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.

<u>Hydrologic data collection</u>

- 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.

<u>Water quality data collection</u>

- 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.

<u>Hydrologic Data Collection</u>

- 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.

<u>Water Quality Data Collection</u>

- 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

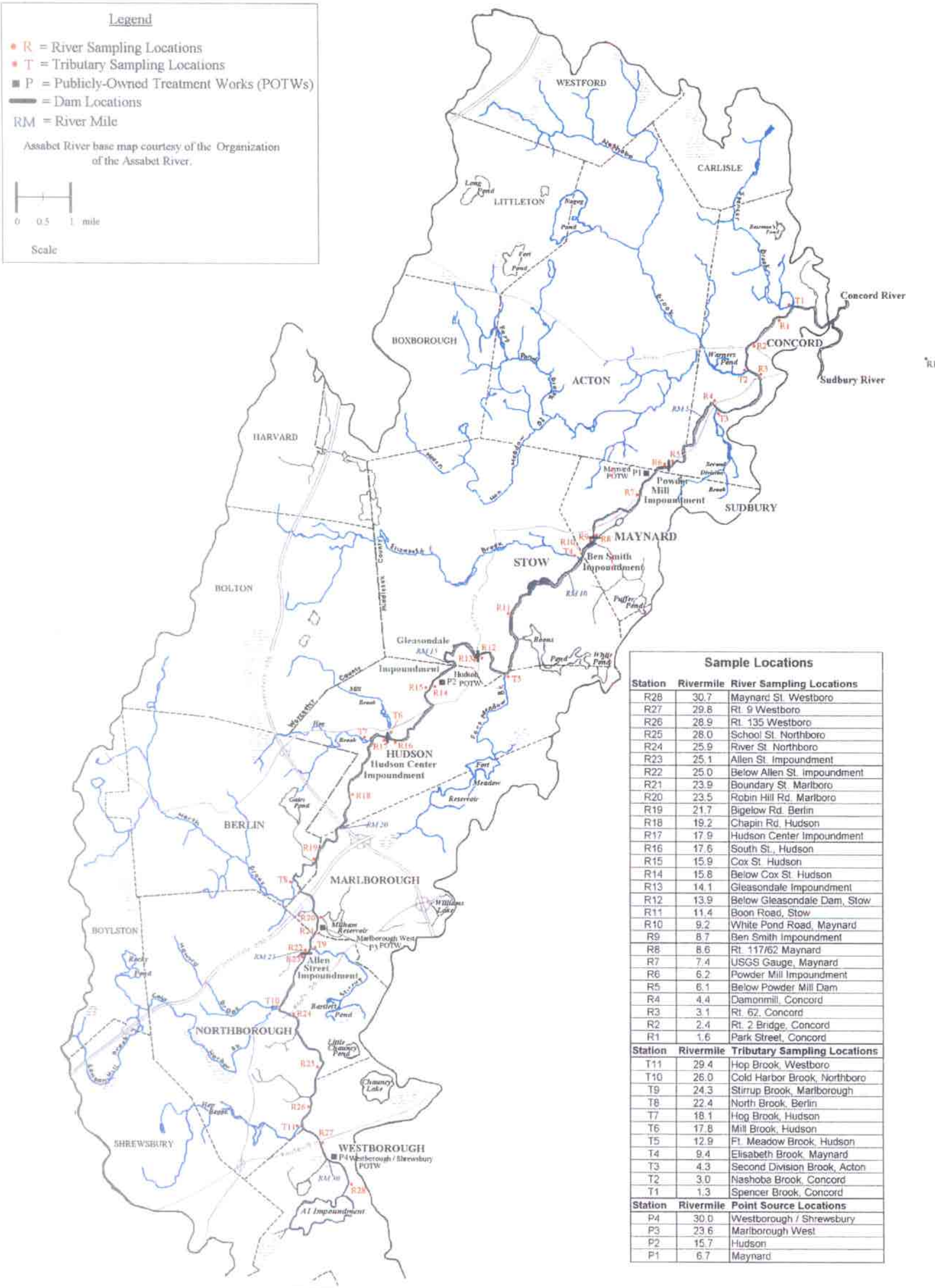
Sample Location			Intensive Summer 1999 Survey	Dry-weather Surveys	Wet-weather Surveys	Intensive Summer 2000 Survey	Time of Travel Surveys	Impoundment Bathymetry/ Thickness Sediment Survey
Station	Rivermile	Description						
R28	30.7	Maynard St. Westborough	X	X		X		
R27	29.8	Rt. 9 Westborough	X			X		
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

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

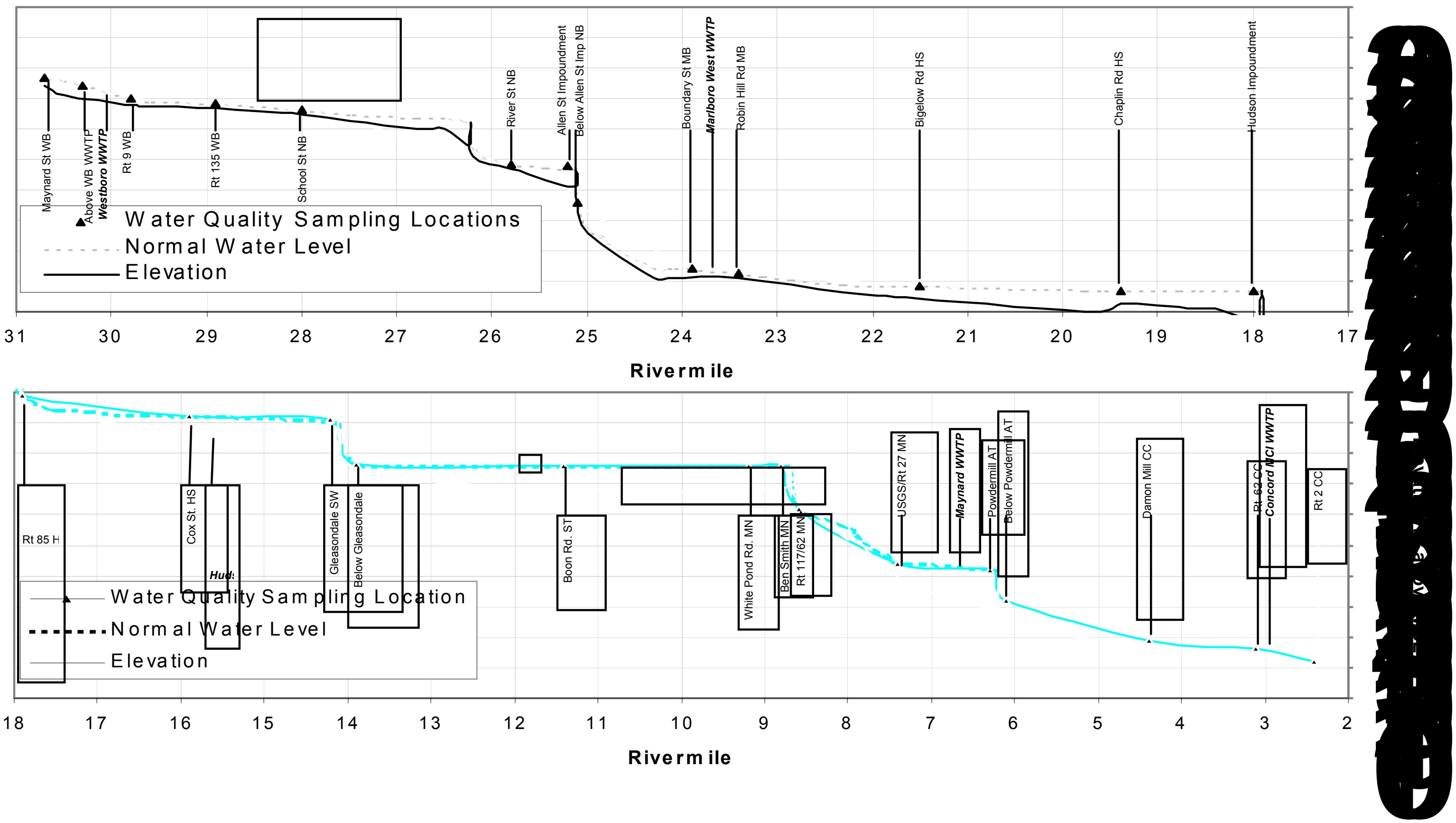
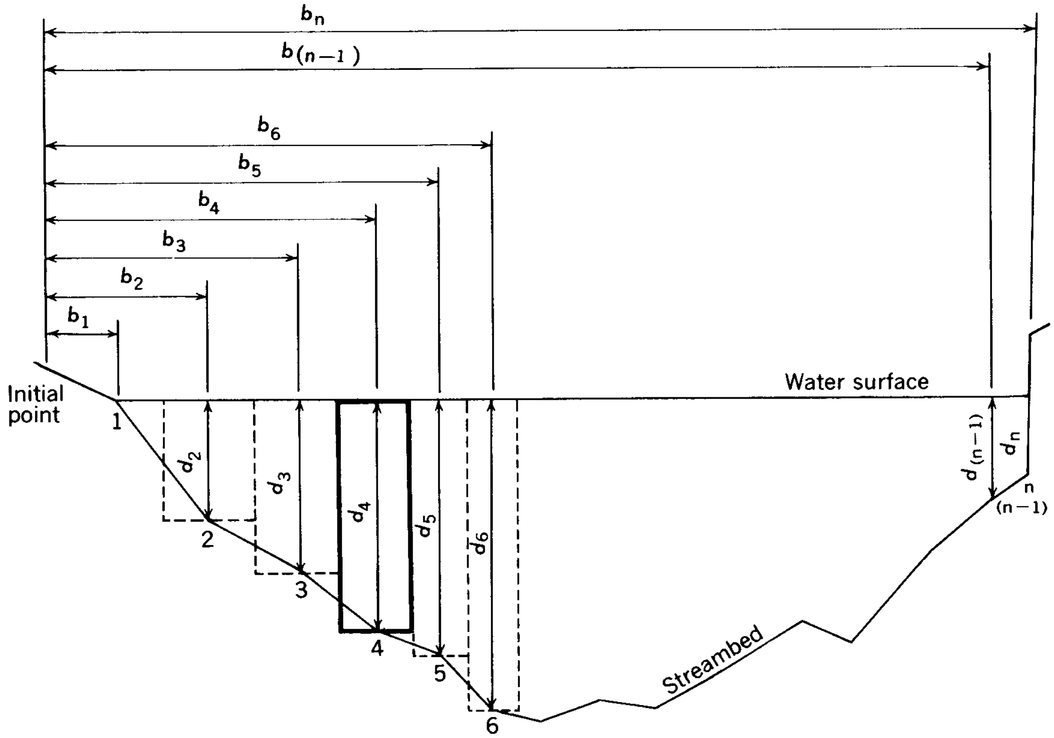


Figure 3-3 Illustration of Channel Cross-Section Showing the Distances of the Measured Velocities from the Shore and the Depths of the Partial Area Cross-Sections (USGS, 1969).



EXPLANATION

1, 2, 3, ... *n*	Observation points
$b_1, b_2, b_3, \ldots b_n$	Distance, in feet, from the initial point to the observation point
$d_1, d_2, d_3, \ldots d_n$	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