	710955						0	8	
71019	HORN POND	17	71	422807	710922	58	1275	45	12050		0	0	3
71023	LITTLE FRESH POND	17	71	422305	710920						0	9	
71027	LOWER MYSTIC LAKE	17	71	422535	710850			80			1	15	5
71040	SPY POND	17	71	422430	710919	102		38	35	8.64	1	16	5
71043	UPPER MYST	17	71	422615	710900	167	4650	82	0	23.3	1	15	

RIVER BASIN CODE = 72

LAKEID	NAME	COUNTY	BASIN	LAT	LONG	AREA	VOLUME	DMAX	SHORE	DAREA	STR	SEVER	TROPHIC
72002	LAKE ARCHER	21	72	420411	712017	79	1247	35	10000	0.42	1	9	3
72008	BOX POND	21	72	0	712930						0	15	5
72011	BULLOUGHS POND	17	72	422023				2		0	0	12	4
72035	ECHO LAKE	17	72	421137	713045	110	1187	22	10000		1	3	1
72039	FARM POND	17	72	421400		123	2406	58	9800		1	6	1
72043	HALLS POND	25	72	422046	710645	2	2.8	8	1000		1	13	5
72045	HARDYS POND	17	72	422430	711433	41	111	6	6200	1.1	0	12	5
72047	HIGHLAND LAKE	21	72	420734	711822	19	71	11	4300		1	14	5
72050	HOUGHTON POND	17	72	421247	712545	13	45.2	6	5000		0	13	5
72053	JENNINGS POND	17	72	421807	711945			5			0	12	4
72060	LEVERETT POND	25	72	421940	710645	12.8	34	6	3100		0	9	4
72067	LOST POND	21	72	421852	711030	0.9	1.4	11	800		0	12	5
72078	MIRROR LAKE	21	72	420517	711932	61	234	6	11000		0	10	4
72079	MORSES POND	21	72	421755	711910	116	685	23	15000		1	12	3
72091	CHOATE PARK POND	23	72	420850	712543			17			0	15	5
72092	LAKE PEARL	21	72	420350	712107	218	2754	34	19000		1	12	3
72096	POPULATIC POND	21	72	420749	712250	46	104	7	8000		0	11	4
72103	ROSEMARY LAKE	21	72	421710	711420	12.8	43	6	3422		0	10	3
72106	SARGENT POND	21	72	421915	710741	2	3.5	4	1200		0	10	4
72109	SOUTH END POND	21	72	421145	712100						0	9	
72125	LAKE WABAN	21	72	421719	711834	108	1602	42	12400		1	9	3
72126	WALKER POND	17	72	422220	711242	2.3	4.7	9	1800		0	9	3
72140	LAKE WINTHROP	17	72	421118	712520	102		20			1	9	3
72142	WILLOW POND	25	72	421957	710650	1	1.7	7	800		0	7	3
72143	SCHOOL POND	25	72	421730	711000						0	11	3

RIVER BASIN CODE = 73

LAKEID	NAME	COUNTY	BASIN	LAT	LONG	AREA	VOLUME	DMAX	SHORE	DAREA	STR	SEVER	TROPHIC
73008	CLARK POND	21	73	420817	711432			18			0	10	3
73009	COBBS POND	21	73	420938	711443			22			1	9	3
73030	MASSAPOAG LAKE	21	73	420615	711037						1	7	
73101	CRACKROCK POND	21	73	420500	711520			0			0	13	5

RIVER BASIN CODE = 74

LAKEID	NAME	COUNTY	BASIN	LAT	LONG	AREA	VOLUME	DMAX	SHORE	DAREA	STR	SEVER	TROPHIC
74007	CRANBERRY POND	21	74	421015	705932			10			0	7	3
74013	LAKE HOLBROOK	21	74	420835	710115						0	12	
74019	STRAITS POND	23	74	421554	705015	82.3	140	5	15166		0	9	3
74020	SUNSET LAKE	21	74	421209	710045	54	377	30	7913		1	8	3
74025	WHITMANS POND	21	74	421215	705615	178	1246	26	31		0	10	3

LAKEID	NAME	COUNTY	BASIN	LAT	LONG	AREA	VOLUME	DMAX	SHORE	DAREA	STR	SEVER	TROPHIC
RIVER BASIN CODE = 81													
81003	BADDACOOK POND	17	81	423708	713152	76	1311	45	100	9.7	1	7	3
81007	BARE HILL POND	27	81	422930	713545	316		20			0	11	
81017	CHAFFIN POND	27	81	421952	715028	109	178	1.6	166	28	0	5	1
81022	COW POND	17	81	423620	713050	38	418	20	4500		1	7	3
81034	EAGLE LAKE	27	81	422121	715308	84	200	11	0	17.1	0	6	2
81035	EAST WAUSHACUM POND	27	81	422445	714500	184	2400	38	15700	9.9	1	4	1
81044	FLANNAGAN POND	17	81	423325	713415			6			0	13	5
81046	FORT POND	17	81	423026	712800	76	1871	45	800	6.5	1	9	3
81051	GREENES POND	27	81	423622	714807						0	11	3
81053	GROVE POND	17	81	423310	713505			15			1	11	4
81054	HARBOR POND	17	81	423907	714040			30			1	8	3
81063	KNOPS POND	17	81	423518	713126	204	1179	30	0	42.5			2
81073	LONG POND	17	81	423415	713224			35			1	12	4
81082	MCTAGGARTS POND	27	81	423440	715045	9	73	9	3550		0	7	3
81084	MIRROR LAKE	27	81	423337	714805	13	38	10	2500		0	8	3
81087	MOSSY POND	27	81	422506	714204	26	380	32	7000	1.7	1	8	3
81098	PARTRIDGE POND	27	81	423215	715625						0	9	3
81107	PUTNAM POND	27	81	423550	714715	4	4	1	1400		0	10	3
81112	ROCKWELL POND	27	81	423139	714607	12	34	9	3600	39.3	0	8	3
81116	LAKE SAMOSET	27	81	422930	714540						1	8	
81117	SANDY POND	17	81	423342	713322	74	1140	25	70	14.1	0	6	3
81118	SAWMILL POND	27	81	423237	715052			5			0	14	5
81122	LAKE SHIRLEY	27	81	423320	714115	358	1998	30	0	224.5	1	11	3
81127	SNOWS MILLPOND	27	81	423338	715115			10			0	6	3
81129	SOUTH MEADOW POND EAST	27	81	422455	714248	38	272	20	9504	2.5	1	9	3
81130	SPECTACLE POND	27	81	423042	714100	66	1558	51	120	5.7	1	4	1
81152	WATTLES POND	17	81	423910	713405	74	58	9	4000		1	10	3
81153	WEST WAUSHACUM POND	27	81	422455	714553	141	1862	28	0	35.7	1	7	3
81154	LAKE WHALOM	27	81	423427	714530	99	1953	40	106	5.7	1	6	1
81155	WHITE POND	27	81	423048	714300	48	8	6	7000		0	7	3
81157	WINNEKEAG LAKE	27	81	423940	715400	118		34			1	10	3
81161	WYMAN POND	27	81	423134	715236	200	1006	15	50000	7	1	12	4
81163	BOWER SPRINGS POND-WEST	27	81	422752	713630	9	29	10	6540		0	8	3
81164	BOWER SPRINGS POND-EAST	27	81	422752	713625	2	5	8	25200		0	8	3
81165	SOUTH MEADOW POND WEST	27	81	422453	714225	32	129	8	9000	28.4	0	9	3
81166	ICE HOUSE POND	17	81	423305	713725			12			0	8	3
81167	PEPPERELL POND	17	81	423845	713500						0	15	5
RIVER BASIN CODE = 82													
82003	ASHLAND RESERVOIR	17	82	421422	712750	155					1	5	1
82004	ASSABET RIVER RESERV	27	82	421545	713830	333	924	5	249	60.9			
82007	BARTLETT POND	27	82	421905	713707	45		8			0	7	
82011	BOONS POND	17	82	422330	713000	163	1844	20	0	17.5	0	11	4
82015	CARDING MILL POND	17	82	422142	712758	45	75	4	7392	14	0	13	
82017	CHAUNCEY LAKE	27	82	421737	713648	177	2100	20	0	12.1	1	6	
82020	LAKE COCHITUATE NORTH	17	82	421805	712210						1	12	
82029	DUDLEY POND	17	82	421945	712215	84		23			1	5	1
82042	FORT MEADOW RESERVOIR	17	82	422200	713300	292		24			1	9	3
82043	FORT POND	17	82	423025	712800	108	1366	35	11555	3	1	10	3
82055	GRIST MILL POND	17	82	422118	712848	28	58	6	7394	6.3	0	15	
82056	HAGER POND	27	82	422059	712916	39	97	6	6864	17.5	0	12	
82059	HEART POND	17	82	423355	712315						1	7	
82060	HOCOMONCO POND	27	82	421621	713900	27	86	6	5780	3.8	0	8	
82071	LITTLE POND	27	82	422525	713915	15	105	13	4000		0	2	1
82072	LONG POND	17	82	423030	712815	62	448	20	9111		1	8	3
82088	NUTTING LAKE - EAST	17	82	423211	711613	78	330	7	1210	93.2	0	10	
82095	ROCKY POND	27	82	422047	714119	61	384	20	1366	4.2	1	2	
82104	STEARNS MILL POND	17	82	422309	712715	24	24	3	7920	47	0	12	
82107	TRIPP POND	17	82	422323	713437			6			0	8	3
82110	WARNERS POND	17	82	422750	712409	58	188	12	194	74.6	1	10	
82112	WAUSHAKUM POND	17	82	421552	712535	82	1196	50	11	20.2	1	8	5
82115	WEST POND	27	82	422540	713450	19	150	18	5166		1	8	3
82118	WHITE POND	17	82	422545	712330	493	7503	55	7273		1	5	1
82120	WHITEHALL RESERVOIR	17	82	421345	713430						1	9	
82123	WINNING POND	17	82	423305	711810			20	4667		0	9	3
82124	NUTTING LAKE-WEST	17	82	423210	711615						0	10	

RIVER BASIN CODE = 83

LAKEID	NAME	COUNTY	BASIN	LAT	LONG	AREA	VOLUME	DMAX	SHORE	DAREA	STR	SEVER	TROPHIC
83001	AMES POND	17	83	423820	711335	82	357	8.5	123	22.1	0	7	3
83006	FOSTERS POND	9	83	423622	710817	109	397	12	238	12.6	1	12	4
RIVER BASIN CODE = 84													
84001	ALTHEA LAKE	17	84	424007	712252	38					1	11	3
84002	LAKE ATTITASH	9	84	425030	705805	360	3280	25	22	42.3	0	5	3
84012	FLINT POND	17	84	424022	712600			6			0	7	3
84013	FLUSHING POND	17	84	423721	712630	18	176	27	4400	1.2	1	7	3
84014	FOREST LAKE	9	84	424340	711452	55		28			1	7	3
84015	FORGE POND	17	84	423434	712924	198	2565	33	0	72.2	1	11	3
84017	FRYE POND	9	84	424820	710500						0	7	
84018	LAKE GARDNER	9	84	425145	705630	80		17					
84027	JOHNSONS POND	9	84	424300	710315						1	6	
84029	KEYES POND	17	84	423652	712752	40	416	19	550	40.9	1	9	3
84032	LONG POND	17	84	424130	712215	163	4	25	19000		0	8	1
84033	LONG SOUGHT FOR POND	17	84	423715	712710	105	1139	30	10	6.1	1	6	2
84037	MASCUPPIC LAKE	17	84	424037	712300						1	14	
84038	MILL POND NORTH BASIN	17	84	423210	713008	22	70	6	7400		0	12	4
84039	MILL POND	9	84	424815	705315						1	11	
84044	NABNASSET POND	17	84	423700	712530						0	7	3
84053	PETERS POND	17	84	424300	711537	102		15	11500		1	11	3
84075	UPTONS POND	17	84	424015	712525	6	16	5	2125		1	11	3
84081	MILL POND SOUTH BASIN	17	84	423155	713025	12	30	5	4800		0	12	4
RIVER BASIN CODE = 91													
91001	BALDPATE POND	9	91	424152	710010	66		41			1	10	3
91010	PENTUCKET POND	9	91	424403	705950	86	207	28	10000	0.58	1	11	
91012	ROCK POND	9	91	424343	710020	52	592	20	8000	6.48	1	12	
RIVER BASIN CODE = 92													
92002	BEAVER POND	9	92	423445	705140			20			0	11	3
92025	HOOD POND	9	92	424222	705640	67		17			1	6	2
92034	LOWE POND	9	92	424035	705908	30	89	6	9000	1.1	0	5	
92038	MARTINS POND	17	92	423545	710730	92		7			0	10	3
92059	SILVER LAKE	17	92	423357	721116			75			1	9	3
92063	STILES POND	9	92	424120	710215	58	904	26	10000	0.59	1	8	
RIVER BASIN CODE = 93													
93002	BARTHOLOMEW POND	9	93	423030	705800						1	6	
93008	BROWNS POND	9	93	423000	705715						1	7	
93014	CHEBACCO LAKE	9	93	423645	704830						1	10	3
93016	COY POND	9	93	423030	704915						0	9	
93023	FLAX POND	9	93	422857	705707	71		26			1	13	5
93024	FLOATING BRIDGE POND	9	93	422908	705672						0	11	3
93056	PILLINGS POND	9	93	423145	710145						0	13	5
93071	SLUICE POND	9	93	422920	705800	50		59			1	10	3
93091	BABSON FARM QUARRY	9	93	424123	703755						1	10	3
RIVER BASIN CODE = 94													
94015	BLOODY POND	23	94	415100	703500			110			1	5	1
94037	FORGE POND	23	94	420622	705252						0	16	
94043	FURNACE POND	23	94	420320	704935	100	436	9	13485		0	6	2
94050	GREAT HERRING POND	23	94	414800	703400	395	6197	35	27000		1	9	3
94057	HALFWAY POND	23	94	415110	703700			40			0	7	3
94077	JACOBS POND	23	94	420943	705058	53	102	5	10070		0	8	3
94096	MAQUAN POND	23	94	420345	705110	48		18			0	7	3
94097	MARE POND	23	94	414622	703730			5			0	5	1
94105	MUSQUASHCUT POND	23	94	421345	704540						0	12	
94114	OLDHAM POND	23	94	420405	705009	231	2080	15	1507		0	6	2
94168	WAMPATUCK POND	23	94	420339	705203	64	85	4	10280		0	10	3
94175	FACTORY POND	23	94	420525	705230	45	99	8	14395		0	12	4
94176	GALLOWS POND	23	94	415145	703700			95			1	6	1
RIVER BASIN CODE = 95													
95020	BUTTONWOOD PARK POND	5	95	413600	705740			15			0	9	3
95088	LITTLE LONG POND	23	95	415210	703650			25			0	6	1
95096	LONG POND	23	95	415130	703615			305			1	6	1

LAKEID	NAME	COUNTY	BASIN	LAT	LONG	AREA	VOLUME	DMAX	SHORE	DAREA	STR	SEVER	TROPHIC
95112	NEW LONG POND	23	95	415110	704045			24			0	9	3
95113	NOQUOCHOKE LAKE-MIDDLE	5	95	413900	710230	19	32	4	5600		1	13	5
95123	ROUND POND	23	95	415136	703618						0	5	
95129	SASSAQUIN POND	5	95	414406	705659	39	257	21	5400		1	5	1
95148	TINKHAM POND	23	95	414100	705130	14	24	4	6200		0	14	5
95151	TURNER POND	5	95	414055	705836	26	44	5	5000		0	12	4
95166	WHITE ISLAND POND -EAST	23	95	414800	703730	159	1067	15	1700		0	7	3
95170	NOQUOCHOKE LAKE - SOUTH	5	95	413915	710200	110	363	10	20400		1	13	5
95171	NOQUOCHOKE LAKE - NORTH	5	95	413830	710250	17	28	4	6120		1	13	5
95173	WHITE ISLAND POND -WEST	5	95	414800	703730	125	533	14	16000		0	7	3
RIVER BASIN CODE = 96													
96004	ASHUMET POND	1	96	413800	703200	203	4796	65	12800		1	7	3
96008	BAKER POND	1	96	414600	700015	25.6	468	60	5300		1	5	1
96012	BEARSE POND	1	96	414035	702000	65.1	579.6	16	8000		0	5	1
96035	CLAPPS POND	1	96	420310	701230	38.1	50.8	4	9880		0	12	5
96039	CLIFF POND	1	96	414530	710030	177.1	5535	88	12200		1	7	2
96050	CRYSTAL LAKE	1	96	414630	695900	33.6	677	44	5000		1	7	2
96061	DEPOT POND	1	96	414952	695850	26.5	358	31	4600		1	2	1
96080	LAKE ELIZABETH	1	96	413825	702000	7	19.44	4	1894		0	11	4
96087	FLAX POND	1	96	414120	703540	19.3	66.8	6	3850		0	5	1
96090	FLAX POND	1	96	414250	701115	15.9	159	29	3000		1	1	1
96101	FRESH POND	1	96	414045	703910	29.2	124.3	8	4600		0	7	2
96106	GOOSE POND	1	96	414140	700025	34.5	801	52	4600		1	5	3
96115	GREAT POND	1	96	415000	695930	108	1399	36	10500		1	7	5
96123	GULL POND	1	96	415725	700030	102.7	3142	61	7150		1	5	1
96133	HERRING POND	1	96	414930	695910	42.7	670	35	5000		1	9	3
96135	HERRING RIVER RESERVOIR	1	96	414055	700707	65.5	220.8	6	10500				3
96140	HINCKLEYS POND	1	96	414250	700530	165.6	2023	28	10000		1	8	3
96146	HOXIE POND	1	96	414350	702605	8.8	104	35	1800		1	11	3
96157	JOHNS POND	1	96	413739	703114	323	6428	62	22704	4.1	1	10	3
96179	LONG POND	1	96	415640	700030	32.7	435	50	7200		1	2	1
96184	LONG POND	1	96	414000	702640	48.7	420	22	8500		0	7	3
96194	MASHPEE & WAKEBY PONDS	1	96	414000	702915	729	20022	87	31200		1	9	3
96246	PILGRIM LAKE	1	96	414552	695845	38	408	28	5800		1	5	1
96253	QUEEN SEWELL POND	1	96	414520	703615	16.8	207	28	3500		0	2	1
96257	RED LILY POND	1	96	414325	701955	4.4	14.9	6	3000		0	12	4
96273	SALT POND	1	96	413235	703735	60.5	324	18	8500		1	12	4
96277	SANTUIT POND	1	96	413915	702730	167.4	706.1	9	16600		0	11	3
96279	SCARGO LAKE	1	96	414450	701100	53	1032	48	6000		1	5	1
96281	SCHOOLHOUSE POND	1	96	414140	695950	18.62	377	47	3500		1	2	1
96285	SHALLOW POND	1	96	414040	701930	75.8	207	6	10000		0	8	3
96289	SHEEP POND	1	96	414415	700405	138.1	4075	60	12200		1	4	1
96293	SHUBAEL POND	1	96	414020	702337	54.9	886.2	41	5500		1	6	2
96302	SNAKE POND	1	96	414100	703115	81.4	925	24	8000		0	3	1
96329	VILLAGE POND	1	96	420158	700525	6	10	5	1800		0	11	3
96333	WEQUAQUET LAKE	1	96	414015	702700	571.9	6972	31	36600		0	5	1
96344	CEDAR LAKE	1	96	413855	703725	19.4	25.8	4	4000		0	4	3
RIVER BASIN CODE = 97													
97006	BRUSH POND	7	97	412732	703445								
97009	CHILMARK POND	7	97	412030	704320								
97014	CRYSTAL LAKE	7	97	412800	703420								
97019	DUARTE POND	7	97	412517	703650								
97028	GIBBS POND	19	97	411625	700101			13					
97037	HUMMOCK POND	19	97	411540	700900			9					
97044	LAGOON POND	7	97	412630	703548						0	5	
97050	LONG POND	19	97	411637	701040			5					
97053	MAXCY POND	19	97	411707	700807			6					
97054	MENEMSHA POND	7	97	412015	704615								
97055	MIACOMET POND	19	97	411445	700700			7					
97060	NASHAQUITSA POND	7	97	411940	704610								
97083	SENGEKONTACKET POND	7	97	412525	703330								
97084	SESACHACHA POND	19	97	411745	695845			12					
97085	SETHS POND	7	97	412600	703950						0	3	
97092	STONEWALL POND	7	97	411938	704530								
97093	SUNSET LAKE	7	97	412720	703348						0	9	
97094	LAKE TASHMOO	7	97	412730	703730								
97096	TOM NEVERS POND	19	97	411445	695915			4					
97097	TRAPPS POND	7	97	412405	703148								
97099	WASHING POND	19	97	411720	700807			12					

DATA SOURCES FOR RIVER MASS BALANCE ANALYSIS

BASIN	RIVER	WWTP	DRAINAGE AREA	RIVER FLOW	7Q10 FLOW	EFFLUENT DISCHARGE	EFFLUENT [P]	RIVER [P]	WWTP DESIGN FLOW
Deerfield	Deerfield R.	Buckland/Shelbourne	a	b	g	d	e	c	j
Deerfield	Deerfield R.	Old Deerfield	a	b	g	d	e	c	j
Deerfield	North R.	Kendall Co.	a	b	c	d	e	c	j
Deerfield	Green R.	Greenfield	a	b	g	d	e	c	j
Millers	Millers R.	Winchendon	a	b	f	d	e	c	j
Millers	Millers R.	S. Royalston	a	b	f	d	e	c	j
Millers	Millers R.	Athol	a	b	f	d	e	c	j
Millers	Millers R.	Orange	a	b	f	d	e	c	j
Millers	Millers R.	Erving Center	a	b	f	d	e	c	j
Millers	Millers R.	Farley	a	b	g	d	e	c	j
Millers	Millers R.	Millers Falls	a	b	g	d	e	c	j
Millers	Otter R.	Gardner	a	b	f	d	e	c	j
Millers	Otter R.	Templeton	a	b	f	d	e	c	j
Millers	Beaver Bk.	Fernald School	a	b	g	d	e	h	j
Millers	Black Bk.	MCI Warwick	a	b	g	d	e	h	j
Assabet	Assabet R.	Westboro Regional	a	b	k	d	e	c	j
Assabet	Assabet R.	Marlboro West	a	b	k	d	e	c	j
Assabet	Assabet R.	Hudson	a	b	k	d	e	c	j
Assabet	Assabet R.	Maynard	a	b	g	d	e	c	j
Assabet	Assabet R.	Concord MCI	a	b	g	d	e	c	j

DATA SOURCE NOTES:

a drainage area approximated based upon river mile location and drainage areas provided in the USGS Stream Gazatteer

b average flow measured during the River Basin Study; typically two to four four instantaneous flow measurements

c average phosphorus concentration measured during the River basin Study at the nearest upstream river sampling location

d average effluent discharge rate measured during the River Basin Study (typically two to four measurements)

e average effluent phosphorus concentration measured during the River Basin Study

f river 7Q10 flow from River Basin Study

g river 7Q10 at point of discharge estimated basin upon 7Q10 cfs/sq. mi. for USGS gauged station as reported in the USGS Stream Gazatteer

h no measured upstream phosphorus concentrations, concentration estimated based upon other stations monitoring during the River Basin Study

i no measured effluent discharge rate; design flow reported in River Basin Study used for analysis

j design effluent flow provided in the River Basin Study

k 7Q10 flow from DEP, 1989

SOURCES:

MDWPC. 1989. 1988 Deerfield River Basin Survey.

MDWPC. 1990. Millers River Water Quality Survey Data.

MDWPC. 1990. Millers River Wastewater Discharge Data.

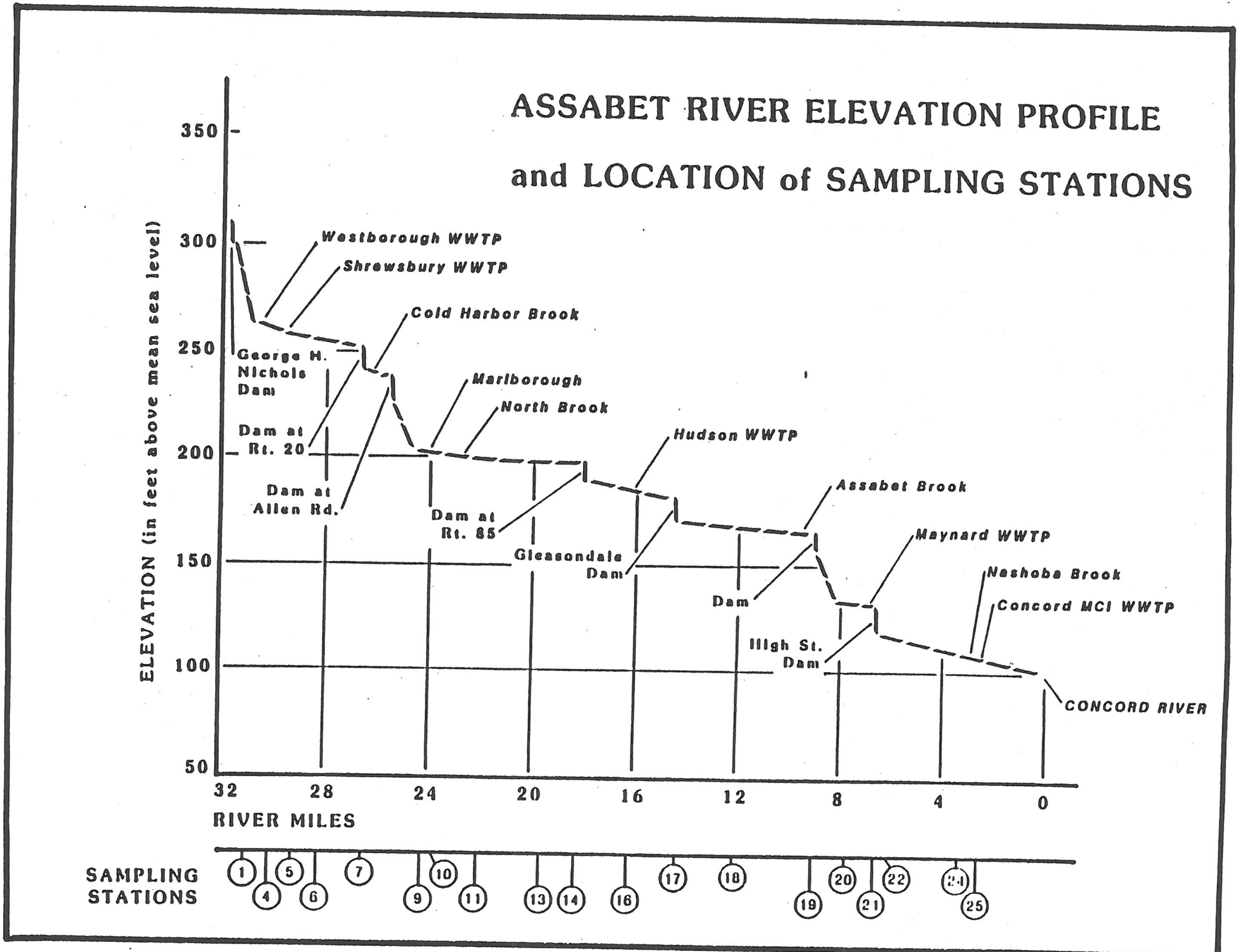
MDWPC. 1988. Assabet River Water Quality Survey Data.

MDWPC. 1986. Assabet River Water Quality Survey Data.

USGS. 1984 Gazatteer of Hydrologic Characteristics of Streams in Massachusetts --Connecticut River Basin.

USGS. 1984 Gazatteer of Hydrologic Characteristics of Streams in Massachusetts --Merrimack River Basin.

DEP. 1989. Pollutant Reductions from WWTP Upgradings in Massachusetts 1978-1988.



SOURCE: MDWPC. 1988. Assabet River Basin 1986-87.

Assabet River Basin
Mass Balance - Monitored Flow Conditions

Upst Nonpoint Export	0.14	lbs/day/mi2
Monitored Runoff	0.28	cfs/mi2
Detergent P Fraction	0.33	
P Removal Max Effl P	1.00	mg/liter

STP Name	River Mile	Upstream Drainage Area mi2	Increm. Drainage Area mi2	Upstream Flow cfs	Measured Upstream P conc ppm	Measured Upstream Load lbs/day	STP Flow cfs	STP P Conc ppm	STP Load lbs/day	Increm. NonPoint Load lbs/day	Detergent Load lbs/day	Non-Det. STP Load lbs/day	Reach Calib. Factor -	Nonpoint Export lbs/mi2-d
		0												
	30.1	7.1	7.1	2.0	0.09	1				1			1.00	0.14
Westboro Regional	30.0	7.1					2.70	5.04	73		24	49		
	24.1	35.4	28.3	9.9	1.15	61				4			0.78	0.14
Marlboro West	24.0	35.4					2.32	13.30	166		55	111		
	16.0	73.7	38.3	20.6	0.83	92				5			0.40	0.14
Hudson	15.9	73.7					3.16	5.72	97		32	65		
	6.8	116.0	42.3	32.4	0.78	136				6			0.70	0.14
Maynard	6.7	116.0					1.93	6.42	67		22	45		
	2.4	177.0	61.0	49.4	0.69	184				8			0.87	0.14
Concord MCI	2.3	177.0					0.29	7.85	12		4	8		

			....Existing....		...Detergent-Ban...		......Phosphorus-Removal.......				..NonPoint-Only..	
STP Name	River Mile	Total Flow cfs	Total Load lbs/day	River Conc ppm	River Load lbs/day	River Conc ppm	Effluent Conc ppm	Effluent Load lbs/day	River Load lbs/day	River Conc ppm	River Load lbs/day	River Conc ppm
			0									
	30.1	2.0	1	0.090	1	0.090			1	0.090	1	0.090
Westboro Regional	30.0	4.7	74	2.945	50	1.986	1.00	14.6	16	0.615	1	0.038
	24.1	9.9	61	1.150	42	0.794			15	0.285	4	0.070
Marlboro West	24.0	12.2	227	3.462	154	2.339	1.00	12.5	28	0.421	4	0.057
	16.0	20.6	92	0.830	63	0.567			13	0.117	4	0.032
Hudson	15.9	23.7	189	1.481	128	1.002	1.00	17.0	30	0.235	4	0.028
	6.8	32.4	136	0.780	93	0.535			25	0.143	6	0.037
Maynard	6.7	34.3	203	1.097	138	0.747	1.00	10.4	35	0.191	6	0.035
	2.4	49.4	184	0.690	127	0.478			38	0.142	13	0.048
Concord MCI	2.3	49.7	196	0.732	136	0.506	1.00	1.6	39	0.147	13	0.048

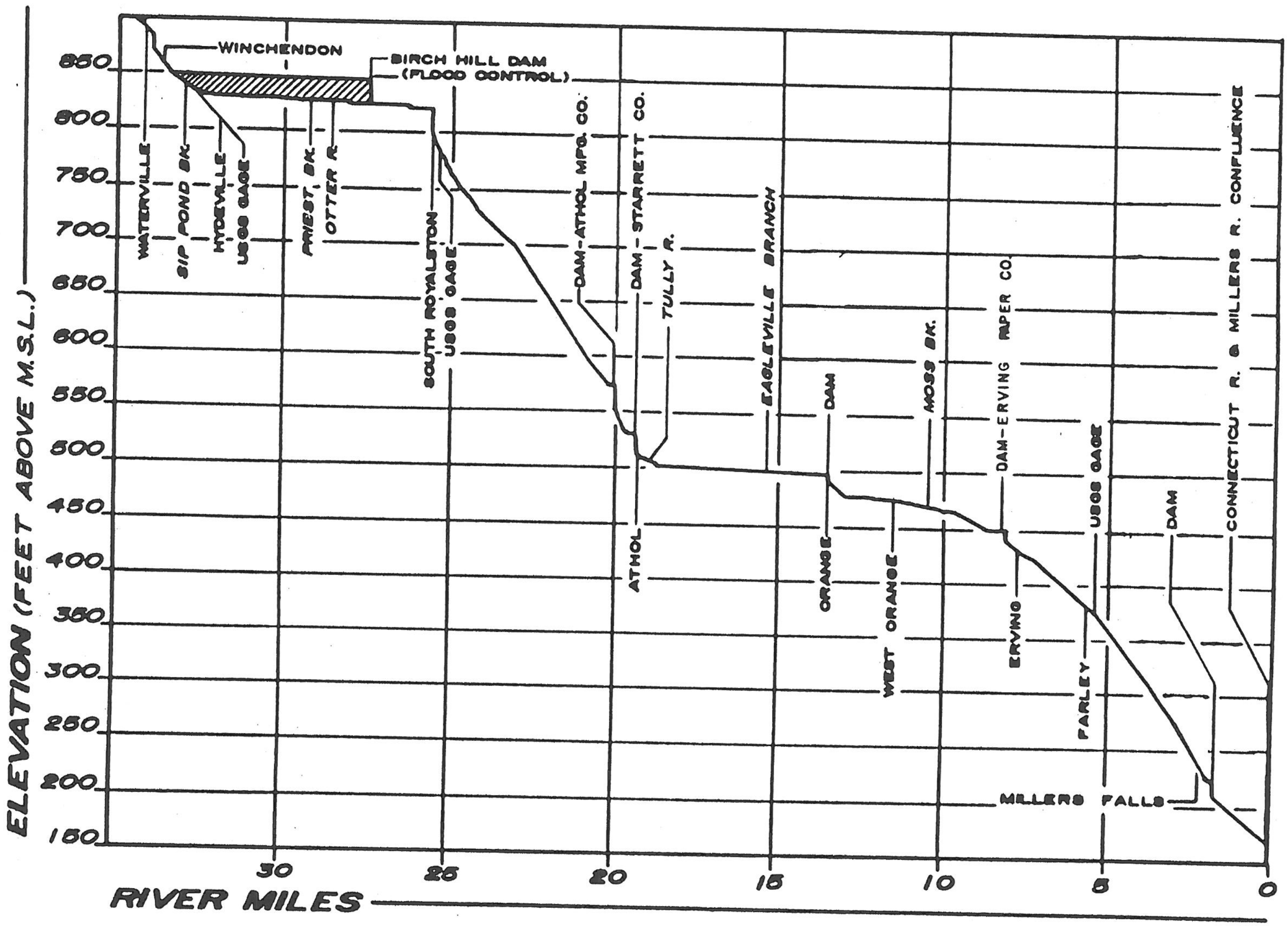
Summary of Predicted Concentrations
Assabet River Basin

		Monitored Flows...							7-Q-10 Flows...						
Discharge	River Mile	Effluent Flow cfs	Effluent Conc ppm	Upstream Flow cfs	Measured Upstream Conc ppm	.... Downstream Concs .... Existing ppm	Ban ppm	Routed ppm	Upstream Flow cfs	Measured Upstream Conc ppm	Downstream Concs Existing ppm	Ban ppm	Upstream N/P -	Existing Downstr N/P -	P Ban Downstr N/P -
Westboro Regional	30.0	2.70	5.04	1.98	0.09	2.94	1.99	1.99	3.51	0.09	2.24	1.52	17.2	5.2	7.7
Marlboro West	24.0	2.32	13.30	9.87	1.15	3.46	2.63	2.34	9.88	1.15	3.46	2.63	2.0	1.8	2.3
Hudson	15.9	3.16	5.72	20.57	0.83	1.48	1.23	1.00	14.00	0.83	1.73	1.38	3.0	2.9	3.6
Maynard	6.7	1.93	6.42	32.37	0.78	1.10	0.98	0.75	15.10	0.78	1.42	1.18	1.3	1.9	2.2
Concord MCI	2.3	0.29	7.85	49.40	0.69	0.73	0.72	0.51	23.00	0.69	0.78	0.75	1.6	1.6	1.7

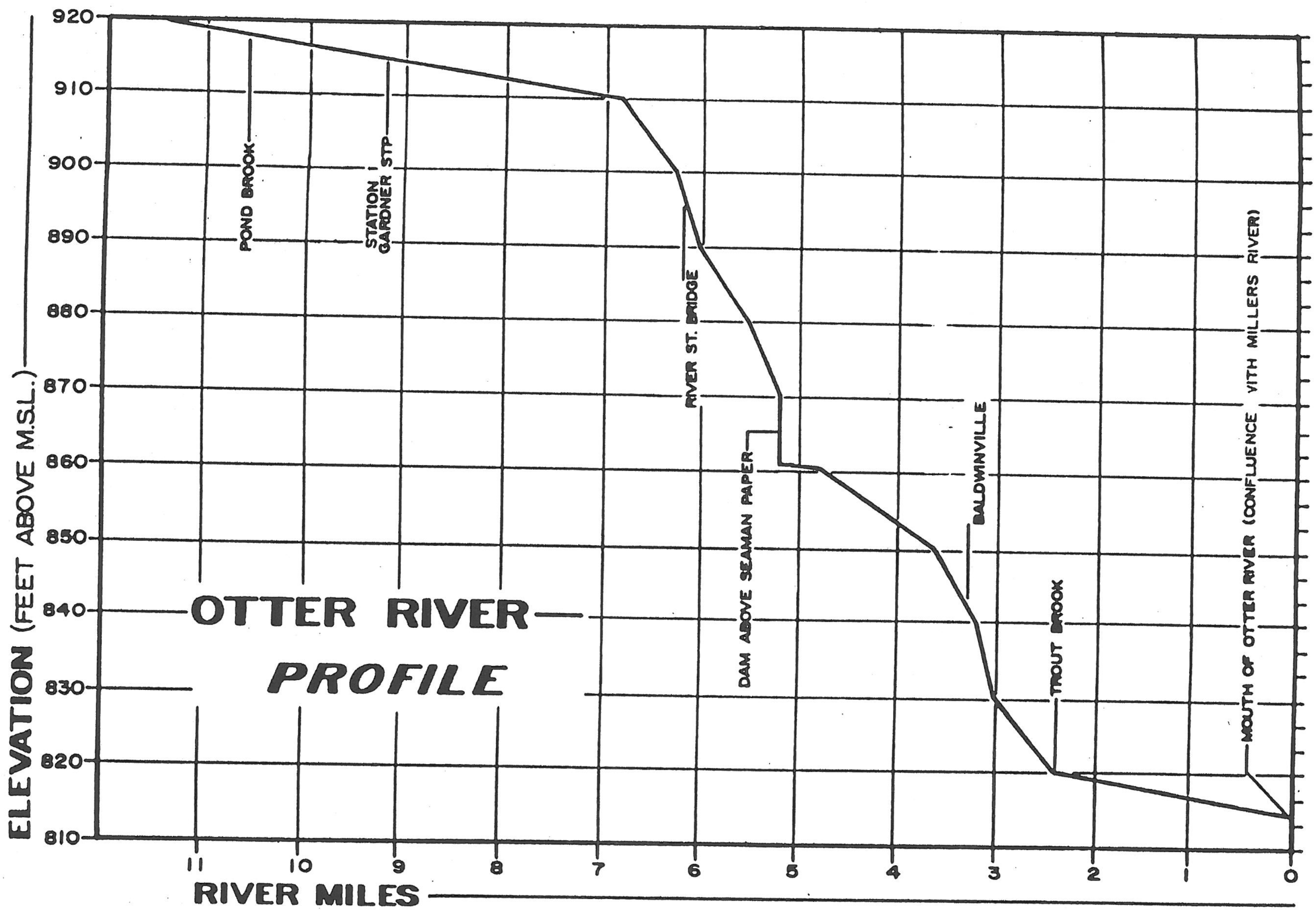
Assabet River Basin

	..... Flow Condition		
Basinwide Summary	Average Flow	Monitored Flow	7-Q-10
Runoff cfs/mi2	1.59	0.28	0.13
Loads (lbs/day)...			
Non-Point	136	24	11
Point Non-Detergent	279	279	279
Detergent	137	137	137
Total	552	440	427
Percent of Total...			
Non-Point	24.7%	5.4%	2.6%
Point Non-Detergent	50.5%	63.4%	65.3%
Detergent	24.9%	31.2%	32.1%
Total	100.0%	100.0%	100.0%

The PROFILE of the MILLERS RIVER



SOURCE: MDWPC. 1973. The Millers River Basin Survey. 1973.



SOURCE: MDWPC. 1973. The Millers River Basin Survey. 1973.

Millers River Basin
Mass Balance - Monitored Flow Conditions

Upst Nonpoint Export	0.37	lbs/day/mi2
Monitored Runoff	0.85	cfs/mi2
Detergent P Fraction	0.33	
P Removal Max Effl P	1.00	mg/liter

STP Name	River Mile	Upstream Drainage Area mi2	Increm. Drainage Area mi2	Upstream Flow cfs	Measured Upstream P conc ppm	Measured Upstream Load lbs/day	STP Flow cfs	STP P Conc ppm	STP Load lbs/day	Increm. NonPoint Load lbs/day	Detergent Load lbs/day	Non-Det. STP Load lbs/day	Reach Calib. Factor -	Nonpoint Export lbs/mi2-d
		0												
	34.8	81.8	81.8	70.5	0.08	30				30			1.00	0.37
Winchendon	34.7	81.8					0.55	2.11	6		2	4		
	31.2	178.0	96.2	153.3	0.10	80				43			1.00	0.45
Otter River STPs	31.1	178.0					8.01	2.59	112		37	75		
	27.1	188.0	10.0	161.9	0.16	140				4			0.71	0.37
Beaver Brk STP's	27.0	188.0					0.06	4.88	2		1	1		
	27.0	189.0	1.0	163.2	0.16	141				0			0.99	0.37
S. Royalston	26.9	189.0					0.01	4.20	0		0	0		
	21.6	200.0	11.0	170.8	0.17	157				16			1.00	1.41
Athol Filter Plant	21.5	200.0					0.07	0.18	0		0	0		
	20.8	203.0	3.0	173.4	0.17	159				2			1.00	0.76
L.S. Starret Co.	20.7	203.0					0.05	0.28	0		0	0		
	19.2	220.0	17.0	187.9	0.14	142				6			0.86	0.37
Athol	19.1	220.0					1.77	4.04	39		13	26		
	17.4	253.4	33.4	216.4	0.15	169				12			0.88	0.37
MCI Warwick	17.3	253.4					0.01	1.04	0		0	0		
	13.9	318.3	64.9	271.9	0.15	220				51			1.00	0.78
Orange	13.8	318.3					0.48	1.82	5		2	3		
	8.2	352.0	33.7	300.7	0.16	259				35			1.00	1.03
Erving Center	8.1	352.0					3.45	0.60	11		4	7		
	5.8	372.0	20.0	311.5	0.14	235				7			0.85	0.37
Farley	5.7	372.0					0.01	2.93	0		0	0		
	0.1	389.0	17.0	332.2	0.16	286				51			1.00	3.02
Millers Falls	0.0	389.0					0.71	0.64	2		1	2		

Millers River Basin

Mass Balance - Monitored Flow Conditions

Upst Nonpoint Export Coef	0.37	lbs/day/mi2
Monitored Runoff	0.85	cfs/mi2
Detergent P Fraction	0.33	
P Removal Max Effl P	1	mg/liter

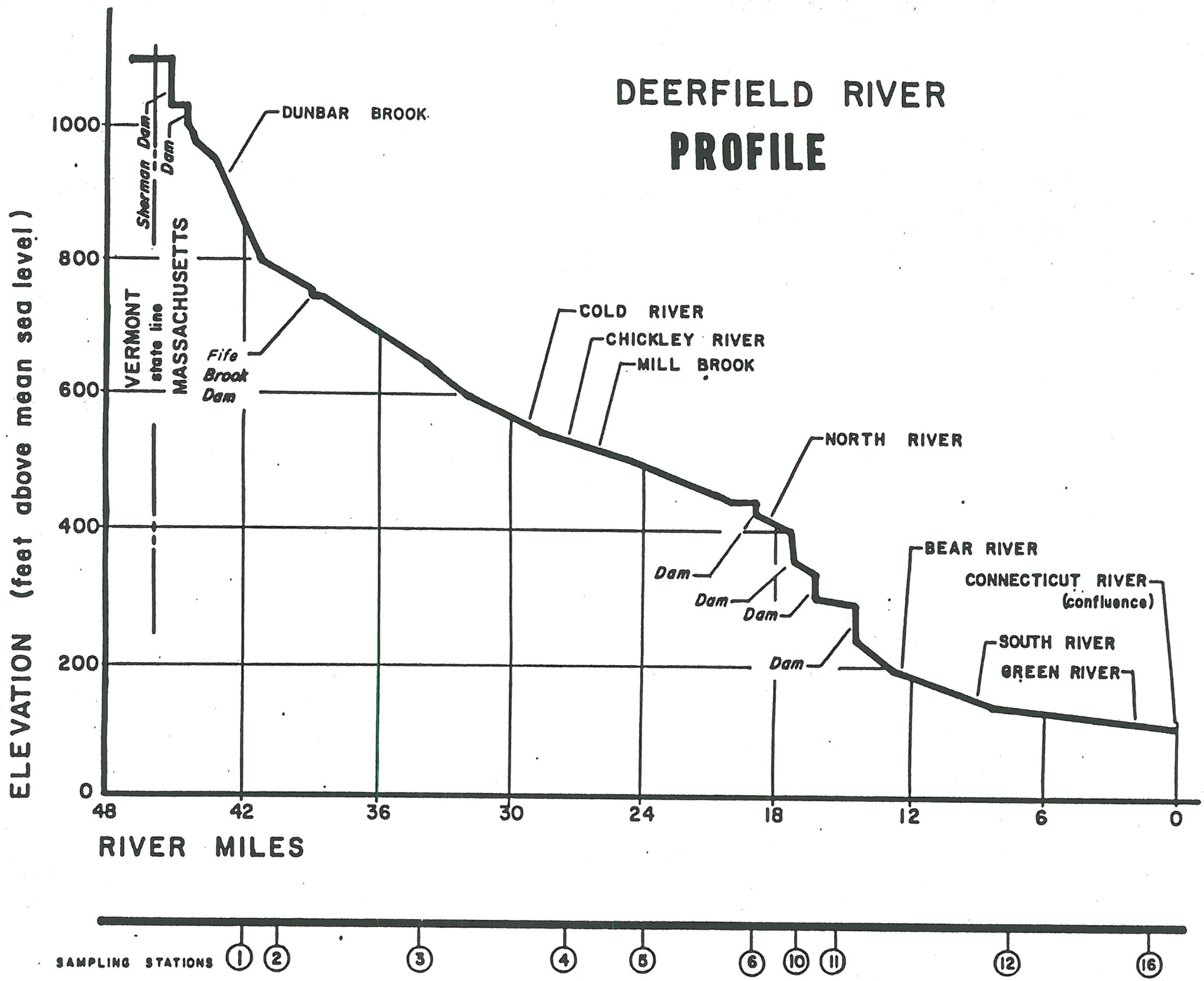
			....Existing....		...Detergent-Ban...		......Phosphorus-Removal.......				..NonPoint-Only..	
STP Name	River Mile	Total Flow cfs	Total Load lbs/day	River Conc ppm	River Load lbs/day	River Conc ppm	Effluent Conc ppm	Effluent Load lbs/day	River Load lbs/day	River Conc ppm	River Load lbs/day	River Conc ppm
			0									
	34.8	70.5	30	0.080	30	0.080			30	0.080	30	0.080
Winchendon	34.7	71.0	37	0.096	35	0.090	1.00	3.0	33	0.087	30	0.079
	31.2	153.3	80	0.097	78	0.094			77	0.093	74	0.089
Otter River STPs	31.1	161.3	192	0.221	153	0.176	1.00	43.2	120	0.138	74	0.085
	27.1	161.9	140	0.160	112	0.128			88	0.101	55	0.063
Beaver Brk STP's	27.0	162.0	141	0.162	113	0.129	1.00	0.3	89	0.102	55	0.063
	27.0	163.2	141	0.160	113	0.128			88	0.101	55	0.063
S. Royalston	26.9	163.2	141	0.160	113	0.128	1.00	0.1	89	0.101	55	0.063
	21.6	170.8	157	0.170	128	0.139			104	0.113	71	0.077
Athol Filter Plant	21.5	170.9	157	0.170	128	0.139	0.18	0.1	104	0.113	71	0.077
	20.8	173.4	159	0.170	131	0.140			106	0.114	73	0.078
L.S. Starret Co.	20.7	173.4	159	0.170	131	0.140	0.28	0.1	106	0.114	73	0.078
	19.2	187.9	142	0.140	118	0.116			97	0.096	68	0.067
Athol	19.1	189.7	180	0.176	143	0.140	1.00	9.5	106	0.104	68	0.067
	17.4	216.4	169	0.145	137	0.117			104	0.089	71	0.061
MCI Warwick	17.3	216.4	169	0.145	137	0.117	1.00	0.1	104	0.089	71	0.061
	13.9	271.9	220	0.150	187	0.128			155	0.106	121	0.083
Orange	13.8	272.3	224	0.153	190	0.130	1.00	2.6	157	0.107	121	0.083
	8.2	300.7	259	0.160	225	0.139			192	0.119	156	0.096
Erving Center	8.1	304.1	270	0.165	233	0.142	0.60	11.2	203	0.124	156	0.095
	5.8	311.5	235	0.140	203	0.121			178	0.106	138	0.082
Farley	5.7	311.5	235	0.140	203	0.121	1.00	0.0	178	0.106	138	0.082
	0.1	332.2	286	0.160	255	0.142			230	0.128	190	0.106
Millers Falls	0.0	332.9	289	0.161	256	0.143	0.64	2.4	232	0.129	190	0.106

Summary of Predicted Concentrations
Millers River Basin

Discharge	River Mile	Effluent Flow cfs	Effluent Conc ppm	Monitored Flows... Upstream Flow cfs	Measured Upstream Conc ppm	.... Downstream Concs .... Existing ppm	Ban ppm	Routed ppm	7-Q-10 Flows... Upstream Flow cfs	Measured Upstream Conc ppm	Downstream Concs Existing ppm	Ban ppm	Upstream N/P -	Existing Downstr N/P -	P Ban Downstr N/P -
Winchendon	34.7	0.55	2.11	70.45	0.08	0.10	0.09	0.09	6.90	0.08	0.23	0.18	9.5	3.9	5.0
Otter River STPs	31.1	8.01	2.59	153.30	0.10	0.22	0.18	0.18	15.01	0.10	0.96	0.67	9.5	1.6	2.3
Beaver Brk STP's	27	0.06	4.88	161.91	0.16	0.16	0.16	0.13	15.86	0.16	0.18	0.17	8.6	7.8	8.1
S. Royalston	26.9	0.01	4.20	163.20	0.16	0.16	0.16	0.13	22.30	0.16	0.16	0.16	8.6	8.5	8.6
Athol Filter Plant	21.5	0.07	0.18	170.80	0.17	0.17	0.17	0.14	30.20	0.17	0.17	0.17	6.5	6.5	6.5
L.S. Starret Co.	20.7	0.05	0.28	173.35	0.17	0.17	0.17	0.14	30.70	0.17	0.17	0.17	6.6	6.6	6.6
Athol	19.1	1.77	4.04	187.90	0.14	0.18	0.16	0.14	33.27	0.14	0.34	0.27	7.7	3.7	4.6
MCI Warwick	17.3	0.01	1.04	216.41	0.15	0.15	0.15	0.12	38.32	0.145	0.15	0.15	7.7	7.7	7.7
Orange	13.8	0.48	1.82	271.85	0.15	0.15	0.15	0.13	40.80	0.15	0.17	0.16	9.7	8.7	9.1
Erving Center	8.1	3.45	0.60	300.65	0.16	0.16	0.16	0.14	46.56	0.16	0.19	0.18	9.1	7.9	8.5
Farley	5.7	0.01	2.93	311.50	0.14	0.14	0.14	0.12	51.30	0.14	0.14	0.14	7.6	7.6	7.6
Millers Falls	0	0.71	0.64	332.20	0.16	0.16	0.16	0.14	53.60	0.16	0.17	0.16	6.9	6.7	6.8

Millers River Basin

Basinwide Summary	..... Flow Condition .... Average Flow	Monitored Flow	7-Q-10
Runoff cfs/mi2	1.71	0.85	0.14
Loads (lbs/day)...			
Non-Point	517	259	42
Point Non-Detergent	119	119	119
Detergent	58	58	58
Total	694	435	219
Percent of Total...			
Non-Point	74.5%	59.4%	19.1%
Point Non-Detergent	17.1%	27.2%	54.2%
Detergent	8.4%	13.4%	26.7%
Total	100.0%	100.0%	100.0%



SOURCE: MDWPC. 1975. Deerfield River Basin.

Deerfield River Basin
Mass Balance - Monitored Flow Conditions

Upst Nonpoint Export	0.30	lbs/day/mi2
Monitored Runoff	1.11	cfs/mi2
Detergent P Fraction	0.33	
P Removal Max Effl P	1.00	mg/liter

STP Name	River Mile	Upstream Drainage Area mi2	Increm. Drainage Area mi2	Upstream Flow cfs	Measured Upstream P conc ppm	Measured Upstream Load lbs/day	STP Flow cfs	STP P Conc ppm	STP Load lbs/day	Increm. NonPoint Load lbs/day	Detergent Load lbs/day	Non-Det. STP Load lbs/day	Reach Calib. Factor -	Nonpoint Export lbs/mi2-d
		0												
	18.8	499.0	499.0	553.4	0.05	149				149			1.00	0.30
Kendall Co. WWTP	18.7	499.0					2.09	6.60	74		25	50		
	16.0	509.5	10.5	565.0	0.07	213				3			0.94	0.30
Buckland/Shelrbourne	15.9	509.5					0.39	2.65	6		2	4		
	4.3	566.0	56.5	627.7	0.06	203				17			0.86	0.30
Old Deerfield WWTP	4.2	566.0					0.39	2.95	6		2	4		
	2.0	663.0	97.0	735.3	0.05	198				29			0.83	0.30
Greenfield WWTP	1.9	663.0					4.95	2.65	71		23	47		

			....Existing....		...Detergent-Ban...		......Phosphorus-Removal.......				..NonPoint-Only..	
STP Name	River Mile	Total Flow cfs	Total Load lbs/day	River Conc ppm	River Load lbs/day	River Conc ppm	Effluent Conc ppm	Effluent Load lbs/day	River Load lbs/day	River Conc ppm	River Load lbs/day	River Conc ppm
			0									
	18.8	553.4	149	0.050	149	0.050			149	0.050	149	0.050
Kendall Co. WWTP	18.7	555.5	223	0.075	199	0.066	1.00	11.3	160	0.054	149	0.050
	16.0	565.0	213	0.070	190	0.062			154	0.051	143	0.047
Buckland/Shelrbour	15.9	565.4	219	0.072	194	0.064	1.00	2.1	156	0.051	143	0.047
	4.3	627.7	203	0.060	182	0.054			149	0.044	138	0.041
Old Deerfield WWTP	4.2	628.1	209	0.062	186	0.055	1.00	2.1	151	0.045	138	0.041
	2.0	735.3	198	0.050	179	0.045			150	0.038	139	0.035
Greenfield WWTP	1.9	740.2	269	0.067	226	0.057	1.00	26.7	176	0.044	139	0.035

Summary of Predicted Concentrations
Deerfield River Basin

		Monitored Flows...							7-Q-10 Flows...						
					Measured					Measured				Existing	P Ban
		Effluent	Effluent	Upstream	Upstream	.... Downstream Concs			Upstream	Upstream	Downstream Concs		Upstream	Downstr	Downstr
	River	Flow	Conc	Flow	Conc	Existing	Ban	Routed	Flow	Conc	Existing	Ban	N/P	N/P	N/P
Discharge	Mile	cfs	ppm	cfs	ppm	ppm	ppm	ppm	cfs	ppm	ppm	ppm	-	-	-
Kendall Co. WWTP	18.7	2.09	6.60	553.40	0.050	0.075	0.066	0.066	85.64	0.050	0.206	0.154	18.0	5.1	6.9
Buckland/Shelrbourne	15.9	0.39	2.65	565.04	0.070	0.072	0.071	0.064	87.44	0.070	0.081	0.078	12.9	11.2	11.8
Old Deerfield WWTP	4.2	0.39	2.95	627.70	0.060	0.062	0.061	0.055	97.14	0.060	0.072	0.068	13.5	11.4	12.1
Greenfield WWTP	1.9	4.95	2.65	735.27	0.050	0.067	0.062	0.057	113.79	0.050	0.158	0.122	28.8	10.0	13.0

Deerfield River Basin

	..... Flow Condition		
	Average	Monitored	
Basinwide Summary	Flow	Flow	7-Q-10
Runoff cfs/mi2	2.30	1.11	0.17
Loads (lbs/day)...			
Non-Point	412	198	31
Point Non-Detergent	105	105	105
Detergent	52	52	52
Total	568	355	187
Percent of Total...			
Non-Point	72.4%	55.8%	16.4%
Point Non-Detergent	18.5%	29.6%	56.0%
Detergent	9.1%	14.6%	27.6%
Total	100.0%	100.0%	100.0%

Phosphorus Balance for Massachusetts

Model Inputs & Assumptions...

Inputs...	Value	Units	Reference................................
Nonpoint Source Export....			
Pervious Export Coef.	10	kg/km2-yr	Walker (1978, 1982)
Impervious Export Coef.	250	kg/km2-yr	Athayede et al (1983), Walker (1978, 1982)
Agricultural Export Coef.	40	kg/km2-yr	Walker (1978, 1982)
Imperv. Acres/Capita	0.05		Huber & Dikinson (1988)
Undev. Impervious Frac.	0.02		Huber & Dikinson (1988)
Watershed Runoff	25	in/yr	NALMS (1990), USGS Streamflow Records
Wastewater Effluent Phosphorus Concentrations...			
Detergent P/Total P	0.33		Walker (1987), Average for Maryland Plants
Total P	5.5	ppm	" ", USEPA (1974) Median for Mass. Plants = 5.4 ppm
Detergent P	1.8	ppm	" "
Other P	3.7	ppm	" "
AWT Effluent P	1.0	ppm	NPDES Permits (Table 6)
Onsite Wastewater Disposal Systems...			
Influent Total P/Capita	2.80	lbs/c-yr	Reckhow et al. (1980), USEPA (1974,1975)
Detergent P/Cap	0.92	lbs/c-yr	" , 33% detergent P (Walker, 1987)
Nondeterg P/Cap	1.88	lbs/c-yr	" , 67% non-detergent P (Walker, 1987)
P Removal	95%		USEPA (1975) 93% for systems within 100 m of stream
Agricultural Land Use Fractions...			
Statewide	0.113		Greenbaum & O'Donnell (1987)
Boston Harbor	0.010		assumed
Other Basins	0.118		calibrated to give statewide fraction of .113
Fraction of Population Using Onsite Disposal Systems....			
Statewide	0.300		Coburn (1989)
Boston Harbor	0.050		assumed
Other Basins	0.355		calibrated to give statewide fraction of .3
WWTP Inventory & Effluent Flows			Coburn (1989)
Basin Populations			Coburn (1989)

Phosphorus Balance for Massachusetts
Results...

Basin	No. of WWTP's	Effluent mgd	Total acres	Population 1988	AWT Effluent with P Limit mgd	WWTP Effluent without P Limit mgd	NonPoint Load lbs/d	AWT Load lbs/d	.....Existing Loads..... Septic Load lbs/d	WWTP Load lbs/d	Total Load lbs/d	... With Detergent Ban... Septic Load lbs/d	WWTP Load lbs/d	Total Load lbs/d	Total With Ban Detergent Load lbs/d	Percent Reduction %
Blackstone *	8	34.30	214020	309400	0.39	33.91	186	3	42	1555	1787	28	1042	1260	527	29.5%
Boston Harbor	3	394.82	193670	1039900		394.82	376	0	20	18110	18506	13	12134	12523	5983	32.3%
Buzzards Bay	5	32.96	245440	241900		32.96	181	0	33	1512	1725	22	1013	1216	510	29.5%
Cape Cod	3	2.19	273300	173000		2.19	173	0	24	100	297	16	67	256	41	13.8%
Charles *	3	6.78	204760	921900	3.79	2.99	362	32	126	137	656	84	92	569	87	13.2%
Chicopee *	8	5.49	462090	168400	2.11	3.38	256	18	23	155	452	15	104	393	59	13.0%
Concord *	4	5.99	142540	196242	2.80	3.19	121	23	27	146	318	18	98	261	57	18.0%
Assabet *	4	9.12	113280	155958		9.12	96	0	21	418	536	14	280	391	145	27.1%
Connecticut *	14	78.80	420050	402600		78.80	306	0	55	3615	3975	37	2422	2764	1211	30.5%
Deerfield *	4	3.36	221600	31400		3.36	108	0	4	154	267	3	103	214	52	19.6%
Farmington *	0	0.00	97500	3600		0.00	45	0	0	0	45	0	0	45	0	0.4%
French *	3	3.73	30940	21000	2.47	1.26	20	21	3	58	101	2	39	81	20	19.8%
Hudson *	2	6.61	131050	42400		6.61	71	0	6	303	380	4	203	278	102	26.8%
Housatonic *	6	13.20	320680	96100	10.56	2.64	172	88	13	121	394	9	81	350	44	11.2%
Ipswich	0	0.00	101820	133000		0.00	85	0	18	0	103	12	0	97	6	5.8%
Islands	2	0.14	102940	18500		0.14	51	0	3	6	60	2	4	57	3	4.9%
Merrimack *	9	58.04	195600	379100		58.04	199	0	52	2662	2912	35	1784	2017	896	30.8%
Millers *	8	8.85	199230	52200		8.85	104	0	7	406	517	5	272	381	136	26.3%
Narragansett	1	25.00	72180	83000		25.00	57	0	11	1147	1215	8	768	832	382	31.5%
Nashua *	6	23.60	288910	187500	20.02	3.58	184	167	26	164	541	17	110	478	63	11.6%
North Shore	9	116.52	100610	370200		116.52	153	0	50	5345	5549	34	3581	3768	1780	32.1%
Parker	0	0.00	54920	29300		0.00	33	0	4	0	37	3	0	36	1	3.5%
Quinebaug *	4	3.71	133260	60300		3.71	77	0	8	170	256	6	114	197	59	23.0%
Shawsheen *	0	0.00	34690	74400		0.00	37	0	10	0	47	7	0	44	3	7.0%
South Shore	5	6.29	146250	139500	2.20	4.09	106	18	19	188	331	13	126	263	68	20.6%
Taunton *	8	21.98	334170	405000	12.72	9.26	268	106	55	425	854	37	285	696	158	18.5%
Ten Mile *	3	6.80	32290	53200	6.80	0.00	30	57	7	0	94	5	0	92	2	2.5%
Westfield *	3	3.04	333010	91500		3.04	176	0	12	139	328	8	93	278	50	15.3%
Statewide Total	125	871.32	5200800	5880500	63.86	807.46	4034	533	679	37038	42284	455	24816	29837	12447	29.4%
Excl. Boston Harb.	122	476.50	5007130	4840600	63.86	412.64	3658	533	659	18928	23778	442	12682	17314	6464	27.2%
Inland Basins *	102	299.69	4055920	3791700	63.86	235.83	2925	533	516	10818	14792	346	7248	11051	3740	25.3%

Phosphorus Balance for Massachusetts
Supplementary Calculations..

						WWTP		..... Average Inflow Concentrations					....	Per Capita Loads		
	Pop	Effluent		Nonpoint	Total	Effluent	Pristine	... Total P Load Diluted in Total Runoff...						Existing	With Ban	Detergent
	Dens	Volume	Imperv	Export	Runoff	/Runoff	P Load	Pristine	NonPoint	Existing	With Ban	Decrease	Nonpoint	Total	Total	Only
Basin	cap/ac	gal/c-d	Frac	kg/km2-y	cfs	%	lbs/day	ppm	ppm	ppm	ppm	ppm	lbs/c-yr	lbs/c-yr	lbs/c-yr	lbs/c-yr
Blackstone *	1.45	111	0.092	35.7	616	8.6%	52	0.016	0.056	0.538	0.380	0.159	0.22	2.11	1.49	0.62
Boston Harbor	5.37	589	0.288	79.6	557	109.6%	47	0.016	0.125	6.161	4.169	1.992	0.13	6.50	4.40	2.10
Buzzards Bay	0.99	143	0.069	30.2	706	7.2%	60	0.016	0.047	0.453	0.319	0.134	0.27	2.60	1.83	0.77
Cape Cod	0.63	20	0.052	25.9	786	0.4%	67	0.016	0.041	0.070	0.060	0.010	0.36	0.63	0.54	0.09
Charles *	4.50	11	0.245	72.4	589	1.8%	50	0.016	0.114	0.207	0.179	0.027	0.14	0.26	0.23	0.03
Chicopee *	0.36	51	0.038	22.7	1330	0.6%	113	0.016	0.036	0.063	0.055	0.008	0.55	0.98	0.85	0.13
Concord *	1.38	47	0.089	34.9	410	2.3%	35	0.016	0.055	0.144	0.118	0.026	0.23	0.59	0.48	0.11
Assabet *	1.38	91	0.089	34.9	326	4.3%	28	0.016	0.055	0.305	0.222	0.083	0.23	1.25	0.91	0.34
Connecticut *	0.96	303	0.068	29.8	1209	10.1%	103	0.016	0.047	0.610	0.424	0.186	0.28	3.60	2.51	1.10
Deerfield *	0.14	166	0.027	20.0	638	0.8%	54	0.016	0.032	0.078	0.062	0.015	1.26	3.10	2.49	0.61
Farmington *	0.04	0	0.022	18.8	281	0.0%	24	0.016	0.030	0.030	0.030	0.000	4.53	4.58	4.56	0.02
French *	0.68	275	0.054	26.5	89	6.5%	8	0.016	0.042	0.211	0.169	0.042	0.35	1.76	1.41	0.35
Hudson *	0.32	242	0.036	22.2	377	2.7%	32	0.016	0.035	0.187	0.137	0.050	0.61	3.27	2.39	0.88
Housatonic *	0.30	213	0.035	21.9	923	2.2%	78	0.016	0.035	0.079	0.070	0.009	0.65	1.50	1.33	0.17
Ipswich	1.31	0	0.085	34.0	293	0.0%	25	0.016	0.054	0.065	0.061	0.004	0.23	0.28	0.27	0.02
Islands	0.18	12	0.029	20.5	296	0.1%	25	0.016	0.032	0.038	0.036	0.002	1.02	1.19	1.13	0.06
Merrimack *	1.94	237	0.117	41.6	563	16.0%	48	0.016	0.065	0.960	0.665	0.295	0.19	2.80	1.94	0.86
Millers *	0.26	263	0.033	21.5	573	2.4%	49	0.016	0.034	0.167	0.123	0.044	0.73	3.62	2.67	0.95
Narragansett	1.15	467	0.077	32.1	208	18.6%	18	0.016	0.051	1.085	0.744	0.341	0.25	5.34	3.66	1.68
Nashua *	0.65	195	0.052	26.1	831	4.4%	71	0.016	0.041	0.121	0.107	0.014	0.36	1.05	0.93	0.12
North Shore	3.68	488	0.204	62.5	290	62.3%	25	0.016	0.098	3.556	2.415	1.141	0.15	5.47	3.72	1.76
Parker	0.53	0	0.047	24.7	158	0.0%	13	0.016	0.039	0.044	0.042	0.002	0.41	0.46	0.45	0.02
Quinebaug *	0.45	95	0.043	23.8	383	1.5%	33	0.016	0.037	0.124	0.095	0.028	0.47	1.55	1.19	0.36
Shawsheen *	2.14	0	0.127	44.1	100	0.0%	8	0.016	0.069	0.088	0.082	0.006	0.18	0.23	0.22	0.02
South Shore	0.95	70	0.068	29.8	421	2.3%	36	0.016	0.047	0.146	0.116	0.030	0.28	0.87	0.69	0.18
Taunton *	1.21	84	0.081	32.9	962	3.5%	82	0.016	0.052	0.165	0.134	0.031	0.24	0.77	0.63	0.14
Ten Mile *	1.65	198	0.102	38.1	93	11.3%	8	0.016	0.060	0.188	0.183	0.005	0.21	0.64	0.63	0.02
Westfield *	0.27	52	0.034	21.6	958	0.5%	81	0.016	0.034	0.063	0.054	0.010	0.70	1.31	1.11	0.20
Statewide Total	1.13	212	0.077	31.8	14966	9.0%	1270	0.016	0.050	0.524	0.370	0.154	0.25	2.62	1.85	0.77
Excl. Boston Harb.	0.97	153	0.068	29.9	14409	5.1%	1222	0.016	0.047	0.306	0.223	0.083	0.28	1.79	1.31	0.49
Inland Basins *	0.93	123	0.067	29.6	11672	4.0%	990	0.016	0.046	0.235	0.176	0.059	0.28	1.42	1.06	0.36