8.0 SUMMARY AND CONCLUSIONS

The field investigation was successful in collecting measurements to support quantification of eutrophic conditions and associated factors in the Assabet River. Measurements of the hydrology, water quality, and the aquatic biology of the Assabet River were collected during thirteen (13) surveys in the Assabet River from July 1999 through September 2000. Field measurements were collected under a variety of conditions including summer and winter, low-streamflow and high-streamflow, dry-weather and wet-weather, and have been described in this report. In this section, the hydrology, water quality, sediment quality, and the aquatic biology of the Assabet River are summarized.

8.1 Hydrologic Data Summary

The USGS has maintained a continuous recording streamflow gauge in the Assabet River at Maynard (RM 7.7) since 1941. This stream gauge captures flow from the upper two-thirds of the Assabet River basin and represents the most valuable source of hydrologic data in the Assabet River system. Average monthly streamflow measurements in the Assabet River at Maynard range from 60 cfs (August) to 405 cfs (March) (see Figure 2-3).

8.1.1 Time of Travel Measurements

Previous time of travel studies conducted by the MA DEP (1968, 1969, and 1980) indicate that the time of travel for a water parcel through the entire Assabet River mainstem (30.7 miles) varied as follows:

- Under low-flow conditions(~23 cfs), time of travel was greater than 18 days,
- Under average summer-time conditions(~54 cfs), time of travel was ~8 days, and
- Under high-flow conditions, time of travel was a few days or less.

ENSR performed two time of travel studies (see Section 4.3) focused on impounded reaches and observed the following:

- Under average summer-time streamflow conditions (55 cfs), the time of travel for a water parcel through the Ben Smith Impoundment (total distance 2.8 miles) was 3.4 days.
- Under average summer-time streamflow conditions (55 cfs), the time of travel for a water parcel through the Powdermill Impoundment and adjacent reaches (total distance 4.2 miles) was 1.3 days.
- Under high-flow conditions (266 cfs), the time of travel for a water parcel through the Ben Smith Impoundment (total distance 2.8 miles) was less than 1 day (20 hours).

8.1.2 Hydrologic Conditions During Water Quality Surveys

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 7Q10 conditions (15 cfs was measured 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; and
- Nashoba Brook, Elizabeth Brook, and North Brook accounted 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:
- Nashoba Brook, Elizabeth Brook, and North Brook were consistently observed to be the largest tributary streamflows;

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 a mathematical modeling application for the Assabet River system.

8.2 Water Quality Data Summary

A brief summary of historic water quality data and of water quality data collected during surveys conducted by ENSR in 1999 and 2000 to support the Assabet River Nutrient TMDL process is provided below.

8.2.1 Historic Water Quality Data Summary: 1970s and 1980s

The State of Massachusetts collected water quality data during 11 summer-time surveys from 1969 to 1990. Typical ranges of ambient river water concentrations for key parameters are provided below:

- Total phosphorus: 0.5 to 3.0 mg/l
- Nitrate: 0.6 to 2.0 mg/l
- Ammonia: 0.1 to 2.0 mg/l
- BOD_5: 2.0 to 6.0 mg/l
- Fecal coliform: 220 to 2,000 col/100ml

Historically, nutrients were present at higher levels in the upper reaches of the Assabet River (RM 24 to 31) than in the lower reaches. Water quality improvements, especially in terms of oxygen demand, ammonia, and solids, were observed in 1987 when a new wastewater treatment facility went on-line in Westborough. During a twenty year period (1969-1989), overall wastewater flowrates to the Assabet River increased by approximately 100%, due primarily to population growth. POTW operators were able to reduce BOD loadings significantly and hold nutrient loadings approximately constant during this time period (see Table 2-8). This represents a significant accomplishment in terms of improved effluent treatment.

8.2.2 Historic Water Quality Data Summary: 1990s

The Organization for the Assabet River (OAR) conducted numerous summer-time water quality surveys of the Assabet River from 1993 to 2000. Typical ranges of ambient river water concentrations for key parameters measured from 1993 to 1997 are provided below:

- Total phosphorus: 0.2 to 1.0 mg/l
- Nitrate: 0.5 to 3.4 mg/l
- Ammonia: 0.06 to 0.3 mg/l
- BOD_5: 0.5 to 5.0 mg/l
- Fecal coliform: 100 to 1,600 col/100 ml

Ambient water concentrations of total phosphorus and ammonia were observed to be generally lower in the 1990s than in the 1980s and 1970s, based on comparison of OAR and State of Massachusetts data. Ambient water concentrations of nitrate, BOD, and fecal coliform were observed to be generally similar throughout the three decades.

8.2.3 Water Quality Data Summary: 1999-2000

Water quality measurements were collected under a variety of conditions; winter and summer; high-flow and low-flow; dry-weather and wet-weather, to support quantification of eutrophication and nutrient loading conditions in the Assabet River system. The following observations were made of water quality conditions in the Assabet River based on the data collection program.

<u>During Summer 1999 and Summer 2000 surveys</u>:

- Water quality conditions in the Assabet River during the Summer 1999 and Summer 2000 surveys were similar.
- DO concentrations experienced large diurnal variations throughout the river, indicating intensive biological activity.
- Nutrient concentrations of both phosphorus and nitrogen species were 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 in the Assabet River 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
  - Ammonia: 0.04 to 0.2 mg/l
- Phosphorus concentration measurements collected in tributaries were generally dramatically lower than those collected in the Assabet River mainstem. In particular, the maximum ortho-phosphorus concentration measurement collected from a tributary was 0.06 mg/l, an order of magnitude lower than typical river ortho-phosphorus concentrations. This observation indicates that tributaries were not dominant sources of available phosphorus during the Summer 1999 and Summer 2000 surveys.
- Nitrogen concentration measurements collected in tributaries were generally similar to those collected in the Assabet River mainstem.

During Dry-weather surveys:

- Water quality measurements collected during January, February, and March 2000 dry-weather surveys were generally similar from survey to survey in terms of nutrient concentration measurements.
- Typical ranges of nutrient concentrations in the Assabet River were:
  - Total phosphorus: 0.2 to 0.6 mg/l
  - Ortho-phosphorus: 0.1 to 0.7 mg/l
  - Nitrate: 0.6 to 2.8 mg/l
  - Ammonia: 0.05 to 0.4 mg/l
- Phosphorus concentration measurements collected in tributaries were generally dramatically lower than those collected in the Assabet River mainstem.
- Nitrogen concentration measurements collected in tributaries were generally similar to those collected in the Assabet River mainstem.
- Assabet River nutrient concentration measurements collected during the dry-weather surveys were generally similar to those collected during the two summer surveys. Nitrate concentrations measurements were moderately lower during the dry-weather surveys relative to summer-time surveys.

During Wet-weather Surveys

- Water quality measurements collected during the three wet-weather surveys varied significantly from survey to survey in terms of nutrient concentration measurements.
- Ortho-phosphorus concentration measurements were low (max. value 0.01 mg/l) in all wet-weather surveys.
- Total phosphorus concentration measurements were elevated (and similar to river survey levels) during one survey (March 27, 2000) with typical values ranging from 0.3 to 0.8 mg/l, but were lower in the other two surveys with typical values ranging from 0.03 to 0.1 mg/l.
- Nitrogen concentration measurements collected during the wet-weather surveys were generally similar to those collected in the river during other surveys.

8.2.4 Summary of Nutrient Loadings to the Assabet River During Six Field Surveys

A nutrient loadings evaluation was performed to enhance understanding of the nature and extent of nutrient sources to the Assabet River. Nutrient loadings were estimated using concurrently measured

flow and nutrient concentration measurements from point sources and tributaries, representing non-point sources. The evaluation of nutrient loadings during 6 field surveys (see Section 5.5) found that point sources contributed the majority of nutrient loadings to the Assabet River during most surveys. Point sources were found to be the dominant source of biologically-available phosphorus (i.e., ortho-phosphorus) during all 6 surveys representing 88% to 98% of the overall available phosphorus load.

Total nutrient loads from all significant sources to the Assabet River for four key nutrient constituents during the 6 surveys ranged as follows:

- Ortho-phosphorus loadings: 52 to 319 lbs/day
- Total Phosphorus loadings: 66 to 1,390 lbs/day
- Nitrate loadings: 982 to 2,250 lbs/day
- Total Nitrogen loadings: 1,190 to 3,850 lbs/day

Point sources contributed a majority of all four nutrient constituents evaluated during 4 of the 6 surveys, including three summer surveys (July 1999, August 2000, and September 2000) and a winter survey (February 2000), with the following point source percentage contributions:

- Ortho-phosphorus: 97% to 98%,
- Total phosphorus: 82% to 97%
- Nitrate: 91% to 99%
- Total Nitrogen: 88% to 97%

Non-point sources were observed to contribute the majority of total phosphorus and total nitrogen during 2 of the 6 surveys. These two surveys were both conducted during wet-weather events in March 2000 (on March 16 and on March 27) and corresponded with relatively large streamflows (375 cfs and 250 cfs). During the March 2000 wet-weather surveys, the largest streamflows and some of the largest nutrient loadings of the 6 water quality surveys were observed. During the two high-flow, wet-weather surveys, the point sources were observed to contribute the following percent contribution of the overall loading:

- Ortho-phosphorus: 88% and 96%
- Total Phosphorus: 23% and 48%
- Nitrate: 41% and 59%
- Total Nitrogen: 31% and 40%

In summary, 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 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 (89% 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.

The water quality data collection program was successful in capturing nutrient and nutrient-related measurements throughout the Assabet River and its tributaries under a variety of conditions. Water quality measurements will be applied to support the TMDL project in numerous ways including supporting estimation of nutrient loadings, characterization of nutrient and biological process dynamics, and supporting development of a mathematical modeling application for the Assabet River system.

8.3 Sediment Data Summary

The following observations were made of sediments in Assabet River impoundments during the data collection program.

- Depth, sediment thicknesses, and sediment quality of the 5 major Assabet River impoundments are generally similar.
- The river impoundments are 1 to 12 feet deep with typical depths of 3 to 7 feet and feature a deeper main channel with shallower side and backwater areas.
- Impoundment soft sediments are generally 1 to 6 feet deep with deeper sediment layers in backwater areas and shallower sediment layers in the main channel.
- Sediment quality sampling found similar sediment concentration measurements of total ortho-phosphorus and total nitrogen in all 5 river impoundments. Extractable nutrient concentration measurements varied significantly from impoundment to impoundment.
- Sediment nutrient flux surveys found a flux of dissolved phosphorus and dissolved nitrogen into river sediments during the winter and a reversal to flux of these constituents out of sediments (and into the water column) during the summer-time. Nitrate was observed to be an exception to this trend, however, as it was observed to flux into sediments during both winter-time and summer-time surveys. The magnitude of these fluxes was found to be relatively small compared to ambient water concentrations.

- A sediment oxygen demand of 1.0 to 1.2 mg/l/day was estimated during the Summer 2000 survey.
- During the Summer 2000 nutrient flux survey, dissolved oxygen and nitrate were removed from the water column and ammonia was released to the water column. These observations are indicative of denitrification processes in river impoundment sediments.
- Under laboratory-induced anoxic conditions, sediment nutrient flux was found to increase dramatically. Anoxic conditions appear to occur only sporadically and in limited areas of the Assabet River impoundments based in dissolved oxygen concentration profile measurements.

In summary, impoundment sediment nutrient flux surveys performed in March and September 2000 confirmed the role of impoundment sediments as sinks for nutrients during the winter-time and sources of nutrients to the water column during the summer-time. Nitrate was observed to be an exception to this trend, however, as it was observed to flux into sediments during both winter-time and summer-time surveys. The extent of sediment nutrient flux was observed to be limited indicating that sediment nutrient flux processes represent a relatively minor component of the overall Assabet River nutrient budget.

The sediment data collection program was successful in capturing bathymetric, sediment thickness, sediment nutrient flux, and sediment quality measurements throughout Assabet River impoundments. Sediment nutrient flux was successfully measured under winter-time and summer-time conditions. Sediment measurements will be applied to support assessment of the relative impact of sediments on the nutrient budget and to support mathematical modeling of the Assabet River system.

8.4 Biological Data Summary

The overall findings of the Assabet River biological data collection program are summarized below, including comparisons of Summer 1999 and Summer 2000 observations.

8.4.1 Phytoplankton and Zooplankton

Phytoplankton density, as cell counts or biomass, was observed to be low to moderate in all 5 river impoundments during the Summer 1999 and Summer 2000 surveys. It should be noted, however, that this assessment did not include algal mats, which were incorporated into the macrophyte assessment. Although phytoplankton productivity (generation of new algae) could be high in this system, the accumulated phytoplankton biomass is not unusually large.

Data for water chemistry and zooplankton suggest that phytoplankton biomass accumulation would not be limited by nutrient availability or grazing. It appears more likely that the low phytoplankton accumulation is a function of light limitation on productivity or flushing of biomass from the

impoundments under sporadic high flows. Even during dry periods, detention times in the impoundments are relatively short compared to pond and lake system (e.g. several days rather that months). Consequently, true phytoplankton populations were not dominant factors in the functioning of the Assabet River impoundments during the biological surveys.

An absence of large bodied zooplankters and the overall low zooplankton biomass (Summer 2000) indicates a major ecological imbalance in the river impoundments. As a result, grazing pressure on phytoplankton is minimal and food for planktivorous fish is scarce. It is possible that this situation is the result of intense predation, toxicity, low oxygen, or potentially high flushing rate. While flushing is undoubtedly a factor in determining the composition and structure of the zooplankton community, it may not be the dominant factor leading to the observed assemblage. It is uncertain as to why the impoundments host such unfavorable zooplankton populations, but some combination of predation, flushing and localized low oxygen appears plausible as an explanation.

8.4.2 Macrophytes

Excess growth of macrophytes was observed in river impoundments during the Summer 1999 and Summer 2000 surveys. The presence of dense macrophyte growths is known to inhibit phytoplankton production and biomass accumulation, and appears to have done so in the Assabet River impoundments. Filamentous algal mats of the division Chlorophyta are grouped with macrophytes in river impoundments, as those growths behave functionally more like vascular plants than phytoplankton. Green algal mats typically begin their life cycle from resting spores in the bottom sediments, growing to visible size before trapping enough photosynthetic gas to float to the surface of each impoundment. If light and nutrient availability is sufficient, algal mats may continue to grow for up to about two months and cover large expanses of impoundment surface.

The chlorophytes *Cladophora* and *Hydrodicton* are the most troublesome mat-forming algae in the Assabet River impoundments, with *Hydrodictyon* more common during the Summer 1999 survey and *Cladophora* more abundant during the Summer 2000 survey. Mats of these algae are functionally equivalent to dense growths of duckweed or watermeal, which are also abundant in the Assabet River impoundments during summer.

The abundance of green algal mats, duckweed and watermeal is indicative of very high inorganic nitrogen concentrations. Available phosphorus must also be abundant to support such extensive growths, but a high N:P ratio is suggested by the species present. At such high densities, oxygen fluctuations could be expected, with high daytime values and low overnight values typical. Just how high or low is partly a function of flushing rate, which was always at least moderate in this system and was quite high during summer 2000 survey. Even during the dry summer of 1999, background flows and discharges keep detention times below those typical for non-impounded lakes in Massachusetts. Flushing also affects biomass build-up, with lower values observed in 2000 when flushing was higher

than in 1999. However, the combination of rooted species and entangled algal mats resulted in large macrophyte biomasses in both years.

The primary rooted species are waterweed and coontail, but there are many other submergent rooted species present in the Assabet River impoundments. The primary introduced species known to be invasive and deleterious to habitat and human uses are water chestnut, fanwort and curlyleaf pondweed. None of these invasive species was a dominant in the system during summer 1999 or summer 2000 surveys, but the potential for expansion by one or more of these species exists. It is suspected that high cover by floating species has kept the submergent invasive species in check to date. This poses a potential dilemma for water quality management; improved water quality should lead to a decrease in floating species (duckweed, watermeal, and filamentous green algae), but could potentially enhance conditions for submergent growth.

8.4.3 Biological Assessment Summary

Vegetation density was observed to be at levels likely to significantly impair water quality and designated uses during both summer surveys. Excess levels of aquatic macrophytes, consistent with the presence of eutrophic conditions, were observed during summer of 1999 and summer 2000 biological surveys. Macrophytes were observed to be dominant in Assabet River Impoundments. Phytoplankton and zooplankton appeared to be relatively minor components of the Assabet River impoundment ecosystem. Far more biomass was represented by vegetation, especially floating species not rooted in sediment and rooted submergent species than by plankton. Filamentous green algae mats were included as floating species and may be a dominant component of the macrophyte community in these impoundments.

Most of the dominant species observed in the Assabet River take their nutrition from the water column, an unusual situation typically associated with high dissolved nutrient levels. In particular, many of the vascular plants in the impoundments are known to take nutrition from the water column. This is not typical of vascular plants, but the nutrient rich waters of the Assabet appear to favor plants that are not rooted firmly in the sediment and can extract nutrients directly from the water column.

All of the species identified above are known to respond positively to eutrophication. Specifically, they grow aggressively to high density in the presence of elevated nutrient concentrations in the water. Also, algal assays with duckweed and the filamentous green alga *Cladophora* indicated that they are highly resistant to short-term reductions in nutrient availability. All of the currently abundant macrophyte species in the Assabet River impoundments are native to New England. Several potentially invasive non-native aquatic macrophytes were identified in the Assabet River, but none of these non-native species has achieved high densities in the Assabet River impoundments.

The biological data collection program was successful in capturing aquatic biological conditions in the Assabet River during the summers of 1999 and 2000. Biological measurements will be applied to

support assessment of biological activity on the nutrient budget and to support development of a mathematical model for the Assabet River system.