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Final Report

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EXECUTIVE SUMMARY

This report serves to document the water quality status of the Assabet River as part of a nutrient Total Maximum Daily Load (TMDL) evaluation and allocation process. A field investigation of the Assabet River system was conducted from July 1999 through October 2000 and a review of historic water quality studies were performed. The field investigation featured collection of measurements of the hydrology, water quality, and aquatic biology of the Assabet River during 13 surveys. The goal of the field investigation was to quantify and document the presence of eutrophic conditions and associated factors in the Assabet River. Nutrient loadings and dynamics in the Assabet River were a primary focus of the investigation. The study also focused on characterizing the aquatic biology of the Assabet River and the interrelationship between nutrients and biology in the system.

The field investigation concluded that the Assabet River receives an excess of the nutrients, phosphorus and nitrogen, resulting in nutrient saturation and excessive growth of aquatic vegetation. Summer-time dissolved oxygen concentration measurements in the Assabet River were frequently below the water quality standard of 5.0 mg/l. Summer-time vegetation densities in the Assabet River were observed to be at levels associated with impairment of water quality and designated uses. The ENSR 1999-2000 Assabet River water quality field investigation along with a review of historic water quality surveys is documented in this report

This executive summary contains the following components:

- An overview of the Assabet River's water quality impairment,
- A description of the TMDL allocation process,
- A brief summary of the review of historic water quality studies,
- A brief summary of the ENSR 1999-2000 Assabet River field investigation, and
- Conclusions.

Overview

The Assabet River experiences a severe ecological condition known as eutrophication. Eutrophication is a process of nutrient accumulation and ecosystem change that can occur in aquatic ecosystems. This process can occur naturally as part of a long-term transition (e.g., from lake to marsh). Eutrophication can also occur culturally whereby the process is dramatically accelerated by the activities of man (McNaughton and Wolf, 1973). In the Assabet River, cultural eutrophication has occurred in the presence of excessive nutrient loadings and dammed impoundments.

The presence of eutrophication in the Assabet River is problematic because high growth rates of biota have been observed to result in production of nuisance aquatic vegetation such as algal mats, floating macrophytes, rooted vegetation, and phytoplankton. These growths are aesthetically undesirable and, due to impacts on dissolved oxygen, they threaten the existence of fish and other aquatic organisms.

Phosphorus and nitrogen are the two primary essential nutrients for plant growth. Phosphorus is found in dissolved and particulate forms in the aquatic environment. Dissolved phosphorus contains ortho-phosphorus that is representative of biologically available phosphorus. Ortho-phosphorus may be readily taken up by aquatic organisms. Total phosphorus represents both the dissolved form (including ortho-phosphorus) and the particulate form that must be converted by natural biological processes prior to aquatic plant uptake. Thus, ortho-phosphorus is readily available phosphorus and total phosphorus represents the total amount of phosphorus that may potentially be taken up by aquatic organisms.

Nitrogen is found in several forms in the aquatic environment. Some nitrogen forms are more readily available for uptake by aquatic organisms than others. Ammonium and nitrate are the two forms of nitrogen that are most readily accessible for biological uptake. Organic nitrogen, in contrast, is bound up in organic material and is unavailable for immediate bioligical uptake. Organic nitrogen is also important, however, because it may converted through natural biological processes into ammonium and nitrate forms and taken up by aquatic organisms.

As a result of water quality problems associated with eutrophication, the Assabet River was placed on a list of impaired waterbodies requiring water quality improvement, known as a Section 303(d) list (SuAsCo, 1996). Specifically, the Assabet River, designated as a Class B waterbody, has been observed to frequently fail to meet applicable numerical water quality standards for dissolved oxygen concentration, fecal coliform bacteria counts, and pH and for applicable narrative criteria for nuisance aquatic vegetation during the summer-time. According to the Clean Water Act, states are required to develop a Total Maximum Daily Load (TMDL) allocation plan for all priority waterbodies on the Section 303(d) list. Thus, the Massachusetts Department of Environmental Protection (DEP), in conjunction with the US Army Corps of Engineers (Corps), is currently developing a TMDL allocation for nutrients in the Assabet River.

Corps involvement with the TMDL process has been limited to the collection of data and study preparation. Authority for Corps participation is provided in its Section 22 “Planning Assistance to States” program (Water Resources Development Act of 1974, Public Law 93-251, as amended) which enables Corps cooperation with the states in preparation of plans for the development, utilization, and conservation of water and related land resources. A Cost Sharing Agreement was signed by the Corps and the DEP (the non-Federal sponsor) on March 25, 1999 (amended on May 3, 2000 and again on January 11, 2001), enabling the Corps and DEP to split the cost of this work on a 50/50 basis.

The TMDL Allocation Development Process

A TMDL allocation is an analysis that establishes the maximum loadings that a waterbody may receive and maintain its water quality standards and designated uses, including compliance with numeric and narrative standards. The TMDL development process has been specified by USEPA (1991) and may be described in five steps, as follows:

1. Determination and documentation of whether or not a waterbody is presently meeting its water quality standards and designated uses,

2. Assessment of present water quality conditions in the waterbody, including estimation of present loadings of constituents of concerns from both point and non-point sources,

3. Determination of the loading capacity of the waterbody. EPA regulations define the loading capacity as the greatest amount of loading that a waterbody may receive without violating water quality standards. If the waterbody is not presently meeting its designated uses, then the loading capacity will represent a reduction relative to present loadings.

4. Specification of load allocations, based on the loading capacity determination, for non-point sources (LAs) and point sources (WLAs), that will ensure that the waterbody will not violate water quality standards.

5. Development of a plan to (1) implement load allocations and wasteload allocations developed based on the waterbody loading capacity determination and (2) monitor the waterbody to ensure compliance with water quality standards.

The TMDL development process begins with assessment of the present condition of a waterbody and concludes with specification and implementation of a set of modified loadings deemed necessary to bring the waterbody into compliance with water quality standards. The steps of the TMDL can be divided into Assessment (Steps 1 and 2); Analysis (Steps 3 and 4), often through numerical modeling; and Planning (Step 5). This report supports the waterbody assessment steps listed above through the 1999-2000 field investigation and the review of previous water quality studies.

Water quality modeling is necessary to determine the loading capacity of the Assabet River and to allocate acceptable point and non-point source loadings (i.e., Steps 3 and 4 above). Determination of the loading capacity of the Assabet River is a complex task requiring sufficient supporting data and an appropriate assessment tool. The most reliable and defensible assessment tool for establishing loading capacities is a mathematical water quality model. A water quality model provides a numerical representation of the physical, hydrological, chemical, and biological characteristics of a river.

The field investigation described in this report was designed to collect the measurements required to support development of a water quality modeling application for the Assabet River. A water quality model requires a sufficient set of data to achieve project objectives. Once established, water quality models are capable of simulating present conditions in the river in terms of hydrology, water quality, and biology. More importantly, water quality models are capable of predicting water quality and biological conditions associated with hypothetical scenarios (e.g., nutrient reduction scenarios). The five steps outlined and discussed above must be performed in order to successfully complete the TMDL allocation process.

Review of Previous Studies

A review of previous studies on the Assabet River system was performed to enhance understanding of the hydrology, water quality, and ecology of the Assabet River. The review of previous studies provided strong evidence that eutrophic conditions have been present in the Assabet River for at least the past 30 years. Results from previous water quality surveys consistently indicate that nutrient concentrations in the Assabet River have long been sufficient to support eutrophic conditions. Other indicators of eutrophic conditions, such as large diurnal DO concentration variations and extensive biomass production were also consistently observed in previous surveys.

Previously collected biological measurements of the Assabet River are scarce. Results of previous biological surveys do, however, provide good circumstantial evidence to indicate that abundant macrophyte communities in the Assabet River have been well established for at least the last 30 years. Limited historic observations suggest that duckweed and pondweed have been important components of the macrophyte community for many years. The presence of duckweed supports the assumption that eutrophic conditions have existed historically as such forms are favored in slow-moving waters with high nutrient enrichment.

The primary factors contributing to the eutrophic status of Assabet River impoundments, namely availability of excess nutrients in slow-moving, impounded waterbodies, and the presence of optimum growth conditions (summer-time) appear to have long been in place and supporting eutrophic conditions in the Assabet River.

Water Quality Field Investigation: 1999-2000

Thirteen (13) field surveys were conducted from July 1999 through September 2000 and featured collection a wide range of measurements including the following:

- River streamflow and time of travel measurements,
- Continuous measurements of dissolved oxygen concentration dynamics,

- Water column sampling and analysis of several nutrient constituent concentrations throughout the Assabet River,
- Point source nutrient load measurements from POTWs,
- Non-point source nutrient loading measurements from tributaries,
- Sediment nutrient flux measurements, and
- Biological surveys quantifying the nature and extent of aquatic vegetation during summer-time conditions.

Field measurements were collected under a variety of conditions including summer-time and winter-time, low-streamflow and high-streamflow, dry-weather and wet-weather to provide measurements required to support the assessment. The following observations were made of water quality conditions in the Assabet River during the field investigation:

- Surveys were performed under a wide range of hydrologic conditions. For example, a worst-case summer-time survey was conducted at near 7Q10 low-flow conditions (15 cfs, July 1999) and a winter-time wet-weather survey was conducted at relatively high-flow conditions (375 cfs, March 2000).
- Time of travel surveys found that travel times through the Assabet River mainstem were greater than 18 days and that travel time through each river impoundment was 1 to 3 days under average summer-time conditions.
- During summer-time surveys, Publicly-Owned Treatment Works (POTW) effluent flows accounted for large proportions of total river streamflow. Under low-flow conditions (July 1999), POTW effluent flows contributed approximately 80% of the total river streamflows. Under near-average flow conditions (August 2000), POTW effluent flows contributed approximately 34% of the total river streamflow.
- During summer-time surveys, dissolved oxygen (DO) concentrations experienced large diurnal variations (e.g., 4 mg/l to 13 mg/l) throughout the river as is indicative of intensive biological activity. DO concentrations were frequently observed below the ambient water quality standard of 5.0 mg/l.
- Nutrient concentrations, both phosphorus and nitrogen species, were observed to be at levels indicative of nutrient saturation (i.e., neither nutrient was limiting) and were more than sufficient to support eutrophication. Typical ranges of nutrient concentrations during the summer-time surveys were:
    - Total phosphorus: 0.2 to 0.8 mg/l
    - Ortho-phosphorus: 0.1 to 0.6 mg/l
    - Nitrate: 0.5 to 8.0 mg/l

- For each nutrient constituent, concentrations were observed to be at least one order of magnitude (i.e., 10 times) higher than nutrient limiting concentrations indicating that concentrations of these nutrients would have to be reduced dramatically before biologic productivity in the system diminished.

- Sediment nutrient flux surveys confirmed the hypothesis that nutrients enter river impoundment sediments during the winter-time and are released from sediments to the water column during the summer-time. The magnitude of sediment nutrient flux was observed to be modest, however, contributing approximately 3% to 5% of ambient water column nutrient concentrations. Laboratory analyses indicated that under anoxic conditions, believed to be unusual in the Assabet River system, impoundment sediments flux would increase dramatically making sediments a major component of the overall nutrient budget. The sediment nutrient flux evaluation concluded that impoundment sediments represent a relatively minor component of the overall Assabet River nutrient budget.

- Eutrophic conditions were measured directly through summer-time phytoplankton and macrophyte surveys, each resulting in findings of extensive volumes of productive biomass. Summer-time vegetation densities in the Assabet River were observed to be at levels associated with impairment of water quality and designated uses.

- Total nutrient loadings to the Assabet River from point and non-point sources were collected during six (6) surveys and ranged as follows:

    - Ortho-phosphorus loadings: 61 to 319 lbs/day
    - Total Phosphorus loadings: 66 to 1,390 lbs/day
    - Nitrate loadings: 980 to 2,250 lbs/day
    - Total Nitrogen loadings: 1,190 to 3,850 lbs/day

- Point sources were observed to contribute the majority of nutrient loadings to the Assabet River during most surveys. The following observations were made based on nutrient loadings estimates from the 6 water quality surveys.

    - During all 6 surveys, the vast majority of available phosphorus (i.e., ortho-phosphorus) loadings came from the point sources (88% to 98%).
    - During summer-time conditions when eutrophication occurs (July 1999, August 2000, and September 2000), the vast majority of all 4 nutrient constituent loadings came from the point sources (83% to 98%).
    - During relatively high-flow and wet-weather events (two March 2000 surveys), the majority of total phosphorus and total nitrogen loadings were observed to come from non-point sources (52% to 77%).

Conclusions

Water quality impairments in the form of excessive growth of aquatic vegetation and failure to meet the water quality standard for ambient dissolved oxygen concentration were documented during several summer-time surveys. In-stream nutrient concentration measurements were typically an order of magnitude higher than potentially limiting concentrations during numerous surveys indicating that nutrient concentrations would have to be reduced dramatically before biological production in the system diminished. Point sources were identified as contributing the majority of nutrient loadings during most surveys and were identified as contributing the vast majority of the critical nutrient constituent, ortho-phosphorus, during all 6 water quality surveys evaluated. Non-point sources were observed to contribute the majority of most nutrient constituents during 2 of 3 surveys conducted under wet-weather and relatively high-streamflow conditions.

The ENSR 1999-2000 field investigations were successful in documenting the presence of eutrophic conditions and factors effecting eutrophic conditions in the Assabet River. Measurements required to support development of a water quality modeling application for the Assabet River were successfully collected. This report represents the successful completion of a major portion of the Assabet River nutrient TMDL allocation development project.

1.0 INTRODUCTION

The objective of this report is to document the water quality status of the Assabet River. A data collection program was designed and implemented to support water quality improvement for the Assabet River and is described in this report. From July 1999 to October 2000, 13 field surveys were conducted to collect hydrologic, water quality, sediment quality, and biological data to support a water quality improvement program. The data collection program quantified water quality conditions associated with summer-time eutrophication in the Assabet River and quantified time-varying nutrient loadings to the river system. The program to improve water quality in the Assabet River is mandated by the United States Environmental Protection Agency (US EPA) and is known as the Total Maximum Daily Load (TMDL) allocation process. This report summarizes the assessment phase of the TMDL development process focused on characterization of the water quality status of the Assabet River through collection and analysis of water quality measurements. The TMDL process is described in Section 1.2 below.

The Massachusetts Department of Environmental Protection (DEP), in conjunction with the US Army Corps of Engineers (Corps), is currently developing a TMDL allocation for nutrients in the Assabet River. Corps involvement with the TMDL process has been limited to the collection of data and study preparation. Authority for Corps participation is provided in its Section 22 “Planning Assistance to States” program (Water Resources Development Act of 1974, Public Law 93-251, as amended) which enables Corps cooperation with the states in preparation of plans for the development, utilization, and conservation of water and related land resources. A Cost Sharing Agreement was signed by the Corps and the DEP (the non-Federal sponsor) on March 25, 1999 (amended on May 3, 2000 and again on January 11, 2001), enabling the Corps and DEP to split the cost of this work on a 50/50 basis.

The Assabet River is designated in the Massachusetts Water Quality Standards as a Class B waterbody. The Assabet River has been placed on the 303d list for failure to comply with numerous standards and criteria including applicable numerical water quality standards for dissolved oxygen concentration and fecal coliform bacteria counts and for applicable narrative criteria for nuisance aquatic vegetation. The majority of water quality concerns associated with the Assabet River are directly related to a severe ecological condition known as eutrophication, described below.

1.1 Eutrophication

Eutrophication conditions occur in water bodies, such as lakes, ponds, and impoundments, when excess levels of nutrients result in very high growth rates of biota (Wetzel, 1983). The term eutrophication is derived from the Greek for “nutrient-rich”. Eutrophication is a process of nutrient accumulation and ecosystem change that occurs in aquatic ecosystems. This process can occur naturally as part of the long-term transition of lakes to marshes. Eutrophication can also occur culturally whereby the process is dramatically accelerated by the activities of man (McNaughton and Wolf, 1973).

Eutrophication is problematic because high growth rates of biota can result in production of nuisance aquatic vegetation such as algal mats, floating macrophytes, rooted vegetation, and phytoplankton. These growths are aesthetically undesirable and, due to impacts on dissolved oxygen, they threaten the existence of fish and other aquatic organisms. High biological activity during eutrophic conditions produces large diurnal changes in dissolved oxygen (DO) concentrations as aquatic biota produce oxygen during daylight conditions and respire, reducing oxygen levels at night. Seasonal declines in DO concentrations are also likely as aquatic vegetation dies and decays. Dramatic DO concentration changes, particularly very low DO levels, can be lethal to fish and benthic organisms.

The following conditions are typically necessary to support eutrophication.

- Nutrient loadings – Excessive levels of phosphorus and/or nitrogen entering a waterbody.
- Physical Configuration – A water body, such as a gently-sloped river, lake, or impoundment with sufficiently long residence time and slow-moving water in which nutrients are retained and are available to support biological activity for an extended period.
- Summer-time Conditions - Factors effecting biological activity, such as water temperature, angle of solar incidence, duration of daylight, and solar irradiance, are most favorable to support aquatic plant growth through photosynthesis during the summer-time.

When the factors listed above are present, eutrophic conditions may occur resulting in abundant nuisance aquatic plant growth and dissolved oxygen concentrations that threaten fish and other aquatic organisms.

This report documents the presence of excess nutrients within the system and the extent of nutrient loadings to the Assabet River. Excess nutrients, combined with the presence of river impoundments and summer-time conditions, result in eutrophic conditions throughout the Assabet River. Specifically, this report documents the presence of eutrophication in the Assabet River during the summers of 1999 and 2000 and reviews previous water quality studies performed over the past 30 years.

1.2 The TMDL Development Process

In 1996, the Assabet River was placed on a list of impaired waterbodies requiring water quality improvement, known as a Section 303(d) list, due to failure to comply with nutrient-related water quality standards (SuAsCo, 1996). According to the Clean Water Act, the states are required to develop a TMDL allocation for all priority waterbodies on the Section 303(d) list. Thus, the Massachusetts Department of Environmental Protection (DEP) is currently developing a Total Maximum Daily Loading

(TMDL) allocation for nutrients in the Assabet River. This TMDL is motivated by the presence of eutrophic conditions in the river during the summer season.

A TMDL allocation is an analysis that establishes the maximum loadings that a waterbody may receive and maintain its designated uses, including compliance with numeric and narrative water quality standards. The TMDL development process may be described in five steps, as follows:

1. Determination and documentation of whether or not a waterbody is presently meeting its designated uses;

2. Assessment of present water quality conditions in the waterbody, including estimation of present loadings of constituents of concerns from point and non-point sources;

3. Determination of the loading capacity of the waterbody. EPA regulations define the loading capacity as the greatest amount of loading that a waterbody may receive without violating water quality standards. If the waterbody is not presently meeting its designated uses, then the loading capacity will represent a reduction relative to present loadings;

4. Specification of load allocations, based on the loading capacity determination, for non-point sources (LAs) and point sources (WLAs), that will ensure that the waterbody will not violate water quality standards; and

5. Development of a plan to (1) implement load allocations developed based on the waterbody loading capacity determination and (2) monitor the waterbody to ensure compliance with water quality standards.

In summary, the TMDL development process begins with assessment of the present condition of a waterbody and concludes with specification and implementation of a set of modified loadings deemed necessary to bring the waterbody into compliance with water quality standards. The steps of the TMDL may be divided into Assessment (Steps 1 and 2); Analysis, often through modeling (Steps 3 and 4); and Planning (Step 5). This report represents a summary of the Assessment steps listed above through a review of previous water quality studies and documentation of 13 water quality surveys performed in 1999 and 2000.

A goal of the data collection task is to collect necessary and sufficient information to support development of a mathematical model of the Assabet River. A mathematical model of the Assabet River, if properly developed, will enable hydrologic, water quality, sediment, and biological processes throughout the Assabet River to be simulated. Water quality modeling will be necessary to determine the total loading capacity of the Assabet River and to allocate acceptable point and non-point source loadings (i.e., Steps 3 and 4 above). Determination of the loading capacity of the Assabet River is a complex task requiring sufficient supporting data and an appropriate assessment tool. The most reliable and defensible assessment tool for establishing loading capacities is a mathematical water quality model. A water quality model provides a numerical representation of the physical, hydrological, chemical, and biological characteristics of a river.

A water quality model requires a sufficient set of data to achieve project objectives. Once established, water quality models are capable of simulating present conditions in the river. More importantly, water quality models are capable of predicting water quality and biological conditions associated with hypothetical scenarios. For example, a water quality model could be developed for the Assabet River that would be capable of predicting water quality and biological conditions in the river that would result from specific reductions in point and non-point source loadings. The modeling tool would then be used to quantify loading capacity and evaluate alternative approaches for achieving acceptable loading capacity. An Assabet River nutrient TMDL modeling project is presently underway to perform the mathematical modeling tasks necessary to complete the TMDL implementation process.

1.3 Report Sections

This report contains the following components:

- Section 2 – summary of existing data from previous studies including physical, hydrologic, water quality, and biological measurements;
- Section 3 – description of the data collection program including the rationale for the data collection program design, a summary of hydrologic, water quality, sediment quality, and biological data collection methods and tasks;
- Section 4 – hydrologic data collection summary;
- Section 5 – water quality data collection summary;
- Section 6 – sediment quality data collection summary;
- Section 7 – biological data collection summary; and
- Section 8 – summary and conclusions.

2.0 REVIEW OF PREVIOUS STUDIES ON THE ASSABET RIVER

A review of previous studies on the Assabet River system was performed to enhance understanding of the hydrology, water quality, and ecology of the Assabet River. A review of previous studies also serves to identify gaps in our understanding of the river system and to provide context for present and future assessments of the Assabet River.

A physical description is provided below including a description of watershed size and Assabet River tributaries. A hydrologic data review, focused on evaluation of previously collected streamflow and time of travel measurements, is then presented. Previously collected hydrologic measurements are evaluated for their applicability in estimating streamflow variations throughout the river and for estimating nutrient loadings.

A water quality and biological data review is also provided with focus on evaluation of previously collected data related to eutrophication conditions. The water quality review includes previously collected nutrient-related parameter measurements and dissolved oxygen concentration measurements. The biological data review includes an evaluation of the types and relative abundance of species observed during previous surveys.

The review of previous studies is organized by physical, hydrological, water quality, and biological components of the Assabet River. In each component, the characteristics of the Assabet River are described. A summary, provided at the end of the section, provides a compilation of key findings of the previous studies and a contains a discussion of the status of the Assabet River.

2.1 Sources of Existing Data

The following organizations were consulted during the process of collecting information on the Assabet River:

- United States Environmental Protection Agency, Region I, Boston, MA (US EPA)
- United States Geological Survey, Northborough, MA (USGS)
- United States Army Corps of Engineers, New England District, Concord, MA (COE)
- Massachusetts Department of Environmental Protection, Worcester, MA (DEP)
- Massachusetts Department of Environmental Management, Boston, MA (DEM)
- Massachusetts Executive Office of Environmental Affairs, Div. of Watersheds, W. Boylston, MA (EOEA)
- Massachusetts Division of Fisheries and Wildlife (MDFW)

- Organization for the Assabet River, Concord, MA (OAR)

The search for existing data included visits by ENSR personnel to libraries at DEP and the USGS. Support and guidance in obtaining documents and information on the Assabet River was provided by Art Screpetis (DEP), Sue Beede (OAR), Barbara Offenhartz (OAR), and Tom Sheppard (USGS).

Thirty-seven documents were evaluated in performing the review of previous studies. Table 2-1 contains a compilation of documents reviewed and includes document name, source, topics, and types of measurements reported.

2.2 Physical Description of the Assabet River

The Assabet River is situated in eastern Massachusetts, approximately 20 miles west of Boston (Figure 2-1). The Assabet begins at a swamp-like impoundment in Westborough, Massachusetts and flows in a generally northeasterly direction for a distance of 31 miles to the confluence of the Concord River in Concord, Massachusetts. The Concord River begins at the confluence of the Assabet and Sudbury Rivers and flows in a generally northerly direction to the Merrimack River in Lowell, Massachusetts.

The Assabet River is relatively narrow and shallow, typically 30 to 60 feet wide and 2 to 4 feet deep. The Assabet River is a gently sloped river, typical of low-lying coastal streams in eastern Massachusetts (USGS, 1994) and has six impoundments. The river impoundments were created by dams originally constructed prior to the 20th century (MWRC, 1975). Long, narrow river impoundments are found upstream of Assabet River dams. Typically, Assabet River impoundments are shallow (5 to 10 feet deep) and narrow (100 to 300 feet wide). Several Assabet River impoundments extend for several miles.

Figure 2-2 contains a schematic cross-sectional view of the Assabet River with rivermile (RM) on the x-axis and elevation (in feet above mean sea level) on the y-axis. Figure 2-2 shows that the Assabet River drops 170 feet in elevation over its 31 mile length for an average slope of 5.5 feet per mile. The Assabet River's slope, however, is approximately 2 feet per mile throughout 27 of its 31 mile length. Several steeper reaches, with slopes as great as 25 feet per mile, are found immediately below impoundment dams and account for the majority of the vertical gradient of the River. Thus, the Assabet River's effective slope is gradual resulting in relatively slow moving water in most reaches.

Fourteen tributaries to the Assabet River have been identified (Blanc and O'Shaughnessy, 1974) and are presented in Table 2-2 along with estimated sub-watershed areas. Data on the physical configuration, hydrology, and water quality of the Assabet River tributaries is sparse.

The Assabet River drains a watershed of approximately 177 square miles of land (USGS, 1974). The watershed is populated by approximately 177,000 people. Thus, the population density in the watershed is approximately 1,000 people per square mile. The Assabet River flows through several highly populated areas including Westborough, Northborough, Hudson, Maynard, and Concord, Massachusetts (MADEQE, 1988).

Wastewater dischargers have released effluent to the Assabet River for many years. Four major publicly-owned sewage treatment works (POTWs), located in Westborough, Marlborough West, Hudson, and Maynard, discharge to the Assabet River. In all four cases, wastewater discharge locations are either within or immediately above river impoundments. Historic POTW discharge effluent characteristics are well documented and are presented later in this section. Several minor dischargers also contribute wastewater to the Assabet River including MCI Concord, Acton Powdermill Plaza, and the Middlesex School (via Spencer Brook).

2.3 Hydrology

An understanding of the quantity and variability of water movement throughout the Assabet River is critical to assessing water quality problems in the Assabet River for several reasons. Ambient surface waters provide dilution for point and non-point source nutrient loads to the river. Also, the quantity of surface water, along with physical configuration, determines the rate of travel (i.e., mean water velocity) of water and nutrient-related chemical constituents through the river system. The rate of travel is important because, in general, slower water movement provides extended exposure of nutrients within the system. This results in increased nutrient cycling by biota in the water column and sediments, that could potentially lead to adverse impacts to water quality. In terms of variability, significant precipitation events tend to result in rapid changes in streamflows. These relatively short duration, high flow events can carry large nutrient loads associated with land surface run-off. Stormwater runoff events and associated high river flowrates can have major impacts on water quality through increased nutrient loading and scouring of riverbed sediments. Thus, the quantity and variability of water movement is a critical component of the Assabet River water quality assessment.

Two sets of streamflow measurements were found in the review of previous studies; continuous measurements at one location and sporadic streamflow measurements throughout the river system. Also, several time of travel studies have been performed on the Assabet River.

2.3.1 Continuous Streamflow Measurement at the USGS Maynard Gauge

Streamflow has been measured consistently at only one location on the Assabet River. In 1941, the United States Geological Survey established a stream gauge in Maynard at rivermile 7.4. Continuous streamflow measurement at RM 7.4 is very useful for quantifying temporal streamflow variations at one location. Approximately one-third of the watershed (61 of 177 square miles) drains below the Maynard gauge and is not captured by the gauge (USGS, 1984). The Maynard gauging station alone cannot assess spatial streamflow variations along the river. Thus, Maynard gauge data, while useful, cannot solely support hydrologic assessments throughout the watershed.

Monthly average streamflows at the USGS Maynard gauge for the period of 1941 to 1997 are presented in Figure 2-3. Average monthly flows at the Maynard gauge range from 60 to 75 cfs during low flow summer-time conditions (July, August, and September). Low flow conditions are of particular interest in this investigation because they are commonly associated with unfavorable water quality conditions (see Section 3.1). The annual minimum seven-day mean discharge for a ten year recurrence interval ($7Q_{10}$) is a low flow metric frequently applied as a reasonable "worst-case" condition. The $7Q_{10}$ value is a statistical representation of the lowest flow conditions that may be expected to occur consistently for a one week period every 10 years.

An appropriate estimate of the $7Q_{10}$ flow at the Maynard gauge has been the subject of much discussion in recent years. A $7Q_{10}$ estimate of 15.1 cfs was provided in a 1983 USGS hydrologic report (USGS, 1984). This estimate was calculated based on a ten year period of record that contained unusually high flows. Because of errors implied by the relatively short period record used in the calculation, the estimate was recently revisited by MADEP (1999) and a $7Q_{10}$ estimate of 4.5 cfs was obtained for the entire period of record. The MADEP also calculated a "rolling 10-year" $7Q_{10}$ calculation that resulted in a $7Q_{10}$ estimate in recent years of approximately 13.5 cfs.

The $7Q_{10}$ low flow statistic is complicated in the Assabet River by the presence of POTW discharge flows that comprise the majority of river streamflows under low flow conditions. Total POTW flowrate measurements, collected during 11 surveys performed between 1969 and 1990, ranged from 7.8 to 13.0 cfs (5.0 to 8.4 MGD). It appears unlikely that low flows in the Assabet River can be lower than the total of the POTW discharge flows, excluding Maynard and Concord MCI effluents, that are downstream of the Maynard gauge. In summary, there is some uncertainty regarding the $7Q_{10}$ flow at the Maynard gauge and estimates range from 4.5 cfs to 15.1 cfs.

2.3.2 Streamflow measurements collected throughout the Assabet River

Table 2-3 contains a summary of the most extensive sets of historic streamflow measurements collected throughout the Assabet River. Streamflow measurements were collected during six surveys performed from 1969 to 1995 and including over 30 total survey days. All measurements were collected during summer-time conditions (June 4 through September 21). Concurrent streamflow measurements collected at the USGS Maynard gauge are included (in bold) in Table 2-3 to provide flow regime context. The most extensive streamflow survey was performed by Blanc and O'Shaughnessy (1974) in September 1973. In general, the historic streamflow data set is considered sparse because there are few surveys and typically few streamflow measurements per survey. A compilation of all streamflow survey measurements collected during the period of record is provided in Appendix A (Table A-1).

Ideally, previously collected streamflow measurements could be applied to develop streamflow vs. rivermile relationships, whereby streamflows associated with a specific flow regime (e.g., at one point in time) could be plotted verses rivermile. A streamflow vs. rivermile relationship could be established to estimate flows throughout the system under different flow regimes. Streamflow vs. rivermile curves would be useful in evaluating critical time-varying parameters such as nutrient loadings and average water velocity throughout the river system.

The historical streamflow data record is not sufficiently robust to support an accurate set of streamflow vs. rivermile curves. Figure 2-4 provides a crude estimate of the streamflow vs. rivermile obtained by plotting measurements from the four largest historical streamflow measurement data sets. Collection of future streamflow measurements throughout the river system will support development of a more accurate set of streamflow vs. rivermile relationships.

In summary, available streamflow data for the Assabet River is sparse. Accurate estimates of nutrient loadings and nutrient flux in river impoundments are dependent upon accurate hydrological characterizations. Thus, a substantial set of streamflow measurement must be collected to support the TMDL allocation for the Assabet River.

2.3.3 Time of travel measurements

Time of travel studies are useful for measuring the rate of movement of water and chemical constituents through the river system. Time of travel measurements are typically collected by releasing a detectable conservative substance (e.g., Rhodamine dye) into the river and tracking its movement downstream.

Table 2-4 contains a summary of measurements collected during four time of travel studies. All of the studies were performed by the Massachusetts Department of Environmental Protection. The studies were performed in December 1968, August 1969, October 1969, and March 1980. A complete compilation of time of travel study measurements in provided in Appendix A (Table A-2). Concurrent streamflows at the Maynard gauge ranged from 54 cfs to 452 cfs. A total of 6 dye release events were performed, 2 in the Upper Assabet, 3 in the Lower Assabet, and one through the entire Assabet River. Dye was observed to take 7.8 days (188 hours) to travel the full length of the Assabet River in October of 1969, concurrent with a Maynard gauge flowrate of 54 cfs.

In August 1969, however, dye released from RM 29.8 in Westborough took 11 days to move roughly one-half the length of the Assabet River to RM 13.9 miles, below the Gleasondale Dam. The August 1969 survey was performed concurrent with a USGS Maynard gauge flowrate of 23 cfs. A third dye release event (October 9-15, 1969) was performed from RM 13.9 to RM 0.5 and took 6.4 days. If considered together with the August 1969 survey a total travel time of 17.5 days is obtained. Based on these limited results, it appears likely that travel times are significantly longer during low flow conditions than during average conditions. Time of travel estimates on the order of one to three weeks were observed to occur at USGS Maynard gauge flowrates of 23 to 69 cfs.

2.4 Water Quality

Water quality measurements collected during eleven surveys from 1969 to 1990 were reviewed. Surveys were performed during summer-time and fall conditions with sampling dates ranging from June 4 to October 23. All of the surveys were performed by the State of Massachusetts. Water sampling locations are compiled in Table 2-5, along with location identifications and rivermiles. Figure 2-5 contains a map indicating sampling locations. In the MADEP water quality studies, the Assabet River is described in two sections, the Upper Assabet River and the Lower Assabet River. The Upper Assabet River begins at the headwaters (RM 31.8) and extends to rivermile 23.9. The Lower Assabet River extends from RM 23.9 to the mouth (RM 0.0).

A summary of historical water sampling for nutrient-related and biological constituents and in-situ measurement of dissolved oxygen concentration measurements collected between 1969 and 1990 is provided in Section 2.4.1 – 2.4.3 below. A summary of measurements collected from 1993 through 1997 by the Organization for the Assabet River is provided in Section 2.4.4. Nutrient budgets are critical to understanding the ecological balance in the Assabet River system. Water quality measurements of nutrient concentrations combined with concurrent streamflow measurements are applied to determine nutrient loadings to and within the Assabet River system.

2.4.1 Water Sampling for Chemical Constituent Concentrations

Water samples were collected in the Assabet River for analysis of nutrient-related and bacterial constituents during eleven previous studies from 1969 through 1990, referred to herein as the period of record. Specifically, total phosphorus, nitrate, ammonia, and BOD_5 concentrations, and fecal coliform counts were measured and are summarized below.

In summary, total phosphorus and nitrate concentration measurements in the Assabet River were each typically greater than 0.5 mg/l during the period of record. Biochemical oxygen demand (BOD_5) concentrations measurements in the Assabet River were typically greater than 2.5 mg/l. Fecal coliform counts varied dramatically, typically on the order of hundreds of colonies per 100 ml and were measured as high as 500,000 colonies/100ml. Since elevated fecal coliform counts are typically associated with wet-weather events, precipitiation records prior to fecal coliform sampling events were obtained and are included in the data summary. In general, the historic in-stream water quality measurements are consistent with nutrient-rich waters with a strong component of human sewage.

Prior to 1987, the most severe water quality problems in the Assabet River were observed between the headwaters and Boundary Street at rivermile 23.9 (Upper Assabet River). Boundary Street is located on town line between Northborough and Marlborough. This reach of the river had the most severe water quality problems, as measured by nutrient concentrations, minimum DO concentrations, and biochemical oxygen demands. According to previous reports (e.g., MADEQE, 1988), extreme water quality problems in the Upper Assabet were due to the presence of the Westborough and Shrewsbury wastewater plant effluent discharges. These two discharges were particularly problematic since they provided relatively large nutrient loadings into the relatively small baseflow of the Upper Assabet River.

In August of 1987, the Westborough and Shrewsbury wastewater plants were combined (Shrewsbury was taken off-line) and upgraded to reduce loadings. Reductions in loadings focused on oxygen demand, ammonia, and solids, and only to a limited degree on phosphorus. Water quality conditions in the Upper Assabet River are reported to have improved significantly since the 1987 Westborough upgrade (MADEQE, 1988).

Figure 2-6 contains total phosphorus concentration measurements vs. rivermile from three previous surveys, Sept. '87, July '85, and Aug. '79, and is typical of the elevated levels of nutrient-related constituents found in the Upper Assabet River in the 1970s and 1980s (prior to 1987). Total phosphorus concentration measurements were observed to range from 0.3 mg/l to 3.2 mg/l throughout the river with the highest concentration in the Upper Assabet. Measurements from the two reaches of the river, Upper and Lower, are presented separately herein since water quality conditions between the two reaches were distinctly different during the period of record.

Tables 2-6 and 2-7 contain summaries of nutrient-related water quality measurements collected in the Upper Assabet and Lower Assabet, respectively, during eleven previous surveys. Results from each survey are represented as typical, high, and low concentration measurements. Data are presented in this manner to provide a concise summary of the data suitable for observing values and temporal trends in values. An awareness of key contextual information is critically important when evaluating in-stream water quality information. Table 2-8 contains key contextual information including streamflow at the USGS Maynard gauge and POTW flow and nutrient loadings collected concurrently during each of the 11 surveys. Streamflows, as measured at the USGS Maynard gauge, concurrent with the water quality surveys were relatively low. During 9 of 11 surveys, streamflows were below 100 cfs. Antecedent rainfall records provide important contextual information and are discussed as part of the data summary.

2.4.1.1 Upper Assabet River Measurements Collected Between 1969 – 1989

POTW nutrient loadings in the Upper Assabet River (31.8 to 23.9) consisted of Shrewsbury and Westborough prior to the summer of 1987 and Westborough alone since 1987. Upper Assabet River POTW nutrient loadings maintained similar levels of phosphorus loadings and nitrate loadings, while nearly doubling in effluent flowrate over a 20 year period between 1969 and 1989 (Table 2-8). The Westborough POTW also reduced its BOD loading by a factor of 3 over the same period. This represents a significant accomplishment in terms of improved effluent treatment.

Upper Assabet River phosphorus concentrations ranged from typical values of 0.7 to 3.0 mg/l over the same period (Table 2-6). Nitrate concentrations were typically approximately 0.6 and 1.0 mg/l. Ammonia concentrations were typically between 1.0 mg/l and 2.5 mg/l prior to the 1987 Westborough

POTW upgrade and were dramatically lower in one survey after the upgrade (i.e. September 1987; typical value 0.1 mg/l). Typical river BOD concentrations ranged from 4.0 mg/l to 11.0 mg/l prior to August 1987 and were measured to be typically 1.8 mg/l in September 1987.

Fecal coliform counts are known to be highly variable and the uncertainty associated with any one fecal coliform measurement is large. As a result, US EPA has developed standards for fecal coliform counts based on statistical populations of measurements rather than a single measurement. For example, the Class B fecal coliform standard is a geometric mean of 200 col./100 ml. Fecal coliform measurements observed in the Assabet River were highly variable during the period of record, ranging from 5 to 460,000 col/100ml in the Upper Assabet River. Historic rainfall records from the Bedford, MA gauge were obtained and reviewed to support the evaluation. Review of the rainfall record indicates that all fecal coliform measurements collected during the 1970's (first 5 surveys listed in Table 2-6) were associated with greater than 0.1 inches of rainfall during the period 3-days prior to and during the surveys. Thus, fecal coliform measurements collected within 3-day of rainfall ranged from 500 to 460,000 col/100 ml and dry-weather fecal coliform measurements ranged from 200 to 440 col/100 ml. Historical values are very high and are indicative a large proportion of flow consisting of sewage.

2.4.1.2 Lower Assabet River Measurements Collected Between 1969 – 1989

POTW nutrient loadings in the Lower Assabet River (RM 23.9 to 0.0) consisted of Marlborough West, Hudson, Maynard, and Concord MCI discharges. Lower Assabet River POTW nutrient and BOD loadings maintained similar levels, while nearly doubling in effluent flowrate during the 20 year period from 1969 to 1989 (Table 2-8). This represents a significant accomplishment in terms of improved effluent treatment.

Ambient concentrations of nutrients and other constituents in the Lower Assabet River were influenced by all loadings upstream of the sampling locations, including, at some locations, POTW loadings from both the Upper and Lower Assabet River. Also, three sets of in-stream nutrient measurements were collected in 1989 and 1990 in Lower Assabet River that were not collected in the Upper Assabet River. These measurements are beneficial in that they extend the period of record and support assessment of the Assabet River after the 1987 upgrade of the Westborough POTW.

Lower Assabet River phosphorus concentrations ranged from typical values of 0.35 to 3.0 mg/l during surveys performed between 1969 and July 1987 and were typically 0.45 mg/l in 1989 and 1990 surveys (Table 2-7). Nitrate concentrations were typically 0.6 and 3.0 mg/l throughout the period of record. Ammonia concentrations were typically between 0.0 mg/l and 0.07 mg/l throughout the period of record.

Lower Assabet River BOD concentrations ranged from 2.0 mg/l to 5.0 mg/l during the period of record. Fecal coliform measurements observed in the Assabet River were highly variable, ranging from 5 to 500,000 col/100ml in the Lower Assabet River. Review of rainfall records, described above, showed that elevated fecal coliform measurements were associated with rainfall events (e.g., September 17-19, 1974). Historical values are very high and reflect a large proportion of flow as human sewage.

2.4.1.3 Comparison Between Upper and Lower Reaches (1969 – 1989)

In general, water quality conditions measured in the Upper Assabet River were worse than those measured in the Lower Assabet River. Total phosphorus and nitrate concentration measurements collected in the Upper Assabet River were higher than those collected in the Lower Assabet River during the period of record. Ammonia and BOD concentration measurements were typically dramatically higher in the Upper Assabet than in the Lower Assabet, by factors of approximately 10 and 2.5, respectively. Fecal coliform counts were found to be highly variable and at levels of concern throughout the river during the period of record.

2.4.1.4 Assabet River Measurements Collected between 1993 and 1999

The Organization for the Assabet River (OAR) collected Assabet River water samples for laboratory analysis of water quality parameters between 1993 and 1999. OAR did not have an approved QAPP during this time period. OAR received an approved QAPP in February 2000. Thus, formal use of the OAR 1993 through 1999 data will require a quality assurance analysis with regulatory approval. Since virtually no other measurements were collected on the Assabet River during the 1990's, water quality measurements collected by OAR represent a valuable resource in assessing water quality in the Assabet River. OAR collected water quality measurements throughout the Assabet River on a monthly basis between May and October of each year from 1993 through 1999. During each survey, samples were typically collected at approximately 20 locations along the Assabet River. These measurements were reviewed and are summarized below.

Phosphorus

During 27 surveys over 300 samples were collected and analyzed for total phosphorus by OAR. Total phosphorus measurements ranged from 0 mg/l to 2.8 mg/l with an average value of 0.4 mg/l. Ortho-phosphorus measurements collected by OAR during 4 surveys and values ranged from 0.01 to 1.36 mg/L with average value of 0.30 mg/l.

Nitrogen

Nitrate-Nitrogen measurements collected by OAR during 20 surveys. Nitrate values ranged from 0.01 to 8.5 mg/L with an average value of 1.7 mg/L. Ammonia-nitrogen measurements were collected by OAR during 14 surveys. Ammonia concentration measurements ranged from 0.04 to 0.54 mg/L with average value of 0.15 mg/L.

Other

Fecal coliform measurements were collected by OAR during 24 surveys ranged from 0 to 7400 col./100ml with an average value of 575 col./100 ml. Lastly, biological oxygen demand (BOD) measurements collected by OAR during 5 surveys. BOD_5 concentration measurements ranged from 0.5 to 20 mg/L with an average value of 2.4 mg/L.

2.4.2 In-situ Dissolved Oxygen Concentration Measurements

In-situ dissolved oxygen measurements were collected in support of most of the water quality surveys discussed above. Prior to 1987, minimum DO concentrations of near-zero in the Upper Assabet River, resulting directly from impacts of the Shrewsbury and Westborough POTWs, were commonly reported (MWRC 1969, 1974, and MADEQE, 1979). Since the 1987 POTW upgrade at Westborough minimum DO concentrations increased significantly. In September 1987, after the POTW upgrade, several minimum DO concentrations below 3.0 mg/l and numerous measurements below the water quality standard of 5.0 mg/l were collected. During the period of record, the water quality standard for dissolved oxygen of 5.0 mg/l has frequently not been met.

In August 1996, EPA personnel collected one set of DO concentration measurements in the early morning at 19 locations. Early morning DO concentration measurements were below 5.0 mg/l at 5 of 19 sampling locations (MADEP 1999). One of the DO concentration measurements (3.1 mg/l) was collected 8 ft deep in the Powdermill Impoundment. Table 2-9 contains a compilation of dissolved oxygen concentration measurements collected by EPA in August 1996. Also, dissolved oxygen concentrated measurements collected by the Organization for the Assabet River (OAR) during the 1990s were reviewed and found to contain frequent summer-time DO concentration measurements below 5.0 mg/l.

2.5 Biology

The purpose of this section is to review and analyze scientific literature and existing data on the aquatic plants in the Assabet River. This analysis will provide a preliminary evaluation of the status of aquatic plant communities in selected reaches and impoundments of the Assabet River, with emphasis on the conditions and ecology of duckweed species (e.g., *Lemna* spp.), a predominant plant in the river.

In-stream vegetation is an important natural component of the river ecosystem. Evaluation of the distribution and abundance of aquatic macrophyte communities can be a useful diagnostic tool in assessing potential impacts to that ecosystem. The term macrophyte is used to distinguish large aquatic plants from unicellular algae (i.e., attached periphyton, floating phytoplankton), but large algal mats are considered macrophytes (“large plants”) in addition to vascular species.

Evaluation of aquatic macrophytes provide insights into the trophic condition of a waterbody since macrophytes usually acquire nutrients accumulated in bottom sediments rather than directly from the water column. It is also important to consider macrophyte growth since an overabundance of macrophytes can threaten water quality due to diurnal oxygen oversaturation/depletion, impact to fishery habitat, and impact to aesthetics and recreational opportunities. Due to this importance, the available information on macrophyte communities in the Assabet River was reviewed and the information compared to existing trends of macrophyte distribution and abundance (Section 3). The ecology of the major class of macrophytes in the Assabet River (i.e., duckweeds) was also considered.

Macrophyte surveys of the Assabet River are very scarce in the watershed water quality literature of the past 30 years. No organized macrophyte surveys were conducted of the river and impoundments from the headwaters to the confluence with the Concord River, but observations and field notes attached to some of the survey documents provide descriptions of conditions historically observed. Due to the level of development in the SuAsCo watershed, it is assumed that observable blooms of duckweed have been present on the Assabet River since at least the 1940’s (see Eaton, 1947).

A 1969 survey of the Assabet River noted heavy growth of aquatic weeds impeding collection of secchi disk measurements at or just below the A-1 Impoundment near River Mile (RM) 31.8 (MWRC, 1969). *Lemna* blooms were reported in the Assabet at the Route 20 dam in Northborough (RM 27.7) as well as at the Ben Smith Impoundment in Maynard (RM 9.2) on August 27, 1969. The Maynard impoundment exhibited a supersaturated dissolved oxygen (DO) content of 13 mg/l at 23^{o}C (149% of saturation). While this indicates intense photosynthetic activity, it does not identify whether macrophytes or phytoplankton (or a combination of both) were responsible. At both impoundments, observers noted very little water going over the dam indicating very limited flushing during late summer (MWRC, 1969).

Oxygen supersaturation in a marshy area upstream of the Ben Smith Impoundment and at the Powder Mill Impoundment was noted in a 1973 summer (late July) survey (Blanc and O’Shaughnessy, 1974). These stations were among those where the Assabet River was noted to “be in a eutrophic condition when compared to other sampling stations.”

Observations of macrophytes were not included in the 1974 and 1979 Assabet River Surveys (MWRC, 1974; MA DEQE, 1979). Both surveys indicate consistent patterns and abundance of the supply of nitrogen and phosphorus to the River from the contributing POTWs. The Assabet River Basin survey of the Flow Augmentation Pond in Westborough indicated that this reservoir was also a rich supply of nutrients. Researchers believe that this may be due to the breakdown of the extensive terrestrial vegetation that had been left in place when the George H. Nichols Dam had been constructed and the basin filled (MA DEQE, 1974).

The 1989 Assabet River Basin Water Quality Management Plan (WQMP) summarized data from summer 1987 and 1988 surveys (MA DEQE, 1989). The WQMP noted that “significant portions of the river still support dense populations of algae and macrophytes during the summer months. Decay of excess vegetation and sediments in many slow moving parts of the Assabet River can cause local odor problems."

The WQMP also compared historical trends in phosphorus concentrations in the Assabet River that suggest that in-stream phosphorus concentrations were increasing with time. One potential reason for this increase would be the recycling of accumulated phosphorus in the sediments to the water column (MA DEQE, 1989). This translocation of phosphorus from the sediments to the water column by macrophytes ("phosphorus pumping") has been demonstrated elsewhere (Horne and Goldman, 1992).

More recent information about the Assabet River macrophytes comes from related biological surveys. A summer 1989 benthic macroinvertebrate survey found that thick growths of vegetation impeded standard Macroinvertebrate Rapid Bioassessment (MRB) protocols (Nuzzo, 1989). Vegetation presence and proliferation were reported at all stations. Sampling downstream of the Marlborough POTW (RM 22), the survey team found the river bottom covered by thick clumps of common waterweed (*Elodea*) with some pondweed (*Potamogeton* sp.) and milfoil (*Myriophyllum* sp.) while dense beds of arrow arum (*Peltandra*) and pickerelweed (*Pontederia*) were growing along the stream margins (Nuzzo, 1989). The team reported "a steady density of *Lemna* floated by on the current and coated the water's surface in the backwater area." Further downstream, the heavily vegetated character of the river was considered symptomatic of extreme nutrient enrichment conditions. The deeper, slow-moving sections were heavily coated with duckweed species (*Lemna, Wolffia*) with dense beds of macrophytes across the stream bottom, even in shallow riffle areas. Periphyton, moss, and rooted macrophytes (*Elodea, Potamogeton, Callitriche*) were abundant.

Observations from a fish collection effort on the Assabet River in the Ben Smith Impoundment noted that "submerged aquatic macrophytes were abundant and the water surface was covered entirely by floating duckweed." (MA DEP, 1997). The pond appeared to be choked by aquatic macrophytes in late summer and early fall, although it was considered to provide excellent habitat for waterfowl and other wildlife. A 1998 fishery survey found "heavy duckweed" in the Assabet River off Summer Hill Road in Maynard (MDFW, 1998).

2.5.1 Ecology of Duckweeds

Duckweed species (*Lemna, Wolffia*) have been historically abundant and are highly significant to the visual aesthetic appearance of the River. Duckweed species are one of the most noticeable species to the lay public. Based on its importance in the Assabet River, the ecology of duckweed was further investigated to identify key factors.

Plants in the duckweed group (*Lemna, Wolffia, and Spirodela*) constitute part of the "free-floating" macrophyte community. Although often visually confused with surface mats of unicellular algae, these plants are actually monocotyledonous angiosperms (flowering plants). These plants do not form true leaves or stems, but are comprised of a floating green plant body, with photosynthetically-active tissue on the dorsal surface and tiny roots on the ventral surface that hang down into the water column. Unlike the more common rooted aquatic macrophytes, these plants move freely in waterbodies due to wind, waves, and currents. Due to their small size, these plants are readily transported between waterbodies by both natural (e.g., waterfowl) and man-made (e.g., boats) factors. Duckweeds derive their nutritional needs by direct uptake from the water column via the suspended roots and/or thin cuticle ventral membrane. Thus, these plants are not dependent on the accumulated nutrients in the bottom sediments. There is evidence that, in some instances, nitrogen-fixing bacteria cover the roots of *Lemna* and presumably provide additional nitrogen inputs to the host plant (Horne and Goldman, 1994).

The historic onset of proliferation of large surface blooms of duckweed in the SuAsCo watershed has been previously described (Eaton, 1947). In the paper "*Lemna minor* as an aggressive weed in the Sudbury River," Eaton noted that, starting in the 1930's, massive blooms of *Lemna* had been observed on that river, while it had been hitherto a minor component of the river flora. Similar observations had been made for the Charles River during the same time period. Eaton concluded that pollution from sewage was the principal factor for *Lemna's* success (Eaton, 1947). While a similar set of historic observations is not documented for the Assabet River, it seems reasonable that the rise of *Lemna* from a ubiquitous, but minor member of the river flora to its predominant role in the River is linked to urbanization and/or effluent discharges of multiple publicly-owned sewage treatment works (POTWs) in the watershed.

In summary, the ecology of duckweeds indicates that these species are favored by eutrophication, particularly the conditions of slow water movement and high nutrient enrichment. In addition, the turbid conditions that limit light for many macrophytes in some eutrophic waterbodies are not relevant to this floating species. Until environmental conditions are shifted towards lower nutrients or fast water movement (i.e., faster flushing rate), the duckweed species are likely to be highly successful and an important component of macrophyte communities in the Assabet River impoundments.

2.6 Summary of the Review of Previous Studies

The review of previous studies provided strong evidence that eutrophic conditions have been present in the Assabet River for at least the past 30 years. Results from all previous water quality surveys consistently indicate that nutrient concentrations in the Assabet River are sufficient to promote to eutrophic conditions. Other indicators of eutrophic conditions, such as large diurnal DO concentration variations and extensive biomass production, were also consistently observed in previous studies.

Results of all previous biological surveys provide good circumstantial evidence to indicate that macrophyte communities in the Assabet River have been well established throughout the period of record. Limited historic observations suggest that duckweed and pondweed have been important components of the macrophyte community for many years. Review of the ecology of duckweeds supports the contention that such forms are favored in slow-moving waters with high nutrient enrichment. Reduction of duckweed populations may require alterations in present nutrient or hydrologic regime.

In summary, the primary factors contributing to the eutrophic status of the impoundments on the Assabet River, namely availability of excess nutrients in slow-moving, impounded waterbodies, with organically rich sediments in the presence of optimum growth conditions (summer-time) appear to have long been in place and supporting eutrophic conditions in the Assabet River.

Table 2-1 A Compilation of Previous Studies of the Assabet River

Document Number	Study Name (Date & Color Key)	Source	Sampling Date(s)	Number of Stations	In-situ Water Quality	Grab Water Quality	Wastewater	Streamflow	Biological	Physical Characterization	Interesting Findings
82-A-1[**]	SUASCO River Study- Background Data on Water Quality	MWRC	Assabet (June 22 & 24, 1965)	12 (on Assabet)	X	X			X		
82-A-2	The Assabet River Report- Part A, Data Record on Water Quality	MWRC	August 18-29, 1969 & October 9-13, 1969	17	X	X		X	X		Time of Travel measurements
82-A-4	The Assabet River-1974 Water Quality Survey Data	MWRC	June 3-7, 1974 & September 16-20, 1974	20 & 22	X	X		X	X	X	
82-A-5	The Assabet River-1979 Water Quality Data. Massachusetts Department of Water Quality	MADEQE	June 4-8, 1979 & August 6-10, 1979	26	X	X	X	X	X	X	
82-A-7	Upper Assabet River-1988 Dissolved Oxygen Data	MADEQE	July 8, 14, 15, 21, 28, 1988, August 4, 11, and 15, 1988, & September 8, 1988	12	X[b]		X	X[a]			
82-AB-2	Assabet River Basin- 1989 Water Quality Data and Wastewater Discharge Data	MADEP	August 9, 1989	13	X	X	X		X	X	
82-AB-3	Lower Assabet River and Powdermill Impoundent- 1990 Water Quality Data and Wastewater Discharge Data	MADEP	July 10, 1990 & August 9 and 21, 1990	10	X	X	X	X	X	X	
82-ABC-3	Assabet River- 1986-1987 Water Quality SurveyData, Wastewater Discharge Data, and Analysis	MADEQE	November 1986 - May 1987 (monthly), June - September 1987 (twice per month), July 22-23, 1987, and September 1-2, 1987	23	X	X					Non-summer sampling
82-B-1[*]	The Assabet River Report- Part B, Wastewater Discharge Data	MWRC	1965, 1968, 1969, and 1970	6			X				
82-B-2[*]	SUASCO River Basin- 1976 Wastewater Discharge Data	MADEQE	1976	18			X				
82-B-3[*]	SUASCO River Basin- 1977 Wastewater Discharge Data	MADEQE	1977	11			X				
82-B-4	Concord (Suasco) River Basin- Part B, 1981-1982 Wastewater Discharge Data	MADEQE	1981-1982	21			X				
82-B-5	Suasco River Basin- Part B, 1983-1985 Wastewater Discharge Data	MADEQE	1983-1985	17			X				
82-B-6	1992 Wastewater Discharge Data	MADEP	1992	7			X				
82-C-3	The Assabet River-1974 Water Quality Analysis	MWRC	1965, 1969, & 1974	~24	X[c]	X[c]	X[c]	X[ac]		X	
82-D-2[*]	The SUASCO River Basin-1981 Water Quality Management Plan	MADEQE	1981 (report date)	NA	NA	NA	NA	NA	NA	NA	
82-D-4	Assabet River-1989 Water Quality Management Plan	MADEQE	1989 (report date)	23	X[c]	X[c]	X[c]	X[c]	X[c]	X	

Document Number	Study Name (Date & Color Key)	Source	Sampling Date(s)	Number of Stations	In-situ Water Quality	Grab Water Quality	Wastewater	Streamflow	Biological	Physical Characterization	Interesting Findings
82-E-1	Baseline Water Quality Studies of Selected Lakes and Ponds- 1974 Assabet River Basin	MADEQE	June - July, 1974		X				X		
N/A	Gazetteer of Hydrologic Characteristics for Streams in Massachusetts—Merrimack River Basin	USGS	Previously existing data through 1981	12 gaging sites & 79 partial-record sites				X			
N/A	Hydrologic Budget Analysis, A-1 Impoundment on the Assabet River, Westborough, MA	GSC	Previously existing data September 1, 1997-August 31, 1998 and New data June 24, 1997-September 30, 1998	6 gaging stations & 5 monitoring wells				X		X	Bathymetric Map
N/A	Draft 1996 SuAsCo River Basin Assessment Report for Review	MADEP	June-August, 1996 (additional fish surveys in September 1997)	9 water quality, 13 benthic invertebrate, and ~1 lakes	X (Dissolved Oxygen only)	X (Total Phosphorous only)	X		X		Benthic assessment, fish toxics monitoring
N/A	Flood Plain Information, Assabet River, Westborough to West Concord, MA, (Summary Report)	USACE	1966	N/A						X	
N/A	1997 Fish Toxics Monitoring Public Request Surveys	MADEP	September 16-18, 1997	4 (Assabet)					X		Fish toxics survey
N/A	Concord River Basin, Inventory and Analysis of Current and Projected Water Use, Vol. 1	MADEM	1984-1986?	N/A							Water use
N/A	Water Quality of Selected Wetland Streams in Central and Eastern Massachusetts, 1988-1989	USGS	1994	2	X	X		X		X	
N/A	Characteristics of Low-Slope Streams that Affect O2 Transfer Rates	USGS	May 1985-October 1988	2	X			X		X	
N/A	Lemna Minor as an Aggressive Weed in the Sudbury River	Eaton							X		
N/A	The Biokinetics of the Assabet River	Blanc, F.C. and O'Shaughnessy, J.C	July-September 1973	29	X	X	X	X	X		Travel times
N/A	A Procedure for Estimating Reaeration Coefficients for Massachusetts Streams	USGS	1983-1984	2 (Assabet)				X			Travel times, non-summer measurements included
N/A	Water-Quality Data for Selected Wetland Streams in Central and Eastern Massachusetts	USGS	June and September 1974, August 1989	4 (Assabet)	X	X					

Document Number	Study Name (Date & Color Key)	Source	Sampling Date(s)	Number of Stations	In-situ Water Quality	Grab Water Quality	Wastewater	Streamflow	Biological	Physical Characterization	Interesting Findings
N/A	Estimation of Low-Flow Duration Discharges in Massachusetts	USGS	1993	N/A							Model to determine basin yield during periods of low-flow
N/A	Technical Memorandum on the Assabet River: Flow at the Maynard Gauge and Nutrients	MADEP	USGS gage data for all years on record	N/A		X (based on 1979 data)	X	X			
N/A	Fish Survey Electro-Shock Log Sheets	MDFW	1979, 1983, 1997 and 1998	N/A					X		
N/A	Effluent and Influent Data for Hudson, Westborough, Maynard, and Marlborough WWTPs for May, June and July 1999	MADEP	1999	N/A			X				
N/A	1999 SOD Sampling	USEPA	July 1999	24							Sediment Oxygen Demand
N/A	Modeling Design Concepts for the Assabet River Using GIS	WPI								X	
N/A	Mill Pond 2005, A Shoreline Survey of the Mill Ponds and Canal, Maynard, MA	OAR									

[*] = Only partial copy
[b] = Dissolved Oxygen only
[**] = Request complete copy of report from MADEP
[c] = analysis of data
[a] = Flow measurement taken from USGS gage only
N/A = Not applicable

Table 2-2 Assabet River Tributaries with Approximate Drainage Areas and Rivermiles

Tributary Name	River Mile	Area (miles^2)	% of Total Area
Nashoba Brook	3.0	47.6	26.9
Elizabeth Brook	10.0	20.0	11.3
North Brook	23.0	18.0	10.2
Cold Harbor Brook	26.8	11.5	6.5
Hop Brook	29.5	9.3	5.3
Fort Meadow Brook	13.4	8.9	5.0
Spencer Brook	1.3	7.7	4.3
Mill Brook	18.4	6.6	3.7
Hog Brook	18.9	6.3	3.5
Stirrup Brook	25.2	4.9	2.8
Boon's Pond Outlet	12.5	3.7	2.1
Milham Reservoir	24.3	3.4	1.9
Second Division Brook	4.4	2.1	1.2
Taylor Brook	9.3	1.8	1.0
Unspecified Tributaries and Shoreline	--	25.3	14.3
Total Watershed Area	--	177	100
Ref: Blanc, F.C. and O'Shaughnessy, J.C. 1974			

Table 2-3 Summary of Streamflow Measurements Collected During Previous Studies

			Flow Rate (cfs)					
			10/21/69	**8/10/73**	**8/16/73**	**9/21/73**	**6/6/79**	**6/7/79**
Location	**Town**	**River Mile**	**MWRC 1970**	**B&O 1974**	**B&O 1974**	**B&O 1974**	**MADEQE 1979**	**MADEQE 1979**
Outfall of Mill Road	Westborough	31.8				24.7		
Maynard Street	Westborough	30.7	0.1	40.3		29.1	8.2	7.6
Route 9	Westborough	29.8	3.5	40.5		21.8		
Route 135	Westborough	28.9	8.0	54.3		43.9		
Brigham Street	Northborough	28.3				31.5		
Route 20	Northborough	27.1	13.0	49.8		23.6		
Hudson Street	Northborough	26.1	15.0	58.7		23.7		
Boundary Street	Marlborough	23.9			93.9	33.9	76.0	63.0
Robin Hill Road	Marlborough	23.4			94.9	29.3		
Bigelow Road	Berlin	21.5				35.6		
Route 495	Marlborough	20.8				59.3		
Chapin Road	Hudson	19.4	27.0			64.3		
Washington Street	Hudson	18.7		87.7		86.0		
Forest Avenue	Hudson	17.9	30.0				152.0	115.0
Cox Street	Hudson	15.9	34.0		111.9	54.3		
Gleasondale	Stow	13.9	40.0	90.5	147.0	73.7		181.0
Boon Road	Stow	11.4	45.0			114.5		
Route 62/117	Maynard	8.6	52.0		167.0			
Route 27/USGS	**Maynard**	**7.4**	**54.0**	**111.0**	**149.0**	**129.5**	**179.0**	**162.0**
Route 62	Acton	6.5						
Route 62	Concord	6.2				184.0	250.0	
Route 62	Concord	4.7				135.0		
Main Street	Concord	3.1	64.0			182.0		
Route 2A	Concord	2.4		112.0	218.0	228.0	292.0	326.0

MWRC. 1970. The Assabet River Report – Part A, Data Record on Water Quality. Massachusetts Water Resources Commission, Division of Water Pollution Control, Boston, MA. December 1969 and September 1970.

Blanc, F.C. and O'Shaughnessy, J.C. 1974. The Biokinetics of the Assabet River. Northeastern University, Department of Civil Engineering, Environmental Engineering Laboratories Report to the Commonwealth of Massachusetts Division of Water Pollution Control Research Project 73-05. Boston, Massachusetts. September 30, 1974.

MADEQE. 1979. The Assabet River – 1979 Water Quality Data. Massachusetts Department of Environmental Quality Engineering, Division of Water Pollution Control, Westborough, MA. November 1979.

Table 2-4 Summary of Time of Travel Measurements Collected During Previous Studies

		Survey Date					
		Dec 11, 1968	**Aug 18-29, 1969**	**Oct 9-15 1969**	**Oct 21-23,1969**	**Mar 20, 1980**	**Mar 20, 1980**
Data Source		**MWRC 1970**	**MWRC 1970**	**MWRC 1970**	**MWRC 1970**	**MADEP Unpublished Data, 1980**	**MADEP Unpublished Data, 1980**
Flow at USGS Maynard Gage (cfs)		126	23	69	54	452	452
From (river mile)		8.6	29.8	13.9	30.7	30.7	17.9
To (river mile)		3.1	13.9	0.7	0.7	21.5	15.9
Total Distance of Dye Travel (miles)		5.5	15.9	13.2	30	9.2	2
Total Elapsed Time (hours)		12.3	267.6	153.8	188	19	2.6
Average Velocity (ft/sec)		0.66	0.09	0.13	0.23	0.71	1.12
Range of Velocities	Maximum (ft/sec)	1.12	0.27	1.47	0.59	1.58	1.8
	Minimum (ft/sec)	0.44	0.05	0.07	0.15	0.43	0.93

MWRC. 1970. The Assabet River Report – Part A, Data Record on Water Quality. Massachusetts Water Resources Commission, Division of Water Pollution Control, Boston, MA. December 1969 and September 1970.

MADEP. 1980. Unpublished Dye Study Information For the Assabet River

Table 2-5 Summary of Sampling Locations of Previous Studies (MADEQE, 1988)

Station Number	Location	River Mile
AS01	Water Outlet, George H. Nichols Multi-Purpose Dam	31.8
AS02	Maynard Street, Westborough	30.7
AS03	Outlet of Hocomonco Pond, Otis Street, Westborough	30.5
AS04	Route 9, Westborough	39.8
AS05	Route 135, Westborough/Northborough line	28.9
AS06	School Street, Northborough	28.0
As07	Above Dam, Route 20, Northborough	26.5
AS09	Boundary Street, Northborough/Marlborough line	23.9
AS10	Robin Hill Road, Marlborough	23.4
AS11	Bigelow Road, Berlin	21.5
AS13	Chapin Road, Hudson	19.4
AS14	Below dam, Route 85, Hudson	17.9
AS16	Cox Street, Hudson	15.9
AS17	Below dam, Route 62, Stow	14.2
AS18	Boon Road, Stow	11.4
AS19	Route 62/117, above dam, Maynard	8.6
AS20	Route 27/62 at USGS gage, Maynard	7.4
AS21	Above Powdermill dam, Acton	6.5
AS22	Route 62, first bridge, Concord	6.1
AS24	Route 62, second bridge, Concord	3.1
AS25	Routes 2/2A, Concord	2.4
SU15	Sudbury River, Nashawtuc Hill Road, Concord	0.0, -0.5
C001	Concord River, Lowell Road, Concord	0.0, +0.1

Table 2-6 Upper Assabet River Water Quality Measurements Collected During Previous Studies

Location	DEP Document ID No.	Date	Maynard gage (cfs)	Assabet River Concentrations														
				Total Phosphorus (mg/L)			Nitrate (mg/L)			Ammonia (mg/L)			BOD$_5$ (mg/L)			Fecal Coliform (per 100 ml)		
				Typ.	High	Low	Typ.	High	Low	Typ.	High	Low	Typ.	High	Low	Typ.	High	Low
Headwaters to Boundary Street (RM 31.8 - 23.9)	82-A-2	Oct. 21-23, 1969	57	2.50	3.70	0.07	1.0	2.0	0.0	2.50	5.30	0.14	5.0	14.0	1.2	50,000	460,000	91
	82-A-4	Jun. 4-6, 1974	154	0.70	1.10	0.03	0.6	1.2	0.0	1.00	1.60	0.00	4.0	7.0	1.8	500	10,000	100
	82-A-4	Sep. 17-19, 1974	53	0.80	1.25	0.02	1.0	1.9	0.0	1.50	2.20	0.01	5.0	9.9	0.8	2,000	68,000	100
	82-A-5	Jun. 4-6, 1979	186	0.90	1.30	0.09	0.7	1.3	0.2	1.00	1.60	0.07	7.0	9.9	4.2	10,000	40,000	500
	82-A-5	Aug. 6-10, 1979	34	1.40	2.00	0.19	1.0	2.0	0.1	2.50	4.20	0.07	8.0	15.3	1.2	800	4,200	100
	82-D-4	Jul. 1985	49	0.90	1.00	0.7	---	---	---	---	---	---	11.0	19.0	5.0	300	2,000	50
	82-ABC-3	Jul. 22, 1987	28	3.00	3.80	0.04	1.0	1.2	0.2	1.50	2.10	0.06	6.5	6.9	4.8	200	440	5
	82-ABC-3	Sep. 2, 1987	26	1.60	2.10	0.07	7.0	9.6	0.5	0.10	0.14	0.02	1.8	2.1	1.5	200	400	100
	82-AB-2	Aug. 9, 1989	99	---	---	---	---	---	---	---	---	---	---	---	---	---	---	---
	82-AB-3	Jul. 10, 1990	38	---	---	---	---	---	---	---	---	---	---	---	---	---	---	---
	82-AB-3	Aug. 21, 1990	72	---	---	---	---	---	---	---	---	---	---	---	---	---	---	---

Notes:

Typ. - Typical concentration are approximate averages observed in Assabet River data.

POTW Loadings from headwaters to Boundary Street consist of the Shrewsbury and Westborough plants prior to 1987 and the combined Westborough plant after 1987. POTW Loadings consist of the Marlborough, Hudson, Maynard, and Concord MCI treatment facilities.

Table 2-7 Lower Assabet River Water Quality Measurements Collected During Previous Studies

Location	DEP Document ID No.	Date	Maynard gage (cfs)	Assabet River Concentrations														
				Total Phosphorus (mg/L)			Nitrate (mg/L)			Ammonia (mg/L)			BOD$_5$ (mg/L)			Fecal Coliform (per 100 ml)		
				Typ.	High	Low	Typ.	High	Low	Typ.	High	Low	Typ.	High	Low	Typ.	High	Low
Boundary Street to Concord River (RM 23.9 - 2.4)	82-A-2	Oct. 21-23, 1969	57	0.70	2.00	0.13	0.8	1.5	0.0	0.20	0.83	0.07	3.5	14.0	1.0	1,000	93,000	36
	82-A-4	Jun. 4-6, 1974	154	0.35	0.60	0.05	0.6	1.1	0.1	0.30	0.45	0.00	2.5	7.2	1.2	1,000	38,000	50
	82-A-4	Sep. 17-19, 1974	53	0.60	1.30	0.02	0.6	1.5	0.0	0.05	1.50	0.01	3.0	6.0	1.0	1,000	500,000	100
	82-A-5	Jun. 4-6, 1979	186	0.35	0.77	0.11	0.6	0.8	0.2	0.25	0.70	0.02	3.5	5.1	1.8	2,500	20,000	400
	82-A-5	Aug. 6-10, 1979	34	0.50	2.00	0.12	0.6	2.5	0.0	0.10	0.59	0.00	2.0	10.0	0.3	1,000	5,300	40
	82-D-4	Jul. 1985	49	3.00	3.10	2.7	---	---	---	---	---	---	3.5	6.5	2.0	2,000	2,000	2,000
	82-ABC-3	Jul. 22, 1987	28	0.75	2.20	0.08	2.0	6.2	0.1	0.15	1.60	0.03	5.0	9.3	4.5	100	1,000	5
	82-ABC-3	Sep. 2, 1987	26	1.00	2.30	0.14	3.0	5.2	0.1	0.25	1.20	0.02	2.5	17.0	0.9	200	1,100	20
	82-AB-2	Aug. 9, 1989	99	0.45	0.45	0.36	0.65	0.73	0.48	0.08	0.11	0.04	2.5	3.0	2.1	200	340	90
	82-AB-3	Jul. 10, 1990	38	0.40	0.47	0.04	0.80	1.30	0.30	0.04	0.08	0.02	---	---	---	---	---	---
	82-AB-3	Aug. 21, 1990	72	0.45	0.48	0.37	0.70	0.88	0.56	0.10	0.13	0.04	---	---	---	---	---	---

Notes:

Typ. - Typical concentrations are approximate averages observed in Assabet River data.

POTW Loadings from headwaters to Boundary Street consist of the Shrewsbury and Westborough plants prior to 1987 and the combined Westborough plant after 1987. POTW Loadings consist of the Marlborough, Hudson, Maynard, and Concord MCI treatment facilities.

Table 2-8 Summary of POTW Flows and Nutrient Loadings Measured During Previous Studies

Location	DEP Document ID No.	Date	POTW discharge (MGD)	POTW discharge (cfs)	POTW Loadings			
					Phos-phorus (lbs/day)	BOD_5 (lbs/day)	Nitrate (lbs/day)	Ammonia (lbs/day)
Headwaters to Boundary Street (RM 31.8 - 23.9)	82-A-2	Oct. 21-23, 1969	2.02	3.01	157	782	92	112
	82-A-4	Jun. 4-6, 1974	2.02	3.01	157	782	92	112
	82-A-4	Sep. 17-19, 1974	2.02	3.01	157	782	92	112
	82-A-5	Jun. 4-6, 1979	3.36	4.99	112	867	104	214
	82-A-5	Aug. 6-10, 1979	2.23	3.32	98	420	131	82
	82-D-4	Jul. 1985	---	---	---	---	---	---
	82-ABC-3	Jul. 22, 1987	3.11	4.63	143	338	617	3.38
	82-ABC-3	Sep. 2, 1987	3.07	4.57	141	115	384	3.08
	82-AB-2	Aug. 9, 1989	3.77	5.61	142	245	94	2.20
	82-AB-3	Jul. 10, 1990	---	---	---	---	---	---
	82-AB-3	Aug. 21, 1990	---	---	---	---	---	---
Boundary Street to Concord River (RM 23.9 - 2.4)	82-A-2	Oct. 21-23, 1969	3.25	4.83	243	845	---	340
	82-A-4	Jun. 4-6, 1974	3.25	4.83	243	845	---	340
	82-A-4	Sep. 17-19, 1974	3.25	4.83	243	845	---	340
	82-A-5	Jun. 4-6, 1979	4.53	6.74	268	846	232	345
	82-A-5	Aug. 6-10, 1979	3.35	4.98	179	775	157	291
	82-D-4	Jul. 1985	---	---	---	---	---	---
	82-ABC-3	Jul. 22, 1987	4.78	7.11	301	1138	139	394
	82-ABC-3	Sep. 2, 1987	4.93	7.33	317	1098	354	459
	82-AB-2	Aug. 9, 1989	4.98	7.41	192	928	289	248
	82-AB-3	Jul. 10, 1990	---	---	---	---	---	---
	82-AB-3	Aug. 21, 1990	---	---	---	---	---	---

Notes:

POTW Loadings from headwaters to Boundary Street consist of the Shrewsbury and Westborough plants prior to 1987 and the combined Westborough plant after 1987. POTW Loadings consist of the Marlborough, Hudson, Maynard, and Concord MCI treatment facilities.

Table 2-9 Dissolved Oxygen Concentration Measurements Collected by US EPA in August 1996

Sample Location		Location	Time	Temperature	DO
Rivermile	Description		(AM)	(•C)	(mg/l)
31.8	Mill Rd	Westborough	5:10	23.5	4.5
29.5	Hop Brook	Northborough	5:20	24.2	8.2
29.2	South St	Northborough	5:30	22.6	3.1
	Rte 20 Dam	Northborough	5:40	23.1	4.3
	Howard Brook	Northborough	5:55	22.5	8
25.6	Allen St	Northborough	6:05	23.5	6.5
25.6	Allen St - 3 ft depth		6:05	23.5	6.5
23.4	Robin Hill Rd	Marlborough	6:15	22	5.2
	North Brook	Berlin	6:20	22.2	5.2
19.4	Chapin Rd	Hudson	6:35	23	5.6
17.9	Rte 85 Dam	Hudson	6:45	24	7.7
14.2	Gleasondale Dam	Stow	6:55	24.1	6.5
11.4	Boon Rd	Stow	7:05	25	5.8
9.2	White Pond	Stow	7:20	24.5	5.7
8.6	Rte 62/117 Dam	Maynard	7:40	25	4.7
6.3	Powdermill Dam	Acton	7:55	25	6.5
6.3	4 ft depth		7:55	24.5	6.1
6.3	8 ft depth		7:55	24	3.1
6.1	Powdermill Dam (below)	Acton	8:05	24.5	5.8
3.1	Rte 62	Acton	8:15	24.5	6.6
3.0	Warners Pond Outlet	Concord	8:30	24.5	6.4
0.0	Assabet Mouth	Concord	8:50	24	5.4

Figure 2-1 Map of the Assabet River (MADEQE, 1988)

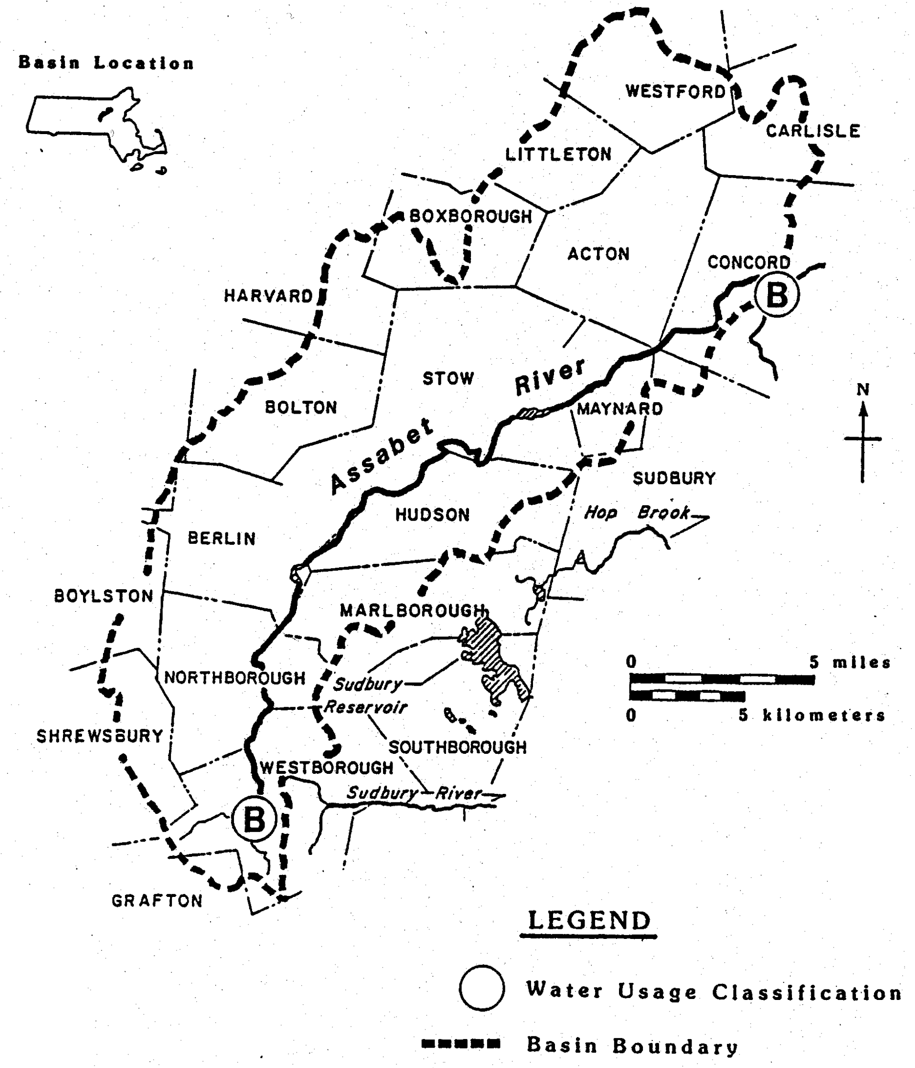


Figure 2-2 Schematic Physical Representation of the Assabet River, Rivermile vs. Elevation with Impoundments and Major Point Source Discharges Identified

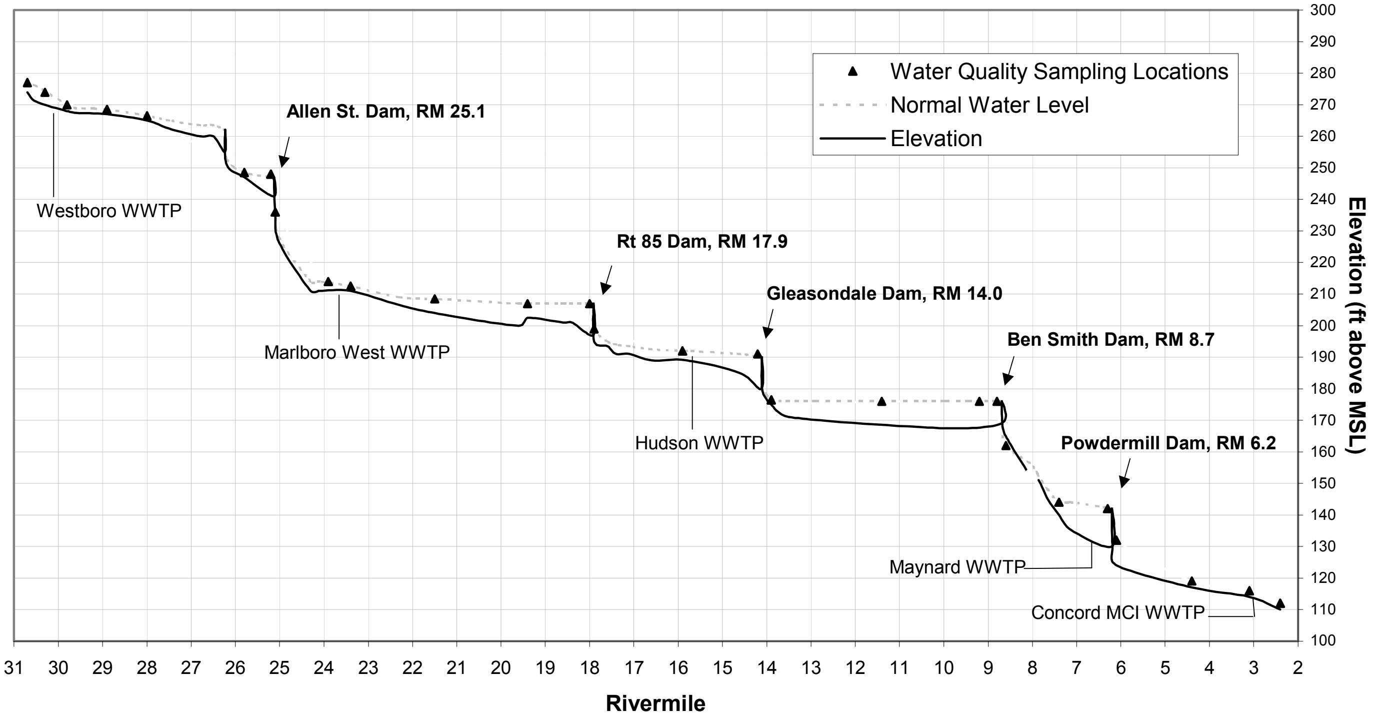


Figure 2-3 Average Monthly Streamflow in the Assabet River as Measured at the USGS Maynard Gauge (RM 7.7). Period of Record 1941-1997.

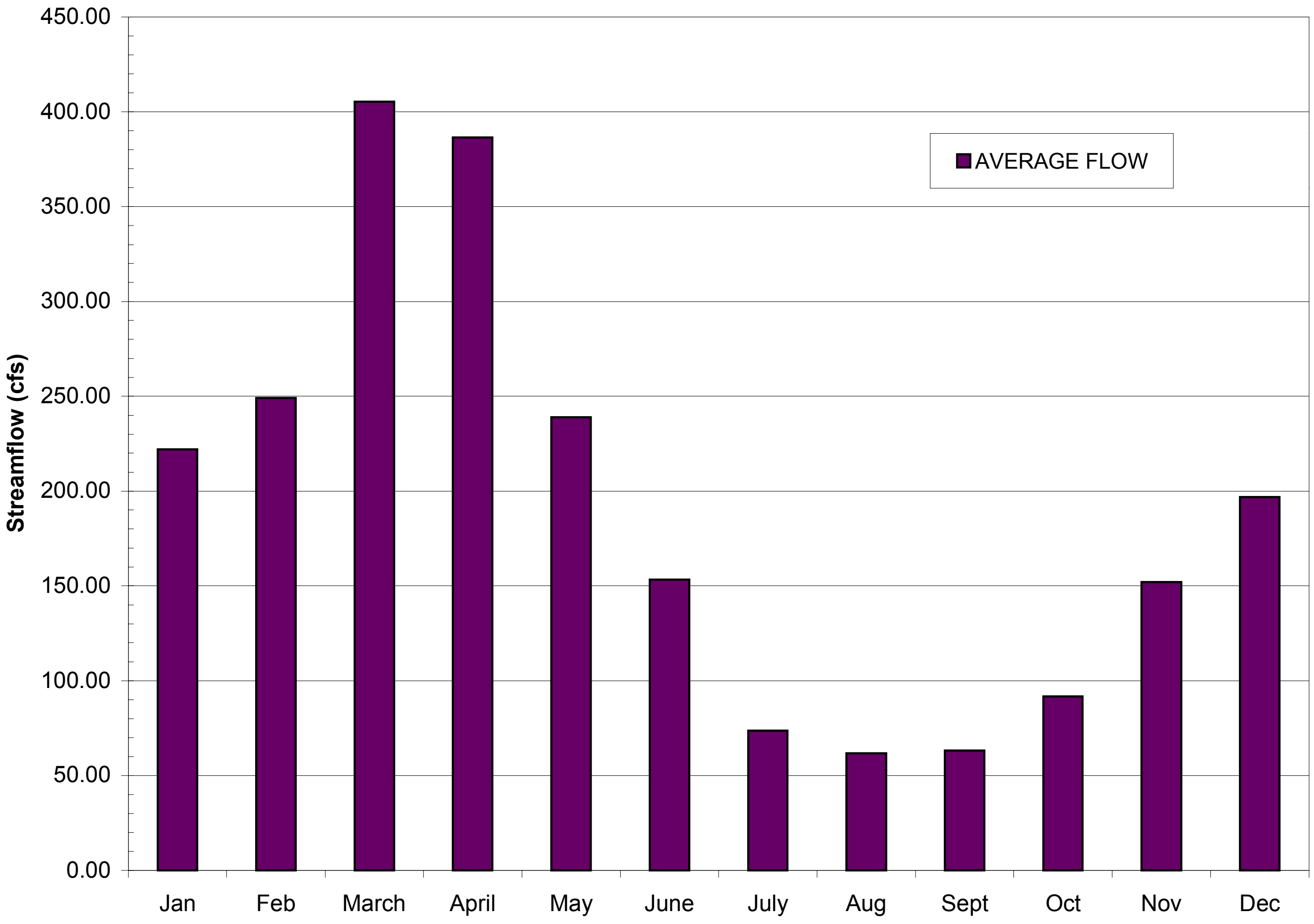


Figure 2-4 Rough Estimate of Streamflow vs. Rivermile Relationships for the Assabet River

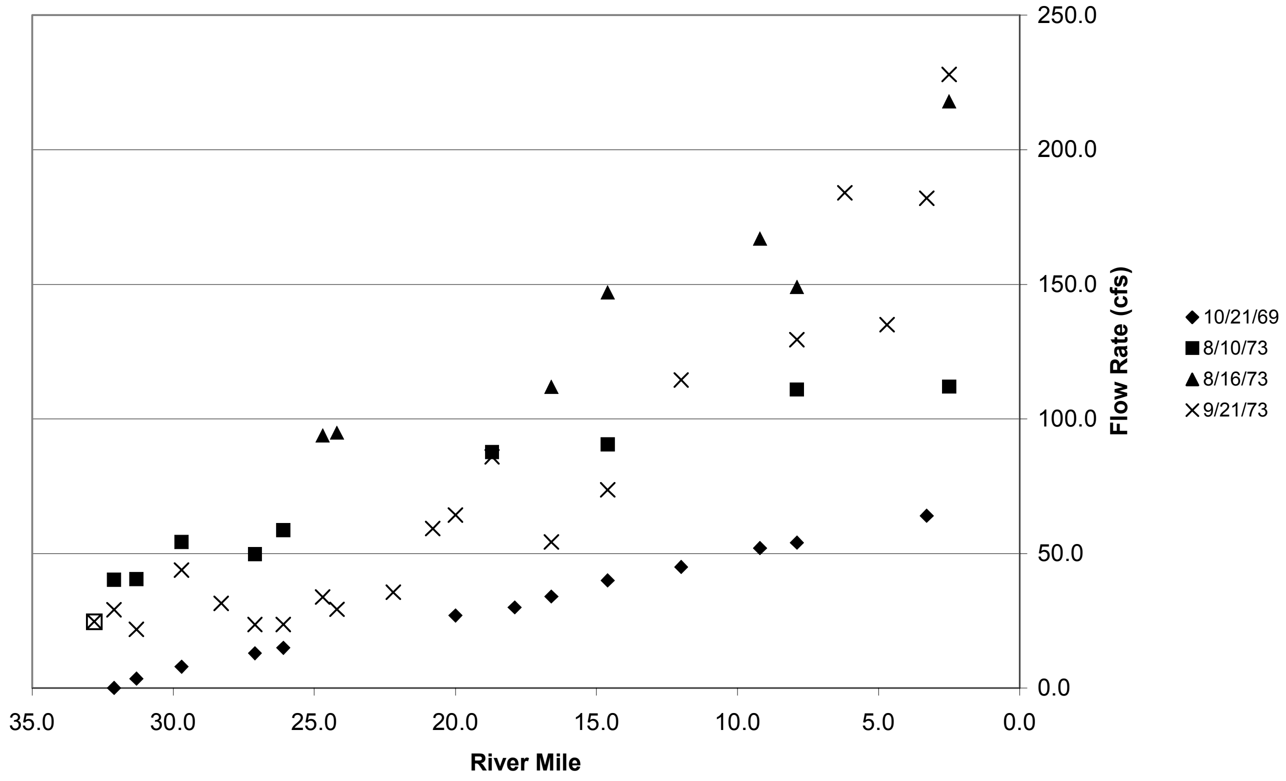


Figure 2-5 Map of the Assabet River with Locations of Sampling Locations of Previous Surveys (MADEQE, 1988)

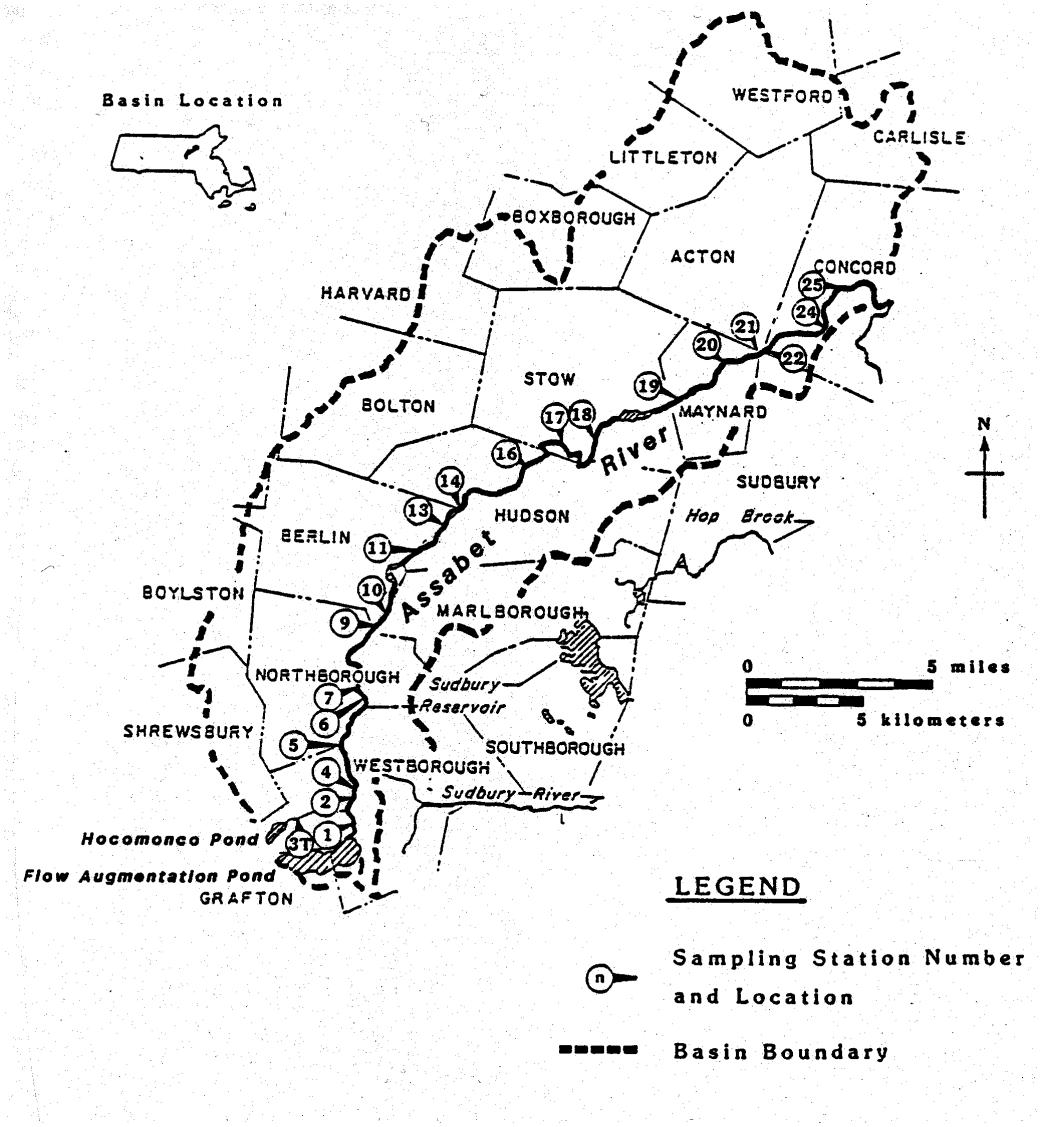
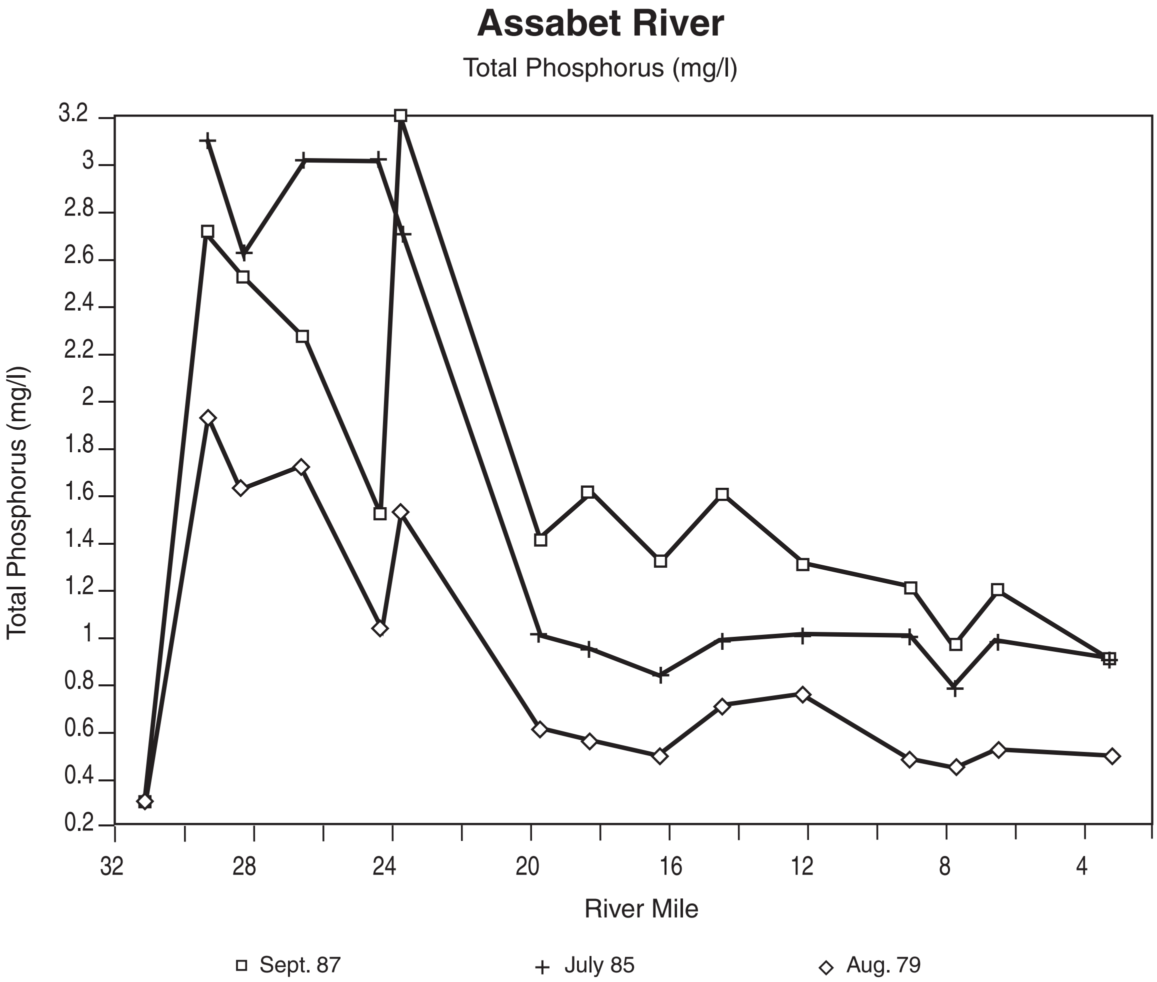


Figure 2-6 Total Phosphorus Concentration Measurements Collected During Three Previous Surveys vs. River Mile (MADEQE, 1988)



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3.0 ASSABET RIVER DATA COLLECTION PROGRAM DESCRIPTION

3.1 Overview

A nutrient TMDL is under development for the Assabet River due to the presence of summer-time eutrophic conditions. Field measurements of hydrologic, water quality, sediment quality, and biology in the Assabet River system were required to support development of a nutrient TMDL. Following completion of a review of available data on the Assabet River (see Section 2), a data collection program was designed and performed to obtain required data. A description of the Assabet River data collection program, including the rationale for field data collection and a description of all surveys performed, is provided in this section.

The goal of the field program was to quantify and document the presence of eutrophic conditions and to support development and application of a nutrient TMDL model of the Assabet River. The field data collection program was designed collaboratively by ENSR, the US Army Corps of Engineers (USACE), the Massachusetts Department of Environmental Protection (MADEP), the Organization for the Assabet River (OAR), and other interested parties. Nutrient loadings and dynamics in the Assabet River system are a primary focus of this study. The study also focused on characterizing the aquatic biology of the Assabet River and the interrelationship between nutrients and biology in the system. The impact of biological activity on ambient dissolved oxygen concentrations was also evaluated. In summary, the field program was designed to gather as much information as possible about nutrient loadings and dynamics, aquatic biology, and ambient dissolved oxygen in the Assabet River system.

A significant effort was made, in collaboration with USACE, MADEP, and OAR, to design the field program to capture both worst-case conditions in terms of eutrophication in the Assabet River system and to capture a set of nutrient loading characterizations under very different seasonal and hydrologic conditions. The field program featured collection of measurements throughout the river, in river impoundments, from point sources, and from tributaries. The field program was designed to provide the information necessary to determine the relative impacts of different processes affecting eutrophication.

The conceptual approach to Assabet River data collection is described in Section 3.2. The Assabet River study area is described in Section 3.3. A description of the data collection program is provided in Section 3.4. Data collection methods are described in Section 3.5.

3.2 Conceptual Approach to Data Collection

The conceptual approach of the data collection program was to obtain sufficient data to support characterization of summer-time eutrophication conditions and to support characterization of nutrient loadings under different seasonal and hydrologic conditions throughout the Assabet River system.

Characterization of summer-time eutrophication conditions will serve to quantify water quality impairment in the Assabet River. Characterization of time-varying nutrient loadings will support assessment of relative impacts of individual nutrient sources and nutrient-related processes on water quality in the Assabet River under a variety of conditions. These characterizations will contribute to an enhanced understanding of the nutrient loadings and associated system response throughout the year.

As described in Section 2, eutrophication has been observed in the Assabet River during the summer months and nutrient loadings have been measured at levels sufficient to support eutrophication in numerous previous surveys. During the summer season, extensive nuisance aquatic vegetation has been frequently observed and dissolved oxygen concentration measurements at levels below the water quality standard of 5.0 mg/l have frequently been collected. Clearly, the summer season, when sufficient nutrients, maximum solar irradiance, and maximum water temperature are present, provides favorable conditions for eutrophication. The data collection program was designed to quantify the hydrologic, water quality, sediment quality, and biological characteristics associated with summer-time eutrophication events.

Characterization of nutrient loadings to the River and nutrient dynamics within the River throughout the year was also a focus of the data collection program. Contributors to the overall nutrient budget include point sources (such as wastewater treatment facilities), non-point sources (such as tributaries), river sediments, and atmospheric deposition. The data collection program was designed to collect sufficient data to support quantification of relative impacts to the river system associated with nutrient loading sources and nutrient processes.

Phosphorus and nitrogen are the two primary essential nutrients for plant growth. Phosphorus is found in dissolved and particulate forms in the aquatic environment. Dissolved phosphorus contains ortho-phosphorus that is representative of biologically available phosphorus. Ortho-phosphorus may be readily taken up by aquatic organisms. Total phosphorus represents both the dissolved form (including ortho-phosphorus) and the particulate form that must be converted by natural biological processes prior to aquatic plant uptake. Thus, ortho-phosphorus is readily available phosphorus and total phosphorus represents the total amount of phosphorus that may potentially be taken up by aquatic organisms.

Nitrogen is found in several forms in the aquatic environment. Some nitrogen forms are more readily available for uptake by aquatic organisms than others. Ammonium and nitrate are the two forms of nitrogen that are most readily accessible for biological uptake. Organic nitrogen, in contrast, is bound up in organic material and is unavailable for immediate bioligical uptake. Organic nitrogen is also important, however, because it may converted through natural biological processes into ammonium and nitrate forms and taken up by aquatic organisms. The field program was designed to quantify all of the forms of phosphorus and nitrogen described above.

The data collection program was also designed to support development and application of a mathematical model of the Assabet River system. Assabet River nutrient TMDL modeling requirements include quantification of nutrient loadings to the system throughout the year, determination of water column chemical and biological processes, and sediment nutrient/water column interactions in the Assabet River system. The data collection program was designed to collect the data required to support nutrient TMDL modeling of the Assabet River.

3.3 Description of Study Area and Data Collection Activities

The Assabet River study area is shown in Figure 3-1. For a physical description of the Assabet River, please refer to Section 2.2. The study area extends from Maynard Street, Westborough, MA (RM 30.7) to Park Street, in Concord, MA (RM 1.6). The study domain included 23 river sampling locations, 10 tributary sampling locations, and numerous river impoundment sampling locations. Figure 3-2 contains a cross-sectional view of the Assabet River with river sampling locations identified. Through schematic physical representation, Figure 3-2 provides a sense of the relative river slope and supports comparison of rates of water movement along the Assabet River.

The Assabet River data collection program involved collection of hydrologic, water quality, sediment quality, and biological data during 13 surveys performed from July 1999 through October 2000. Table 3-1 provides a matrix of survey events and data collection activities. Field survey events are presented in chronological order in Table 3-1 with an "X" signifying performance of data collection activities.

The data collection program involved collection of measurements at 23 river locations, in 5 river impoundments and in 10 river tributaries throughout the Assabet River system. Table 3-2 provides a matrix of field survey types and sampling locations. Sampling locations are provided along with rivermile designations and may be viewed spatially in Figure 3-1. For each survey type, data were collected at all locations designated with an "X" in Table 3-2. Survey types are described in Section 3.5 and correspond to designations provided in Table 3-1. Methods applied to collect hydrologic, water quality, sediment quality, and bioligical data are described in Section 3.5. A summary of all data collection results is provided in Sections 4 through 7.

3.4 Description of Field Surveys

This section provides a description of each survey type, including survey objectives, sampling design rationale, and specific sampling tasks. The 13 field surveys presented in Table 3-1 may be categorized into 6 types of surveys as follows:

- *Intensive summer surveys (2) - conducted July 1999 and August 2000*
- *Dry-weather surveys (3) – conducted January, February, and March 2000*
- *Wet-weather tributary surveys (3) – conducted March (2) and September 2000*

- _Sediment nutrient flux surveys (2)_ *– conducted March and September 2000*
- _Impoundment bathymetry/sediment thickness survey (1)_ *– conducted May/June 2000*
- _Time of travel surveys (2)_ *– May and September/October 2000*

Each type of survey is described below.

3.4.1 Intensive Summer Surveys

Intensive summer surveys were designed to characterize the Assabet River system during summer-time eutrophication conditions and to support calibration and validation of the Assabet River nutrient TMDL model. Summer conditions in the Assabet River are worst-case in terms of water quality because the factors associated with favorable biological growth are optimal (e.g., optimal solar conditions and water temperature to support photosynthetic activity). Two intensive summer surveys were performed to collect hydrologic, water quality, sediment quality, and biological measurements throughout the Assabet River mainstem, in tributaries, and in river impoundments.

The intensive summer-time surveys were performed during summer-time low flow and average flow conditions in July 1999 and August/September 2000, respectively. Data were collected during two different hydrologic conditions to support model calibration and validation tasks. Low-flow summer-time conditions in the river are likely worst-case because water movement is relatively slow allowing biomass extended exposure to available nutrients. Also, during low-flow conditions, publicly-owned treatment works (POTWs) effluents receive minimal dilution in ambient waters and thus likely have greatest impact on river water quality.

Specific data collection tasks performed during the two intensive summer-time surveys are described below.

3.4.1.1 Intensive Summer 1999 Survey

During the Intensive Summer 1999 Survey, water quality sampling was conducted at the locations shown in Figure 3-1 as indicated in the data collection matrix of Table 3-2. The following data collection activities were performed as part of the Summer 1999 survey.

Hydrologic data collection

- In the river, streamflow and average water velocity measurements were collected at 4 river locations.
- In tributaries, streamflow and average water velocity measurements were collected at 2 tributary locations.

- In point sources, average flowrates from 4 point source discharges were measured and obtained from POTWs.

Water quality data collection

- In the river, in-situ water quality measurements of temperature, dissolved oxygen concentration, pH, and conductivity were collected at 21 river locations throughout a 3-day period including early morning and late afternoon measurements to capture diurnal variations. Also, continuous in-situ water quality measurements were collected at 5 locations over an approximately 24-hour period to more intensively quantify diurnal variations.
- In the river, grab samples were collected for laboratory analysis of nutrient-related chemical parameters (compiled in Table 3-3) at 21 river locations and in 5 river impoundments to support quantification of water quality conditions on two separate days (i.e., two complete rounds of sampling).
- In tributaries, in-situ water quality measurements of temperature, dissolved oxygen concentration, pH, and conductivity were collected at 5 tributary locations.
- In tributaries, grab samples were collected for laboratory analysis of nutrient-related chemical parameters (Table 3-3) at 5 tributary locations to support quantification of water quality conditions.
- In point sources, grab samples were collected for laboratory analysis of nutrient-related chemical parameters (Table 3-3) at 4 POTWs (obtained from POTWs).

Biological data collection

- In the river, aquatic macrophyte sampling and analysis was performed including identification and estimation of total biomass in 5 river impoundments. Locations of the 5 river impoundments are shown in Figure 3-1.
- In the river, phytoplankton sampling and analysis was performed including identification and estimation of total biomass in 5 river impoundments.

Additional data collection

- Obtained precipitation and air temperature records for the watershed during and preceeding the study period. These meteorologic data were collected from local airports, USGS gauging stations, and POTWs.
- Obtained USGS Maynard streamflow gauge data preceeding and concurrent with study period.

3.4.1.2 Intensive Summer 2000 Survey

During the Intensive Summer 2000 Survey, water quality sampling was conducted at the locations shown in Figure 3-1 as indicated in the data collection matrix of Table 3-2. The following data collection activities were performed as part of the Summer 2000 survey.

Hydrologic data collection

- In the river, streamflow and average water velocity measurements were collected at 8 river locations.
- In tributaries, streamflow and average water velocity measurements were collected at 10 tributary locations.
- In point sources, average flowrate from 4 point source discharges were measured and obtained from POTWs.

Water quality data collection

- In the river, in-situ water quality measurements of temperature, dissolved oxygen concentration, pH, and conductivity were collected at 23 river locations throughout a 3-day period including early morning and late afternoon measurements to capture diurnal variations. Also, continuous in-situ water quality measurements were collected at 6 locations over an approximately 48-hour period to more intensively quantify diurnal variations.
- In the river, grab samples were collected for laboratory analysis of nutrient-related chemical parameters (Table 3-3) at 23 river locations and in 5 river impoundments to support quantification of water quality conditions.
- In tributaries, in-situ water quality measurements of temperature, dissolved oxygen concentration, pH, and conductivity were collected at 10 tributary locations including early morning and late afternoon measurements to capture diurnal variations. The 10 tributary locations were selected because they drain the largest 10 sub-basins in the watershed (see Table 2-2).
- In tributaries, grab samples were collected for laboratory analysis of nutrient-related chemical parameters (Table 3-3) at 10 tributary locations.
- In point sources, grab samples were collected for laboratory analysis of nutrient-related chemical parameters (Table 3-3) at 4 POTWs (obtained from POTWs) discharging to the Assabet River during the week of the field survey.

Biological data collection

- In the river, aquatic macrophyte sampling and analysis was performed including species identification and estimation of total biomass in 5 river impoundments. Locations of the 5 river impoundments are shown in Figure 3-1.
- In the river, phytoplankton sampling and analysis was performed including identification and estimation of total biomass in 5 river impoundments.
- In the river, zooplankton sampling and analysis was performed including identification and estimation of total biomass in 5 river impoundments.

Additional data collection

- Obtained precipitation and air temperature records for the watershed during and preceeding the study period. These meteorologic data were collected from local airports, USGS gauging stations, and POTWs.
- Obtained USGS Maynard streamflow gauge data preceeding and concurrent with study period.

3.4.2 Dry-weather Surveys

Dry-weather surveys were performed to measure nutrient loads from tributaries and in the river mainstem during the winter and spring months. Nutrient loadings were measured in the 6 largest Assabet River tributaries and above and below the 5 major Assabet River impoundments. Winter-time nutrient loads were measured to support estimation of the time-varying nutrient budget of the Assabet River system. Tributaries and river impoundments nutrient loadings were evaluated because they represent an important component of the overall nutrient budget.

Nutrient loads from tributaries were measured to support quantification of non-point source loadings throughout the year. Nutrient loads of waters entering and leaving 5 river impoundments were also measured as part of the winter-time dry-weather surveys. Nutrient loadings associated with river impoundments were measured to evaluate the capacity of river impoundments to act as nutrient reservoirs. Specifically, the capacity for river impoundments to act as nutrient “sinks” (i.e., a place where nutrients are stored) during the winter-time and nutrient “sources” during summer-time was evaluated through the dry-weather survey program.

During the dry-weather surveys, water quality sampling was conducted at the locations shown in Figure 3-1 as indicated in the data collection matrix of Table 3-2. The three dry-weather water quality surveys on the Assabet River were performed during the Winter of 2000 (Table 3-1). The surveys included collection of hydrologic and water quality measurements at 16 locations, 10 locations along the mainstem and 6 locations in contributing tributaries (Table 3-2). The following data collection activities were performed as part of the dry-weather surveys.

Hydrologic data collection

- In the river, streamflow and average water velocity measurements were collected at 10 river locations.
- In tributaries, streamflow and average water velocity measurements were collected at 6 tributary locations
- In point sources, average flowrate from 4 point source discharges were measured and obtained from POTWs.

Water quality data collection

- In the river, in-situ water quality measurements of temperature, dissolved oxygen concentration, pH, and conductivity were collected at 10 river locations.
- In the river, grab samples were collected for laboratory analysis of nutrient-related chemical parameters (Table 3-3) at 10 river locations.
- In tributaries, in-situ water quality measurements of temperature, dissolved oxygen concentration, pH, and conductivity were collected at 6 tributary locations.
- In tributaries, grab samples were collected for laboratory analysis of nutrient-related chemical parameters (Table 3-3) at 6 tributary locations.
- In point sources, grab samples were collected for laboratory analysis of nutrient-related chemical parameters (Table 3-3) at 4 POTWs (obtained from POTWs) discharging to the Assabet River during the week of the field survey.

Additional Data Collection

- Obtained precipitation and air temperature records for the watershed during and preceeding the study period. These meteorologic data were collected from local airports, USGS gauging stations, and POTWs.
- Obtained USGS Maynard streamflow gauge data preceeding and concurrent with study period.

3.4.3 Wet-weather Surveys

Wet-weather surveys were performed to measure nutrient loads from tributaries during precipitation events. Nutrient loadings from non-point sources are highly variable over time. In general, nutrient non-point source loadings increase dramatically during precipitation events as overland and subsurface flows carry nutrients to the receiving waterbody. Wet-weather non-point source nutrient loads were measured to evaluate the time-varying nutrient budget of the Assabet River system. Wet-weather nutrient loads were measured in the 10 largest Assabet River tributaries because they represent an important component of the overall nutrient budget.

The wet-weather surveys were designed to quantify non-point nutrient loads and support assessment of the relative contribution of non-point source loads to the overall Assabet River nutrient budget. Specifically, wet-weather surveys were designed to capture nutrient concentrations in tributaries to the Assabet River during the rising limb of storm hydrographs induced by precipitation events. By capturing storm induced nutrient concentrations in tributaries, nutrient loadings from overland flow may be estimated and determinations made regarding the relationship between nutrient loads and landuse practices within the tributary watersheds.

During the wet-weather surveys, water quality sampling was conducted at the locations shown in Figure 3-1 as indicated in the data collection matrix of Table 3-2. Three wet-weather water quality surveys were performed during precipitation events during the Winter and Summer of 2000 (Table 3-1). The surveys included collection of hydrologic and water quality measurements at 10 tributary locations. Wet-weather survey methods featured deployment of automated water sampling equipment. A complete description of data collection methods is provided in Section 3.5. The following data collection activities were performed as part of the wet-weather surveys.

Hydrologic Data Collection

- In tributaries, streamflow and average water velocity measurements were collected at 10 tributary locations prior to the precipitation event to quantify baseflow conditions.
- In point sources, average flowrate from 4 point source discharges were measured and obtained from POTWs.

Water Quality Data Collection

- In tributaries, in-situ water quality measurements of temperature, dissolved oxygen concentration, pH, and conductivity were collected at 10 tributary locations.
- In tributaries, grab samples were collected for laboratory analysis of nutrient-related chemical parameters (Table 3-3) at 10 tributary locations.
- In point sources, grab samples were collected for laboratory analysis of nutrient-related chemical parameters (Table 3-3) at 4 POTWs (obtained from POTWs) discharging to the Assabet River during the week of the field survey.

Additional Data Collection

- Obtained precipitation and air temperature records for the watershed during and preceeding the study period. These meteorologic data were collected from local airports, USGS gauging stations, and POTWs.
- Obtained USGS Maynard streamflow gauge data preceeding and concurrent with study period.

3.4.4 Sediment Nutrient Flux Surveys

Sediment nutrient flux surveys were performed to evaluate the impact of impoundment sediments on the nutrient budget of the Assabet River system. Nutrients are cycled between the water column and sediments in river impoundments and this process may represent a significant portion of the overall nutrient budget. The overall objective of the nutrient flux surveys was to quantify the flux of selected nutrients and oxygen between the sediments and their overlying waters. The magnitude of sediment nutrient fluxes is influenced by many environmental factors including temperature and availability of labile organic carbon and oxygen. In particular, the sediment nutrient flux surveys are important to quantify phosphorus retention in river impoundments including recycling rates and sediment storage capacity.

Two sediment nutrient flux surveys were performed as part of the Assabet River data collection program. The first survey, performed in March 2000, featured collection and analysis of sediment nutrient flux from 8 sediment cores collected in the Ben Smith Impoundment. The second survey, performed in September 2000, featured collection and analysis of sediment nutrient flux from 8 sediment cores from the Ben Smith Impoundment and from 8 sediment cores collected in the Powdermill Impoundment. The September 2000 survey also featured sediment quality analyses of ortho-phosphorus, ammonia, total nitrogen, total carbon, dry weight density, and porosity in the 5 major river impoundments; Allen St Impoundment (RM 25), Hudson Impoundment (RM 18), Gleasondale Impoundment (RM 14.5), Ben Smith Impoundment (RM 9), and Powdermill Impoundment (RM 6.5).

Sediment nutrient flux measurement methods are described in Section 3.5 below and are summarized in Section 6.

3.4.5 Time of Travel Surveys

Time of travel surveys were performed to support hydrologic characterization of the river system. Time of travel measurements, together with streamflow measurements, provide sufficient data to support development and application of the hydrologic component of the Assabet River water quality model. Time of travel surveys also provide supporting information to water quality and sediment quality characterizations. Specifically, time of travel surveys were performed at the same locations and under similar hydrologic conditions as the sediment nutrient flux surveys. Thus, time of travel surveys provide measurements of duration of exposure of water masses to impoundment sediments. These measurements will support assessment of water quality impacts associated with river impoundment sediments.

Time of travel studies were performed in May 2000 and September/October 2000 to measure travel time through the Ben Smith Impoundment and adjacent reaches and through the Powdermill Impoundment and adjacent reaches. The two time of travel studies were performed following methods described in Section 3.5 and are summarized in Section 4.

3.4.6 Impoundment Bathymetric and Sediment Thickness Survey

Impoundment bathymetry and sediment thickness surveys were performed to support characterization of sediment effects on water quality in the Assabet River system. River impoundments are of particular interest because water is detained in impoundments for longer periods than in free-running reaches allowing for greater impacts on the water column from underlying sediments.

A bathymetric and sediment thickness survey was performed in 5 river impoundments; Powdermill, Ben Smith/Crow Island, Gleasondale, Hudson, and Allen Street. Bathymetry measurements support estimation of impoundment volume and average residence time. Sediment thickness measurements support assessment of sediment impacts on river water quality. Bathymetry and sediment thickness surveys were performed by volunteers from the Organization for the Assabet River (OAR) with support from ENSR personnel during the Spring of 2000. The impoundment bathymetric and sediment thickness survey was performed following methods described in Section 3.5 and are summarized in Section 6.

3.5 Data Collection Methods

This section provides a summary of data collection methods applied in performing sampling and analysis activities associated with all of the Assabet River field surveys. A Quality Assurance Program Plan (QAPP) was submitted to and approved by MA DEP and US EPA Region 1 and describes data collection methods in detail (ENSR, 1999). All data collection activities were performed in compliance with the approved Assabet River QAPP. Methods associated with hydrologic, water quality, sediment quality, and biological data collection are described and summarized below.

3.5.1 Field Operations

Field sampling crews and sampling equipment were mobilized from ENSR's Acton, MA and Northborough, MA offices for all surveys. For the intensive summer surveys, field operations were performed by five samplers organized in two teams of two, with one designated sample courier. One team was assigned to collect measurements in the upper-half of the Assabet River and the second team was assigned to collect measurements in the lower-half of the Assabet River. A halfway point was arbitrarily identified as Route 85 in downtown Hudson (RM 18). Equipment provided to each team included a vehicle, a canoe or skiff, a water quality meter, calibration fluids, coolers containing water sample bottles and ice, a first-aid kit, and a cellular phone.

For dry-weather and wet-weather surveys, field sampling crews were mobilized from ENSR's Acton, MA office. Dry-weather and wet-weather surveys were each completed in two days by a two-member team with logistical support from a third person.

Volunteers and staff from the Organization for the Assabet River (OAR) contributed significantly to numerous surveys including impoundment bathymetric surveys, time of travel surveys, sediment nutrient flux surveys, and water quality sampling surveys. OAR volunteers provided essential guidance in designing the field program and many hours of field labor. The efforts of OAR volunteers enhanced the quality and overall scope of the field program.

A health and safety meeting was held prior to each survey and all personnel were provided with appropriate health and safety instruction and gear. Health and safety instructions included use plastic gloves when collecting sampling to minimize potential for exposure to waterborne disease, use of waders when entering the river, and importance of working in teams. Sampling personnel followed ENSR Health and Safety procedures throughout the surveys.

3.5.2 Hydrologic Data Collection Methods

Two primary hydrologic data collection methods were employed on the Assabet River; streamflow measurements and time of travel measurements. Each method is described below.

3.5.2.1 Streamflow Measurements

Average stream velocity and discharge measurements were collected using either a Price-pygmy rotating cup current meter or the Marsh McBirney electro-magnetic meter, in accordance with guidance provided by the United States Geological Survey. ENSR followed a protocol provided by the USGS (USGS, 1969) and excerpted below.

1. Select a cross-section from a straight, uniform reach with parallel streamlines and a relatively uniform bottom. The depth of the section and the velocity of flow that can be measured are limited by the dimensions of the current meter used. The pygmy current meter can measure velocities in water that is approximately 2 inches deep or greater and at velocities of 0.05 feet per second or more. If possible, the section should be free of large eddies with upstream circulation near the banks, slack water, or excessive turbulence caused by upstream bends, radical changes in cross-section shape, and irregular obstructions such as boulders, trees, vegetation, and other debris in the vicinity.

2. Select a time period for measurement when the flow is not expected to change. If the flow changes rapidly during the flow measurement the reading will have to be abandoned. The determination of flow variability during a measurement is made by noting water level before and after collecting measurements.

3. String a tape measure across the stream channel perpendicular to flow. This will allow for a record of the transverse location of the current meter during a measurement. Visually divide up the flow through the cross-section into at least 20 compartments (depending on the width of the channel) such that each compartment has roughly the same amount of flow passing through.

As shown in the channel cross-section diagram illustrated in Figure 3-3, measure the distances (b) and depths (d) for each average velocity measurement. The mean velocity is measured at a point six-tenths of the depth from the stream surface at each location (b). The partial area flows are calculated by multiplying the width of the individual areas by the corresponding depths in those areas. This calculation is made according to the following equation:

$$q_x = v_x \left[\frac{b_x - b_{(x-1)}}{2} + \frac{b_{(x+1)} - b_x}{2} \right] d_x$$

where qx = volumetric flowrate, and

vx = water velocity

5. Compute the total flow as the sum of the partial flows using the equation:

$$Q = \Sigma q_x$$

3.5.2.2 Time of Travel Measurements

A fluorescent dye was introduced to the Assabet River at concentrations capable of being measured using an *in-situ* fluorometer at a downstream location. A Turner Model 10 AU with flow-through cell, on-board temperature compensation and datalogger from the US EPA New England Regional Lab in Lexington was used to collect dye concentration measurements. The dye used in the study was Rhodomime WT. The fluorometer was calibrated to Rhodamine WT prior to each survey, including setting temperature correction parameters. The quantity of dye required for this application was estimated from the dye-dosage formula in Kilpatrick and Wilson (1989).

The Turner Model 110 fluorometer is capable of measuring concentration of fluorescent dye by two methods; (1) direct measurement along the river shoreline via a flow-through cell and (2) measurement of a grab sample in a laboratory setting. Both of these methods were applied during the Assabet River time of travel surveys.

For direct measurement of fluorescent dye concentration, the concentration of the dye was continuously monitored downstream using a recording Turner Model 110 fluorometer and a graphic representation of the dye concentration over time was obtained. Measurements were recorded approximately every 10 minutes throughout the study period.

For measurement of fluorescent dye concentration in grab samples, grab samples were collected approximately every hour and were transported, in a closed container to the laboratory for analysis. Samples were labeled following the protocol established for the water quality sampling protocol. Samples were decanted into a clean 40 ml cuvette and placed into a chamber of the Turner fluorometer for dye concentration measurement. Dye concentration measurements recorded in a field log book.

3.5.3 Water Quality Data Collection Methods

Two primary water quality data collection methods were employed on the Assabet River; in-situ water quality measurements and laboratory analysis of water samples for nutrient-related parameters. Each water quality method is described below.

3.5.3.1 Synoptic In-Situ Water Quality Measurements

In-situ measurements of temperature, dissolved oxygen concentration (and % saturation), pH, and conductivity were collected using YSI 6820 water quality meters. The water quality meter is comprised of two units; an instrument sonde and a display unit, with a communications cable connecting the two. The sonde unit contains several instrument probes and houses electronics to store the instrument readings and/or relay readings to the display unit.

The YSI meter was pre-calibrated each day of the survey prior to collection of measurements and post-calibrated each day immediately after survey operations were complete. All meter calibration activities were documented in field logbooks.

The water quality meter sonde was lowered into the water by a sampler on a bridge, in the river, or in a small boat. The sonde was deployed at approximately mid-channel and mid-depth at each sampling location. During deployment, the sonde was held steady at a selected depth until ambient currents resumed and meter readings equilibrated. YSI meter readings were recorded in a field log book along with sampling location, depth, date, time, sampler name, and other supporting information. Between sampling events, water quality meters were stored in containers partially filled with deionized water to maintain moisture on the sensors.

3.5.3.2 Continuous In-Situ Water Quality Measurements

Continuous in-situ measurements of temperature, dissolved oxygen concentration (and % saturation), pH, and conductivity were collected using YSI 6820 XL water quality meters. The YSI 6820 XL meter is similar to the YSI 6820 meter described above and has an additional data storage capability. The YSI 6820 XL meter comes with a battery and data storage unit within the underwater housing and a software/communications cable to enable direct communication between the instrument and a personal computer.

Deployment of the continuous-recording water quality meter involved programming of the meter to collect measurements at 10-minute intervals, attaching the sonde to a cinder block using hose clamps, and deploying the sonde in the river. The sonde was deployed at mid-channel and approximately mid-depth at each sampling location. An attempt was made to place the instrument in an inconspicuous location in the river to reduce the potential for vandalization.

Retrieval involved removing the sonde from the river, connecting the communications cable between the sonde and a laptop computer, and downloading data from the data storage device in the instrument. Data was reviewed in the field as a preliminary quality assurance check.

The recording YSI meter was pre-calibrated prior to each deployment and post-calibrated immediately following retrieval. All meter calibration activities were documented in field logbooks.

3.5.3.3 Water Sample Collection for Laboratory Analysis

Ambient water samples were collected for laboratory analysis at numerous sampling locations throughout the study area. At each location, samples were collected at mid-channel and mid- depth. Water samples were collected primarily by samplers in waders. In some cases, such as in river impoundment sampling, samples were collected using teflon-coated Beta water sampling bottles manufactured by Wildco Inc. Each water sample collection method is described below.

Water samples were placed in sample bottles prepared and provided by the laboratory. Sample coordination and labeling protocols were developed in advance of the surveys by personnel from ENSR and Thorstensen Laboratory of Westford, MA. All samples were labeled with information including a unique sample identification alpha-numeric, analysis type, sampling time and date, and sample location. Samples were collected and labeled in a manner that uniquely identified each individual sample bottle. Once filled, sample bottles were immediately put in a cooler filled with ice. Samples were kept cold and hand delivered to the analytical laboratory within 4 hours or sample collection in order to enable compliance with the shortest sample holding time of 6 hours for fecal coliform.

Water samples were primarily collected by sampling personnel wading to the river's mid-channel and collecting a measurement. Samples waded to mid-channel with a sample bottle and then stood still to allow ambient current to be re-established and any disturbance to subside. Personnel then lowered a capped water sample bottle (e.g., 1 liter plastic) to mid-depth and waited again. The sampler then opened the bottle in-situ allowing it to fill and capped it. The bottle was then brought to the surface and labeled with time and date of sample collection (other sample information was pre-entered on the label). Sampling information was logged in field notebooks.

Water samples collected using a Beta bottle were collected at mid-depth by lowering the bottle to depth and closing the bottle using a messenger. The messenger activates a spring which closes the Beta bottle in-situ. The full bottle was then brought the surface and drained into plastic sample bottles. The Beta bottle was de-contaminated between sampling events using mild, non-phosphorus detergent and deionized water. Sampling using Beta bottles were documented in field notebooks.

Water samples were analyzed for the suite of parameters presented in Table 3-3. Table 3-3 includes analysis methods and holding time requirements associated with each analyte.

3.5.3.4 Automated Sample Collection for Laboratory Analysis

Wet-weather grab samples were collected using simple automated grab samplers. Wet-weather grab samples were analyzed for the set of parameter values presented in Table 3-3. The automated grab sampler design is shown in Figure 3-4 and consists of a sample bottle equipped with a stopper with two tubes, one shorter (to allow water to enter) and one longer (to allow air to exit). The sample bottle was attached to a post and placed in the river such that the shorter tube is approximately one inch above the water line (depending on the characteristics of the tributary cross-section). When the water level in the river rises due to storm water runoff, the sample bottle were filled with water.

Sampling personnel were not present at the time of automated sample collection. Personnel visited the sampling location within 20 hours of commencement of the storm event. Upon arrival at the sampling location, sampling personnel gathered pre-collected grab samples. All analytes were collected using the automated sample except for fecal coliform bacteria. Fecal coliform samples were not collected using the automated sampler because of the short holding time (6 to 8 hours) associated with that analyte. Rather, fecal coliform samples were collected immediately following the automated sampling event.

3.5.4 Sediment Quality Data Collection Methods

Two primary sediment quality data collection methods were employed on the Assabet River; sediment thickness and sediment nutrient flux. Each water quality method is described below.

3.5.4.1 Bathymetry and Sediment Thickness Survey Methods

The Organization for the Assabet River performed the impoundment bathymetric and sediment thickness surveys in accordance with the methods summarized below. Bathymetry and sediment thicknesses were measured in river impoundments using a pole to detect the sediment/water interface and the soft sediment/hard sediment interface. The bathymetry/sediment thickness surveys were boat-based and involved collection of measurements across transects to support bathmetric and sediment thickness mapping. There were no analyses conducted as part of the bathymetry and sediment thickness survey and therefore no samples or associated holding times.

In each impoundment, approximately 120 measurements of water depth and sediment thickness were collected. In each impoundment, approximately 12 transects each containing 10 measurements were collected. Measurements were obtained using a graduated pole placed through the water column to determine water depth. The pole was then forced through the surface sediment to determine soft sediment thickness. Water depths and thickness of soft sediments were measured by probing with a graduated rod as follows:

- Depth from water surface to sediment surface was recorded; an attachment may have been placed on the bottom of the rod if the sediment was too loose to allow easy detection of the sediment-water interface.
- Depth from water surface to first refusal (rock, tight sand, gravel or clay) was measured with the same graduated rod.
- Soft sediment depth (sediment-water interface to first refusal) was calculated as the difference between the two measurements described above.

Decontamination of equipment was not required and investigation-derived waste (IDW) were not generated during any part of this investigation.

The river impoundments are long and narrow in shape such that when traveling by boat the shoreline is always nearby and affords numerous landmarks as reference locations. Thus, locations of measurements were identified using landmarks and recorded on topographic maps. A Geographic Positioning System was not used for the survey.

3.5.4.2 Sediment Nutrient Flux Survey Methods

The Center for Marine Science and Technology (CMAST), University of Massachusetts at Dartmouth performed sediment nutrient flux surveys in accordance with the methods summarized below.

Measurements of benthic nutrient flux were conducted by the measurement of oxygen and nutrient flux across the sediment/water interface in 8 cores (6" diameter) collected from river impoundments.

Sediment cores were collected by divers and were maintained at in-situ temperatures in a boat until returned to a shore-based laboratory. Incubations were performed at the "field" laboratory very near the impoundment in order to prevent disturbance to the cores in transit. All of the sediment samples were incubated immediately upon return to the field laboratory. CMAST provided the equipment required for this purpose and has conducted these incubations in a variety of field sites (including a remote interior site in Antarctica).

The flux of nutrients and nutrient-related parameters was measured by incubating sediment cores and monitoring sediment/water column exchange over time. Nutrient species concentrations were measured over time and under four scenarios; (1) ambient temperature, (2) moderately increased temperature, (3) summer-time temperature, and (4) anoxic conditions. These scenarios provided valuable measurements of sediment/water column nutrient interactions during both non-summer and summer time conditions, as well as quantifying chemical release of phosphorus from sediments. The sediment flux surveys included measurement of sediment oxygen demand over an extended time period.

3.5.5 Biological Data Collection Methods

Biological data collection was conducted as part of the summer intensive investigations of July 1999 and August 2000 and was focused on determination of the types of aquatic vegetation present in the system and their distribution in the Assabet River impoundments. The methods applied during this investigation are outlined below.

3.5.5.1 Phytoplankton Assessment Methods

Plankton samples were collected at the same stations as the impoundment surface water samples. As with the water samples, the phytoplankton samples are meant to be representative of the entire water body. These were preserved with gluteraldehyde concentrated by settling, as needed, and viewed in a Palmer-Maloney counting chamber at 400X magnification and phase contrast optics. Between the concentration and the area scanned for identification/counting, the multiplication factor (cells recorded to cells/ml) is <50, usually <20. Counting proceeded until each successive strip does not change the ratio of the dominant algal types (those comprising >50% of all cells cumulatively) by more than 10%. A detailed description of this analysis procedure is provided in the QAPP (ENSR, 1999).

3.5.5.2 Aquatic Macrophyte Assessment

Macrophyte assessment is primarily based on visual examination of the overall lake and stream habitat. Its purpose is to determine the range of algal types in the system and relative dominance by coverage or frequency of occurrence. Macrophytes in this case include mats found in the river impoundments. These samples are collected directly from mats, preserved as with phytoplankton samples, and viewed the same way but without any enumeration. Macrophyte assessment was performed as follows.

1. Aquatic plant distribution and density was surveyed during summer-time, with mapping of distribution by species, overall percent cover, and portion of the water column filled.

2. Plants were identified to species in the field or lab according to Hellquist and Crow (1980-1985).

3. Plant cover was estimated on a scale of 0-5 as follows:

   - 0: No cover, plants absent
   - 1: 1-25% cover
   - 2: 26-50% cover
   - 3: 51-75% cover
   - 4: 76-99% cover
   - 5: 100% cover

4. Plant biomass was estimated on a scale of 0-4 as follows:

   - 0: No biomass, plants absent
   - 1: Low biomass, plants growing only as a low layer on the bottom sediment
   - 2: Moderate biomass, plants protruding into the water column, but rarely reaching the surface and not at nuisance densities
   - 3: High biomass, plants filling more than half the water column and often reaching the surface, nuisance conditions and/or habitat impairment perceived
   - 4: Extremely high biomass, water column filled and/or surface completely covered, nuisance conditions and habitat impairment severe
   - 5. Water column completely filled with plants

Biomass based on the 0-5 scale can be converted to a mean mass in kilograms, based on the plant biomass ratings and actual mass determined from other systems.

Biomass harvesting was also performed to provide a quantitative measure of aquatic species biomass in the river system. Biomass harvesting served to quantify species abundance ranked on a scale of 0 to 5 (as described above). Biomass harvesting was performed in river impoundments and quantified the 0 to 5 scale by harvesting approximately 20, ¼ square meter plots for each size range from 1 through 4 (20 x 4 = 80 total harvest plots). Biomass harvesting resulted in wet weights of biomass per unit area and served to “calibrate” biomass measurements associated with both the Summer 1999 and Summer 2000 surveys.

3.5.5.3 Algal Assays

Algal assays were conducted for filamentous green algae (FGA) and duck weed (*Lemna minor)* in the Assabet River. These species were selected because they are dominant in the Assabet River system. Algal assay assessment involved growing each of the algal species independently in a laboratory environment using various dilutions of Assabet River water. The response of the algae species to the diluted water provided an indication of species-specific response to alterations in nutrient concentrations in Assabet River water.

There is no standard or recognized method to reference for FGA and duckweed algal assay assessment because an assay of the growth response of these species is an atypical analysis. However, the method outlined below is designed to provide an effective assay using a series of controlled incubation experiments and concurrent nutrient measurements.

1) Assess the response of sampled algae to changes in P concentration and N:P ratio by measuring the change in biomass over time in varying media.
2) Collect Assabet River water to provide a representative sample.
3) Collect algae from a river impoundment; material should be suitable for separation into distinct inocula for assays.
4) Test TKN, Nitrate-N and total P level in the collected water (analysis of water was conducted at Thorstensen Laboratory in Westford, Massachusetts).
5) Dilute a portion (approx. 10 L) of the collected water such that P=0.10 mg/L, another portion to P=0.05 mg/L, and another to P=0.01 mg/L; nitrogen will also be diluted, but the ratio will remain stable.
6) Treat another portion of Assabet River water with buffered aluminum sulfate at a dose of 25 g Al/L to coagulate P; decant and filter the supernatant and test for TKN, nitrate-N and total P level.
7) Set up 3 chambers (1-2 L each) for each of 6 treatments:
    - Ambient Assabet River water
    - Assabet River water @ P=0.10 mg/L
    - Assabet River water @ P=0.05 mg/L
    - Assabet River water @ P=0.01 mg/L
    - Alum-treated Assabet River water (low P, high N)

- De-ionized water (P=0.00 mg/L)
- Add 5 g (+ 0.5 g) of algae (wet weight after blotting mat with absorbent) to each chamber.

The algal assays were performed over a 7-day period.

Data collection results, presented in the following sections, were obtained following the methods described above.

Table 3-1 Data Collection Matrix: Survey and Data Collection Activities

Surveys In Chronological Order			Hydrologic Data Collection		Water Quality Data Collection			Sediment Data Collection			Biological Data Collection			
#	Survey Description	Dates	Streamflow Measurement	Dye Monitoring	In Situ	Grab Sampling	Continuous DO	Nutrient Flux	Nutrient Quality	Thickness	Plankton Sample	Macrophyte	Biomass	Bio Assay
1	Intensive Summer Survey 1999	July 19-25, 1999	X		X	X	X				X	X	X	
2	Dry-weather Survey	January 18-19, 2000	X		X	X								
3	Dry-weather Survey	February 8-9, 2000	X		X	X								
4	Wet-weather Survey	March 16-17, 2000	X			X								
5	Dry-weather Survey	March 27, 2000	X		X	X								
6	Wet-weather Survey	March 27-28, 2000	X		X	X								
7	Sediment Nutrient Flux Survey	March 29-30, 2000						X						
8	Time of Travel Survey	May 8-12, 2000		X										
9	Impoundment Bathymetry/Sediment Survey	May/June 2000								X				
10	Intensive Summer Survey 2000	August 28-31, 2000	X		X	X	X				X	X	X	X
11	Sediment Nutrient Flux Survey	Sept. 11-12, 2000						X	X					
12	Wet-weather Survey	September 12-13, 2000	X		X	X								
13	Time of Travel Survey	Sept. 28-Oct. 6, 2000		X										

Table 3-2 Data Collection Matrix: Survey Type and Sampling Locations

Sample Location			Intensive Summer 1999 Survey	Dry-weather Surveys	Wet-weather Surveys	Intensive Summer 2000 Survey	Time of Travel Surveys	Impoundment Bathymetry/ Thickness Sediment Survey
Station	Rivermile	Description						
R28	30.7	Maynard St. Westborough	X	X		X		
R27	29.8	Rt. 9 Westborough	X			X		
R26	28.9	Rt. 135 Westborough	X			X		
R25	28.0	School St. Northborough	X			X		
R24	25.9	River St. Northborough	X	X		X		
R23	25.1	Allen St. Impoundment	X			X		X
R22	25.0	Below Allen St. Impoundment	X			X		
R21	23.9	Boundary St. Marlborough	X	X		X		
R20	23.5	Robin Hill Rd. Marlborough	X			X		
R19	21.7	Bigelow Rd. Berlin	X	X		X		
R18	19.2	Chapin Rd. Hudson	X			X		
R17	17.9	Hudson Center Impoundment	X			X		X
R16	17.6	South St., Hudson	X	X		X		
R15	15.9	Cox St. Hudson	X	X		X		
R14	15.8	Below Cox St. Hudson				X		
R13	14.1	Gleasondale Impoundment	X			X		X
R12	13.9	Below Gleasondale Dam, Stow	X	X		X		
R11	11.4	Boon Road, Stow	X			X	↓ ↓	
R10	9.2	White Pond Road, Maynard	X			X	↓ ↓	
R9	8.7	Ben Smith Impoundment	X			X	↓ ↓	X
R8	8.6	Rt. 117/62 Maynard	X			X	↓ ↓	
R7	7.4	USGS Gauge, Maynard	X	X		X	↓	
R6	6.2	Powder Mill Impoundment	X			X	↓	X
R5	6.1	Below Powder Mill Dam	X	X		X	↓	
R4	4.4	Damonmill, Concord	X			X	↓	
R3	3.1	Rt. 62, Concord	X	X		X		
R2	2.4	Rt. 2 Bridge, Concord	X			X		
R1	1.6	Park Street, Concord				X		

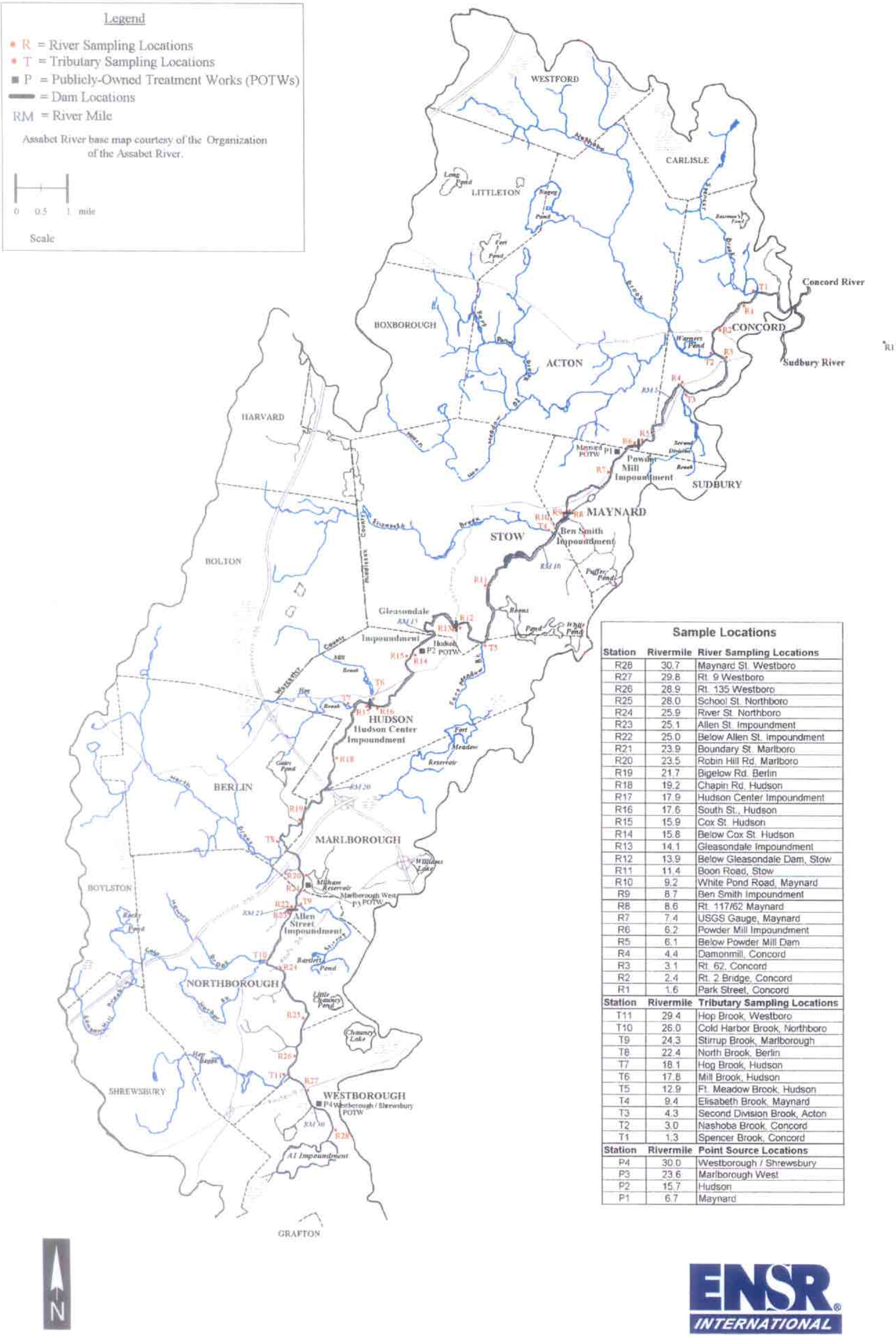
Station	**Tributary Sampling Locations**							
T11	29.4	Hop Brook, Westborough	X	X	X	X		
T10	26.0	Cold Harbor Brook, Northborough		X	X	X		
T9	24.3	Stirrup Brook, Marlborough			X	X		
T8	22.4	North Brook, Berlin		X	X	X		
T7	18.1	Hog Brook, Hudson	X		X	X		
T6	17.8	Mill Brook, Hudson	X		X	X		
T5	12.9	Ft. Meadow Brook, Hudson		X	X	X		
T4	9.4	Elizabeth Brook, Maynard		X	X	X		
T3	4.3	Second Division Brook, Concord	X					
T2	3.0	Nashoba Brook, Concord	X	X	X	X		
T1	1.3	Spencer Brook, Concord			X	X		

Notes:
Bold horizontal line indicates approximate impoundment locations.

Table 3-3 Analyses Performed in Support of the Assabet River Water Quality Surveys

Analysis	Method Number	Method Detection Limit (mg/L)	Hold Time
Total Phosphorus	EPA 365.2	0.01	28 days
Orthophosphorus	EPA 365.2	0.01	2 days
Ammonia Nitrogen	EPA 350.3	0.03	28 days
Nitrate	EPA 300.0	0.01	28 days
Total Kjeldahl Nitrogen	EPA 351.3	0.05	28 days
BOD_5	EPA 405.1	1.0	2 days
BOD_{30}	EPA 405.1	1.0	2 days
TSS	EPA 160.2	1.0	7 days
Total settleable solids	EPA 160.5	0.1	7 days
Chlorophyll a	S.M. 10200	0.1	(frozen filter)
Fecal coliform	SM9222D	0	6 hours

Figure 3-1: Assabet River Watershed with Sampling Locations Indicated.



Sample Locations

Station	Rivermile	River Sampling Locations
R28	30.7	Maynard St. Westboro
R27	29.8	Rt. 9 Westboro
R26	28.9	Rt. 135 Westboro
R25	28.0	School St. Northboro
R24	25.9	River St. Northboro
R23	25.1	Allen St. Impoundment
R22	25.0	Below Allen St. Impoundment
R21	23.9	Boundary St. Marlboro
R20	23.5	Robin Hill Rd. Marlboro
R19	21.7	Bigelow Rd. Berlin
R18	19.2	Chapin Rd, Hudson
R17	17.9	Hudson Center Impoundment
R16	17.6	South St., Hudson
R15	15.9	Cox St. Hudson
R14	15.8	Below Cox St. Hudson
R13	14.1	Gleasondale Impoundment
R12	13.9	Below Gleasondale Dam, Stow
R11	11.4	Boon Road, Stow
R10	9.2	White Pond Road, Maynard
R9	8.7	Ben Smith Impoundment
R8	8.6	Rt. 117/62 Maynard
R7	7.4	USGS Gauge, Maynard
R6	6.2	Powder Mill Impoundment
R5	6.1	Below Powder Mill Dam
R4	4.4	Damonmill, Concord
R3	3.1	Rt. 62, Concord
R2	2.4	Rt. 2 Bridge, Concord
R1	1.6	Park Street, Concord
Station	**Rivermile**	**Tributary Sampling Locations**
T11	29.4	Hop Brook, Westboro
T10	26.0	Cold Harbor Brook, Northboro
T9	24.3	Stirrup Brook, Marlborough
T8	22.4	North Brook, Berlin
T7	18.1	Hog Brook, Hudson
T6	17.8	Mill Brook, Hudson
T5	12.9	Ft. Meadow Brook, Hudson
T4	9.4	Elisabeth Brook, Maynard
T3	4.3	Second Division Brook, Acton
T2	3.0	Nashoba Brook, Concord
T1	1.3	Spencer Brook, Concord
Station	**Rivermile**	**Point Source Locations**
P4	30.0	Westborough / Shrewsbury
P3	23.6	Marlborough West
P2	15.7	Hudson
P1	6.7	Maynard

ENSR INTERNATIONAL

Figure 3-2 Schematic Representation of the Assabet River Rivermile vs. Elevation with Sampling Locations Identified

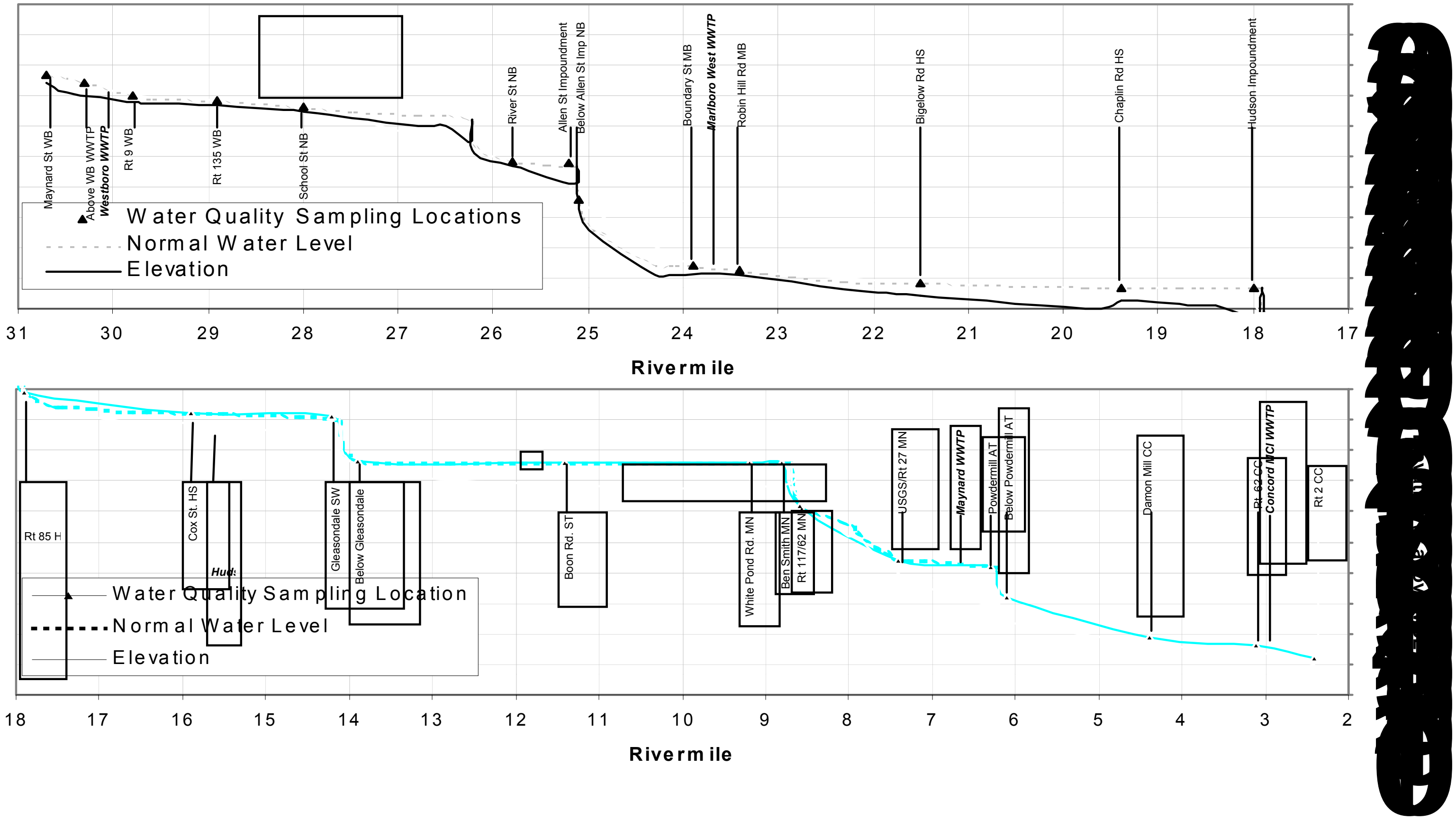
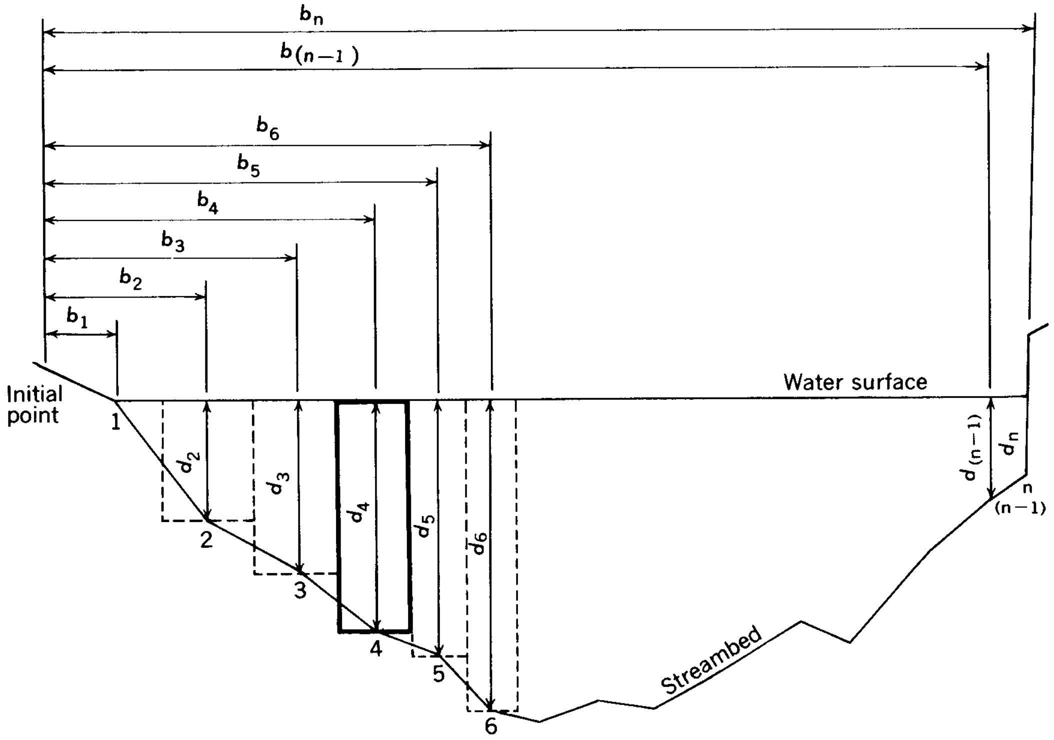


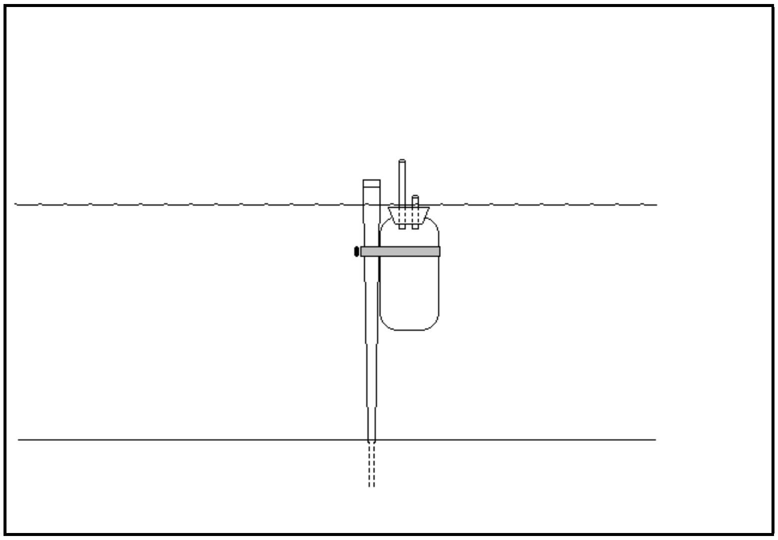
Figure 3-3 Illustration of Channel Cross-Section Showing the Distances of the Measured Velocities from the Shore and the Depths of the Partial Area Cross-Sections (USGS, 1969).



EXPLANATION

1, 2, 3, ... n	Observation points
$b_1, b_2, b_3,$ . . . . b_n	Distance, in feet, from the initial point to the observation point
$d_1, d_2, d_3,$ . . . . d_n	Depth of water, in feet, at the observation point
Dashed lines	Boundary of partial sections; one heavily outlined discussed in text

Figure 3-4 Illustration of Automated Wet-Weather Grab Sampler



4.0 HYDROLOGIC DATA COLLECTION SUMMARY

Streamflow measurements and time of travel measurements were collected as part of the Assabet River data collection program. Reference hydrologic data, streamflow measurements, and time of travel measurements are summarized below.

4.1 Reference Hydrologic Data

The United States Geologic Survey (USGS) maintains a continuous-recording streamflow gauging station on the Assabet River at Maynard (RM 7.4). Figures 4-1, 4-2, and 4-3 contain daily average streamflow measurements collected at the USGS Maynard gauge during the Summer of 1999, the Winter/Spring of 2000, and the Summer of 2000, respectively. Daily precipitation data were also collected by the USGS at the Maynard gauge and are presented in these figures. Assabet River surveys are indicated in the figures to place each survey in hydrologic and meteorologic context. Measurements provided by the USGS streamflow gauging station at Maynard are an invaluable hydrologic reference resource.

4.2 Streamflow Measurements

Streamflow measurements were collected during 7 field surveys in the Assabet River and its tributaries. Table 4-1 contains a summary of all streamflow measurements collected as part of the field program. USGS Maynard streamflow measurements collected concurrently with ENSR field measurements are provided in italics in Table 4-1. The surveys captured streamflows under a range of flow conditions including summer low-flow (July 1999), summer below-average flow (August 2000), and winter flow conditions (February and March 2000).

Streamflow measurements collected during each survey are summarized below. A complete set of streamflow and associated measurements, including average water velocity, water levels, stage, river cross-sectional area, and river widths, is provided in Appendix A.

4.2.1 Intensive Summer 1999 Survey

Figure 4-1 contains daily average streamflow measurements collected at the USGS Maynard gauge during July and August 1999. Daily average flows during the survey (July 19 – 25, 1999) ranged from 14 cfs to 22 cfs and were typically near 15 cfs. A rainfall event occurred towards the end of July 19, 1999 and resulted in an increase in streamflow at the Maynard gauge on July 20.

The $7Q_{10}$ flow at the Maynard gauge is estimated to be between 4.5 and 15.1 cfs (see Section 2.3.1). Based on these estimates of $7Q_{10}$ flow, river flowrates during the July 1999 survey were at or near

$7Q_{10}$ levels indicating that the survey was successful in capturing worst-case conditions in terms of minimal river flow.

On July 19 and July 21, 1999, streamflow measurements were collected at 4 river locations and 2 tributary locations. Streamflow measurements were collected on July 19, 1999, prior to commencement of a rainfall event. The rainfall event subsequently led to the postponement of sampling activities on July 20. Sampling was resumed on July 21, 1999. Table 4-1 contains streamflow measurements collected during each of the two days of the July 1999 survey. Average water velocity measurements ranged from 0.2 to 0.5 ft/sec (see Appendix B-1). Review of the USGS Maynard gauge streamflow record (Figure 4-1) indicates that sampling was performed just prior to an increase in streamflow (on July 19) and during a decrease in streamflow (on July 21) associated with the precipitation event. Measurement of streamflow was intended to occur during “steady-state” or nearly constant conditions. Thus, the streamflow measurements collected during the July 1999 survey are useful, but not ideal for characterizing spatial variations in flow throughout the river.

4.2.2 Intensive Summer 2000 Survey

On August 28, 2000, ENSR measured instantaneous streamflow at 8 river locations and 10 tributary locations. Streamflow measurements collected during the Summer 2000 survey (#10) are presented in Table 4-1. The Assabet River was experiencing below-average summer-time streamflow conditions (40 cfs) during Summer 2000 survey (based on the USGS Maynard gauge historic record, see Figure 2-3). Streamflow near the headwaters was nearly zero (0.01 cfs at RM 30.7) and increased to 11 cfs over the next 5 miles (at RM 25.6). Streamflows were observed to double in magnitude over the next 6 miles to a flowrate of 23 cfs at RM 19. Over the next 10 miles, streamflow increased by 50% reaching a flowrate of 35 cfs at RM 8.6 and remained nearly constant for the remaining 8 rivermiles to its mouth.

Assabet River tributary flows from Nashoba Brook, Elizabeth Brook, and North Brook were most substantial with measured streamflows of 9 cfs, 4 cfs, and 3 cfs, respectively. Measured streamflows from the remaining 7 tributaries were each 1.0 cfs or less. By comparison, the flow in the Assabet River at Maynard Street, Westborough(RM 30.7) was smaller than the flow from any of the 10 largest tributaries. Also, the flow entering from Nashoba Brook was of similar magnitude as the total Assabet River flow at Allen Street in Hudson, RM 25.1 (9 cfs and 11 cfs, respectively).

A simple water budget estimate based on the August 2000 survey indicates the following percentage distribution of total streamflow:

- Headwater contribution: ~0% (contributing 0.1 cfs of 35 cfs total)
- Tributary contribution: ~61% (contributing 21.3 cfs of 35 cfs total)
    - Nashoba Brook: ~26%
    - Elizabeth Brook: ~11%

- North Brook: ~9%
- Several Other tributaries: ~15%

- Point source contribution: ~ 34% (contributing ~12 cfs of 35 cfs total)

This simple water budget accounts for 95% of measured flow, but neglects important water balance processes, such as evaporative losses, groundwater/surface water exchange, and effects of impoundments on water movement.

4.2.3 Dry-weather surveys

Streamflow measurements were collected during the second and third dry-weather surveys (#3 and #5) in February and March 2000. Streamflow measurements collected during these surveys are presented in Table 4-1. During this time, the Assabet River was experiencing winter baseflow conditions with streamflow five to ten times greater than that of summer-time conditions.

On February 8 and 9, 2000 (survey #3), streamflow measurements were collected at 9 river locations and 4 tributary locations. As seen in the Summer 2000 data, streamflow steadily increased with distance downstream from the headwater flow of 5 cfs (RM 30.7) to a flow of 95 cfs near the confluence (RM 6.1). Tributary streamflow measurements collected during the February dry-weather survey ranged from 5 cfs to 33 cfs, representing a significant portion of the total Assabet River flow.

On March 27, 2000 (survey #5), streamflow measurements were collected at 6 river locations and 9 tributary locations. High waters and strong currents made streamflow measurement untenable in some downstream river sampling locations (e.g., at RM 13.9). Streamflow measurements collected on March 27, 2000 were immediately prior to a rainfall event (Figure 4-2) included in the wet-weather survey program. Thus, tributary streamflow measurements performed on March 27, 2000 support both dry-weather (#5) and wet-weather (#6) baseflow assessments. On March 27, 2000, river streamflow measurements ranged from 16 cfs near the headwaters (RM 30.7) to 250 cfs in Maynard (RM 7.2). Tributary streamflow measurements ranged from 7 cfs to 76 cfs, representing a significant portion of the total Assabet River flow

4.2.4 Wet-weather Surveys

As part of each wet-weather tributary survey, streamflow measurements were collected at 10 tributary locations prior to commencement of a rainfall event. Streamflow data for the three wet-weather surveys (surveys #4, #6, and #12) are presented in Table 4-1. Streamflow measurements collected during each of the wet-weather surveys were well correlated with basin areas of the tributaries.

On March 16, 2000 (survey #4), streamflow measurements were collected in the 10 tributaries. Tributary streamflow measurements ranged from 9 cfs to 163 cfs. The concurrent streamflow in the

Assabet River at Maynard was 375 cfs. Streamflow in Nashoba Brook was more than double that of the next largest tributary. Of the ten tributaries measured, Nashoba Brook has the largest contributing watershed area. Flows from Elizabeth Brook (77 cfs) and North Brook (50 cfs) were the next largest contributors.

On March 27, 2000 (survey #6), streamflow measurements were collected in the 10 tributaries. Tributary streamflow measurements ranged from 7 cfs to 76 cfs. The concurrent streamflow in the Assabet River at Maynard was 250 cfs. Of the ten tributaries measured, Nashoba Brook (76 cfs), Elizabeth Brook (44 cfs) and North Brook (35 cfs) were the largest contributors.

On September 12, 2000 (survey #12), streamflow measurements were collected in the 10 tributaries. Tributary streamflow measurements ranged from 0 cfs to 6 cfs. The concurrent streamflow in the Assabet River at Maynard was 30 cfs. Of the ten tributaries measured, Nashoba Brook (6 cfs), Elizabeth Brook (5 cfs) and North Brook (2 cfs) were the largest contributors.

4.3 Time of Travel Measurements

Time of travel measurements were collected to support mathematical modeling of the Assabet River system and to support the overall water quality assessment. Time of travel is important because the impact of chemical and biological processes of water in the system is time-dependent. For example, the impact of sediments and biological growth on water quality in river impoundments is a function of the time period that a given water parcel is in the river impoundment. The time of travel surveys were performed by releasing a conservative substance into the river and measuring how long it took to reach a downstream location. Through this process, the time of travel, residence time, and longitudinal dispersion characteristics of the river were measured.

Two surveys were performed to measure the time of travel of water moving through the Assabet River system. The results of each time of travel survey are presented below.

4.3.1 May 2000 Time of Travel Survey

A conservative and inert substance, Rhodomine WT dye, was released into the Assabet River at Boon Road, Stow (RM 11.4) in a single event (i.e., one “pulse” of dye) at 8:53 PM on Tuesday, May 9, 2000. Dye concentration measurements were collected 2.8 miles downstream at Rt. 117/62, Maynard (RM 8.6). The May 2000 time of travel survey measured the residence time of the Ben Smith Impoundment and adjacent reaches (see Figure 3-1).

Figure 4-4 presents dye concentration measurements collected during the May 2000 survey at RM 8.6. The average USGS Maynard streamflow at the time of the survey is also presented in Figure 4-4. The average USGS Maynard streamflow was 266 cfs for the survey period.

In the May 2000 survey, the mean time of travel was estimated to be ~0.84 days (20 hours and 17 minutes) and the average velocity was estimated to be 0.20 ft/sec. Mean dye travel time is defined as the time to the centroid (center of gravity) of the area under the time-concentration curve (Figure 4-4). To estimate mean travel time, the tail of the curve in Figure 4-4 was extended to the time when dye concentrations returned to background level using an exponential decay term. Area under the curve was calculated using the trapezoidal rule for integration (the sum of average concentrations multiplied by difference in times for each interval).

4.3.2 September/October 2000 Time of Travel Survey

Rhodomine WT dye was released into the Assabet River at Boon Road, Stow (RM 11.4) in a single event at 1:48 PM on Thursday September 28, 2000. Dye concentration measurements were collected at the following two downstream locations:

- At Rt. 117/62, Maynard (RM 8.6), below Ben Smith Impoundment and a distance of 2.8 miles downstream of the release point, and
- At Damonmill, Concord (RM 4.4), below Powdermill Impoundment and a distance of 7.0 miles downstream of the release point.

The September/October time of travel survey measured the residence time of the Ben Smith Impoundment, the Powdermill Impoundment, and adjacent reaches. Figure 4-5 presents dye concentration measurements collected at RM 8.6 and RM 4.4. USGS Maynard streamflow measurements are also presented in Figure 4-5. The average USGS Maynard streamflow measurement was 55 cfs during the study period.

Mean time of travel to the two sampling locations was estimated to be:

- Total distance 7.0 miles (Boon Road to Damonmill): ~4.7 days (112 hours 47 minutes)
- First reach (2.8 miles), including Ben Smith Impoundment: ~3.4 days (81 hours 32 minutes)
- Second reach (4.2 miles), including Powdermill Impoundment: ~1.3 days (31 hrs. 15 minutes)

Average river velocity estimated to be:

- Total distance (7.0 miles): 0.09 ft/sec
- First reach (2.8 miles): 0.05 ft/sec
- Second reach (4.2 miles): 0.20 ft/sec

Mean travel time was calculated using the method described in Section 1.6.2.1 above.

4.4 Summary

The following observations were made of hydrologic conditions in the Assabet River during the data collection program.

During the Summer 1999 survey:

- Streamflows were near $7Q_{10}$ conditions (15 cfs at USGS Maynard gauge);
- Average water velocity measurements ranged from 0.2 to 0.5 ft/sec (~6 miles/day) in free-flowing (i.e. not impounded) reaches; and
- POTW effluent flows accounted for approximately 80% of river streamflows.

During the Summer 2000 survey:

- Streamflows were below-average for summer-time conditions (40 cfs at USGS Maynard gauge compared to an August average streamflow of 60 cfs);
- Average water velocity measurements typically ranged from 0.5 to 0.7 ft/sec (~10 miles/day) in free-flowing reaches;
- POTW effluent flows accounted for approximately 34% of river streamflows;
- Tributary streamflows accounted for approximately 61% of river streamflows with Nashoba Brook, Elizabeth Brook, and North Brook accounting for 75% of tributary flows.

During Dry-weather and Wet-weather surveys:

- Streamflows were measured under four different hydrologic regimes associated with USGS Maynard gauge streamflows of 30 cfs, 110 cfs, 250 cfs, and 350 cfs, and
- Nashoba Brook, Elizabeth Brook, and North Brook were consistently observed to be the largest tributary streamflows.

Time of Travel Studies

- Under relatively high streamflow conditions (266 cfs), the time of travel through the Ben Smith Impoundment (total distance 2.8 miles) was less than 1 day (20 hours).
- Under average summer-time streamflow conditions (55 cfs), the time of travel through the Ben Smith Impoundment was 3.4 days.

- Under average summer-time streamflow conditions (55 cfs), the time of travel through the Powdermill Impoundment and adjacent reaches (total distance 4.2 miles) was 1.3 days.

The hydrologic data collection program was successful in capturing streamflow, water velocity, and time of travel measurements under a variety of conditions. Hydrologic measurements will be applied to support estimates of nutrient loadings throughout the river system and to support the hydrologic component of the mathematical model of the Assabet River.

Table 4-1 Summary of Streamflow Data Collection Results for All Surveys (in cfs)

Sample Location			Survey1 – Summer 1999	Survey 3- Dry Weather	Survey 4 - Wet Weather	Survey 5 – Dry-weather	Survey 6 – Wet Weather	Survey 10 - Summer 2000	Survey 12 - Wet Weather
Station	Rivermile	Description	July 19 and 21, 1999	February 8-9, 2000	March 16, 2000	March 27, 2000	March 27, 2000	August 28th, 2000	September 12, 2000
R28	30.7	Maynard St. Westboro		5	21	16		0.1	
R27	29.8	Rt. 9 Westboro							
R26	28.9	Rt. 135 Westboro							
R25	28.0	School St. Northboro	5						
R24	25.9	River St. Northboro		23		80			
R23	25.1	Allen St. Impoundment						11	
R22	25.0	Below Allen St. Impoundment							
R21	23.9	Boundary St. Marlborough		40		87			
R20	23.5	Robin Hill Rd. Marlborough							
R19	21.7	Bigelow Rd. Berlin	16	47		118			
R18	19.2	Chapin Rd. Hudson						23	
R17	17.9	Hudson Center Impoundment							
R16	17.6	South St., Hudson		50		136			
R15	15.9	Cox St. Hudson	13	54		113		28	
R14	15.8	Below Cox St. Hudson							
R13	14.1	Gleasondale Impoundment							
R12	13.9	Below Gleasondale Dam, Stow		62				26	
R11	11.4	Boon Road, Stow							
R10	9.2	White Pond Road, Maynard							
R9	8.7	Ben Smith Impoundment							
R8	8.6	Rt. 117/62 Maynard						35	
R7	7.4	USGS Gauge, Maynard	*15,16*	*147,111*	*375*	*250*	*250*	*40*	*30*
R6	6.2	Powder Mill Impoundment							
R5	6.1	Below Powder Mill Dam		95				34	
R4	4.4	Damonmill, Concord							
R3	3.1	Rt. 62, Concord	18						
R2	2.4	Rt. 2 Bridge, Concord							
R1	1.6	Park Street, Concord						35	

Station	Tributary Sampling Locations		Summer 1999	Winter 2	Wet-weather 1	Winter 3	Wet-weather 2	Summer 2000	Wet-weather 3
T11	29.4	Hop Brook, Westboro	0.6	5	22		16	0.9	0.7
T10	26.0	Cold Harbor Brook, Northboro			23		17	0.5	0
T9	24.3	Stirrup Brook, Marlborough			9		7	0.2	0.1
T8	22.4	North Brook, Berlin		11	50		35	3	2
T7	18.1	Hog Brook, Hudson			10		9	1.0	0.6
T6	17.8	Mill Brook, Hudson			24		10	0.9	0.5
T5	12.9	Ft. Meadow Brook, Hudson			13		8	1	0.4
T4	9.4	Elizabeth Brook, Maynard		14	77		44	4	5
T3	4.3	Second Division Brook, Concord							
T2	3.0	Nashoba Brook, Concord	2	33	163		76	9	6
T1	1.3	Spencer Brook, Concord			21		16	0.8	0.1

Note: Streamflow units are cubic feet per second (cfs)

Figure 4-1 Summer Survey 1999: Assabet River Streamflow and Precipitation Data for Intensive

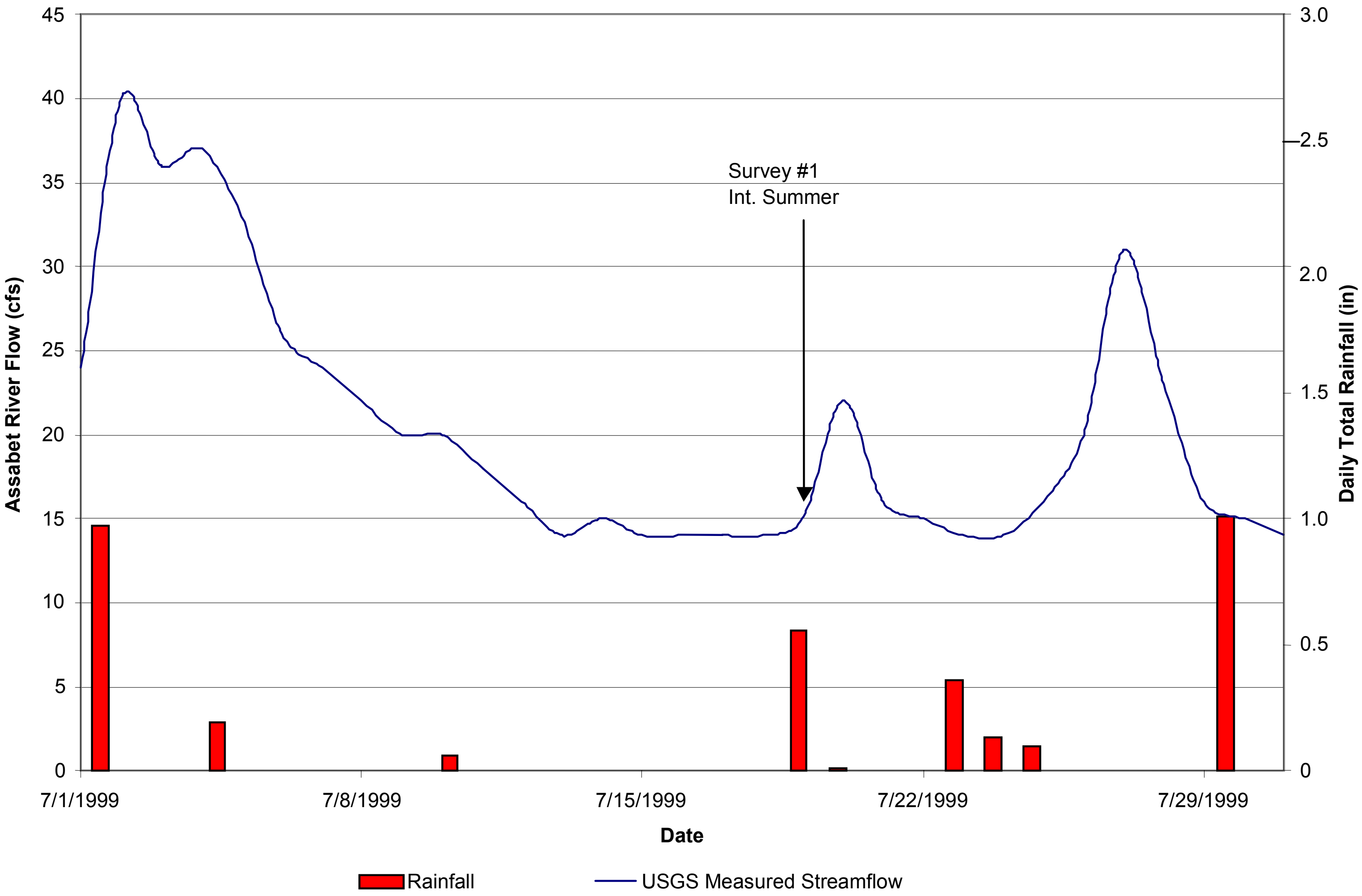


Figure 4-2 Surveys #2-#8: Assabet River Streamflow and Precipitation Data at USGS Maynard (RM 7.4)

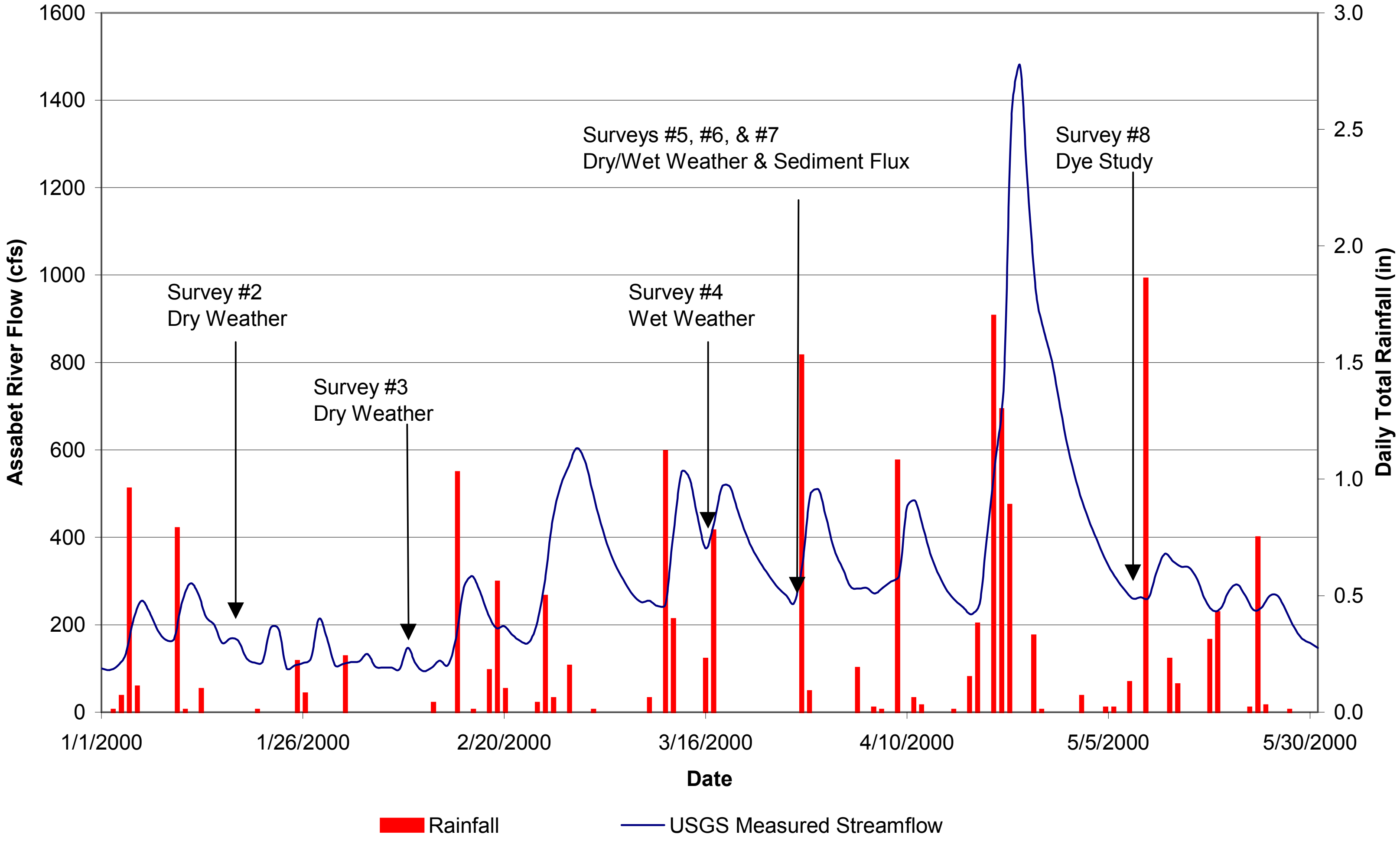


Figure 4-3 Surveys #10-#13: Assabet River Streamflow and Precipitation Data at USGS Maynard (RM 7.4)

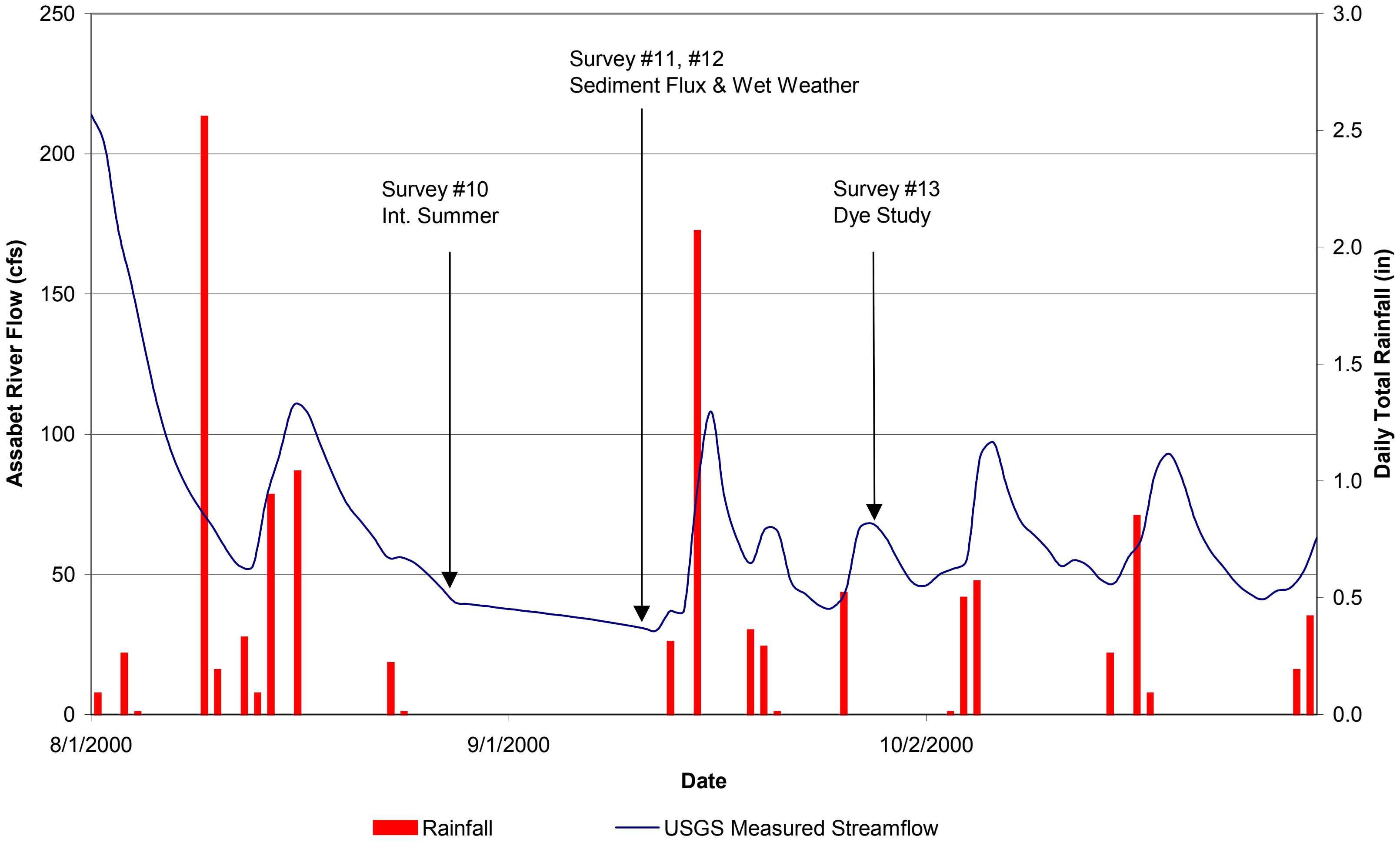


Figure 4-4 May 2000 Time of Travel Survey: Dye Concentration vs. Time at Rt. 117/62 (RM 8.6)

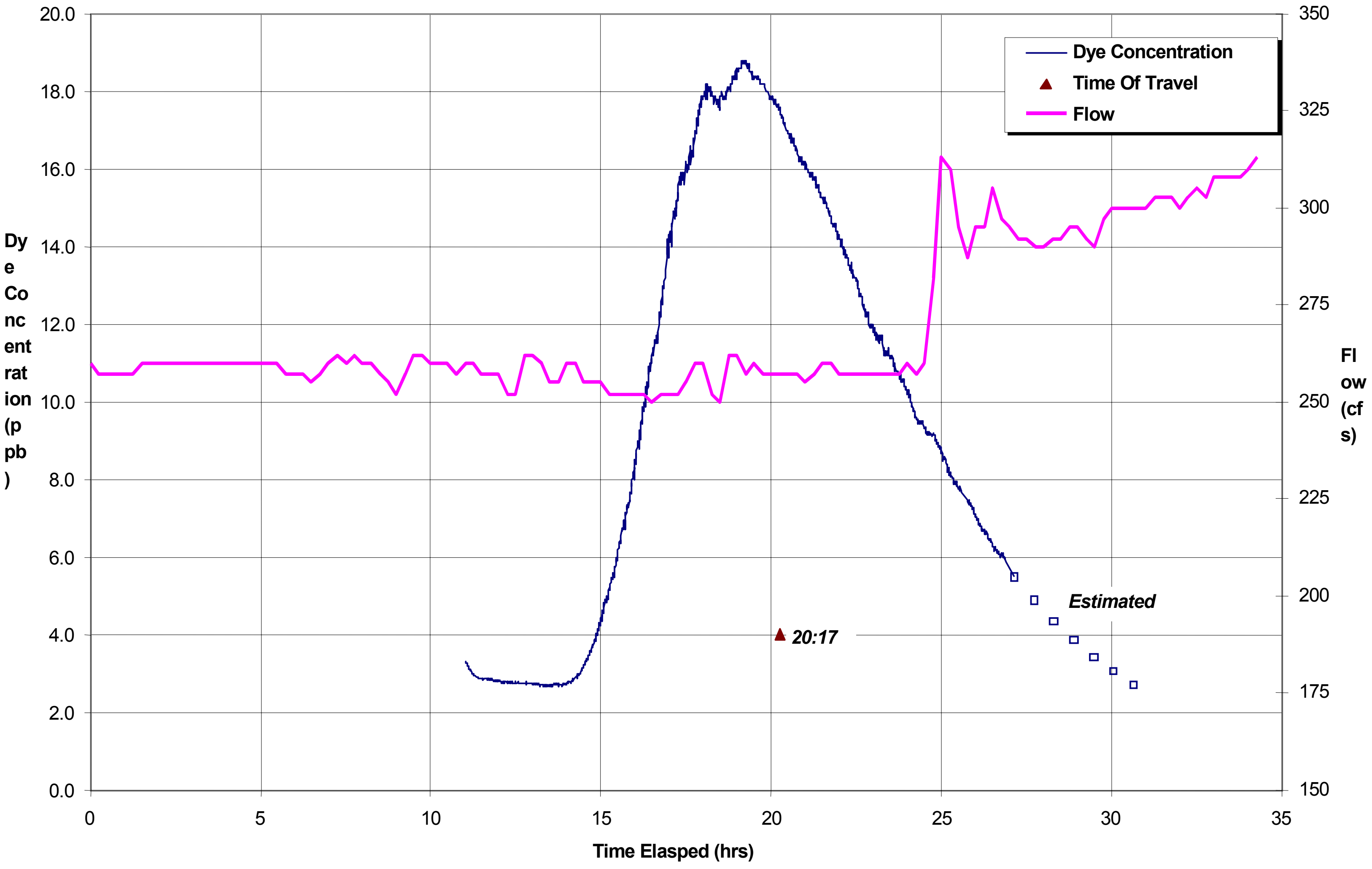


Figure 4-5 September/October 2000 Time of Travel Survey: Dye Concentration vs. Time at Two Locations (RM 8.6 and RM4.4)