HOP BROOK
SEDIMENT AND DAM REMOVAL STUDY

MARLBOROUGH AND SUDBURY
MASSACHUSETTS

DRAFT REPORT

Department of the Army
New England District
U.S. Army Corps of Engineers
Concord, MA

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INTRODUCTION

Study Authority

This investigation is being conducted by the Corps of Engineers, New England District under the Work for Others authority pursuant to 31 U.S.C Sec 6505 (Intergovernmental Cooperation Act). The study was performed using 100% non-Federal funding from the Massachusetts Department of Environmental Protection (MADEP).

Study Background

Hop Brook and its impoundments currently do not meet state requirements for water quality. Areas behind dams experience low dissolved oxygen and excessive growth of aquatic vegetation. Both factors result in degraded aquatic habitat. The primary issue is too much phosphorus input to the waterway. Phosphorus, a nutrient, when elevated above normal background levels causes excessive production of floating and rooted aquatic plants. This vegetation growth and decomposition negatively impacts the water column's dissolved oxygen levels. Adequate dissolved oxygen is required to support aquatic life. Phosphorus loadings originate from both point and non-point sources. Point sources include the Marlborough East Wastewater Treatment Plant (MWWTP), while non-point sources include internal recycling of phosphorus from sediments and storm water runoff.

Current wastewater discharge permit (September 2004) jointly issue by the U.S. Environmental Protection Agency (EPA) and MADEP sets long term limits for phosphorus to 0.1 mg/l from April through November and 0.75 mg/l from December through March. The permit requires compliance with the phosphorus limit within four years. The earlier NPDES permit limits allowed for phosphorus levels to be 0.75 mg/l in the effluent (EPA press release # 04-09-10).

Hop Brook has been the subject of several water quality studies during recent years due to the excessive nutrients (phosphorus and nitrogen) that have entered the brook from the watershed. The MWWTP discharges into Hop Brook near its headwaters, and it is believed that excess nutrients (phosphorus and nitrogen) from this discharge are primarily responsible for eutrophication at four downstream impoundments, resulting in excessive aquatic macrophytes and algal growth. Current upgrades to the MWWTP include improvements to its tertiary treatment to limit concentrations of phosphorus and nitrogen. The impact of this wastewater treatment plant is significant in that during periods of low flow (July-September) it is believed that at least 75% of the total stream volume in Hop Brook is comprised of effluent from this facility (ENSR Report, 2001).

The downstream impoundments affected by these excess nutrients lie within six miles of the headwaters of Hop Brook, in the City of Marlborough and town of Sudbury. These include (in order from upstream to downstream) Hager Pond, Grist Millpond, Carding Millpond and Stearns Millpond. The Study Area is shown in Figure 1. In addition to the nutrients entering these impoundments from the MWWTP, existing cycling of nutrients from the sediments in these ponds, as well as other non-point sources may be contributing to the ongoing eutrophication problem. The purpose of this effort is to identify potential solutions to reduce nutrient recycling in these impoundments and the river system as well as any impacted resources associated with changes to the current system.

Goals and Objectives

The goals for Hop Brook is to identify and assess alternatives for reducing internal phosphorus recycling from sediments through sediment removal, partial or complete dam removal.

Potential aquatic ecosystem objectives include restoration of habitats in different portions of the river that support both the typical warm-water species and fluvial dependents and improvements in the migratory corridor for species such as American eel. Initial discussions with regulatory, resource agencies and stakeholders targeted sediment and dam removal as alternatives for water quality improvement.

Study Area

Hop Brook is a small stream located in Marlborough, Massachusetts that is formed by runoff from Ward Hill, within the Sudbury River watershed in east central Massachusetts. Hop Brook flows a distance of approximately 12 miles to its confluence with the Sudbury River in Sudbury, Massachusetts. The Sudbury River watershed lies within the Merrimack River basin which includes north and south central New Hampshire and northeastern Massachusetts. Precipitation averages 47 inches/year and average temperatures range from 25 degrees Fahrenheit in January to 71 degrees Fahrenheit in July (USGS, 2004).

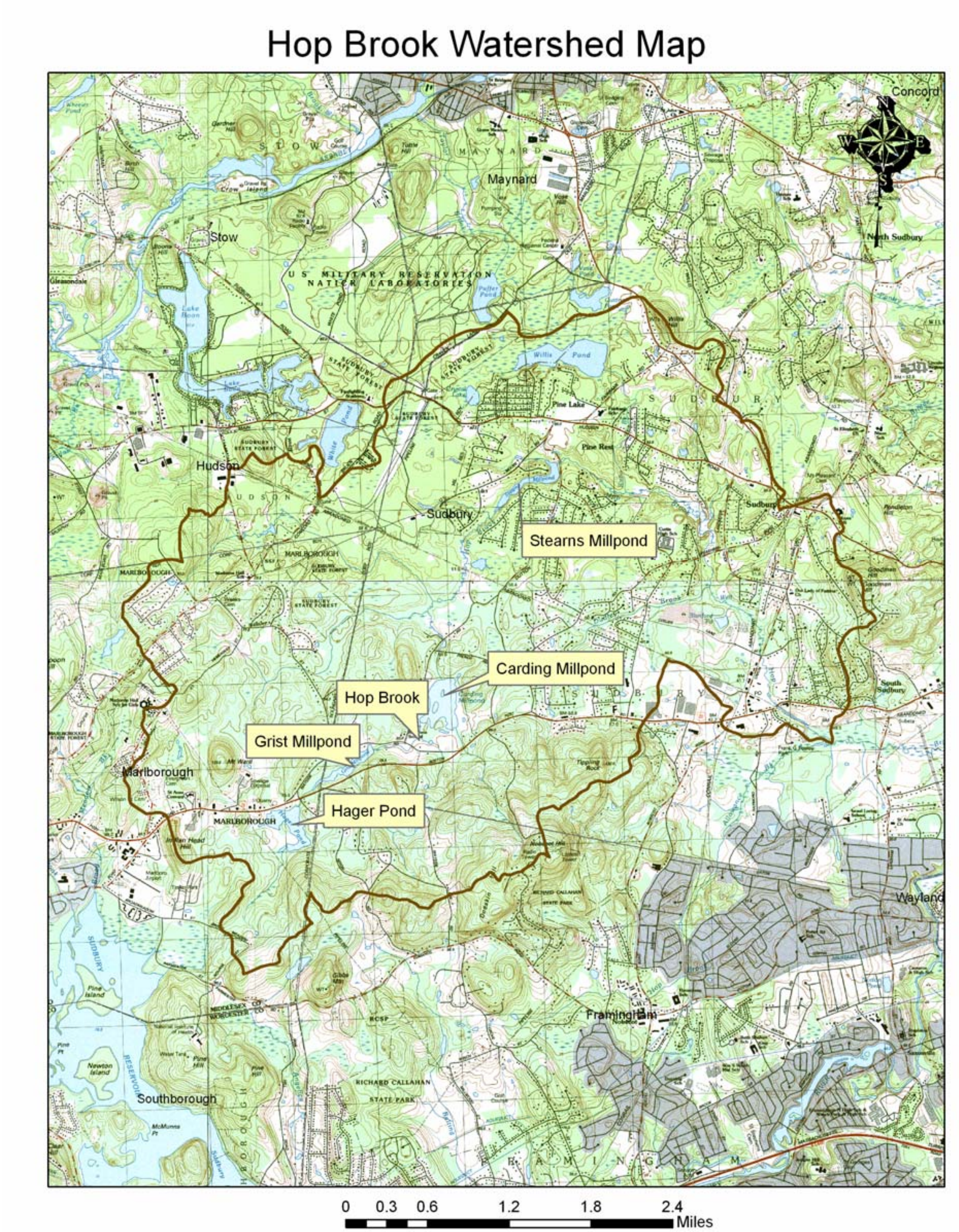
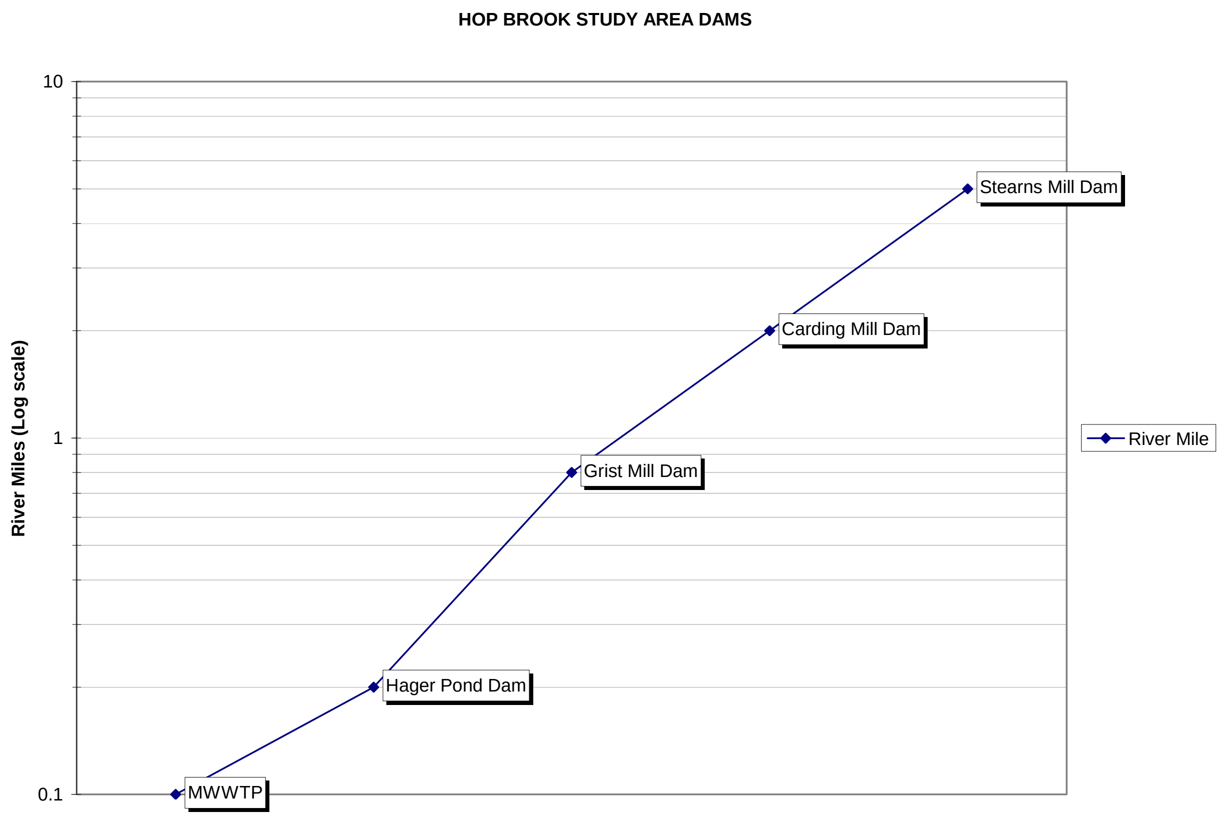


Figure 1. Basin Map

As noted above, there are four impoundments in Hop brook: Hager Pond, Grist Millpond, Carding Millpond and Stearns Millpond. The wastewater treatment plant is an important factor in river water quality. A schematic representation of the dams and impoundments relative to the Hop Brook is shown in Log scale in Figure 2.

Figure 2. River Schematic



Prior Studies and Reports

Numerous studies have investigated Hop Brook and its impoundments. Studies conducted prior to 2000 were summarized by ENSR (2001). These include a variety of water quality studies, stream flow, flood boundary and flood management studies, wastewater discharge studies, and biological studies conducted during the 1960's through 1990's. Some of the studies used for this effort include:

- ENSR, Nutrient loading evaluation of Hop Brook, Sep 2004.
- ENSR, Nutrient impact evaluation of Hop Brook in Marlborough and Sudbury, Oct 2000.
- Wetland mapping from Massachusetts Wetlands Conservancy Program -wetland mapping is based on interpretation of 2001 color aerial photography.
- Natural Resource habitat mapping available from the Massachusetts resource agencies including Bio-Maps and Living Waters. The Massachusetts Bio-Map identifies critical upland and wetland habitat needed to maintain biodiversity. Living Waters Core Habitat represent lakes, ponds, rivers, and streams habitat for rare freshwater species, or that are known to be exemplary aquatic habitat.
- MA Division of Fisheries and Wildlife field data on the Assabet River

EXISTING CONDITIONS

Dam Conditions

As part of this study effort, Corps staff performed brief site visits to each dam to determine the general characteristics of the dam and the existing condition at the site. See Appendix A for photographs and information on each dam. Corps staff also researched the National Inventory of Dams database and obtained available information from the Massachusetts Office of Dam Safety.

Research confirmed that many of the current dams were constructed either in the early 1900s or pre-1900s (see Table 1). Table 2 provides general characteristics of the impoundments associated with the dams and Table 3 provides general characteristics of the dams.

Table 1. Dam Information, Year Built

Dam Name	Town	ID	Year Built	Dam site dates
Hager Pond	Marlborough	MA00452	1800	1800. Modifications in mid-1900
Grist Millpond	Sudbury	MA01109	1800	1800
Carding Millpond	Sudbury	MA00742	1930	1930
Stearns Millpond	Sudbury	MA01132	1900	1900

Table 2. Impoundment Characteristics

Dam Name	Estimated Thalweg Length from ENSR report (ft.)	Impoundment Area from ENSR report (acres)	Impoundment Average Water Depth from ENSR report (ft.)
Hager Pond	1375 ft.	31	2.5
Grist Millpond	2955 ft.	17.5	2.2
Carding Millpond	2005 ft.	41.4	2.3
Stearns Millpond	3380 ft.	20.4	1.0

Table 3. General Characteristics of Dams

Dam Name	**Comment**
Hager Pond	The existing dam is built of a formed mass concrete box founded in part on an old masonry wall of the old dam and the stone ledge. The dam has a structural height of 14 feet and a crest width (including the inlet channel banks) of about 225 feet. The width of the weir opening is about 4 feet and the entire concrete dam structure is about 12 feet wide. The rest of the dam is an earthen embankment.
Grist Millpond	The dam is constructed of earthen materials with a sluiceway to the Grist Mill. The earthen dam has an estimated structural height of about 15 feet and an estimated crest width of 400 feet.
Carding Millpond	The earthen dam has two spillways, one gated and the other uncontrolled. The width of the spillway is about 60 feet. The spillways are primarily masonry with granite blocks in some areas. The gated spillway is in fair condition but the metal stop logs at the mill building have started to rust and deteriorate.
Stearns Millpond	The dam is constructed of earth fill materials and concrete abutment walls with a concrete spillway section. The embankment has a structural height of 10 feet and a crest width of about 300 feet.

Dam Safety

In Massachusetts, the Office of Dam Safety at the Department of Conservation and Recreation is responsible for overseeing the safety of the dams. Recent legislation has required that dam owners be responsible for completing periodic inspections of their dams and implementing any required maintenance or repair.

Hazard Ratings for each of the dams were obtained from DCR and are shown in Table 4.

Table 4. Dam Safety Hazard Rating

Dam Name	**Town**	**DCR DAM ID**	**DCR – Dam Hazard Rating**
Hager Pond	Marlborough	MA00452	H
Grist Millpond	Sudbury	MA01109	L
Carding Millpond	Sudbury	MA00742	H
Stearns Millpond	Sudbury	MA01132	S

H = High Hazard Potential dam refers to dams located where failure will likely cause loss of life and serious damage to home(s), industrial or commercial facilities, important public utilities, main highway(s) or railroad(s).

S = Significant Hazard Potential dam refers to dams located where failure may cause loss of life and damage home(s), industrial or commercial facilities, secondary highway(s) or railroad(s) or cause interruption of use or service of relatively important facilities.

L= Low Hazard Potential dam refers to dams located where failure may cause minimal property damage to others. Loss of life is not expected.

Existing Uses

Existing uses of the dams and impoundments were identified through meetings with the dam owners and observations during field visits. Table 5 provides a summary of existing uses at each dam and Appendix B provides additional details.

Table 5. Existing Uses

Hager Pond Dam	
Land Use/Recreation	Commercial and residential/recreational use minimal
Water Supply	Not used for water supply
Hydropower	Not used for hydropower
Grist Mill Dam	
Land Use/Recreation	Commercial/ recreational use minimal
Water Supply	Not used for water supply, but occasionally used to power Grist Mill.

Hydropower	Not used for hydropower
Carding Mill Dam	
Land Use/Recreation	Residential, recreational use for canoeing
Water Supply	Not used for water supply
Hydropower	Not used for hydropower
Stearns Mill Dam	
Land Use/Recreation	Residential, private open areas, recreational use for canoeing but access limited
Water Supply	Not used for water supply
Hydropower	Not used for hydropower

Sediment Quantity and Quality

The most comprehensive study of Hop Brook was accomplished by ENSR in 2000 and described in their reports dated 2000 and 2004. To supplement the data, the Corps conducted a detailed sediment study in the fall of 2006. The study determined the chemistry of sediments in the four main impoundments and the riverine sections. Both core samples and surface sediments were collected and analyzed for bulk sediment phosphorus, organic carbon, metals, Polycyclic aromatic hydrocarbon (PAHs), Polychlorinated biphenyl (PCB), pesticides, and petroleum hydrocarbons. Test results were compared with sediment quality guidelines for potential effects on aquatic life, human contact, and landfill reuse.

Sediment volumes estimated for the four impoundments by ENSR ranged from approximately 16,000 cubic yards in the Grist Mill impoundment to about 58,000 cubic yards in the Hager Pond impoundment. See Table 6.

ENSR has developed general sediment depth maps for each impoundment and these are included in the ENSR report. These will be helpful in estimating dredging volumes once specific dredging sites are identified.

Table 6. Sediment Volumes

Impoundment Name	**Volume (cubic yards)**
Hager Pond	55,700
Grist Millpond	15,700
Carding Millpond	63,100
Stearns Millpond	33,100
TOTAL	167,600

The Corps sampling studies done in December 2006 showed that concentrations of some metals, PAHs, and PCBs occasionally exceeded Massachusetts Department of Environmental Protection aquatic life guidelines. Also in some cases sediment quality exceeded MA310CMR acceptable residential soils concentrations.   This may limit the option of upland disposal of dredge material.

Table 7 summarizes the findings on sediment quality. Appendix C contains additional information on the level of contaminants by impoundments. Multiple charts displaying the chemical results can also be found in Appendix C.

Table 7. Chemical groups where one or more samples exceeded guidelines

	Chemical groups that exceed aquatic life guidelines	**Chemical groups that exceed MA landfill re-use standards**	**Chemical groups that exceed MA 310CMR40, residential soils standards**
Hager Pond	As, Cd, Cu, Pb, Ni, Zn	none	Be, Cd, Cr, Pb
Grist Millpond	Cd, Pb, Ni, Zn	none	Be, Cd
Carding Millpond	As, Cd, Cu, Pb, Ni, Zn	none	Be, Ni
Stearns Millpond	As, Ni	none	Be, As, Ni

<u>Phosphorus</u>

The Corps study measured total phosphorus in the sediments at locations from all four ponds at incremental depths of 0-1 ft., 1-2 ft., 2-3 ft., 3-4 ft. and 4-5 ft, wherever possible.

Results indicate that phosphorus concentrations tend to decrease with depth in the sediments in all ponds except Hager pond. This observation is demonstrated in the graphs shown in Appendix C.

The data shows that total phosphorus concentrations generally decreased below depths of about 2 to 3 feet, except Hager pond which shows an increase in concentration at locations HP-04 (near the dam) and HP-05 (center of the pond) followed by a sharp drop in phosphorus levels at the 4-5 ft. range. The change with depth in the sediments may be reflective of the changing nature of the pollutant loading in the ponds over time. Hager Pond, which is the closest to the waste water treatment plant, however, exhibits an atypical trend at locations HP-04 and HP-05. Since these two sample locations are near the MWWTP, either some sediment mixing has occurred or, more likely the higher phosphorus concentrations at deeper depths represent higher discharge concentrations in previous years followed by lower discharge concentrations due to tightening of discharge standards at shallower depths over time.

Natural Resources

<u>Introduction</u>

Natural Resources in the impoundments and along the Assabet River are discussed in detail in Appendix D. Resources discussed include:

- Riparian Habitat
- Fish Populations
- Aquatic Invertebrates
- Wetlands
- Invasive Species
- Wildlife
- Rare Species Habitat

This information will be useful in developing environmental compliance documentation for future projects and assist with identification of potential benefits and impacts associated with different alternatives.

In general, the alternatives of sediment dredging and dam removal will benefit the Hop Brook aquatic ecosystem in at least three ways.

- Removal of nutrient rich sediments will provide a cleaner substrate for benthic organisms that form the base of the aquatic food web.

- Water quality improvements will provide improved dissolved oxygen levels for both cold and warm-water fisheries.

- Dam removal or breachings will improve the efficiency of American eel migration. USFWS is considering listing American eel as an endangered species.

However, removal of dams will result in changes in wetland types upstream of the impoundments due to lower water levels. Areas of expected change with dam removal can be identified with further surveying and modeling.

Fish

American eel, *Anguilla rostrata*, a catadromous species, was sampled at each of the sites. This is the only migrating species that is currently able to pass over or around the dams on Hop Brook and downstream to the Sudbury River.

Hop Brook is not stocked and there was no fishery data available from the MA Division of Fish and Wildlife. Fisheries data collected by the Corps indicated that Hop Brook possesses a warm water fishery (see table for summary). Two lacustrine species - largemouth bass and bullhead were observed. American Eel was also observed.

Table 8. List of Warm-water Fish Species

Common Name	Scientific Name
Banded sunfish	*Enneacabthus obesus*
Black crappie	*Pomoxis nigromaculatus*
Black nosed dace	*Rhinichthys nigromaculatus*
Bluegill	*Lepomis macrochirus*
Brown bullhead	*Ameiurus nebulosus*
Chain pickerel	*Esox niger*
Common carp	*Cyprinus carpio*
Creek chubsucker	*Erimyzon oblongus*
Fallfish	*Semotilus corporalis*
Goldfish	*Carrassius auratus*
Golden shiner	*Notemigonius crysoleucas*
Green sunfish	*Lepomis cyanellus*
Largemouth bass	*Micropterus salmoides*
Pumpkinseed	*Lepomis gibbosus*
Redbreast sunfish	*Lepomis auritus*
Spottail shiner	*Notropis hudsonius*
Tiger muskie	*Esox lucius* x *E. msquinongy*
White perch	*Morone Americana*
Yellow bullhead	*Ameiurus natalis*
Yellow perch	*Perca flavescens*

Aquatic Invertebrates

Zooplankton studies completed in October1999 by ENSR showed low densities of zooplankton at all the impoundments with the exception of Hager Pond. Zooplankton density increased over the growing season at Hager Pond but remained fairly stable in Grist Millpond, Carding Millpond and Stearns Millpond. Rotifers, copepods and cladocerans were observed in almost all samples with low densities. For the Hager Pond sample, the greatest density of zooplankton was dominated by cladocerans. Average body size for zooplankton community was low, especially during periods of low flow. Predation by young of the year fish or by being flushed from the ponds during high flow may be the cause of the small average size of these invertebrates since such an enriched environment would be expected to support a greater zooplankton community.

Hop Brook upstream and downstream of Hager Pond, Grist Millpond, Carding Millpond and Stearns Millpond is a mix of riffles and pools depending on the gradient of the flow. A qualitative examination of the undersides of rocks from the streambed of the riffle area revealed a diverse assemblage of stonefly, caddis fly and Dobson/alderflies. The area of Hop Brook just downstream from Carding Millpond dam where fish sampling was done contained a dense growth of freshwater sponges. The many lightly colored sponge colonies were very conspicuous growing on the darkly colored stones in the streambed. This diverse assemblage of benthic invertebrates may be unique to this area.

<u>Wetlands and Riparian Vegetation</u>

Within the study area, the most extensive wetland areas were:

a) south and east of Carding Millpond,
b) the area to the east and west of Hop Brook downstream of Carding Millpond from French Road to the inflow of Stearns Millpond,
c) the area upstream and adjacent to Grist Millpond,
d) Wetland complex just south of Hager Pond.

There were smaller wetlands such as the wetland complex incorporated in a recreational area at the Raytheon Plant located on the west shore of Hager Pond. Greater detail on each wetland is included in Appendix D of this report.

Riparian areas that have the greatest importance in the study area are as stated above. They are adjacent to Hop Brook from the Dutton Road culvert downstream of the Carding Millpond dam discharge and they extend to the inflow of Hop Brook into Stearns Millpond. The riparian vegetation is characteristic of a series of diverse wetland communities. The riparian flora found is typically associated with wooded deciduous swamp dominated by red maple/high bush blueberry/winterberry, shrub swamp dominated by willow/alder/button bush, deep marsh dominated by tussock sedge and cattail and mixed wooded swamp consisting of red maple and slightly elevated areas with white pine and hemlock. There are several certified vernal pools in and adjacent to these riparian areas. It is important the riparian corridor remains since it is connected to two large parcels to the east and west of Hop Brook classified by MA Natural Heritage as "Estimated Habitats of Rare Wildlife". The larger portion of these parcels is west of Hop Brook with much of this habitat being U.S. Fish and Wildlife property associated with the

Assabet River and Oxbow National Wildlife Refuge. The riparian corridor provided by the wetland habitats associated with Hop Brook is critical for listed and other animals to access these large areas to the east and west.

To estimate the impact of the various alternatives on wetland resources, a hydraulic model (HEC-RAS Model) was prepared. Calculations of Channel Surface Water Elevation (CWSEL) in feet National Geodetic Vertical Datum (NGVD) and Velocity Channel (VCH) in cubic feet per second (cfs) were developed with the HEC-RAS Model at several stations upstream and downstream of each impoundment. The calculations were made using average August low flows, 10, 50, 100 and 500-year average flows. Results of these model runs can be found in Appendix G.

Eight alternatives were considered for this study as discussed in the "Alternatives" section of this report: Alternative 1, removal of Hager Pond Dam; Alternative 2, removal of Carding Millpond and Stearns Millpond Dams; Alternative 3, removal of Carding Millpond Dam; Alternative 4, a partial breach of Hager Pond Dam; Alternative 5, a partial breach of Carding Millpond Dam; Alternative 6, a partial breach of Carding Millpond and Stearns Millpond Dams; Alternative 7, a partial breach of Hager Pond, Carding Millpond, and Stearns Millpond Dams; and Alternative 8, dredging of all ponds. Modeling indicates that Alternative 2, removal of Carding/Stearns Millpond dams and Alternative 3, removal of Carding Millpond dam have impacts on wetlands between Grist Millpond and Carding Millpond. An elevation drop of 0.5 ft for August averages was observed. Alternative 2 has a similar impact on the wetlands between Carding Millpond and Stearns Millpond. An elevation drop of 0.1 ft for August average flows was observed. The other change was upstream of Stearns Millpond in the riparian corridor which connects the State Listed "Estimated Habitats for Rare Wildlife".

The overall effects of Alternatives 1-7 on CWSEL and VCH appear to be minimal as calculated by the HEC-RAS Model. However, since there is no detailed elevation data for Hop Brook, the effects of the dam removal or notching on the wetland areas upstream of the dams cannot be accurately calculated. Table 9 estimates approximate acreages from United States Geographical Survey (USGS) topographic maps. With dam removal the decline in water level will obviously impact wetlands upstream of the impoundment as well as other peripheral fringing wetlands. There is insufficient data for a quantitative estimate of the wetlands acreages lost with each of the alternatives. Should this project continue, a detailed survey and groundwater monitoring will be required to provide an accurate estimate for the impact of the various alternatives on the surrounding wetlands.

It is however possible to identify the wetlands with potential for some acreage loss with each of the alternatives. Since the Grist Millpond dam cannot be considered for dam removal, the vicinity of Carding Millpond that possesses the largest wetland area may be affected due to complete or partial dam removal. Another wetlands complex possibly affected by the partial/complete removal of Carding Millpond is an area just north and east of Carding Mills, connected by a culvert under the cart road that traverses the north side of the pond. From topographical sheets this inflow may provide water to a wetland complex north of French Road listed as "Estimated Habitats for Rare Wildlife" by MA Natural Heritage. Other wetland losses due to partial/complete dam removal may be the two wetland complexes associated with the southern and western side of Hager Pond and the complex assemblage of wetland habitats upstream of the inflow to Stearns Millpond.

Table 9. Estimated Wetland Areas

Impoundment/River	**Estimated Wetlands in acres, includes open water areas**
Hager Pond	49.5
Grist Millpond	49.25
Carding Millpond	76.18
Stearns Millpond	39.66
Between Carding and Stearns Millponds	223.96
Downstream of Stearns Millpond	59.83
Total	498.38

Open water is the dominant community type, followed by emergent, scrub-shrub, and forested wetlands. A more detailed description of wetland communities is provided in Appendix D.

<u>Invasive Species</u>

The extensive distribution of filamentous green alga and aquatic macrophytes, both non-native/invasive and native floating and rooted species, have seriously impaired aquatic life, limited primary and secondary contact and the general aesthetics of the impoundments. The stated goal of this study is to limit/remove these impairments from the study area. Invasive aquatic macrophytes include *Potamogeton crispis*, curly-leaf pondweed, and *Trapa natens*, waterchestnut. Also noted within the study area were isolated stands of the non-native *Phragmites australis*, common reed, and *Lythrum salicaria*, purple loosestrife. The *Phragmites* was not ubiquitous, but present in large stands. In the future should any of the dam removal alternatives be selected, active measures should be employed to prevent the exposed areas of sediment from being overgrown with *Phragmites*. Without appropriate control measures, the areas of nutrient rich sediment exposed by the loss of the impoundments will be quickly overgrown by *Phragmites*.

Since Hop Brook is very eutrophic, native floating and rooted aquatic macrophytes such as *Lemna* (Duckweed) and Frog bit are a nuisance. These native varieties are individually less than a centimeter in diameter but with the high concentration of phosphorus and nitrate/nitrite in the water and the sediment these small floating macrophytes become abundant forming a layer an inch or more in thickness across the entire surface area of each of the ponds. At Carding Millpond windrows of the decomposing floating macrophytes were present throughout the spring/summer and fall. At Carding Millpond, Duckweed and Frog bit were visible into the winter.
Another nuisance species is the microscopic green alga, *Hydrodictyon* (water net), which forms dense, green mats. Other native green algae species that become nuisance varieties in the presence of the unlimited nutrient supply contained and flowing through the study area are *Oedogonium* and *Nitella*.

To control the downstream discharge of this virulent crop of nuisance and invasive plant species, a silt curtain was deployed across the discharge/spillway of Carding Millpond. The aquatic macrophytes, especially water chestnut are present in large quantities requiring the used of mechanized aquatic weed harvesting several times over the summer months to limit the effects of accumulating decomposing plant material.

<u>Wildlife</u>

Hop Brook and the four millponds provide a green belt/riparian corridor through the industrial/commercial/ suburban development associated with Route 20. This corridor connects to the Assabet and Concord Rivers. These corridors are the connections to allow various animal species to utilize the isolated parcels of undeveloped conservation land/state forest. Research indicates smaller habitats are able to support greater numbers and diversity of animal species if there are connections with other similar habitats. The ability of various populations to exchange genetic information may encourage diversity within the species.

The area included in this study contains many habitat magnets and more importantly is connected spatially and hydrologically to adjacent habitat. Habitat magnets are key landscape features that attract wildlife by providing niches (food, water, shelter, and breeding space). The area from the culvert under Dutton Road to the inflow into Stearns Millpond possesses greater habitat diversity than upstream areas. The habitat magnet hypothesis is supported in an informal study conducted by the Sudbury Conservation Commission on U.S. Fish and Wildlife property now a portion of the Assabet River National Wildlife Refuge, formally part of the Fort Devens Annex South. This property abuts the west bank of Hop Brook between the culvert under Dutton Road and the inflow to Stearns Millpond. The numbers of amphibians and reptiles identified in this area were large, including several species listed as rare and of concern by MA Natural Heritage.

Rare Species Habitat

The Massachusetts Natural Heritage Program has identified numerous areas within the Hop Brook watershed as potential habitat for rare species as listed in Table 10. The U.S. Fish and Wildlife Service determined there were no federally listed, proposed threatened, endangered species or critical habitat known to occur within the footprint of the Study. They also determined a Biological Assessment or consultation under Section 7 of the Endangered Species Act was not required at this time.

Table 10: Rare Species List

Scientific Name	**Common Name**	**State Status**
Ixobrychus exilis	Least Bittern	Endangered
Botaurus lentiginosus	American bittern	Endangered
Gallinula chloropus	Common Moorhen	Special Concern
Terrapene Carolina	Eastern Box Turtle	Special Concern
Gylptemys insulpta	Wood Turtle	Special Concern
Ambystoma laterale	Blue-spotted Salamander	Special Concern

Restoration of Anadromous Fish

MA Fish and Wildlife and the U.S. Fish and Wildlife Service have a common long term goal for the removal of dams which block the return of anadromous and catadromous species to most rivers where possible. This is especially relevant to Hop Brook. Hop Brook flows into the Sudbury River, which joins the Assabet River to from the Concord River, which discharges into the Merrimack River. There are several dams in various states of disrepair on Hop Brook, the Assabet, Concord and Merrimack Rivers that presently block the return of anadromous fish species such as river herring and alewife. A study similar to this one was recently completed on the Assabet River. Discussions with the U.S. Fish and Wildlife during the Assabet Study revealed their interest in restoring the Assabet River to an anadromous fishery. Although no discussions have occurred with either MA Fish and Wildlife and the U.S. Fish and Wildlife with regard to restoration of an anadromous fishery on Hop Brook, the removal or breach of any or all of the four dams within the study area will be progress toward the goal of fishery restoration. Unfortunately, the continued presence of the Grist Mill Dam could block upstream passage of fish, although fish data indicates the American eel, a catadromous species, presently is able to pass over/around the Grist Mill Dam. See below for a discussion of the American eel.

American Eel

American eel, *Anguilla rostrata*, was found at each of the fish sampling locations. American eel was found in Hager Pond which indicates the species is able to access the entire length of Hop Brook including the headwaters upstream of the MWWP. American eel is a catadromous species. A catadromous species returns in a larval form to a freshwater habitat like Hop Brook and the various impoundments along Hop Brook where they grow to maturity and return to the ocean to breed. Fresh water eels may spend as much as 40 years reaching several feet in length before migrating back to the marine environment to breed.

In 2004, with data indicating declining populations, the Atlantic States Marine Fisheries Commission requested Endangered Species status be extended to the American eel. The U.S. Fish and Wildlife Service determined in 2005 that there was sufficient data indicating declining eel populations to examine the situation. However, after a more extensive study the U.S. Fish and Wildlife service determined the Endangered Species Protection Act for the American eel was not necessary. However, it was determined that that the declining American eel population in certain areas required special actions. These actions will be included in a future directive from the U.S. Fish and Wildlife Service. Although the present dams in their general state of disrepair do not impede American eel passage, the breaching or removal of the dams will improve eel passage. Eel ladders could be constructed on any of the dams that remain, such as the Grist Mill Dam.

Cultural Resources Identification

Cultural resources research was completed for the study area to identify any potentially significant prehistoric and historic archaeological sites, and historic structures, which might be impacted by dam or sediment removal. Details of the cultural resources investigation can be found in Appendix E.

Once specific projects are identified, known historic structures which may be eligible for the National Register of Historic Places (NR) should be coordinated with the Massachusetts State Historic Preservation Officer (MA SHPO) and the Historic Resources Commission, as appropriate. Project alternatives will also be subject to consultation and review with the Wampanoag Tribal Historic Preservation Officer (THPO), as well as the Nipmuc THPO.

Initial investigations did identify known pre-historic sites along Hop Brook and historic structures at the dam sites. The Grist Millpond dam is the only dam in the study that is located within a historic district and is listed on the NR. Stearns Millpond dam is currently listed as a historic archaeological site in the Massachusetts Historical Commission (MHC) Inventory. It is likely that the Stearns Millpond dam site may be eligible for the NR, and the integrity of the mill and dam at the Carding Millpond could make this site significant as well. Detailed information on the cultural resources of the study area and each dam site is provided in Appendix E.

Real Estate Identification

Preliminary investigations were made into the ownership of each dam for planning purposes. Detailed information on the findings is presented in Appendix F. Below is a summary of the identified dam owners based on a review of public records. It is expected that additional research will be needed on ownerships in the impoundments upstream of the dams once specific project areas are identified.

Table 11. Dam Owners

Dam	Town	Owner
Hager Pond	Marlborough	Anthony P Scerra Trustee & Philip J. Bailey and Anne D. Fish
Grist Millpond	Sudbury	The Wayside Inn Corp.
Carding Millpond	Sudbury	Town of Sudbury Conservation Commission
Stearns Millpond	Sudbury	Town of Sudbury Conservation Commission

ALTERNATIVES

To achieve the objective of reducing internal phosphorus recycling from sediments, a combination of dam removals, partial dam removals or sediment removal was considered. The study analyzed the effects of lowering impoundment water levels and increasing channel velocities to achieve a reduced level of regulated phosphorous behind the impoundments. The hydraulic analysis used the Corps' HEC-RAS computer program to examine seven dam configuration alternatives for the four dams on Hop Brook: existing conditions (no structural alterations); removal of Hager Pond Dam; removal of Carding Millpond and Stearns Millpond Dams; removal of Carding Millpond Dam; a partial breach of Hager Pond Dam; a partial breach of Carding Millpond Dam; a partial breach of Carding Millpond and Stearns Millpond Dams; and a partial breach of Hager Pond, Carding Millpond, and Stearns Millpond Dams. No structural alternatives for this hydraulic analysis were proposed for the Grist Mill Dam. A partial breach represents the smallest flow area (most restrictive channel without dam) to expect on the brook and a complete removal represents the largest flow area (similar to pre-dam conditions). For this study, a partial breach is removal of 50% of the hydraulic height of the dam for the complete length. Flows ranging from the August average daily flow up to the 500-year flood flows were modeled to provide a detailed profile of Hop Brook for these different flow conditions. These results are used to determine what effects the proposed alternatives will have on water levels and channel velocities in the brook and wetland areas of concern. Details of the hydraulic analysis can be found in Appendix G.

<u>Alternative 1: Removal of Hager Pond Dam</u>

This alternative involves the removal of the concrete outlet works of the dam with a height of approximately 14 feet and a length of approximately 12 feet. Nothing would be done to Grist Mill, Carding Mill, and Stearns Millpond Dams.

<u>Alternative 2: Removal of Carding Millpond, and Stearns Millpond Dams</u>

This alternative involves the removal of Carding and Stearns Millpond dams. The Carding Millpond dam is an earthen dam with a height of approximately 15 feet and a crest length of 450 feet. For this alternative only 250 feet of the total of 450 feet was assumed to be removed. Stearns Millpond dam is an earth fill dam with concrete abutment walls and a concrete spillway section. The embankment has a structural height of 10 feet and a crest length of approximately 300 feet. For this alternative only 126 feet of the total of 300 feet was assumed removed. Nothing would be done at Hager Pond, and Grist Millpond dams.

<u>Alternative 3: Removal of Carding Millpond Dam</u>

This involves the removal of Carding Millpond Dam. The Carding Millpond dam is an earthen dam with a height of approximately 15 feet and a crest length of 450 feet. For this alternative only 250 feet of the total 450 feet was assumed removed. Nothing would be at Hager Pond, Grist Millpond, and Stearns Millpond dams.

Alternative 4: Partial Breach of Hager Pond Dam

This involves the removal of approximately 7 feet of the hydraulic height of the dam for a length of approximately 50 feet. Nothing would be done at Grist Mill, Carding Mill, and Stearns Millpond dams.

Alternative 5: Partial Breach of Carding Millpond Dam

This involves the removal of approximately 7.5 feet of the hydraulic height of the dam for a length of approximately 250 feet. Nothing would be done at Hager, Carding Mill, and Stearns Millpond dams.

Alternative 6: Partial Breach of Carding Millpond and Stearns Millpond Dams

For Carding Millpond dam this involves the removal of approximately 7.5 feet of the hydraulic height of the dam for a length of approximately 250 feet.   For Stearns Millpond dam this involves the removal of approximately 5.0 feet of the hydraulic height of the dam for a length of approximately 126 feet. Nothing would be done at Hager Pond, and Grist Millpond dams.

Alternative 7: Partial Breach of Hager Pond, Carding Millpond and Stearns Millpond Dams

For Hager Pond dam this involves the removal of approximately 7 feet of the hydraulic height of the dam for a length of approximately 50 feet. For Carding Millpond dam this involves the removal of approximately 7.5 feet of the hydraulic height of the dam for a length of approximately 250 feet.   For Stearns Millpond dam this involves the removal of approximately 5.0 feet of the hydraulic height of the dam for a length of approximately 126 feet. Nothing would be done at Grist Millpond dam.

Alternative 8: Dredging of Hager Pond, Grist Millpond, Carding Millpond and Stearns Millpond

This alternative looked into dredging the nutrient rich sediments from all four ponds: Hager Pond to a maximum depth of 4 ft, Grist Millpond to a maximum depth of 2 ft, Carding Millpond to a maximum depth of 2ft and Stearns Millpond to a maximum depth of 2 ft.

For the partial dam removal and complete dam removals, an average thalweg depth of 2 feet was planned and modeled behind the impoundments. Thalwegs helps the channel restoration process within the former impoundment in an accelerated fashion. Thalweg widths were designed to pass a 2-year flood event without the banks being overtopped. The model results (Appendix G) show that the width needs to vary from 16-feet (in steeper sections) to 110-feet (flatter sections) in order to pass a 2-year storm flow. In addition, for a partial dam removal, limited sediment removal (dredging) was also included to remove the nutrient rich sediment from the smaller pond created by the breaching. Plan views for existing condition, partial dam removal and thalweg creation, complete dam removal and thalweg creation, and dredging options for all the four impoundments are individually shown in Appendix B, Sheets 1 through 5.

Sediments that are removed will most likely be hydraulically dredged and dewatered using a belt-press plant to stabilize the organic material prior to disposal. The pressed "cakes" will then be stockpiled at the sites. Stockpiled cakes will then be analyzed for contaminant levels. For planning purposes, it is assumed that the stockpiled materials (rich in Nitrogen and Phosphorus) will have metals concentrations that fall within accepted landfill, aquatic and residential use criteria. Potentially these types of materials can be augmented and disposed of in a landfill as daily cover or could be combined with sandy material and reused as loam for residential reuse if it can meet the MADEP requirements.

MODELING RESULTS AND COMPARISONS OF ALTERNATIVES

The HEC-RAS model was run from just upstream of the confluence with the Sudbury River to just upstream of Hager Pond dam. Starting water surface elevations and flows for the flood-flow analyses were taken from the profiles and information found in FEMA's Sudbury Flood Insurance Study. Starting water surface elevations for the August average daily flow were calculated by the normal depth computation in the HEC-RAS model using the slope of the stream bottom. Profiles were computed from just upstream of the confluence to Sudbury River to above Hager Pond dam. Computed elevations and velocities are presented in Table 2 of Appendix G for three sections of the river that showed differences between existing conditions and the seven alternatives.

The three sections that showed elevation differences are: upstream of Hager Pond dam, an area upstream of Carding Millpond dam (river station 363.05 to river station 396.53), and an area upstream of Stearns Millpond dam (river station 227.1 to river station

287.55). For Alternative 2 (removal of Carding and Stearns Millpond dams), the flow elevations dropped by approximately 0.1 ft between Stearns Millpond and Carding Millpond for the August average flows. For higher flows under alternatives 2, 3, 5, 6 and 7 the model showed elevation drops upstream of Carding Millpond and Stearns Millpond.

Alternative 2 and 3 has impacts on wetlands between Grist Millpond and Carding Millpond. An elevation drop of 0.5 ft for August averages was observed. Alternative 2 also has a similar impact on the wetlands between Carding Millpond and Stearns Millpond. An elevation drop of 0.1 ft for August average flows was observed.

The rest of the study showed no change in water surface elevations or velocities between existing conditions and the partial and complete dam removal alternatives. The information summarized in Appendix G, Table 2 is for August average daily flow, and FEMA's 10, 50, 100, and 500-year flood flows. Appendix G, Plates 1-18 present backwater profiles for the area upstream of Carding Millpond to downstream of Stearns Millpond dam, river stations 206.5 to 401.5. Alternatives 2, 3, 5, 6, and 7 were presented because they represent the most significant changes in water surface elevations and channel velocities from the existing conditions.

Flows analyzed ranged from August average daily flows of 4 cfs, to the 500-year flood event of 890 cfs. Results from this range of flows defined the local flow characteristics needed to identify possible areas susceptible to scour and erosion due to velocity increases, and characterize the change of water surface profiles within the wetland areas for the seven alternatives. The velocities provide information needed in the planning and design for any needed stream bank protection. Velocity increases upstream and downstream of Carding Millpond and Stearns Millpond dams for the 10 to 500-year flows ranged from 0.5-5 feet per second (fps) for the proposed Alternatives 2 and 3.

PRELIMINARY COSTS

Preliminary costs for the different alternatives are shown below -

1. **Alternative 1, Removal of Hager Pond Dam –** this option along with a new thalweg was estimated to cost approximately $723,000.
2. **Alternative 2, Removal of Carding Millpond and Stearns Millpond Dams** - this option along with new thalwegs was estimated to cost approximately $1,857,000.
3. **Alternative 3, Removal of Carding Millpond Dam** - this option along with a new thalweg was estimated to cost approximately $578,000.

4. **Alternative 4, A partial breach of Hager Pond Dam** - this option along with a new thalweg was estimated to cost approximately $2,719,000.
5. **Alternative 5, A partial breach of Carding Millpond Dam** - this option along with a new thalweg was estimated to cost approximately $2,894,000.
6. **Alternative 6, A partial breach of Carding Millpond and Stearns Millpond Dams** - this option along with new thalwegs was estimated to cost approximately $5,129,000.
7. **Alternative 7, A partial breach of Hager Pond, Carding Millpond, and Stearns Millpond Dams** - this option along with new thalwegs was estimated to cost approximately $7,847,000.
8. **Alternative 8, Preliminary costs for Dredging** are shown below –
    a. Dredging of Hager Pond - $3,119,000
    b. Dredging of Grist Millpond - $1,096,000
    c. Dredging of Carding Millpond - $4,699,000
    d. Dredging of Stearns Millpond - $2,017,000

Detailed cost breakdowns of each alternative and costs of individual dam removals or breachings can be found in Appendix B. These cost estimates were developed using Government contract prices as found in the Corps' Micro-Computer Aided Cost Estimating System (MCACES) software.

One cost not discussed in this report is the repair of the existing dams to bring them into compliance with MA DCR inspection findings/recommendations. Corps personnel conducted dam inspections in June 2007 to document the conditions of the 4 dams. Details of these inspections can be found in Appendix A. Following are some of the deficiencies summarized from the Corps inspections –

<u>Hager Pond Dam:</u>
The concrete dam weir structure and supporting masonry are in very poor condition. Both sides of the weir are in need of major repairs. The left abutment has considerable seepage flowing under (even at low flows) and through the masonry concrete walls. The seepage is shown in Figure 8, Appendix A (HAGER POND). The right abutment has numerous cracks due to freeze-thaw actions in the concrete. The stability of the weir structure and masonry walls is very vulnerable during a high flow event when the dam would be overtopped. The toe of the dam and the downstream culverts are also in need of required maintenance. These areas have debris such as dead branches and trees as well as boulders and cobbles that may raise some concerns of past problems with erosion or seepage near the toe of the dam. The downstream channel will also need some erosion

protection near the Hager Street culvert and removal of sediments in the channel downstream.

Grist Millpond Dam:

Overall, the earthen dam is in fair condition. However, maintenance of overgrown vegetation and trees is desperately needed on the downstream slope and toe of the dam as shown in Figure 3, Appendix A (GRIST MILLPOND). The left abutment of the existing dam has been modified with an uncontrolled rock spillway that allows for overflows into the field downstream. The width of the uncontrolled spillway is about 20 feet wide with a drop of approximately 2 feet from the crest of the earth dam. At the time of the inspection there was water flowing through the lower levels of the riprap downstream of the crest. The uncontrolled spillway is shown in Figure 4, Appendix A (GRIST MILLPOND). The uncontrolled spillway is in fair condition. However, like the dam, maintenance is required to remove overgrown vegetation and trees from the spillway.

Carding Millpond Dam:

The gated spillway is in fair condition but the metal stop logs at the mill building have started to rust and deteriorate. The inlet and stop logs for the controlled spillway are shown in Figures 4 and 5 of Appendix A (CARDING MILLPOND). The uncontrolled spillway is in poor condition with areas of active erosion and an abundance of vegetation on the downstream side of the spillway. The inlet for the uncontrolled spillway is shown in Figure 6, Appendix A (CARDING MILLPOND). Two areas of concern for seepage problems exist downstream of the dam. These areas had flowing water (< 1gpm) and significant iron algae staining around the outflows. The first location of the seepage is behind the mill building and is about ten feet off the northwest corner of the mill building. The seepage exits the ground and flows for about 20 feet before returning into the downstream channel. The iron algae staining for this seepage area is shown in Figure 7, Appendix A (CARDING MILLPOND).

The second area of seepage is located about 50 feet downstream from the uncontrolled spillway. This area is considered part of the left abutment and the seepage area is well hidden by very dense vegetation. The seepage area is shown in Figure 8, Appendix A (CARDING MILLPOND). The flows from this area are stained with algae and drains off the abutment and downhill to the downstream channel.

Stearns Millpond Dam:

The embankment portion of the dam is in very poor condition. Normal and required maintenance of the dam has been neglected for many years. The dam is well overgrown with vegetation and trees. This creates a very high potential for seepage problems through the dam. The left abutment of the dam has a 3 foot thick concrete wall about 20 feet in length and a 1 foot thick wall section along the side of the pond. These sections are shown in Figure 3, Appendix A (STEARNS MILLPOND). The one-foot wall section is cracked and displaced in many areas by tree roots and overall wall instability as shown in Figure 3, Appendix A (STEARNS MILLPOND). It is assumed the right abutment has similar structures as the left abutment, since this side could not be fully inspected due to excessive vegetation growth at the time of inspection. The concrete spillway section of the dam is in very poor condition. The spillway is composed of an ogee weir concrete section and configured with stoplogs for additional freeboard. The concrete in the spillway section below the crest is spalling off and exposing the ledge and rock fill below the structure. The concrete has also deteriorated to the point where the middle stop log post has cracked and fallen over onto the spillway. This area is in need of immediate repairs to prevent the Brook from potentially eroding the spillway section.

Another structure at the dam site that is of some concern is the culvert under Dutton Road. The culvert has stone masonry headwalls and an arched metal roof which was not original to the structure. The double arched culvert as shown in Figure 6, Appendix A (STEARNS MILLPOND) is about 150 feet downstream of the dam. The culvert also supports a large diameter water main that is adjacent to the road surface. The culvert appears in fair condition and has areas of erosion and deterioration at the head walls supports. There is also little to no bank protection around the inlet and significant areas of overgrowth and vegetation along the channel the needs to be removed.

ADDITIONAL ALTERNATIVES

Per DEP's request the Corps studied two additional alternatives in addition to the eight mentioned previously. The alternatives are:

1. Converting Hager Pond into a free water surface constructed wetland system to further treat the nutrients from the effluent wastewater, and
2. By-passing (piping) the effluent wastewater from the MWWTP to the Sudbury River along Route 20.

Details of the above alternatives are shown in Appendix H of this report. For the first alternative, a free water surface constructed wetland with three zones is planned. The zones allow for floating and emergent plants in an aerobic zone (zone 1), submerged growth plants in a deeper zone (zone 2), and floating and emergent plants immediately upstream of the outlet (zone 3). Recommended retention times in the three zones, for maximum nitrogen removal is about 5.5 days. Studies shows that a typical three zone wetland treatment system has been proven to be effective in reducing Nitrogen in treated waste water by approximately 75%, and Phosphorus by about 10 %.

The second alternative analyzed the effect on the Hop Brook system if the effluent from the MWWTP is directly piped from the treatment facility to the Sudbury River. The primary concern with this option was the possibility that there might not be sufficient flows into Hop Brook and the ponds. However, a hydraulics analysis showed that the base inflow during a dry month at each reservoir is expected to exceed the evaporation from the pond surface, and the ponds would not dry up.

Estimated construction cost for constructing a free water surface wetland is approximately $2 million, and to pipe the effluent from MWWTP to Sudbury River is approximately $4 million.

SUMMARY

The purpose of this report is to display information gathered and reviewed on existing conditions in Hop Brook and its dams and impoundments, along with hydraulic modeling results and cost estimates for the various alternatives examined. This information is intended to be used in the development and assessment of sediment and dam removal alternatives. General information on each topic is presented in the main report and detailed information is presented in the report appendices. Topics include dam characteristics and existing uses, sediment analysis, dam site visit reports and sediment management plan, natural resources investigation, cultural resources investigation, real estate and hydraulic analysis.

The City of Marlborough, Town of Sudbury and the MADEP will use the information from this report as well as other reports to select those alternatives that will be examined in more detail.

REFERENCES

Massachusetts Natural Heritage and Endangered Species Program. 2004. *BioMap and Living Waters. Core Habitats of Concord, Acton, Stow, Maynard, Hudson, Northborough, and Westborough.* Internet downloads.

MassWildlife. 2006. Trout Stocked Waters. www.mass.gov/dfwele/dfw/dfwtroutwaters.

U.S.F.W.S. 2003. *Eastern Massachusetts National Wildlife Refuge Complex. Draft Comprehensive Conservation Plan and Environmental Assessment.* April 2003.

ENSR, Nutrient Loading Evaluation of Hop Brook, Sep 2004.

ENSR, Nutrient Impact Evaluation of Hop Brook in Marlborough and Sudbury, Oct 2000.

Appendix A – Dam Site Visit Reports and Sediment Management Plan

Stearns Millpond Dam, Sudbury, MA

General Inspection Information

Stearns Millpond Dam is situated on the westerly side of Dutton Road in Sudbury, Massachusetts. Figure 1 shows the location of Stearns Millpond Dam. The dam was part of an old powder mill used during the Civil War. The mill building does no longer exist at the site. The dam is listed in the National Inventory of Dams (NID) as ID No. MA 01132

Figure 1: Location of Stearns Millpond Dam

According to the NID, the dam was constructed in 1900. The dam is constructed of earthfill materials and concrete abutment walls with a concrete spillway section. The embankment has a structural height of 10 feet and a crest width of about 300 feet. The pond side view of the dam is shown in Figure 2. The dam is listed in the NID as a significant hazard dam indicating substantial loss of property downstream due to a dam failure.

The embankment portion of the dam is in very poor condition. Normal and required maintenance of the dam has been neglected for many years. The dam is overgrown with vegetation and trees that indicate a very high potential for seepage problems through the dam. The left abutment of the dam has a 3 foot thick concrete wall about 20 feet in length and a 1 foot thick along the side of the pond. These sections are shown in Figure 3. The left abutment wall section is cracked and displaced in many areas by tree roots and overall wall instability as shown in Figure 3. It is assumed the right abutment has similar structures to the left, however, this side could not be fully inspected due to excessive vegetation growth at the time of inspection.

Figure 2: Pond Side View of Stearns Millpond Dam
(Note: Vegetation and tree growth on dam)

Figure 3: Concrete Walls on Left Abutment

Figure 4: Displaced and Cracked Walls on Left Abutment
(Note: trees and vegetation around walls)

The concrete spillway section of the dam is in very poor condition. The spillway is composed of an ogee weir concrete section and configured with stoplogs for additional freeboard. The concrete in the spillway section below the crest is spalling off and exposing the ledge and rock fill below the structure. The concrete has also deteriorated to the point where the middle stop log post has cracked and fallen over onto the spillway. This area is in need of immediate repairs to prevent potential erosion of the spillway section.

Figure 5: Concrete Spillway Section

Another structure at the dam site of some concern is the culvert under Dutton Road. The culvert has stone masonry headwalls and an arched metal roof which was not original to the structure. The double arched culvert as shown in Figure 6 is about 150 feet downstream of the dam. The culvert also supports a large diameter water main that is adjacent to the road surface. The culvert appears in fair condition and has areas of erosion and deterioration at the head wall supports. There is little to no bank protection around the inlet. Significant areas of overgrowth and vegetation along the channel need to be removed.

Figure 6: Culvert under Dutton Road

Potential Dewatering Sites

Dewatering sites are a problem for this dam due to the density of populated areas around the dam. The existing parking area downstream of the left abutment is much too small to locate a dewatering facility. The privately owned field adjacent to the right abutment is not of sufficient size and would have safety issues with trucks entering and exiting the site. There are two potential dewatering site that have been identified and are shown in Figure 7.

The first site is just downstream of the dam on the easterly side of Dutton Road. It is on privately owned property that is currently used as open mowed area. Access for trucks and dewatering equipment would have to be made to Dutton Road as no access is currently available.

The second site would be downstream of the dam about 1 mile at the site currently occupied by the Ephraim Curtis Middle School on Pratt's Mill Road. Dredging pipelines would have to be run down the river and then pumped up to the existing fields at the middle school site. The use of this site does have concerns over operating during times when school is in session but truck access to the site (and location of access point) can be limited. This problem has been addressed on projects with similar dewatering sites on or near school locations.

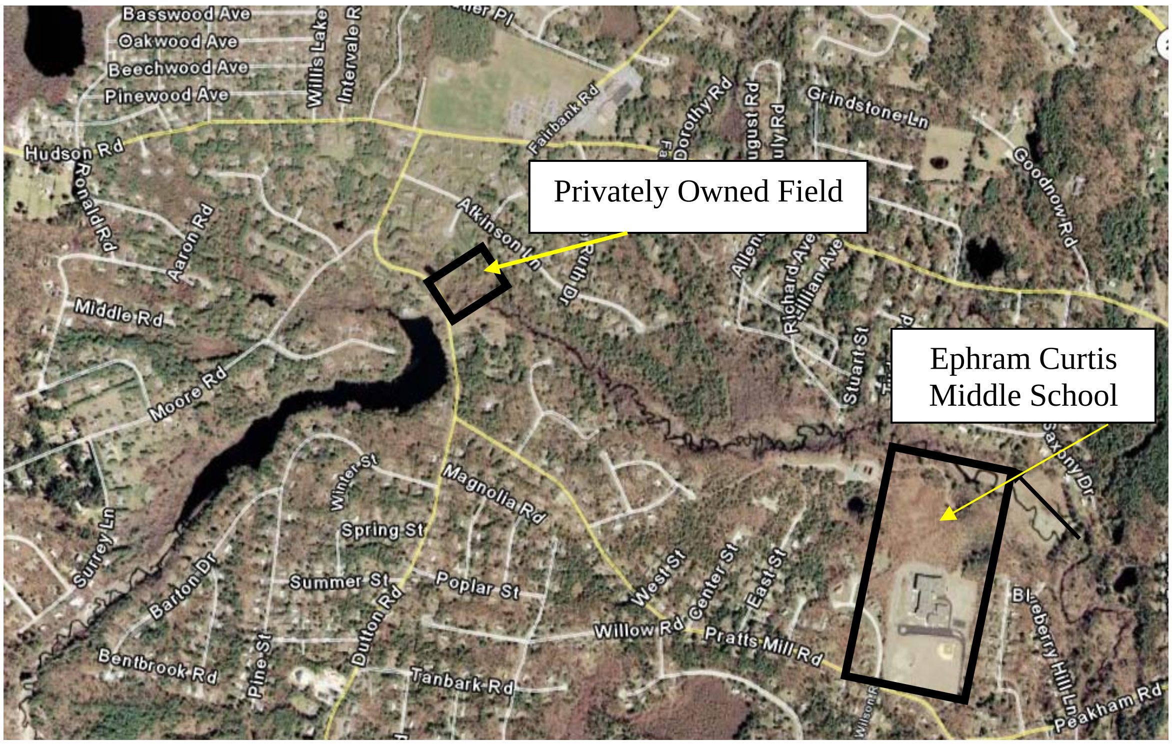


Figure 7: Potential Dewatering Sites for Stearns Millpond Dam

<u>Recommended Modifications to Dam if no Alternative is selected</u>

The options for Stearns Millpond Dam are either dam removal or dam breaching. If none of these options are selected, reconstruction of the existing dam needs to be done to be in compliance with dam safety inspections. The dam is currently in a state of disrepair and in need of significant repairs and modifications to make it in compliance with current dam safety standards. Given this dam is classified by NID as a significant hazard dam, remediation actions should be taken as soon as possible to further inspect and stabilize the dam.

Another option for the dam could be a fish ladder. However, the existing dam would have to be fully rehabilitated before a fish ladder could be adapted to the site. Other modification options such as a nature like by-pass and a rock ramp dam would not be possible at this site due to the current location of the culvert downstream of the dam.

Material Testing for Sediments in Stearns Millpond Dam

Sediments in Stearns Millpond were sampled and analyzed in the laboratory to assist with identifying the dredging, transportation and disposal options for Stearns Millpond. Three sample cores up to a depth of 4.3 feet were taken at the locations and GPS coordinates as shown in Figure 8 and in Table 1. Field core logs were also developed for each sample location and are attached to the end of this section.

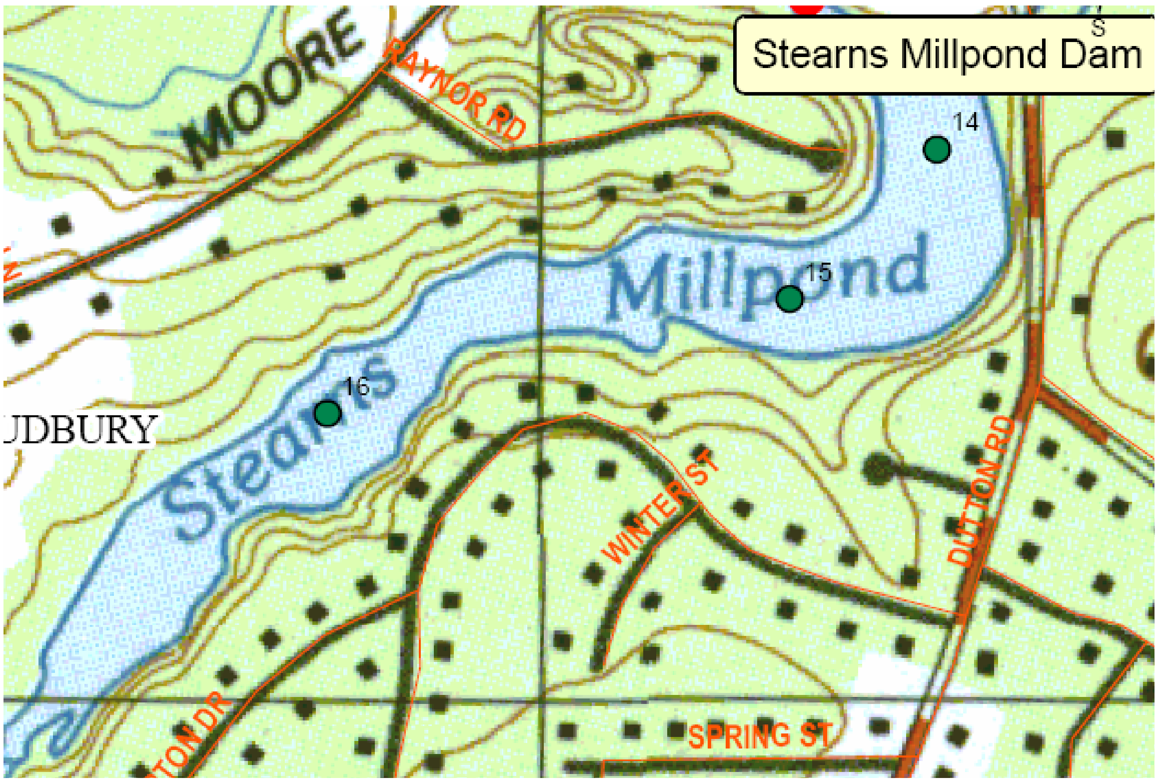


Figure 8: Sediment Sample Locations in Stearns Millpond

Table 1: GPS Coordinates (MA State Plane NAD83) for Sediment Sample Locations in Stearns Millpond

Sample No.	Northing	Easting
14	204136.9366	904046.2869
15	204027.2236	903928.2147
16	203675.0969	903829.9954

Sediments from the cores were tested in approximately foot increments for grain size (ASTM D422), organic content (ASTM D2974), Atterberg Limits (ASTM D4318) and in-situ moisture content (ASTM D22216). The materials were classified by the Geotechnical Engineering Section staff both visually and the using laboratory gradation data using the Unified Soil Classification System (USCS). Note that the testing regime performed on the samples were established based on a visual inspection in the laboratory, therefore not all the samples had exactly the same sequence of tests performed. Chemical analysis of all the samples are not included in this write-up but in the section of the report on chemical analysis of the sediments.

A majority of the sediments that may be required to be dredged from Stearns Millpond are mainly organic silts (OH) with very high water contents (>150%). These organic sediment are present down to about 2 to 3 feet from the bottom of the pond. Below the organic there is silty sand (ML) and sand (SP) deposits that appear to be the native bedding material. A summary of the laboratory testing data for Stearns Millpond is shown in Table 2. The actual laboratory test data sheets are included at the end of this section.

Table 2: Summary of Laboratory Testing for Stearns Mill Pond

		Depth	USCS CLASS	Sieve & Hydrodrometer D422			Organic	Atterburg Limits	Moisture Content
Stearns Pond				%Gravel	%Sand	%Silt& Clay		LL/PL/PI	
SP	14	1-1.5 ft	OH	0	25.3	74.7	28.2	-	769
		1.5-2.5 ft	OH	0	22.6	67.6	40.5	332/148/184	300
		2.5-3.5 ft	SP	4.9	90.6	4.5	0.5	-	16
		3.5-5 ft	SP	0	86.6	13.4	-	-	-
	15	1-1.8 ft	OH	0	4.7	95.3	32.3	-	896
		1.8-2.8 ft	OH	0	26.3	73.7	24.5	259/130/129	377
		2.8-3.4 ft	OH	0	47.2	52.8	10.2	104/64/40	82
		3.4-3.9 ft	SP	33.5	62.2	4.3	1.4	-	25
	16	1-2 ft	OH	0	18.4	81.6	31.8	-	803
		2-3 ft	OH	0	31.4	68.6	42.5	340/135/205	314
		3-4.3 ft	OH	0	29	71	34.6	360/185/175	290
7		4.6-5 ft	SP	0	89.6	10.4	2.5	-	36

Dredging, Transportation and Disposal Options for Materials in Stearns Millpond

The recommended technique to remove the pond sediments would be to use a hydraulic dredge and belt filter press plant to dewater and stabilize the organic material prior to disposal. Mechanical removal of the material in the pond would be very difficult given the type of material (organic, high water content, low permeability) and depth to a solid ground surface for machinery to operate.

Transportation of the materials after being dewatered and stabilized can be accomplished using 30-yard dump trucks. The disposal location of the materials will need to meet the requirement of the MADEP regulations for residential reuse. Potentially these types of materials can be augmented and disposed of in a landfill as daily cover or could be combined with sandy material and reused as loam for residential reuse if it can meet the MADEP requirements.

Summary of Dam Modifications for Stearns Millpond

Dam Removal Option

- Hydraulic dredging of top foot of material to remove and eliminate any unwanted vegetation regrowth after dewatering
- Dewater site using an incremental dewatering scheme to keep existing stream banks stable
- Period of dewatering will take between 6 to 12 months (or more) depending upon how fast the materials can dewater
- Channels
  - Natural channels should form during dewatering (use those if at all possible)
  - Mechanical operation with possible some hydraulic to remove unwanted sediments from deeper sections
  - 10 foot bottom with of channel into native material (sand/gravel)
  - 1:4 sides slopes – turf reinforce or vegetate as required
  - Taper channel into dams that are removed – 1:6 slopes or greater

Partial Removal/Leave Dam As-IS or Rehab Dam

- Hydraulic dredging – remove organics from silt and sand
- Dredge to depths indicated – taper to dam and from shoreline and islands
- Disposal of materials
  1. Augment the materials for daily cover – pay for materials (sand) and disposal costs will only be trucking
  2. Reuse – sand, organic/silt – contract transportation and disposal
- Slopes to inlet channels to new weirs if partial removal – 1:6 slopes or greater

Field Logs from Stearns Millpond

To be provided in a supplemental report.

Laboratory Testing from Stearns Millpond

To be provided in a supplemental report.

Carding Millpond Dam, Sudbury, MA

General Inspection Information

Carding Millpond Dam is situated east of Dutton Road and south of Henry's Mill Lane in Sudbury, Massachusetts. The access to the dam is from a private gated way located on the easterly side of Dutton Road. No driving access is available from Henry Mills Lane or Carriage Way. Figure 1 shows the location of Carding Millpond Dam.

Figure 1: Location of Cardings Millpond Dam

The dam is listed in the National Inventory of Dams (NID) as ID No. MA00742. According to the NID, the dam was constructed in 1930. The dam has a structural height of 15 feet and a crest width of 450 feet. There is an adjacent wooden mill building near the dam as shown in Figure 2. The dam is listed as a high hazard dam by NID due to concerns with housing developments just downstream of the dam.

The earthen dam has two spillways, one gated and the other uncontrolled as shown in Figure 3. The width of the spillway is about 60 feet. The spillways are primarily masonry with some granite block in areas. The gated spillway is in fair condition but the metal stop logs at the mill building have started to rust and deteriorate. The inlet and stop logs for the controlled spillway are shown in Figures 4 and 5. The uncontrolled spillway is in poor condition with areas of active erosion and an abundance of vegetation on the downstream side of the spillway. The inlet for the uncontrolled spillway is shown in Figure 6.

Figure 2: Carding Millpond Building Adjacent to Spillway
(Note: Orange staining beyond rock foundation)

Figure 3: Controlled (left in figure) and Uncontrolled (right in figure) Spillways at Carding Millpond Dam

Figure 4: Inlet for Controlled Spillway

Figure 5: Stop Logs – Controlled Spillway

Figure 6: Inlet for Uncontrolled Spillway
(Note: Erosion and vegetation around inlet)

Two areas of concern for seepage problems exists downstream of the dam. These areas had flowing water (< 1gpm) and significant iron algae staining around the outflows. The first location of the seepage is behind the mill building and is about ten feet off the northwest corner of the mill building. The seepage exits the ground and flows for about 20 feet in length before returning into the downstream channel. The iron algae staining for this seepage area is shown in Figure 7.

Figure 7: Seepage and Iron Algae Staining Behind Mill Building

The second area of seepage is located about 50 feet downstream from the uncontrolled spillway. This area is considered part of the left abutment and the seepage area is well hidden by very dense vegetation. The seepage area is shown in Figure 8. The flows from this area are stained with algae and drained off the abutment back downhill to downstream channel.

.

Figure 8: Seepage and Iron Algae Staining on Left Abutment

Potential Dewatering Sites

A potential dewatering site has been identified for use in sediment dewatering and as a project staging area. This site is shown in Figure 9. The site is adjacent to the west side of the Carding Millpond impoundment and is on land owned by the dam owner (Sudbury Conservation Commission). The dewatering site is currently vegetated and has a slight pitch toward the Carding Millpond. This site could be used either for mechanical or belt filter press dewatering processes. The site could also be used as a permanent disposal area for the dredged materials if they meet MADEP residential reuse criteria. However, one of the disadvantages of this site is road width of Dutton Road and the sight clearance for trucks exiting the site onto Dutton Road. These disadvantages would create some limitations for using larger (30 cy+) dump trucks for transportation of the dredged materials.

There is also another potential dewatering area on east side of the pond (off Carriage Way) but construction equipment access to the site is only through a residential neighborhood.

Figure 9: Potential Dewatering Sites for Cardings Millpond Dam

<u>Recommended Modifications to Dam if no Alternatives are selected</u>

The dam is currently in serious need of some major modifications and/or repairs at this time. The dam is a major safety concern given the existing condition of the spillways and seepage through the structure and the fact that this is a high hazard dam. Options for the Carding Millpond Dam would be either complete dam removal or partial removal of the earthen dam structure and modifications to the spillway sections to maintain limited flow for the historical mill building. A partial dam removal probably would be a good option for the dam given its current condition. The partial removal of the dam would need close coordination with Town of Sudbury officials to insure that downstream flows would not affect the road crossings at French Road and Dutton Road. However, there are some major drawbacks with the dam removal option that will need to be addressed especially with being able to protect or keep the existing Carding Mill structure.

Other possible options for this site are a fish ladder or a nature like by-pass channel. These options would be feasible within the left abutment since there is enough available real estate to construct either option. However, even with a fish ladder or a by-pass, the spillways and seepage would still need some major repairs to be done to be in compliance with dam safety inspections. Also, the option of a rock ramp dam would not be possible on this site due to a narrow sinuous channel downstream of the dam.

Material Testing for Sediments in Carding Millpond Dam

Sediments in Carding Millpond were sampled and analyzed in the laboratory to assist with identifying the dredging, transportation and disposal options for Carding Millpond. Five sample cores up to a depth of 4.3 feet were taken at the locations and GPS coordinates as shown in Figure 10 and in Table 1. Field core logs were also developed for each sample location and are attached to the end of this section.

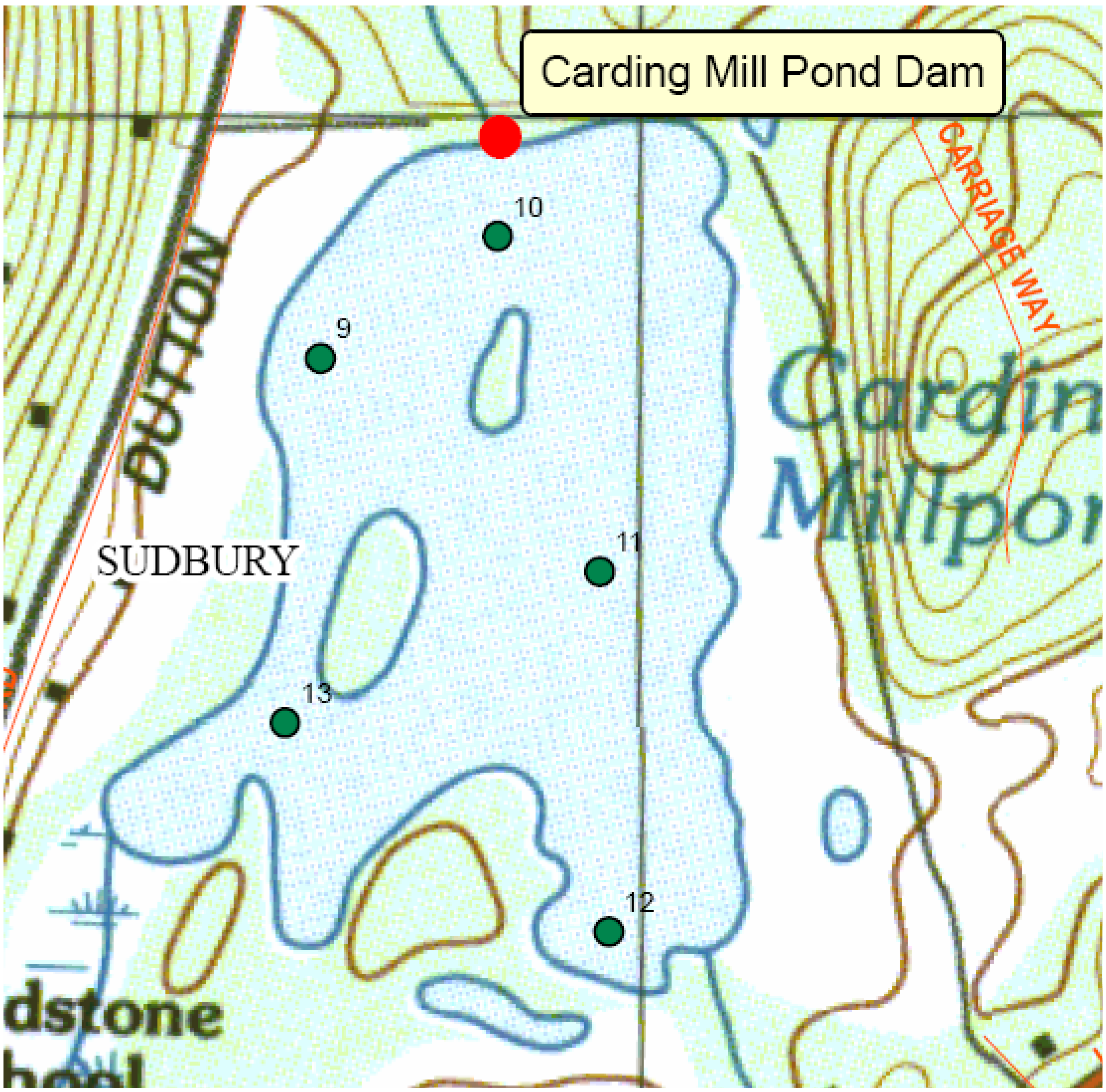


Figure 10: Sediment Sample Locations in Carding Millpond

Table 1 GPS Coordinates (MA State Plane NAD83) for Sediment Sample Locations in Cardings Millpond

Sample No.	Northing	Easting
9	202685.2728	901409.6813
10	202807.5028	901499.9259
11	202886.3241	901264.6045
12	202900.0321	901009.8634
13	202668.1377	901151.5131

Sediments from the cores were tested in approximately foot increments for grain size (ASTM D422), organic content (ASTM D2974), Atterberg Limits (ASTM D4318) and in-situ moisture content (ASTM D22216). The materials were classified by the Geotechnical Engineering Section staff both visually and the using laboratory gradation data using the Unified Soil Classification System (USCS). Note that the testing regime performed on the samples were established based on a visual inspection in the laboratory, therefore not all the samples had exactly the same sequence of tests performed. Chemical analysis of all the samples are not included in this write-up but in the section of the report on chemical analysis of the sediments.

A majority of the sediments that may be required to be dredged from Carding Millpond are mainly organic silts (OH) with very high water contents (>150%). These organic sediment are present down to about 2 to 3 feet from the bottom of the pond. Below the organic there is silty sand (ML) and sand (SP) deposits that appear to be the native bedding material. A summary of the laboratory testing data for Cardings Millpond is shown in Table 2. The actual laboratory test data sheets are included at the end of this section.

Table 2: Summary of Laboratory Testing for Cardings Millpond

		Depth	USCS CLASS	Sieve & Hydrodrometer D422			Organic	Atterburg Limits	Moisture Content
Carding Mill									
CM	09	1-2.4 ft	OH	0	22	78	28.3	-	585
		2.4-3 ft	OH	0	41.7	58.3	43.7	365/159/206	334
		3.6-4.3 ft	SP	0.6	99.2	0.2	0.9	-	30
	10	0-12 in	ML	0	56.1	43.9	32	-	814
		12-24 in	OH	0	13.7	86.3	31	288/167/121	254
	11	1-2 ft	OH	0	13.7	86.3	34.9	348/182/166	411
		2.6-3.8 ft	SP	0	94.8	5.1	1.2	-	28
	12	0-8 in	SM	0	66.3	32.8	10.6	-	163
		12-24 in	ML	28.7	45.8	25.5	3.2	47/31/16	50
	13	1-2.8 ft	OH	0	17.5	82.5	27.4	-	524

Dredging, Transportation and Disposal Options for Materials in Cardings Millpond

The recommended technique to remove the pond sediments would be to use a hydraulic dredge and belt filter press plant to dewater and stabilize the organic material prior to disposal. Mechanical removal of the material in the pond would be very difficult given the type of material (organic, high water content, low permeability) and depth to a solid ground surface for machinery to operate.

Transportation of the materials after being dewatered and stabilized can be accomplished using 30-yard dump trucks. The disposal location of the materials will need to meet the requirement of the MADEP regulations for residential reuse. Potentially these types of materials can be augmented and disposed of in a landfill as daily cover or could be combined with sandy material and reused as loam for residential reuse if it can meet the MADEP requirements.

Summary of Dam Modifications for Cardings Millpond

Dam Removal Option

- Hydraulic dredging of top foot of material to remove and eliminate any unwanted vegetation regrowth after dewatering
- Dewater site using an incremental dewatering scheme to keep existing stream banks stable
- Period of dewatering will take between 6 to 12 months (or more) depending upon how fast the materials can dewater
- Channels
  - Natural channels should form during dewatering (use those if at all possible)
  - Mechanical operation with possible some hydraulic to remove unwanted sediments from deeper sections
  - 10 foot bottom with of channel into native material (sand/gravel)
  - 1:4 sides slopes – turf reinforce or vegetate as required
  - Taper channel into dams that are removed – 1:6 slopes or greater

Partial Removal/Leave Dam As-IS or Rehab Dam

- Hydraulic dredging – remove organics from silt and sand
- Dredge to depths indicated – taper to dam and from shoreline and islands
- Disposal of materials
  1. Augment the materials for daily cover – pay for materials (sand) and disposal costs will only be trucking
  2. Reuse – sand, organic/silt – contract transportation and disposal
- Slopes to inlet channels to new weirs if partial removal – 1:6 slopes or greater

Field Logs from Cardings Millpond

To be provided in a supplemental report.

Laboratory Testing from Cardings Millpond

To be provided in a supplemental report.

Grist Millpond Dam, Sudbury, MA

General Inspection Information

Grist Millpond Dam is situated just south of Wayside Inn Road and northerly of Route 20 in Sudbury, Massachusetts. Figure 1 shows the location of Grist Millpond Dam. The Grist Millpond is currently listed on the National Registry of Historic Places and is frequently visited by tourists. Figure 2 shows the existing mill building with water wheel and overflow sluiceway.

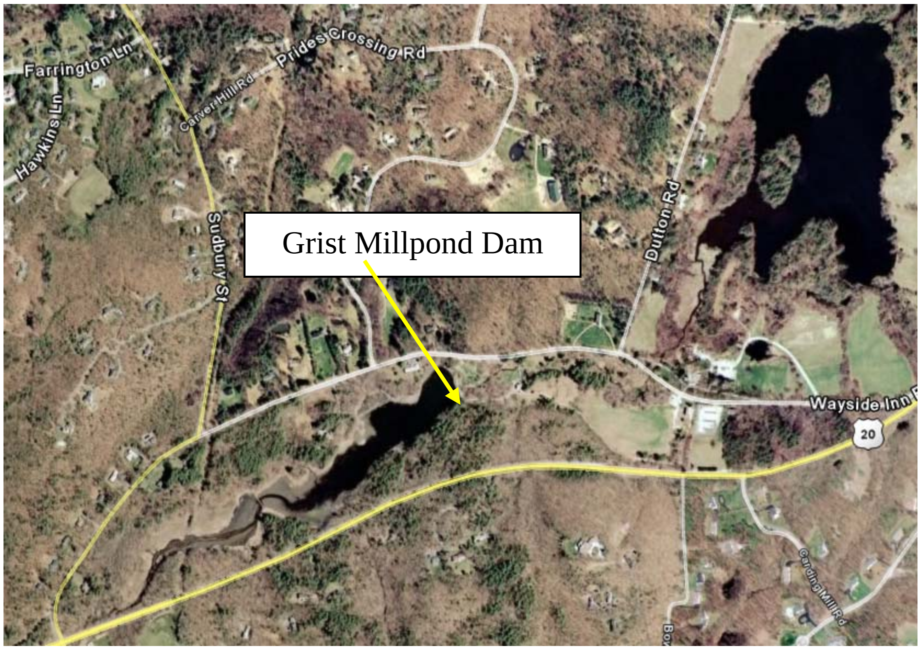


Figure 1: Location of Grist Millpond Dam

Figure 2: Grist Mill

The dam is listed in the National Inventory of Dams (NID) as ID No. MA 01109. According to the NID, the original dam was constructed in 1800. The dam is considered a low hazard dam due to the absence of residential properties downstream of the dam and since Carding Millpond is immediately downstream. The dam is constructed of an earthen materials with a sluiceway to the Grist Mill. The earthen dam has an estimated structural height of about 15 feet and an estimated crest width of 400 feet. The crest of the earth dam is shown in Figure 3. Overall, the earthen dam is in fair condition; however, maintenance on overgrown vegetation and trees is severely needed on the downstream slope and toe of the dam as shown in Figure 3.

Figure 3: Crest of Earthen Dam

The left abutment of the existing dam has been modified with an uncontrolled rock spillway that allows for overflows into the field downstream. The width of the uncontrolled spillway is about 20 feet wide with a drop of approximately 2 feet from the crest of the earth dam. At the time of the inspection there was water flowing through the lower levels of the riprap downstream of the crest. The uncontrolled spillway is shown in Figure 4. The uncontrolled spillway is in fair condition; however, like the dam maintenance is required to remove overgrown vegetation and trees from the spillway.

Figure 4: Uncontrolled Rock Spillway

The earthen dam has a 12-inch cast iron outlet pipe at the downstream toe of the earth dam. This pipe appears to be a modification to the original dam and is shown in Figure 5. The purpose of this outlet structure is to maintain a constant flow (for aesthetical purposes) in the channel to the historical mill site downstream. This outlet pipe does have a manhole on the center line of the dam with a valve to control the flow.

Figure 5: Outlet pipe at Toe of Earth Dam

The sluiceway to the Grist Mill is on the right abutment of the dam. The channel is approximately 10 feet wide and 2 feet deep. Figures 6 and 7 show the upstream and downstream views of the sluiceway respectively. The sluiceway has trash racks at the intake and a gated (to water wheel) and uncontrolled section about 10 feet wide at the Grist Mill. These are shown in Figures 8 and 9. The sluiceway is in good condition.

Figure 6: Sluiceway looking toward dam

Figure 7: Sluiceway looking toward Grist Mill

Figure 8: Sluiceway Intake and Trash Racks

Figure 9: Outfalls at Grist Mill

There are culverts under both Wayside Inn Road and the service road to the Inn downstream of the Grist Millpond Dam. The culvert under the Wayside Inn Road is not original construction but replaced in the past 20 years or so. The culvert is composed of a reinforced concrete span and supporting abutments (with a granite block veneer). The culvert width is about 15 feet wide and about 4 feet high. The channel around the structure was in good condition with little sedimentation.

The culvert under the service road to the Wayside Inn is the original structure built in the 1800's (Figures 10 (a) and (b)). The structure is composed of a two bay culvert built of granite block walls and supports a granite slab roof. The culvert has two 6 foot openings and is about 3 feet in height. The channel around this culvert is in good condition with little sedimentation.

Figure 10(a): Culvert under Wayside Inn Road

Figure 10(b): Stone Culvert under Service Road to Wayside Inn

Potential Dewatering Sites

There are two dewatering sites that has been identified for staging areas for sediment dewatering and transportation. These sites are on the southerly side of Wayside Inn Road and owned currently by the Wayside Inn. These locations are shown in Figure 11. The first site is just downstream of the left abutment of the dam. This site has good access to Wayside Inn Road and is not in proximity to the public areas. The second site is larger in acreage, cleared and flatter but is close to both the Grist Mill and the restaurant parking lot. This could create potential problems for truck traffic control and dust control issues.

Figure 11: Potential Dewatering Sites for Grist Mill Dam

Suggested Modifications to Dam

The earth dam is in good condition and not in need of any repairs other than maintenance of the downstream slopes and toe for trees and vegetation. The sluiceway is in good condition. Since dam removal is not a recommended option for this site, the other option for this structure would be to create a nature like by-pass channel with a controlled low flow spillway section on the left abutment, if permits allow. This by-pass would also be helpful in passing algae blooms present in the pond during low flow periods since this is the area on the dam where the algae blooms tend to concentrate in density. The by-pass would be located in the existing uncontrolled spillway section and would run downhill to intersect with the existing channel prior to Grist Mill. The grade of this by-pass would be limited by the existing topography of the site.

Material Testing for Sediments in Grist Mill Dam

Sediments in Grist Millpond were sampled and analyzed in the laboratory to assist with identifying the dredging, transportation and disposal options for Grist Millpond. Three sample cores up to a depth of 4 feet were taken at the locations and GPS coordinates as shown in Figure 12 and in Table 1. Field core logs were also developed for each sample location and are attached to the end of this section.

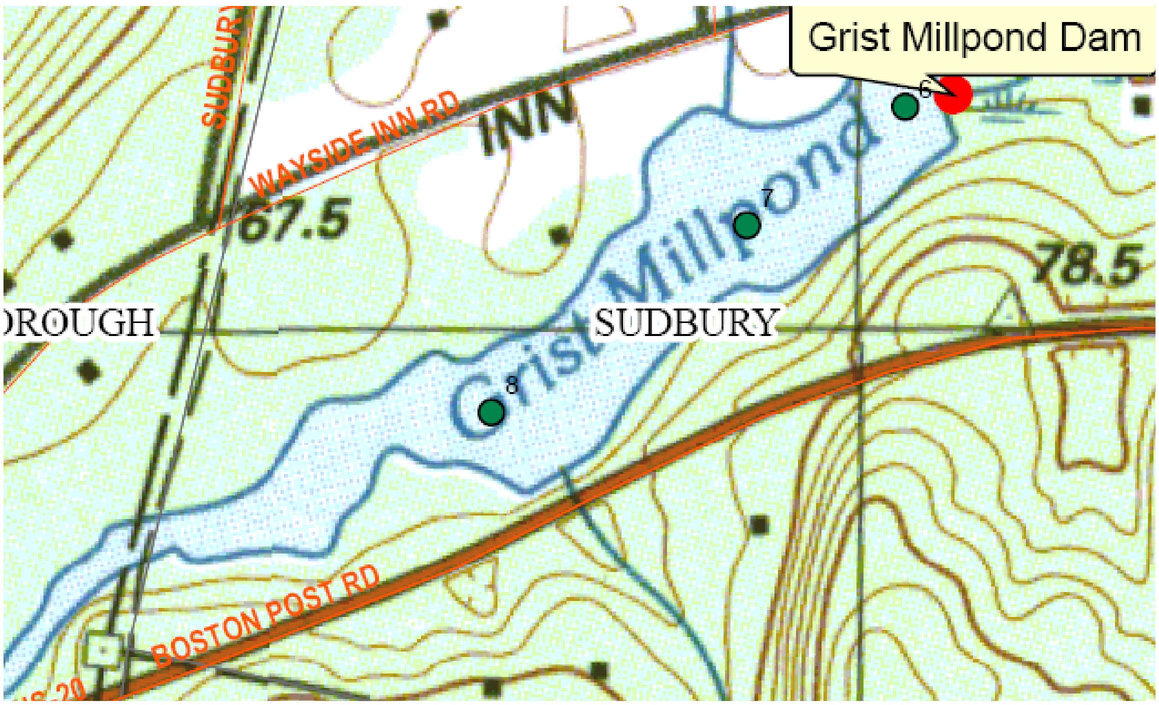


Figure 12: Sediment Sample Locations in Grist Millpond

Table 1 GPS Coordinates (MA State Plane NAD83) for Sediment Sample Locations in Grist Millpond

Sample No.	Northing	Easting
6	201965.341	900731.2473
7	201845.719	900635.5497
8	201652.3301	900484.0285

Sediments from the cores were tested in approximately foot increments for grain size (ASTM D422), organic content (ASTM D2974), Atterberg Limits (ASTM D4318) and in-situ moisture content (ASTM D22216). The materials were classified by the

Geotechnical Engineering Section staff both visually and the using laboratory gradation data using the Unified Soil Classification System (USCS). Note that the testing regime performed on the samples were established based on a visual inspection in the laboratory, therefore not all the samples had exactly the same sequence of tests performed. Chemical analysis of all the samples are not included in this write-up but in the section of the report on chemical analysis of the sediments.

A majority of the sediments that may be required to be dredged from Grist Millpond are mainly organic silts (OH) with very high water contents (>300%). These organic sediment are present down to about 3 to 4 feet near the dam and increase to 1 to 2 feet deep near the middle of the pond. Below the organic material there is silty sand (ML) and sand (SM) deposits that appear to be the native bedding material. A summary of the laboratory testing data for Grist Millpond is shown in Table 2. The actual laboratory test data sheets are included at the end of this section.

Table 2: Summary of Laboratory Testing for Grist Millpond

		Depth	USCS CLASS	Sieve & Hydrodrometer D422			Organic D2974	Atterburg Limits D4318	Moisture Content D2216
Grist Mill									
GM	06	1-2 ft	OH	0	18.7	81.3	25.7	-	458
		2-2.6 ft	OH	0	17.5	82.5	32.4	-	834
		3-3.5 ft	OH	0	44.3	55.7	22.7	-	-
		3.5-4.6 ft	OH	0	3.7	96.3	-	-	-
	07	0-18 in	SM	0	66.7	33.3	18.6	-	390
		18-21 in	SP	0	97	3	-	-	-
	08	0-1.3 ft	OH	0	35.1	64.9	21.1	-	315
		1.3-1.5 ft	ML	0	51.2	48.8	-	48/32/16	-

Dredging, Transportation and Disposal Options for Materials in Grist Millpond

The recommended technique to remove the pond sediments would be to use a hydraulic dredge and belt filter press plant to dewater and stabilize the organic material prior to disposal. Mechanical removal of the material in the pond would be very difficult given the type of material (organic, high water content, low permeability) and depth to a solid ground surface for machinery to operate.

Transportation of the materials after being dewatered and stabilized can be accomplished using 30-yard dump trucks. The disposal location of the materials will need to meet the requirement of the MADEP regulations for residential reuse. Potentially these types of materials can be augmented and disposed of in a landfill as daily cover or could be combined with sandy material and reused as loam for residential reuse if it can meet the MADEP requirements.

Summary of Dam Modifications for Grist Millpond

Leave Dam As-is or Add By-Pass Channel

- Hydraulic dredging – remove organics from silt and sand
- Dredge to depths indicated – taper to dam and from shoreline and islands
- Disposal of materials
    1. Augment the materials for daily cover – pay for materials (sand) and disposal costs will only be trucking
    2. Reuse – sand, organic/silt – contract transportation and disposal
- Slopes to inlet channels to new weirs if partial removal – 1:6 slopes or greater

Field Logs from Grist Millpond

To be provided in a supplemental report.

Laboratory Testing from Grist Millpond

To be provided in a supplemental report.

Hager Pond Dam, Marlborough, MA

General Inspection Information

Hager Pond Dam is situated west of Hager Street and south of Route 20 which is also called Boston Post Road in Marlborough, Massachusetts. The dam is located downstream of the Marlborough Waste Water Treatment Plant (WWTP) and is the head of the Hop Brook River. Figure 1 shows the location of Hager Pond Dam and the Marlborough WWTP.

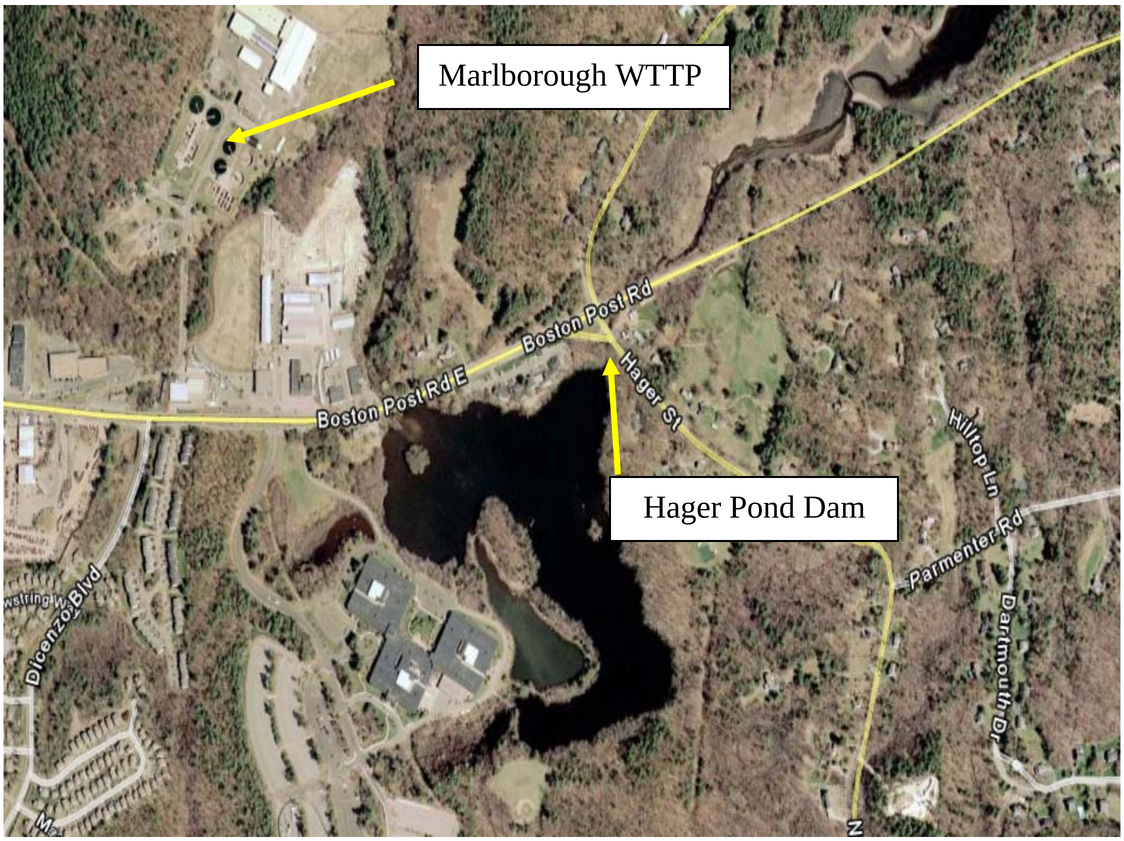


Figure 1: Location of Hager Pond Dam

The dam is listed in the National Inventory of Dams (NID) as ID No. MA00452. According to the NID, the original dam was constructed in 1800 but there have been some modifications in the mid-1900's to add a concrete section to maintain the weir elevation of the dam. The existing dam is built of a formed mass concrete box founded in part on an old masonry wall of the old dam and the stone ledge. The dam is filled with stone and miscellaneous debris. The dam has a structural height of 14 feet and a crest width (including the inlet channel banks) of about 225 feet. The width of the weir opening is about 4 feet and the entire concrete dam structure is about 12 feet wide. Figures 2 and 3 shows the existing weir structure at Hager Pond. The inlet channel for the dam, as shown in Figure 4, is about 5 feet wide and has a stony and rock ledge on the bottom.

Figure 2: Weir Structure at Hager Pond Dam – Upstream View

Figure 3: Weir Structure at Hager Pond Dam – Downstream View

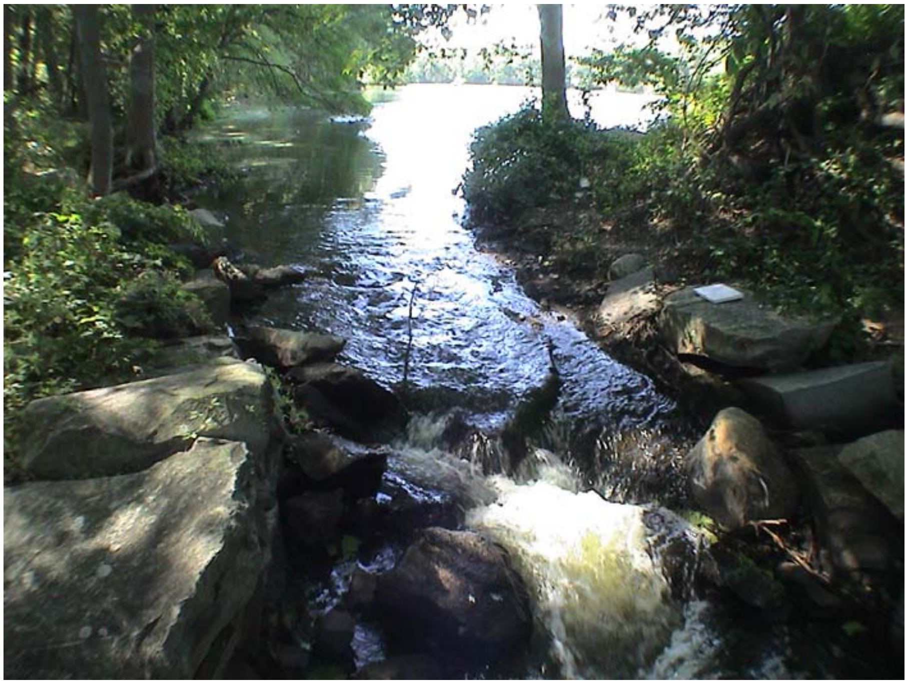


Figure 4: Inlet to Hager Pond Dam

Hager Pond Dam is listed in the NID as a high hazard dam due to urban development downstream of the dam and the location of two culverts that pass under nearby roads. The first culvert downstream is under Hager Road. The existing culvert has a stone arch side as the base with a corrugated metal roof and is about 75 feet downstream from the dam. Figure 5 shows the picture of the upstream face of the culvert. There have been recent repairs made to the culvert structure in Hager Road as the road surface has recently been repaved. These repairs to Hager Road are shown in Figure 6.

The second culvert downstream from Hager Pond Dam runs under Route 20. The structure is a concrete box culvert and about 200 feet downstream of Hager Road. This culvert has a low clearance from the existing water level to the roof span (about 1 foot above the existing water level flowing during the inspection). The channel both upstream and downstream of the culvert has active sedimentation present which reduces the overall channel function through the structure.

As shown in Figures 2 and 3, the concrete dam weir structure and supporting masonry structure are in very poor condition. Both sides of the weir are in need of major repairs. The left abutment has a major seepage flowing under the concrete wall (even at low flows) and through the masonry walls. The seepage is shown in Figure 8. The right abutment has numerous cracks due to freeze-thaw action in the concrete. The stability of the weir structure and masonry walls is very vulnerable during a high flow event where the box would be overtopped. Significant velocities would be present due to the necking at the inlet to the dam to create instability and erosion of the foundation and collapse of the dam.

The toe of the dam and the downstream culverts are also in need of required maintenance. These areas have debris such as dead branches and trees as well as boulders and cobbles that may raise some concerns of past problems with erosion or seepage near the toe of the dam. The downstream channel also will need some erosion protection near the Hager Street culvert and cleaning of sediments in the channel downstream.

Figure 5: Culvert under Hager Street downstream of Hager Pond Dam

Figure 6: Repairs to Culvert under Hager Street (looking toward Hager Dam)

Figure 7: Culvert under Route 20 downstream of Hager Pond Dam

Figure 8: Seepage around Left Abutment at Hager Pond Dam

Potential Dewatering Sites

Five potential dewatering sites have been identified as potential dewatering sites for sediment from Hager Pond. These sites are shown in Figure 9. The first site is located on the westerly side of Hager Pond on the southerly side of Route 20. The site is currently occupied by Evie's Attic Antiques whose building and land are currently up for lease at this time. The parking area and adjacent land as shown in Figure 10 would be sufficient for a staging area needed for hydraulic dredging equipment and truck access. The major benefits of this site are the access to the pond and access to Route 20. This would be the recommended dewatering site for this project.

The second dewatering site would be about ¼ mile west on the northerly side of Route 20 at the site occupied currently by the Wayside Golf Center. This site is currently a driving range which is flat and cleared and has access to Route 20. The site has sufficient acreage for a staging area; however the dredging pipelines would have to pass through an existing culvert under Route 20 at the head of the pond and would also require three or four pump-up stations to move the materials up 8 feet in elevation to the dewatering site. This site would also require the use and access of private lands for the pipeline.

The third dewatering site is on the southeast side of the pond on private property owned by Raytheon Network Centric System. The site is currently used as a ball field that could be utilized easy for the staging area. The site would have easy access to the pond and more than sufficient acreage for a dewatering plant. The drawback to this site is the high level of security required at this Raytheon facility and liability of transporting of materials through public areas on the Raytheon site.

The fourth dewatering site is the Greenridge Farm located easterly of the dam on the east side Paramenter Road (Hager Road) in Marlborough, Massachusetts. This site is currently utilized as a working horse farm that has barns and fences throughout the property. The site is gently sloping toward the river and has many green pastures. The drawback to using this site is there is not direct access to the pond. The dredge pipelines would have to go downstream past Hager Pond and be pumped back up over private lands. This site is not recommended for use as a dewatering site unless all other options are exhausted.

The fifth site is a privately owned residence located at 1000 Paramenter Road, Framingham, Massachusetts. The property has access to the easterly side of Hager Pond through a densely wooded area on the property. The residence currently has a large field used as a single hole golf course which could be used as a dewatering site. The drawback to this site is the truck traffic on a very narrow Paramenter Road and tree cutting required on the private property for the dredge pipelines and pump stations.

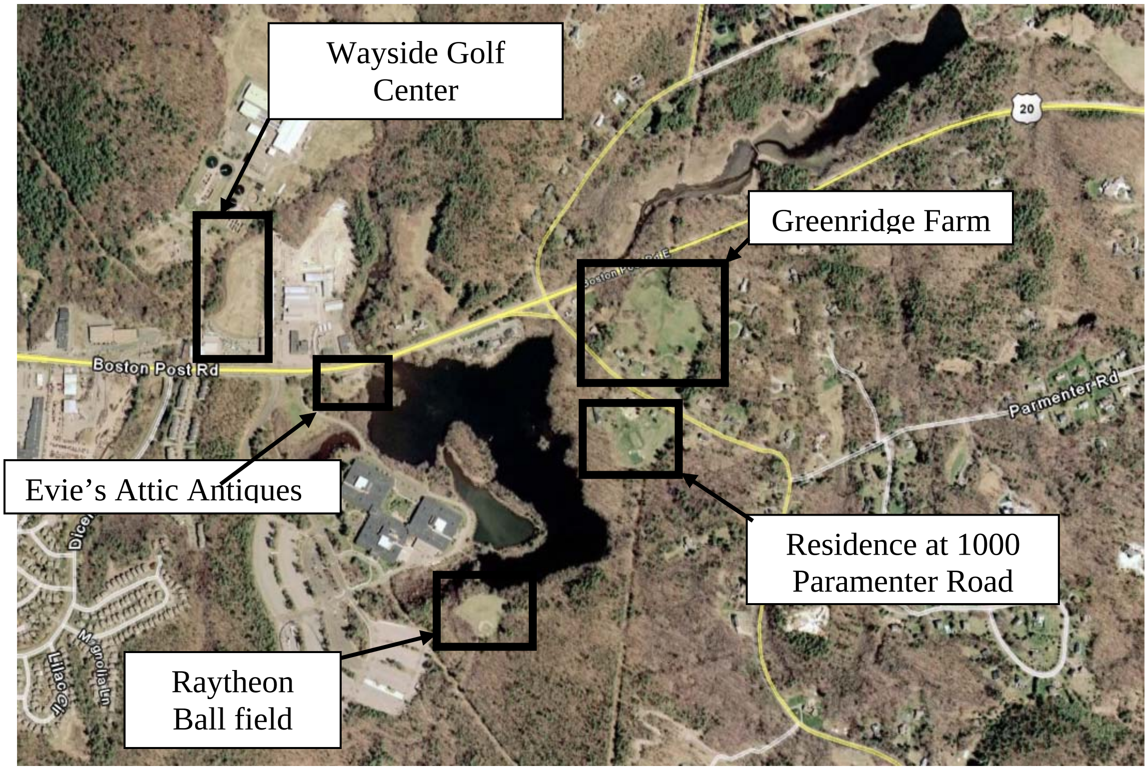


Figure 9: Potential Dewatering Sites for Hager Pond Dam

Figure 10: Recommend Dewatering Site – Evie's Attic Antiques

Recommended Modifications to Dam if no Alternatives selected

Hager Pond Dam is currently in serious need of major repairs to meet the dam safety requirement for a high hazard dam. The options for this dam would be either dam removal or dam breaching. If none of these options are selected, it is recommended rebuilding the entire dam as well as protecting the downstream channel and culverts to be in compliance with dam safety inspections.

Under the dam removal option, the dam could be taken down to the original ledge surface that exists under the existing dam structure. Since this would be slightly lower than the current weir this would create a natural rock falls in this area. However, protection of the culvert downstream would be required.

Under the dam rebuilding option, the existing site would have to be demolished and a new concrete structure placed at the head of the inlet. This structure would have to be anchored and grouted to the bedrock surface for stability. Other dam modification options such as a nature like by-pass channel or rock ramp dam would not be possible due to site constraints and the closeness of the downstream culvert.

Material Testing for Sediments in Hager Pond Dam

Sediments in Hager Pond were sampled and analyzed in the laboratory to assist with identifying the dredging, transportation and disposal options for Hager Pond. Five sample cores up to a depth of 4.5 feet were taken at the locations and GPS coordinates as shown in Figure 11 and in Table 1. Field core logs were also developed for each sample location and are attached to the end of this section.

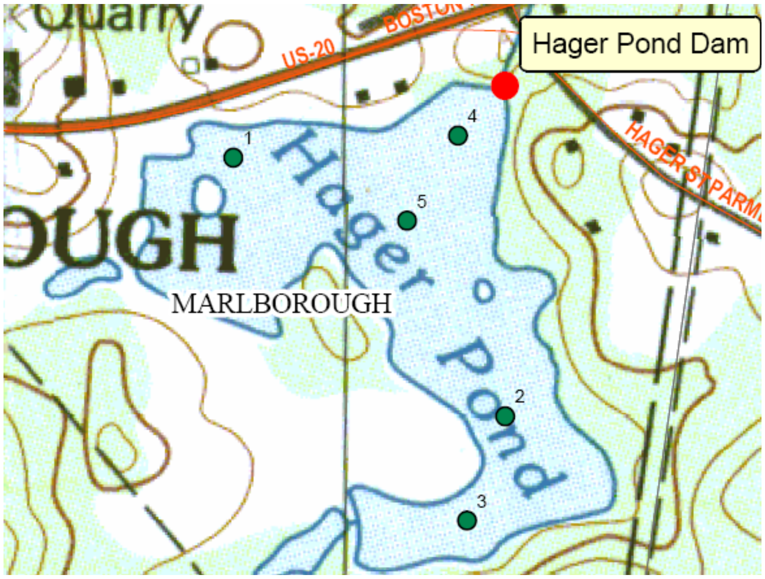


Figure 11: Sediment Sample Locations in Hager Pond

Table 1 GPS Coordinates (MA State Plane NAD83) for Sediment Sample Locations in Hager Pond

Sample No.	Northing	Easting
1	200831.3562	899984.0073
2	201133.9331	899711.4941
3	201096.111	899597.058
4	201073.8057	900015.0408
5	201021.4366	899920.9704

Sediments from the cores were tested in approximately foot increments for grain size (ASTM D422), organic content (ASTM D2974), Atterberg Limits (ASTM D4318) and in-situ moisture content (ASTM D22216). The materials were classified by the Geotechnical Engineering Section staff both visually and the using laboratory gradation data using the Unified Soil Classification System (USCS). Note that the testing regime performed on the samples were established based on a visual inspection in the laboratory, therefore not all the samples had exactly the same sequence of tests performed. Chemical analysis of all the sediment samples is included in Appendix C of the report.

A majority of the sediments that may be required to be dredged from Hager Pond are mainly organic silts (OH) with very high water contents (>100%). These organic sediment are present down to about 3 to 4 feet from the bottom of the pond. Below the organic there is silty sand (ML) and sand (SM) deposits that appear to be the native bedding material. A summary of the laboratory testing data for Hager Pond is shown in Table 2. The actual laboratory test data sheets are included at the end of this section.

Table 2: Summary of Laboratory Testing for Hager Pond

		Depth	USCS CLASS	Sieve & Hydrodrometer D422			Organic D2974	Atterburg Limits D4318	Moisture Content D2216
Hager Pond				%Gravel	%Sand	%Silt& Clay		LL/PL/PI	
HP	01	0.5-2 ft	OH	0	38.6	61.4	21.4	-	366
		2.7-4 ft	OH	0	42.9	57.1	12.6	-	128
		4-4.5 ft	OH	0	34.5	65.5	12.9	-	107
	02	0-1.5 ft	OH	0	44.9	55.1	79.2	-	951
		1.5-3 ft	OH	17.8	49.9	32.3	85.9	-	649
		3-4 ft	SM	0	81.7	18.3	-	-	-
		4.2-4.5	SM	0	71.8	28.2	-	-	-
	03	1-3 ft	OH	0	27.1	72.9	49.2	-	687
		3-3.7 ft	OH	0	21	79	25.4	-	216
		3.7-4 ft	ML	0	47.7	52.3	1.6	23/22/1	31
	04	1-3 ft	OH	0	2.2	97.8	37.9	-	1157
		3-5 ft	OH	0	47.3	52.7	47.2	-	900
	05	0-2 ft	OH	0	6.4	93.6	38.1	-	977
		3-4 ft	OH	0	34.2	65.8	30.3	-	435
		4.7-5 ft	SM	0	83.5	16.5	-	-	-

Dredging, Transportation and Disposal Options for Materials in Hager Pond

The recommended technique to remove the pond sediments would be to use a hydraulic dredge and belt filter press plant to dewater and stabilize the organic material prior to disposal. Mechanical removal of the material in the pond would be very difficult given the type of material (organic, high water content, low permeability) and depth to a solid ground surface for the machinery to operate.

Transportation of the materials after being dewatered and stabilized can be accomplished using 30 yard dump trucks. The disposal location of the materials will need to meet the requirement of the MADEP regulations for residential reuse. Potentially these types of materials can be augmented and disposed of in a landfill as daily cover or could be combined with sandy material and reused as loam for residential reuse if it can meet the MADEP requirements.

Summary of Dam Modifications for Hager Pond

Dam Removal Option

- Hydraulic dredging of top foot of material to remove and eliminate any unwanted vegetation regrowth after dewatering
- Dewater site using an incremental dewatering scheme to keep existing stream banks stable
- Period of dewatering will take between 6 to 12 months (or more) depending upon how fast the materials can dewater
- Channels
  - Natural channels should form during dewatering (use those if at all possible)
  - Mechanical operation with possible some hydraulic to remove unwanted sediments from deeper sections
  - 10 foot bottom with of channel into native material (sand/gravel)
  - 1:4 sides slopes – turf reinforce or vegetate as required
  - Taper channel into dams that are removed – 1:6 slopes or greater

Partial Removal/Leave Dam As-IS or Rehab Dam

- Hydraulic dredging – remove organics from silt and sand
- Dredge to depths indicated – taper to dam and from shoreline and islands
- Disposal of materials
  1. Augment the materials for daily cover – pay for materials (sand) and disposal costs will only be trucking
  2. Reuse – sand, organic/silt – contract transportation and disposal
- Slopes to inlet channels to new weirs if partial removal – 1:6 slopes or greater

Field Logs from Hager Pond

To be provided in a supplemental report.

Laboratory Testing from Hager Pond

To be provided in a supplemental report.

Appendix B – Cost Estimates

Breakdown Costs, 22 Jan 2008

	Unit	Unit Cost	HAGER POND Quantity	HAGER POND Cost	GRIST MILLPOND Quantity	GRIST MILLPOND Cost	CARDING MILLPOND Quantity	CARDING MILLPOND Cost	STEARNS MILLPOND Quantity	STEARNS MILLPOND Cost
Option 1						N/A				
Demo Dam and Create Thalweg										
Mob/Demob	LS		1	$25,000				$25,000		$25,000
Dam Removal	LS		1	$15,000				$5,000		$22,500
Disposal of Dam Material	LS		1	$5,000				$5,000		$5,000
New Stone (Rip-rap)	CY	66.0	750	$49,500			350	$23,100	550	$36,300
Dewatering	LS		1	$20,000				$20,000		$20,000
Environmental Protection	LS		1	$30,000				$30,000		$30,000
Dam area excavation	CY	10.0	2000	$20,000			700	$7,000	1350	$13,500
Thalweg Exc	CY	10.0	6721	$67,210			5847	$58,470	19600	$196,000
Disposal of Material (clear/grub)	CY	10.0	6721	$67,210			5847	$58,470	19600	$196,000
Thalweg Buttom (Gravel)	Cy	40.0	815	$32,600			1188	$47,520	2002	$118,400
Channel Planting	EA	50.0	1940	$97,000			1333	$66,650	2331	$116,550
Channel Erosion Mat	SY	4.4	7760	$34,144			5335	$23,474	8924	$39,266
465300				$462,664				$369,684		$818,516
Mark-up				$578,330				$462,105		$1,023,145
Total Cost (w/Contingency)				**$722,913**				**$577,631**		**$1,278,931**
Option 2						N/A				
Partial Dam Demo & Create Thalweg										
Mob/Demob (up-front cost for dredging)	LS			$50,000				$50,000		$50,000
Dam Removal	LS			$13,500				$6,000		$21,000
Disposal of Dam Material	LS		1	$3,000				$3,000		$3,000
New Stone (Rip-rap)	CY	66.0	375	$24,750			175	$11,550	275	$18,150
Dewater tank/enclosure creation	LS			$20,000				$20,000		$20,000
Environmental Protection	LS			$30,000				$30,000		$30,000
Dam area excavation	CY	10.0	1000	$10,000			350	$3,500	675	$6,750
Thalweg Exc	CY	10.0	3500	$35,000			3000	$30,000	16000	$160,000
Disposal of Material (clear/grub)	CY	10.0	3500	$35,000			3000	$30,000	16000	$160,000
Thalweg Bottom (Gravel)	Cy	40.0	400	$16,000			600	$24,000	1840	$73,600

Hydraulic Dredge	CY	16.9	45000	$760,500			50000	$845,000	26000	$439,400
Dewater	CY	14.1	45000	$634,500			50000	$705,000	26000	$366,600
Transportation (disposal 1mi)	CY	2.0	45000	$90,000			50000	$100,000	26000	$52,000
Channel Planting	EA	50.0	1000	$50,000			650	$32,500	1200	$60,000
Channel Erosion Mat	SY	4.4	4000	$17,600			2600	$11,440	4500	$19,800
				$1,739,850				$1,851,990		$1,430,300
Mark-up				$2,174,813				$2,314,988		$1,787,875
Total Cost (w/Contingency)				**$2,718,516**				**$2,893,734**		**$2,234,844**
Option 3										
Dredge										
Mob/Demob (up front cost)	LS			$50,000		$50,000		$50,000		$50,000
Hydraulic Dredging	CY	16.9	55,000	$929,500	16000	$270,400	63000	$1,064,700	33000	$557,700
Beltpress	CY	14.1	55,000	$775,500	16000	$225,600	63000	$888,300	33000	$465,300
Transportation (disposal 1mi)	CY	2.2	55,000	$121,000	16000	$35,200	63000	$138,600	33000	$72,600
Access	LS			$25,000		$25,000		$25,000		$50,000
Environmental Protection	LS			$75,000		$75,000		$75,000		$75,000
Dewater tank/enclosure creation	LS			$20,000		$20,000		$20,000		$20,000
				$1,996,000		$701,200		$2,261,600		$1,290,600
Mark-up				$2,495,000		$876,500		$2,827,000		$1,613,250
Total Cost (w/Contingency)				**$3,118,750**		**$1,095,625**		**$3,533,750**		**$2,016,563**

Preliminary Cost Estimate
Hop Brook Dams

22-Jan-08

Assumptions:
Hydraulic Dredging only at $10/cy based on
Lump sum costs (not all) provided by civil engineer
Dredge materials dispose at the site (per PM)
Quantities provided by civil engineer
Contractor Markup is included at 25%
Contingency 25% is added

	Hager Pond	Grist Mill Pond	Carding Mill Pond	Stearns Pond
Option 1				
Dam Removal / Create Thalweg	**$722,913**	**NA**	**$577,631**	**$1,278,931**
Option 2				
Partial Dam Removal / Create Thalweg	**$2,718,516**	**NA**	**$2,893,734**	**$2,234,844**
Option 3				
Dredge	**$3,118,750**	**$1,095,625**	**$3,533,750**	**$2,016,563**

Piping treated WW to Sudbury River

	Quantity	$/unit	total	
Piping, water dist, 24" dia, 150 PSI, CCP, 5 MI. L (ft)	26400	70	$	1,848,000.00
Excavate trench, mdm soil, 1 CY excavator (CY)	15628.8	17.73	$	277,098.62
Backfill reuse existing, front end loader, 1.5 CY	15640	2.85	$	44,574.00
compaction, 1 ton roller	15640	4.05	$	63,342.00
Pump	2	50000	$	100,000.00
Misc - pump house etc.	LS		$	200,000.00
Sub Total			$	2,533,014.62
Total with mark-up	0.25		$	3,166,268.28
Total with contingency	0.25		**$**	**3,957,835.35**

FWS creation estimate

1 Zone exc/fill					
zone 1	no change				
zone 2	excavate	1*5*43560/27		8067	cy
zone 3	fill	2*10*43560/27		-32267	
zone 4	excavate	2*5*43560/27		23230	
zone 5	excavate	0.5*5*43560/27		5240	
		net		4270	
	use 35,000 CY	for exc/fill	$17/cy		595000
2 Dredge mob/demob		LS	$100,000		
3 Silt curtain		600 LF	$50/LF		30000
4 Pipe transfer		1950 LF	$50/LF		97500
5 Distr. Manifold		350 LF	$50/LF		17500
6 Plants	assume 30 ac	30*43560/3ft*3ft grid	145,200	plants	
		$2/plants	$292,000		
		sub Total	$1,132,000		
	Total with	30% markup	$ 1,471,600.00		
	Total with	30% contingency	**$ 1,913,080.00**		

Appendix C – Sediment Quality

SEDIMENT QUALITY

The purpose of this appendix is to present a brief review of pertinent information on sediment quality presented in the USACE report entitled "Hop Brook Sediment and Dam Removal Study, January 2008".

USACE collected sediment cores from 16 sampling sites in the four ponds- Hager Pond, Grist Millpond, Carding Millpond, and Stearns Millpond and analyzed the cores for the following parameters. The chemical data from these analyses are presented in detail in the 2007 USACE report. The locations of these sampling locations are shown in Figures 1, 2, 3, 4 and 5.

Organics

- SVOCs – semivolatile organic compounds.[1]
- EPH – extractable petroleum hydrocarbons[2]
- VPH – volatile petroleum hydrocarbons[2]
- PCBs – Polychlorinated bi-phenyls
- Organochlorine pesticides
- VOCs – volatile organic compounds

Metals Assessed [3]

Target Analyte List (TAL) metals

Nutrients

- Phosphorus
- Nitrate/Nitrite
- Ammonia

[1] A subset of SVOCs are the Polynuclear Aromatic Hydrocarbons (PAHs), which are a group of chemicals that are formed during the incomplete burning of coal, oil, gas, wood, garbage, or other organic substances, such as tobacco and charbroiled meat. There are more than 100 different PAHs. Some PAHs are known animal carcinogens and others are probable carcinogenic to humans.

[2] EPH and VPH are designed to assess exposure to petroleum hydrocarbons that may cause health hazards. Some of the petroleum products detected by this method include gasoline, kerosene, diesel oil and some lubricating oils.

[3] TAL metals are Al, Sb, As, Ba, Be, Cd, Ca, Cr, Co, Cu, Fe, Pb, Mg, Mn, Hg, Ni, K, Se, Ag, Na, Tl, V, and Zn.

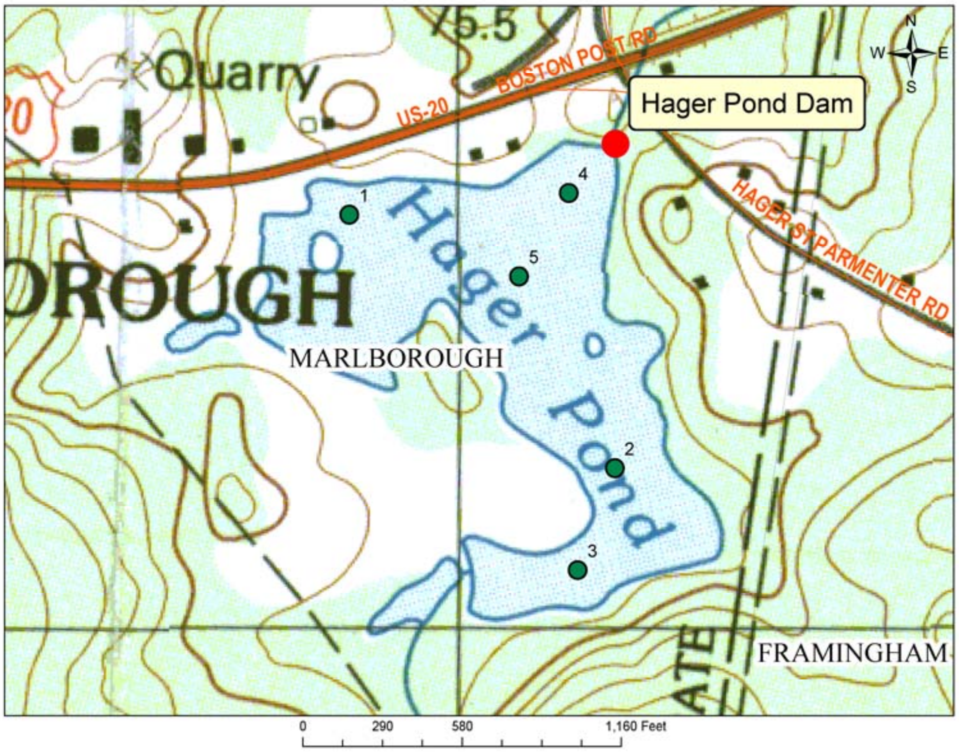


Figure 1: Sampling locations at Hager Pond

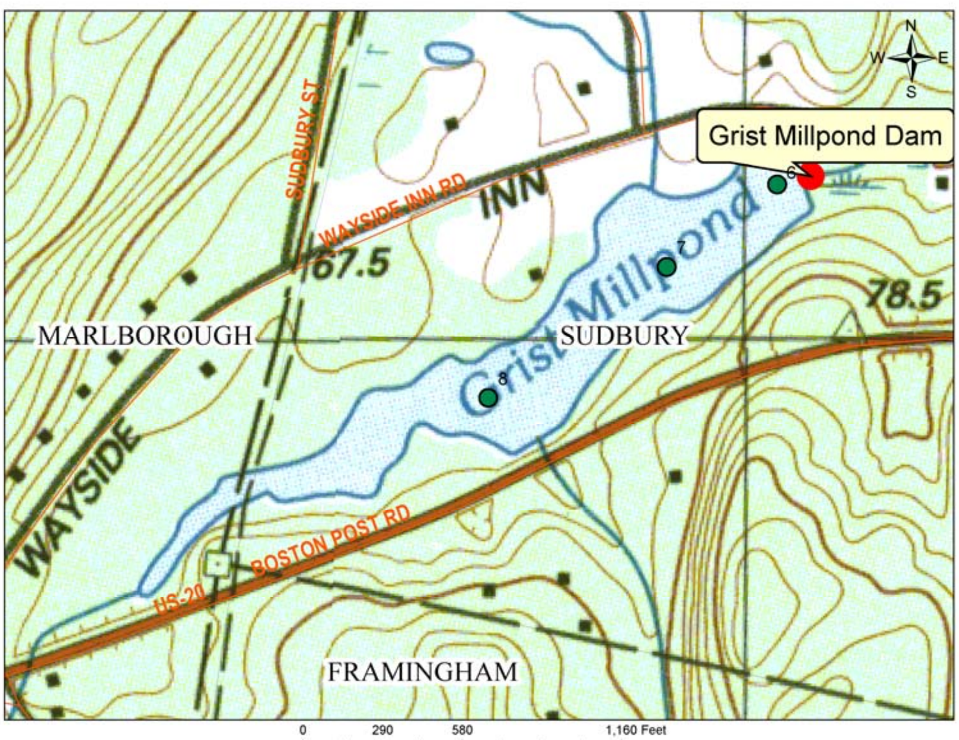


Figure 2: Sampling locations at Grist MillPond

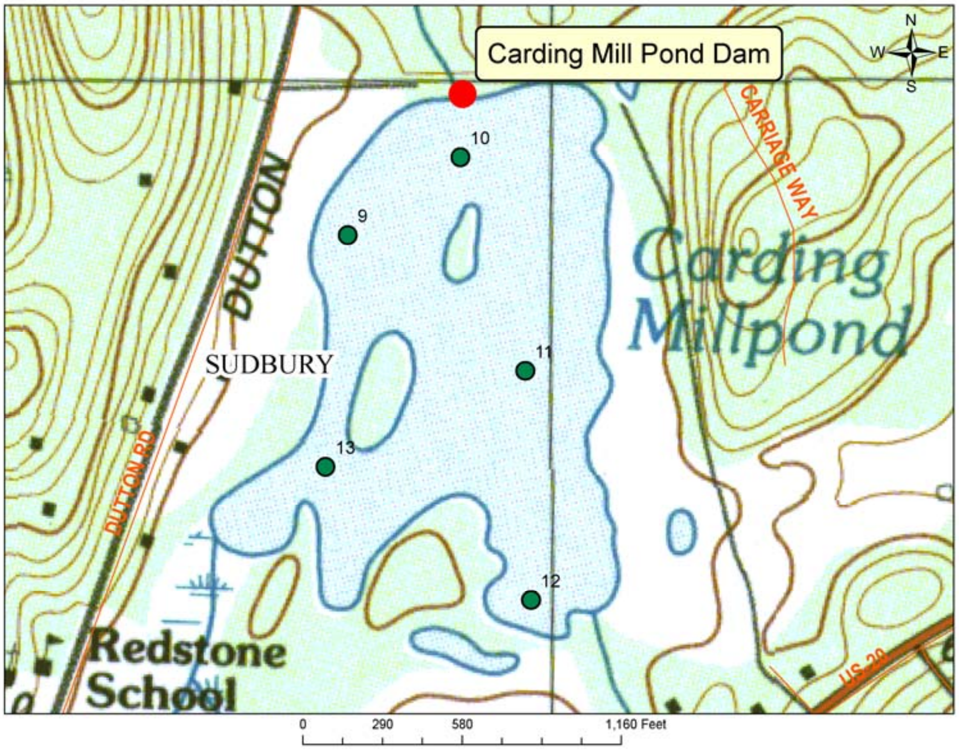


Figure 3: Sampling locations at Carding MillPond

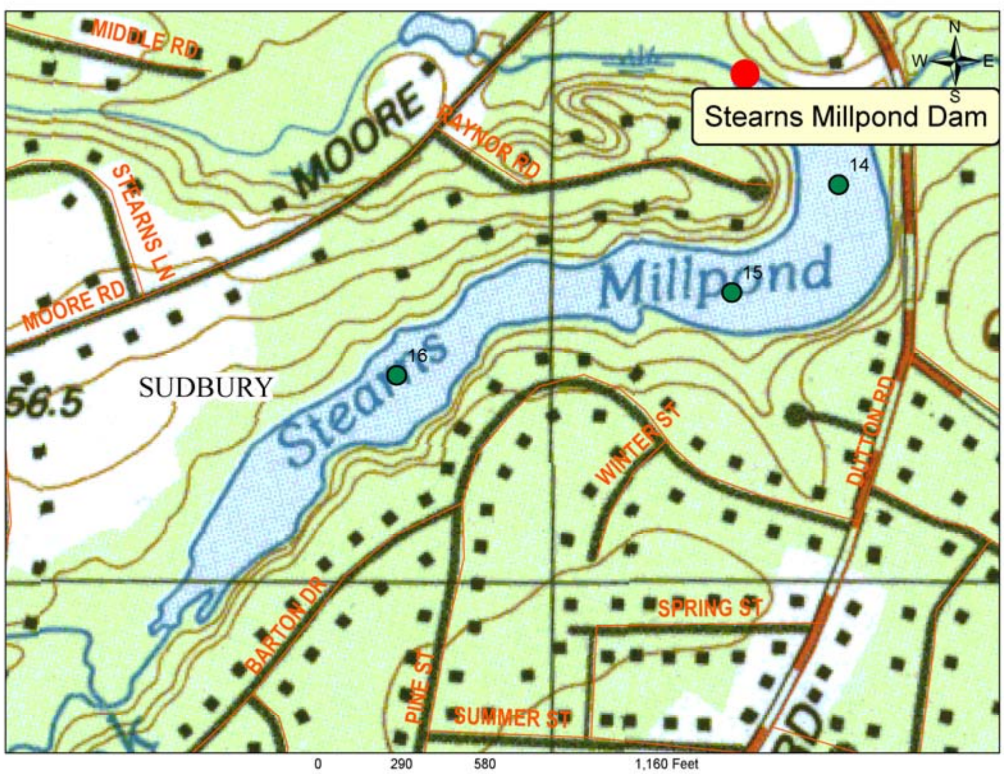


Figure 4: Sampling locations at Stearns MillPond

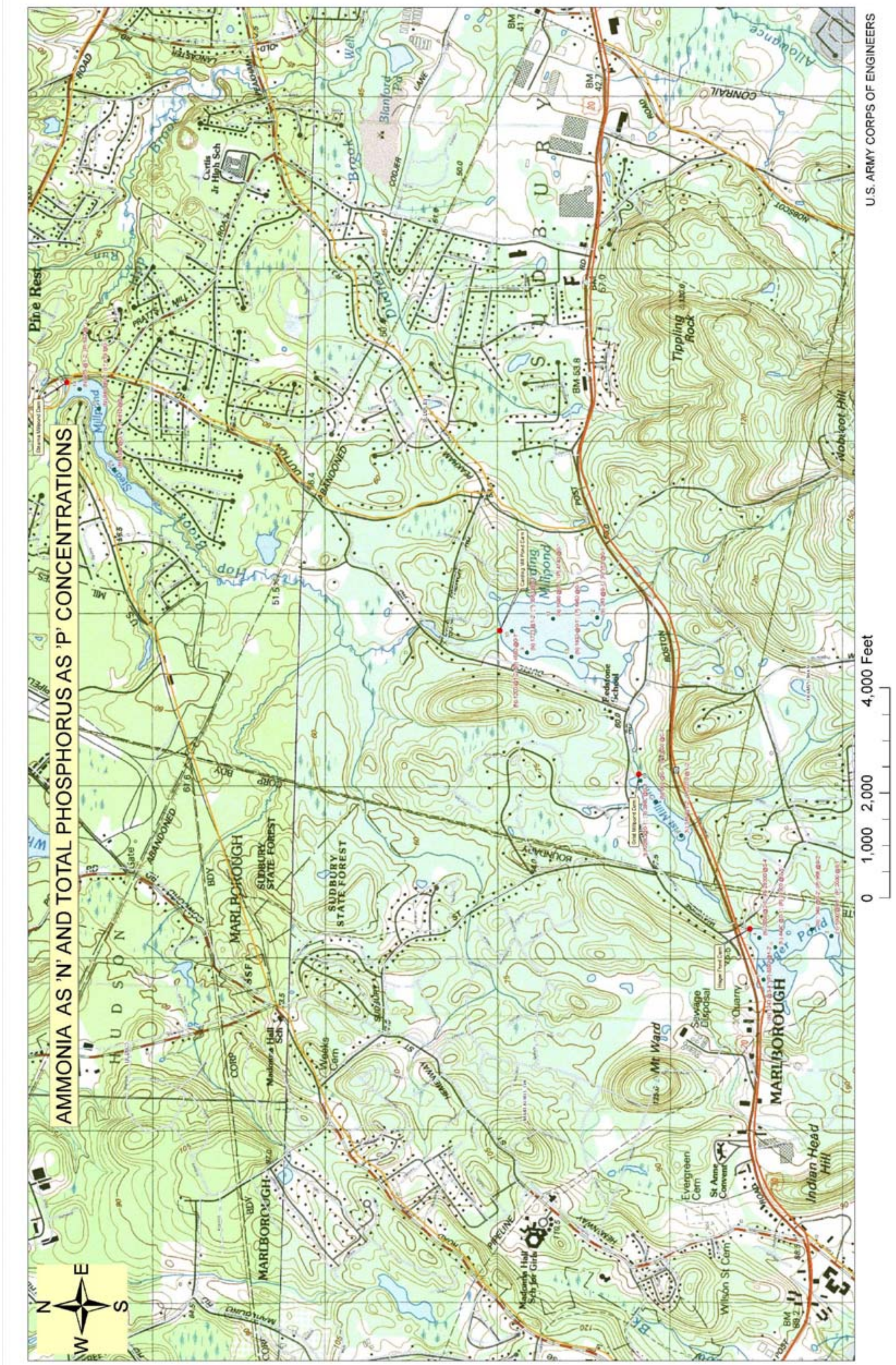
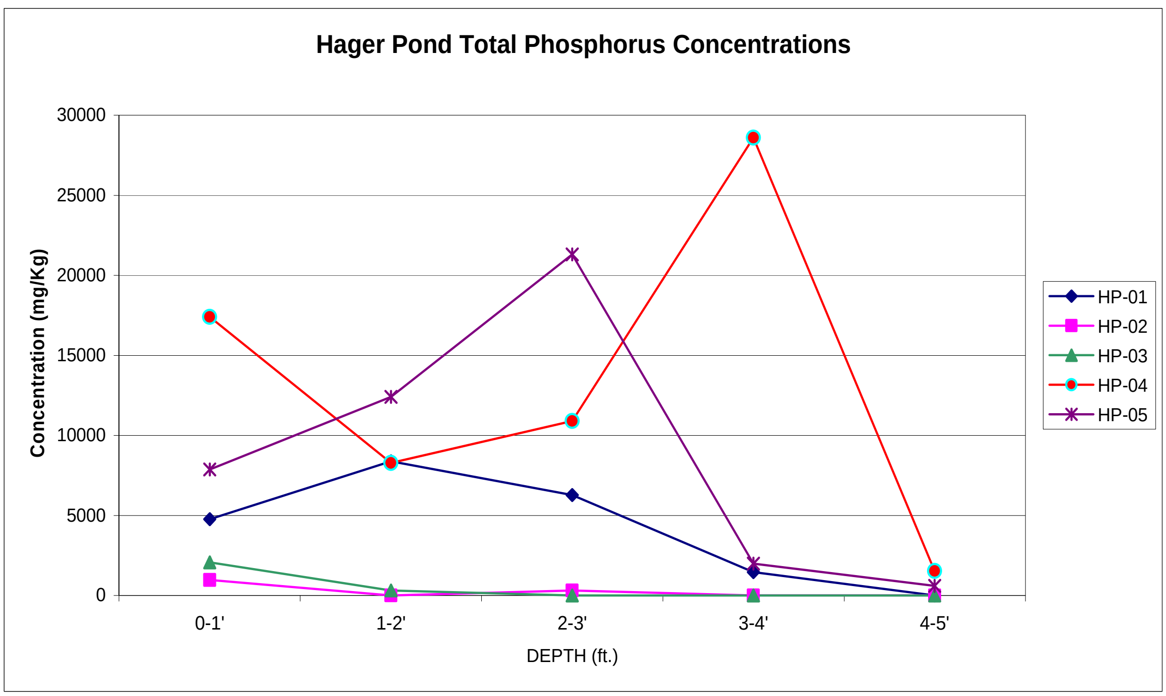


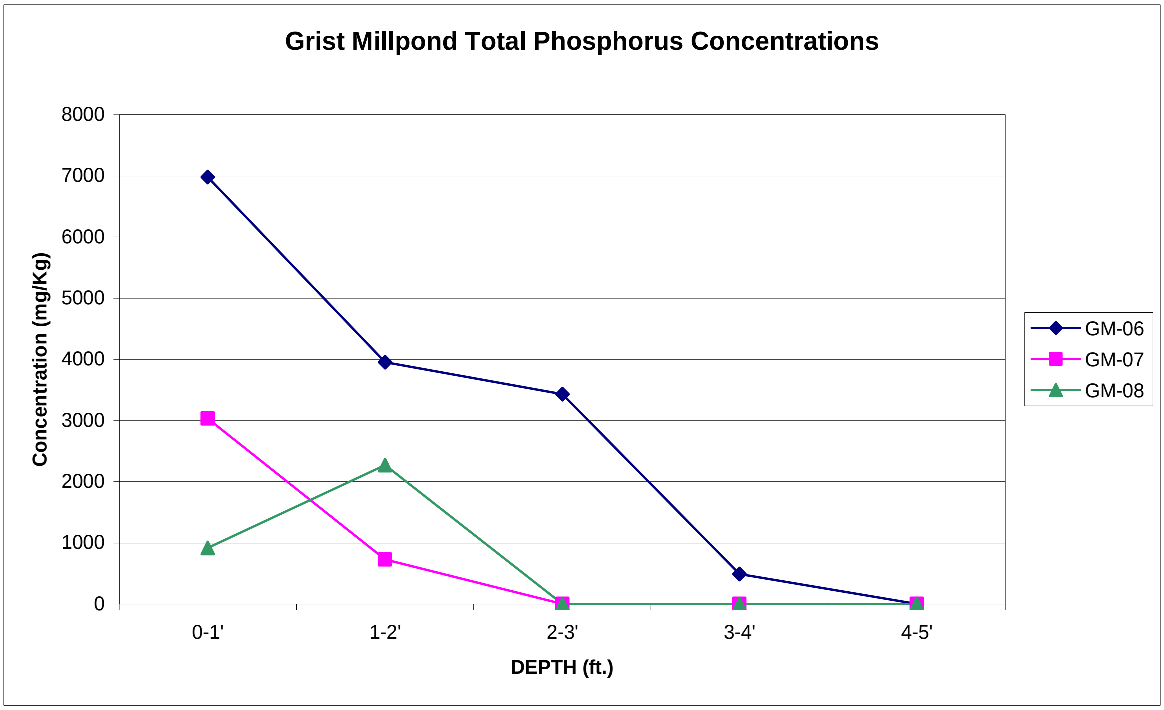
Figure 5: Sampling results for Nitrogen and Phosphorus

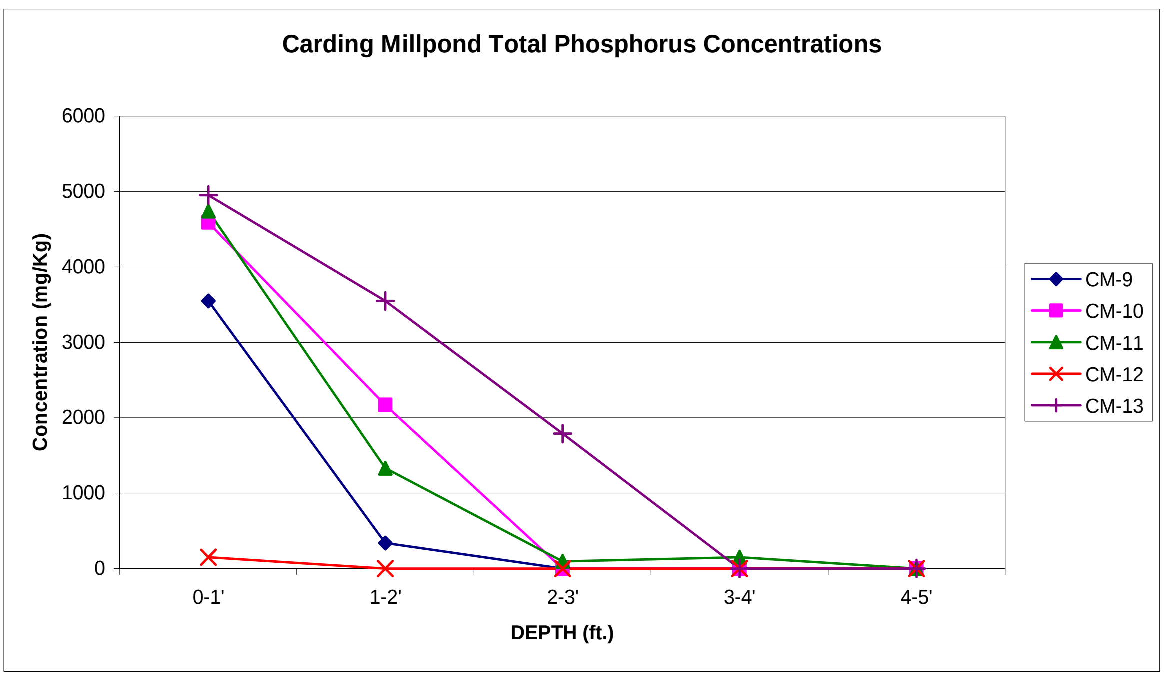
Phosphorus

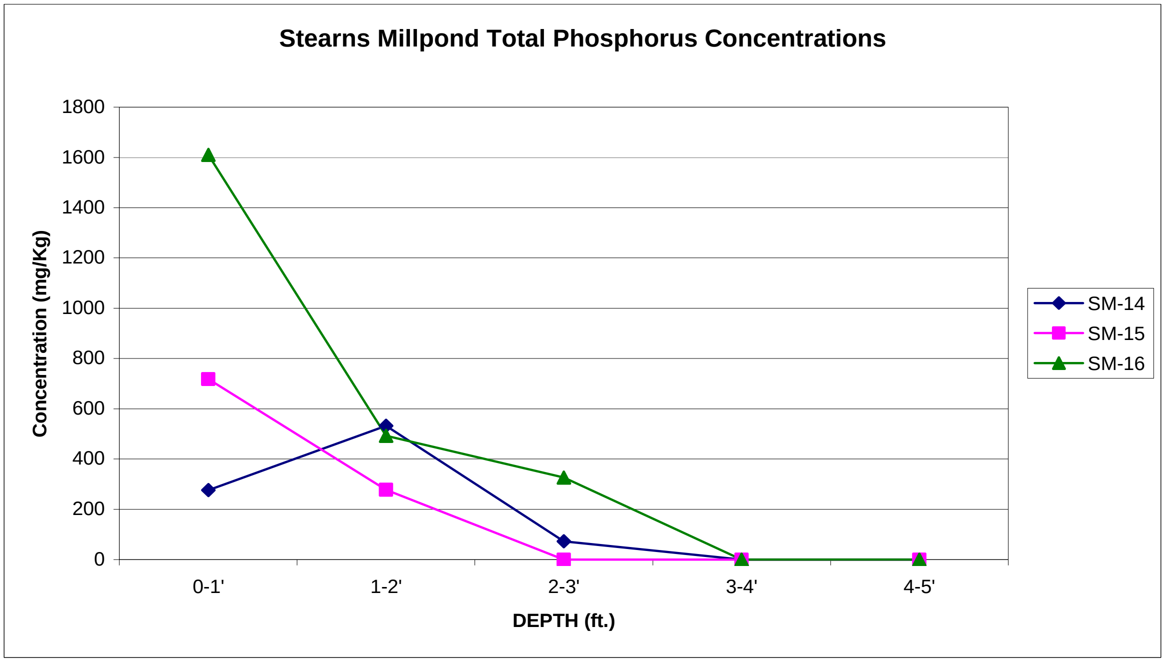
The USACE study measured total phosphorus in the sediments at locations from all four ponds at depths of 0-1 ft., 1-2 ft., 2-3 ft., 3-4 ft. and 4-5 ft, wherever possible. Results indicate that phosphorus concentrations tend to decrease with depth in the sediments in all ponds except Hager pond. This observation is demonstrated in the graphs shown below.

The data shows that total phosphorus concentrations generally decrease below depths of about 2 to 3 feet, except Hager pond which shows an increase in concentration at locations HP-04 (near the dam) and HP-05 (center of the pond) followed by a sharp drop in phosphorus levels at the 4-5 ft. range. The change with depth in the sediments may be reflective of the changing nature of the pollutant loading in the ponds over time. Hager pond, which is the closest to the waste water treatment plant (WWTP), however, exhibits an atypical trend at locations HP-04 and HP-05. Since these two sample locations are near the WWTP, either some sediment mixing has occurred or, more likely the higher phosphorus concentrations at deeper depths represent higher discharge concentrations in previous years followed by lower discharge concentrations due to tightening of discharge standards at shallower depths over time.




Grist Millpond Total Phosphorus Concentrations
Concentration (mg/Kg)
8000
7000
6000
5000
4000
3000
2000
1000
0
0-1'
1-2'
2-3'
3-4'
4-5'
DEPTH (ft.)
GM-06
GM-07
GM-08

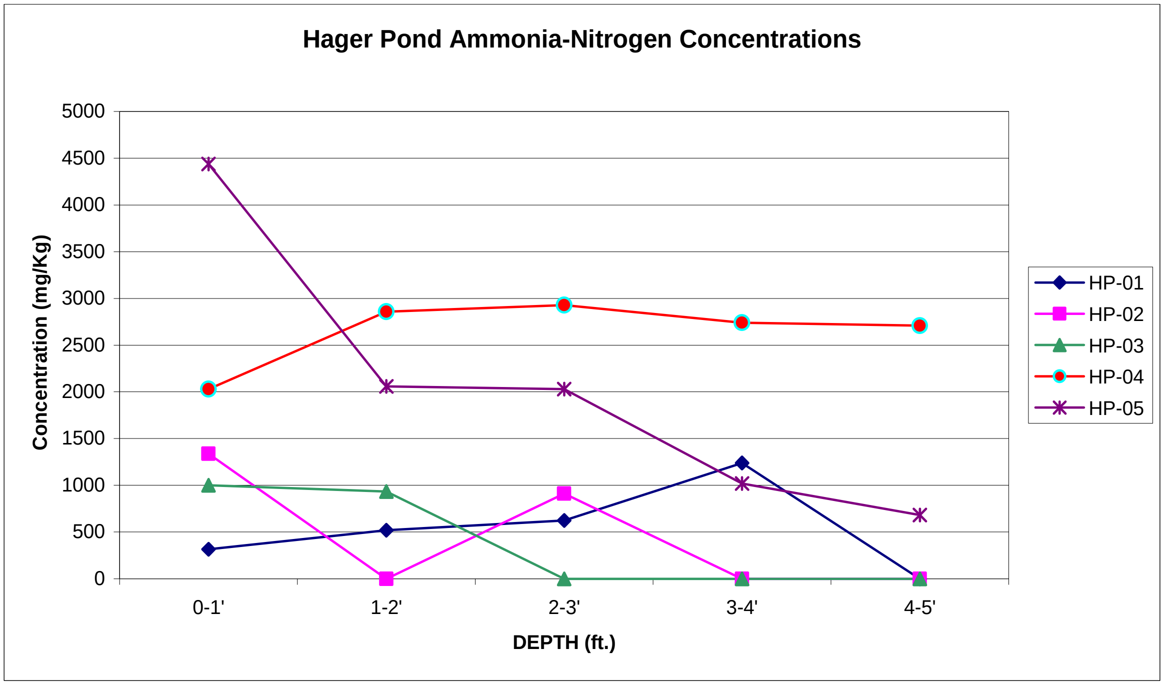

Carding Millpond Total Phosphorus Concentrations
Concentration (mg/Kg)
6000
5000
4000
3000
2000
1000
0
0-1'
1-2'
2-3'
3-4'
4-5'
DEPTH (ft.)
CM-9
CM-10
CM-11
CM-12
CM-13

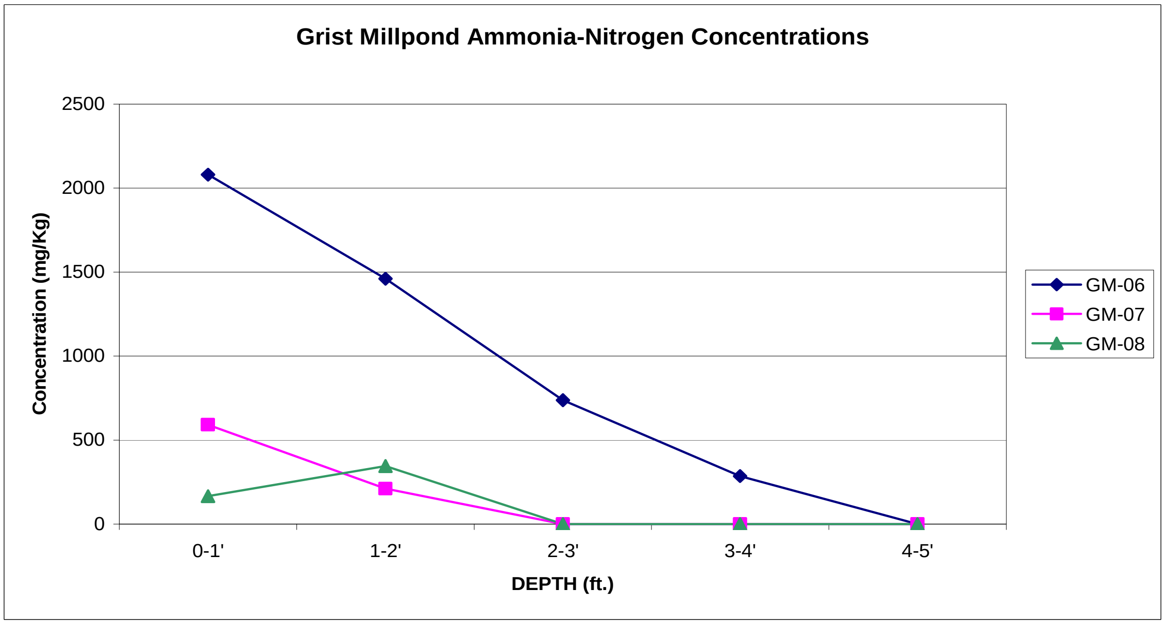


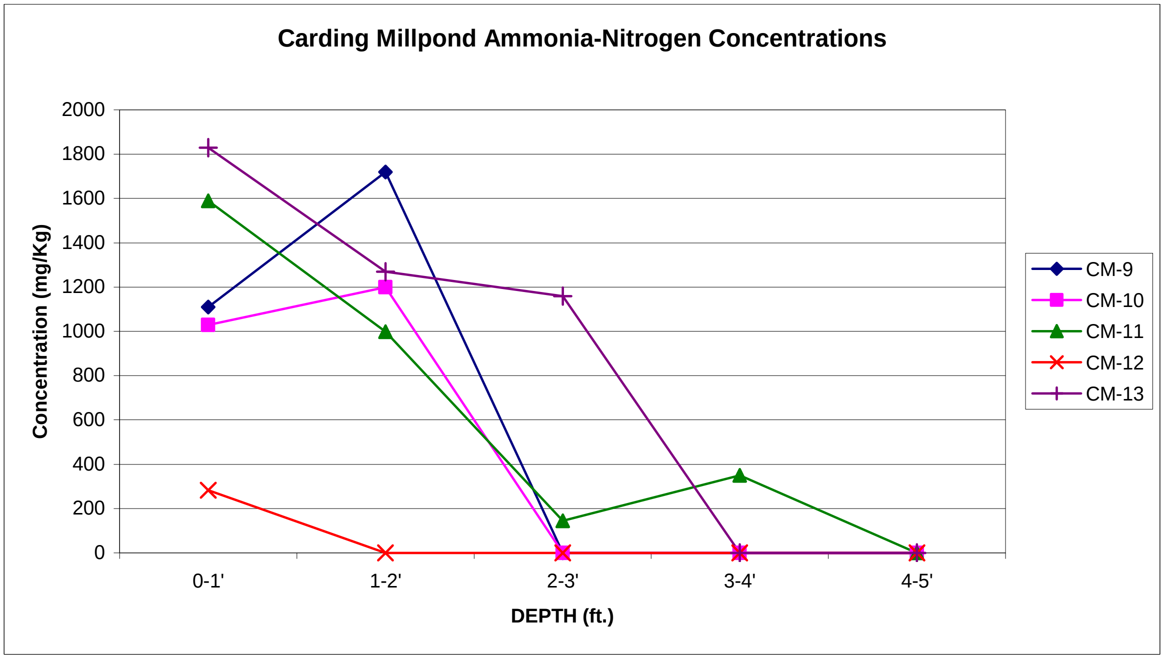
Ammonia Nitrogen

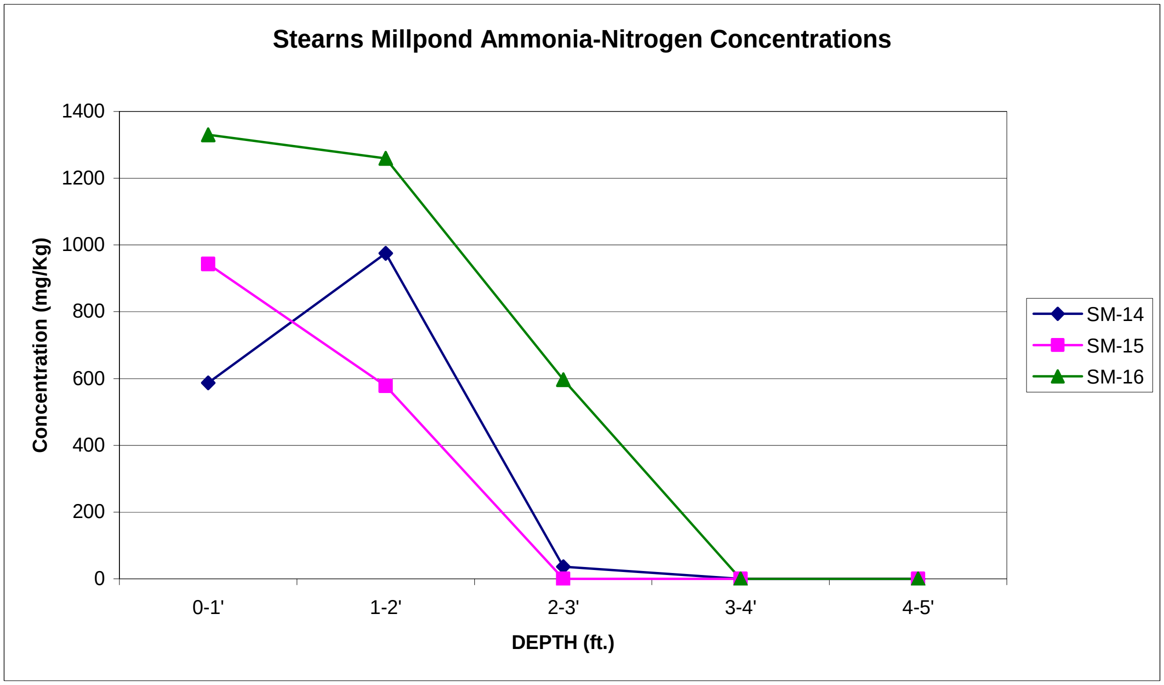
The USACE study measured ammonia nitrogen in the sediments at locations from all four ponds at depths of 0-1 ft., 1-2 ft., 2-3 ft., 3-4 ft. and 4-5 ft, wherever possible. Results indicate that ammonia nitrogen concentrations tend to decrease with depth in the sediments in all ponds except Hager pond. This observation is demonstrated in the graphs shown below.

The data shows that Ammonia nitrogen concentrations generally decrease below depths of about 1-2 ft. Again, Hager pond is the exception, most likely due to the same reasons as presented above for total phosphorus. The difference being that the closest sampling location, HP-04, to the WWTP exhibits steady concentrations up to the 4-5 ft. range and does not drop off as seen with total phosphorus.


Hager Pond Ammonia-Nitrogen Concentrations
5000
4500
4000
3500
3000
2500
2000
1500
1000
500
0
Concentration (mg/Kg)
0-1'
1-2'
2-3'
3-4'
4-5'
DEPTH (ft.)
HP-01
HP-02
HP-03
HP-04
HP-05


Grist Millpond Ammonia-Nitrogen Concentrations
2500
2000
1500
1000
500
0
Concentration (mg/Kg)
0-1'
1-2'
2-3'
3-4'
4-5'
DEPTH (ft.)
GM-06
GM-07
GM-08





<u>Nitrate Nitrogen</u>

Results for nitrate nitrogen were mostly non-detect and were, therefore not plotted on a graph. Minor detections of 1.88 mg/Kg in HP-02 and 0.33 mg/Kg in HP-03 were noted.

Landfill Re-use and Soils Criteria

If dredging is pursued to restore aquatic habitat and water quality, no contaminants were observed in the USACE study that would likely limit the options for sediment disposal.

Table 1 provides a summary of the USACE study findings relative to Massachusetts Landfill re-use criteria and residential soils criteria. Soils criteria are from MA 310CMR40.

If dredging is one of the selected alternatives for restoration, additional testing will still be required of the dewatered stockpiles from specific project areas per applicable state requirements and specific disposal facility requirements.

Aquatic Life Criteria

Sediments in the ponds contain contaminants that can negatively impact aquatic life. This finding is based on a comparison of the concentrations of the contaminants to likely toxic effect levels from the literature. No site specific sediment bio-assay work was performed by USACE.

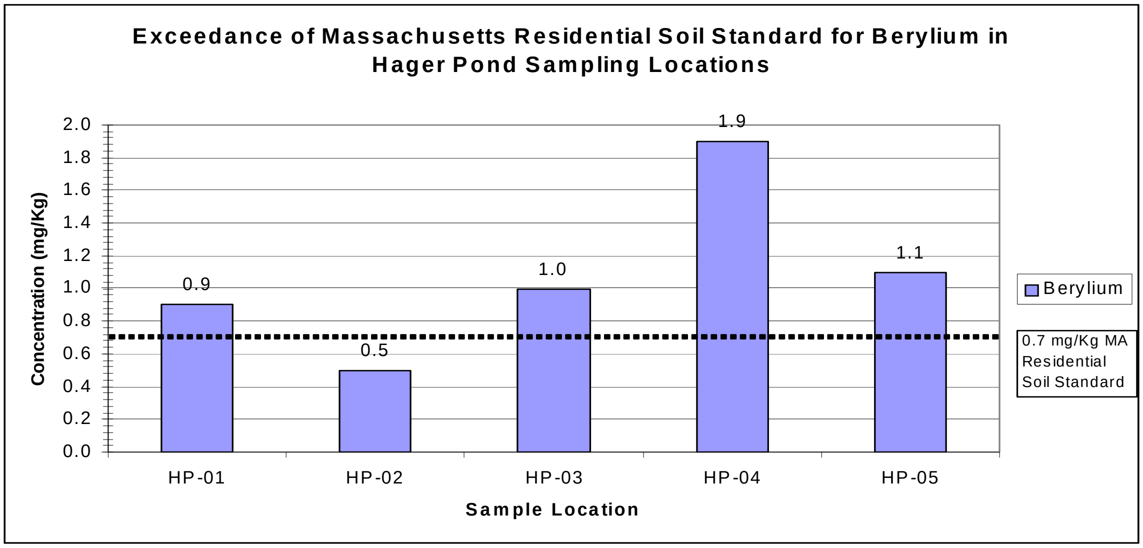
Residential Soil Criteria

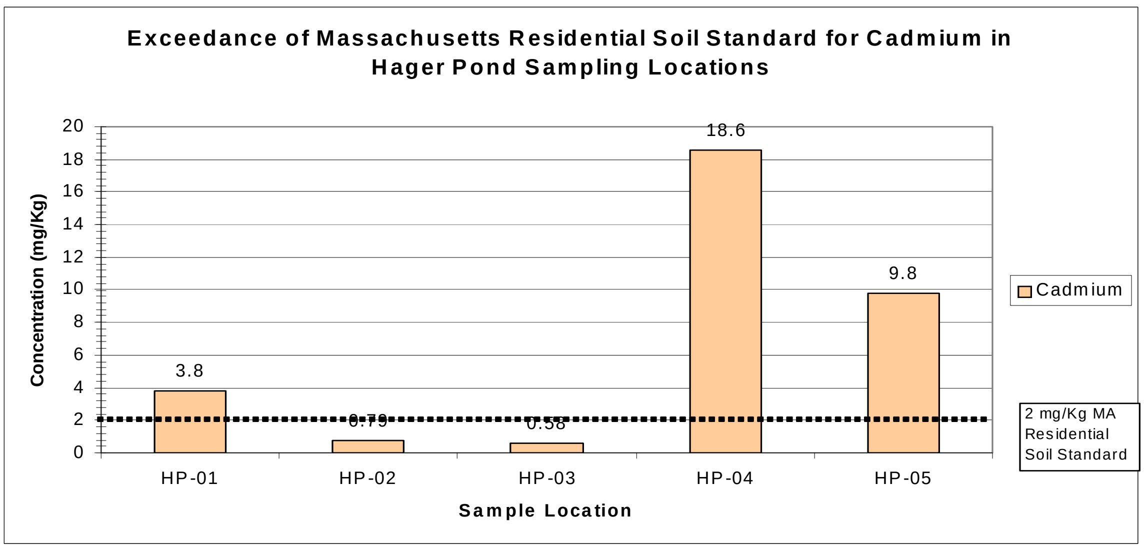
Sediments in the ponds contain contaminants whose levels exceed Massachusetts standards for unrestricted residential use.

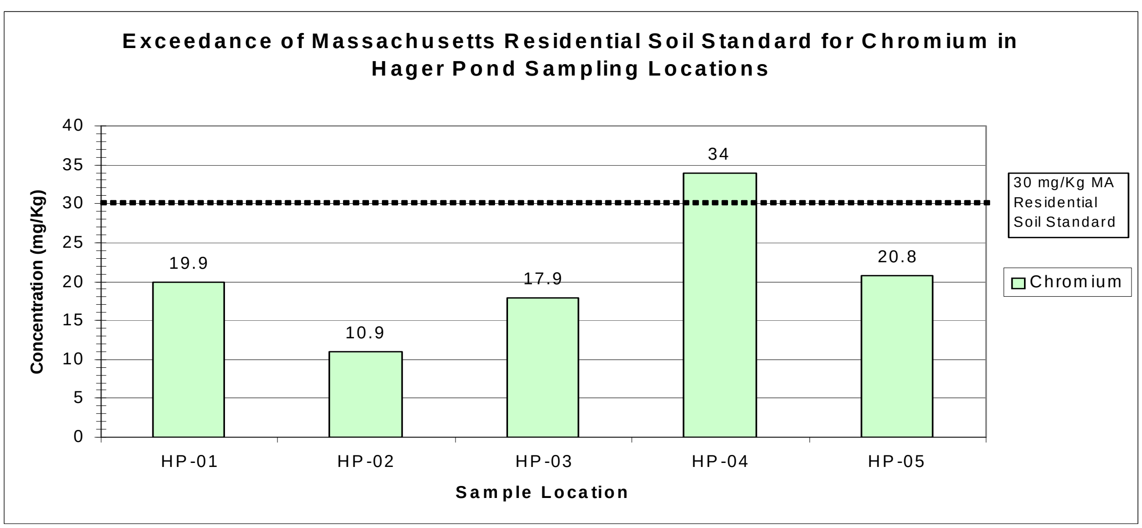
Table 1. Chemical Consituents where one or more samples exceeded guidelines

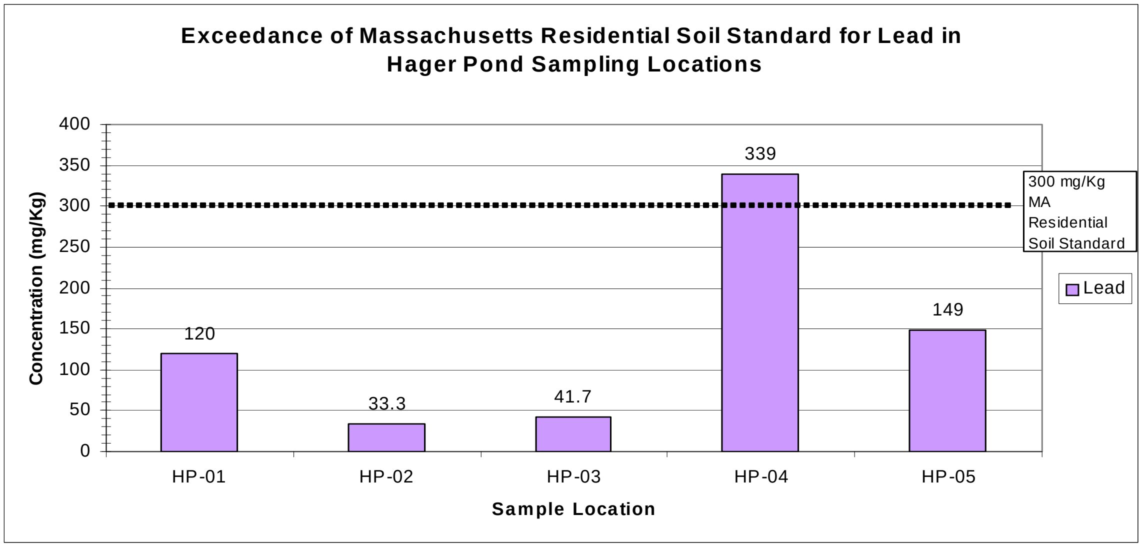
	Chemical groups that exceed aquatic life guidelines	**Chemical groups that exceed MA landfill re-use standards**	**Chemical groups that exceed MA 310CMR40, residential soils standards**
Hager Pond	**As, Cd, Cu, Pb, Ni, Zn**	**none**	**Be, Cd, Cr, Pb**
Grist Millpond	**Cd, Pb, Ni, Zn**	**none**	**Be, Cd**
Carding Millpond	**As, Cd, Cu, Pb, Ni, Zn**	**none**	**Be, Ni**
Stearns Millpond	**As, Ni**	**none**	**Be, As, Ni**

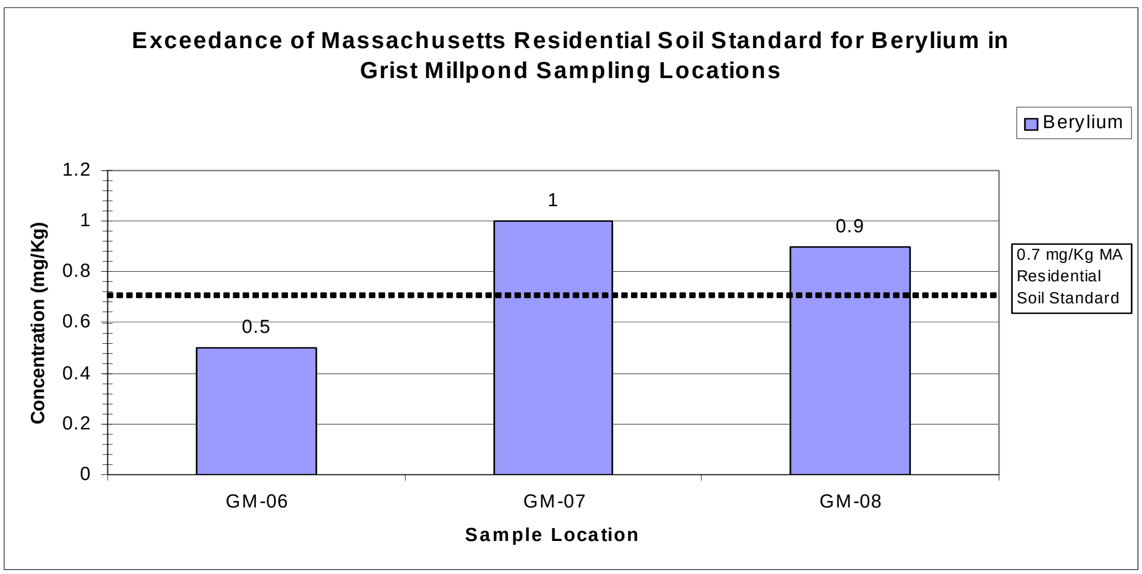
The exceedances cited in Table 1 are depicted graphically in the following charts.

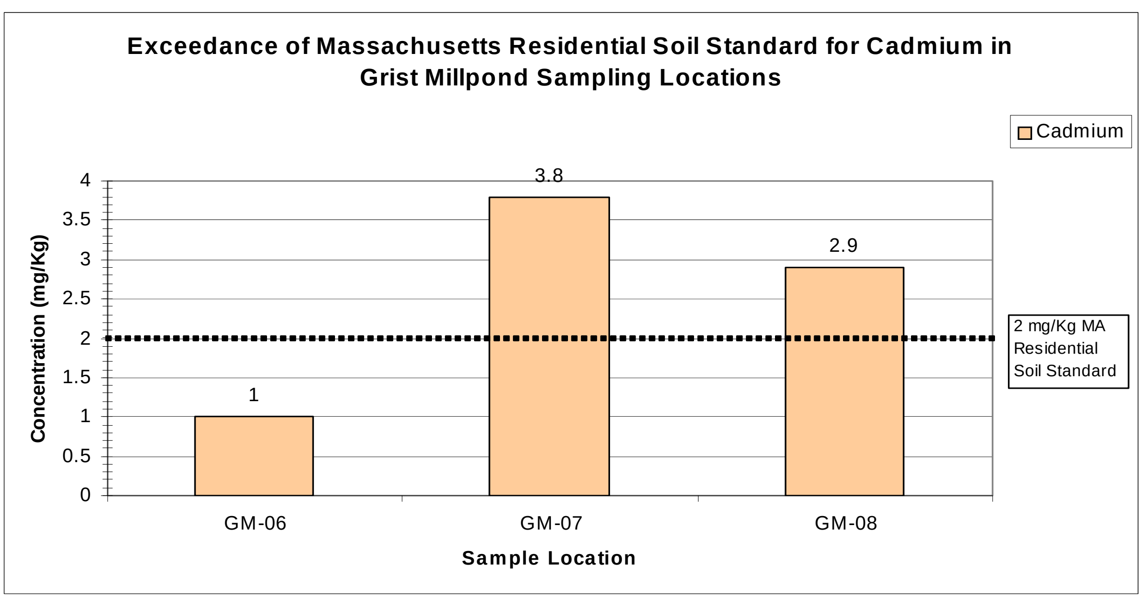

Exceedance of Massachusetts Residential Soil Standard for Berylium in Hager Pond Sampling Locations
Concentration (mg/Kg)
2.0
1.8
1.6
1.4
1.2
1.0
0.8
0.6
0.4
0.2
0.0
0.9
0.5
1.0
1.9
1.1
HP-01
HP-02
HP-03
HP-04
HP-05
Sample Location
Berylium
0.7 mg/Kg MA Residential Soil Standard

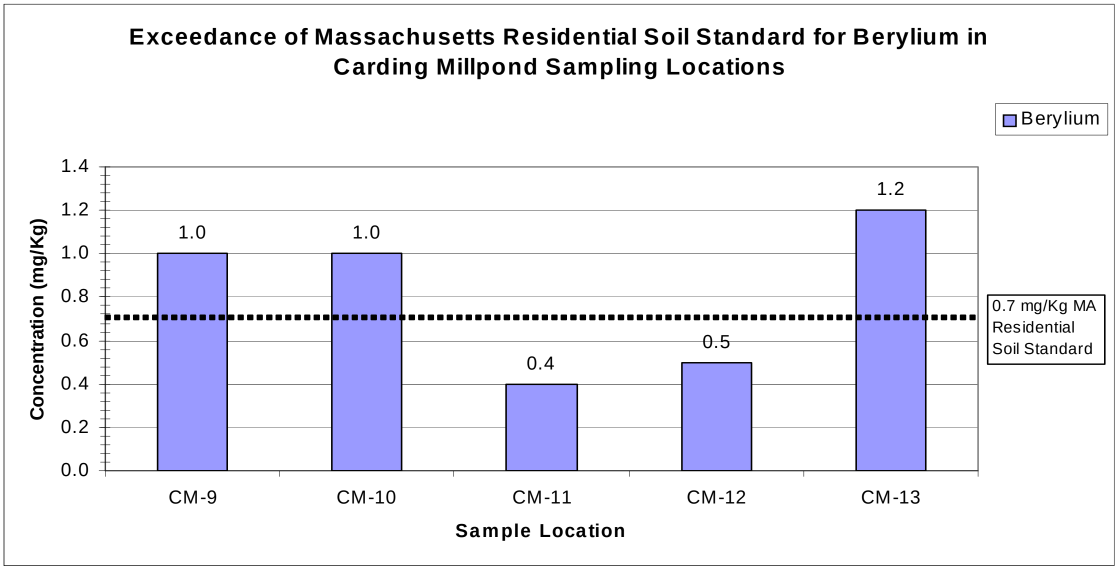

Exceedance of Massachusetts Residential Soil Standard for Cadmium in Hager Pond Sampling Locations
Concentration (mg/Kg)
20
18
16
14
12
10
8
6
4
2
0
3.8
0.79
0.58
18.6
9.8
HP-01
HP-02
HP-03
HP-04
HP-05
Sample Location
Cadmium
2 mg/Kg MA Residential Soil Standard

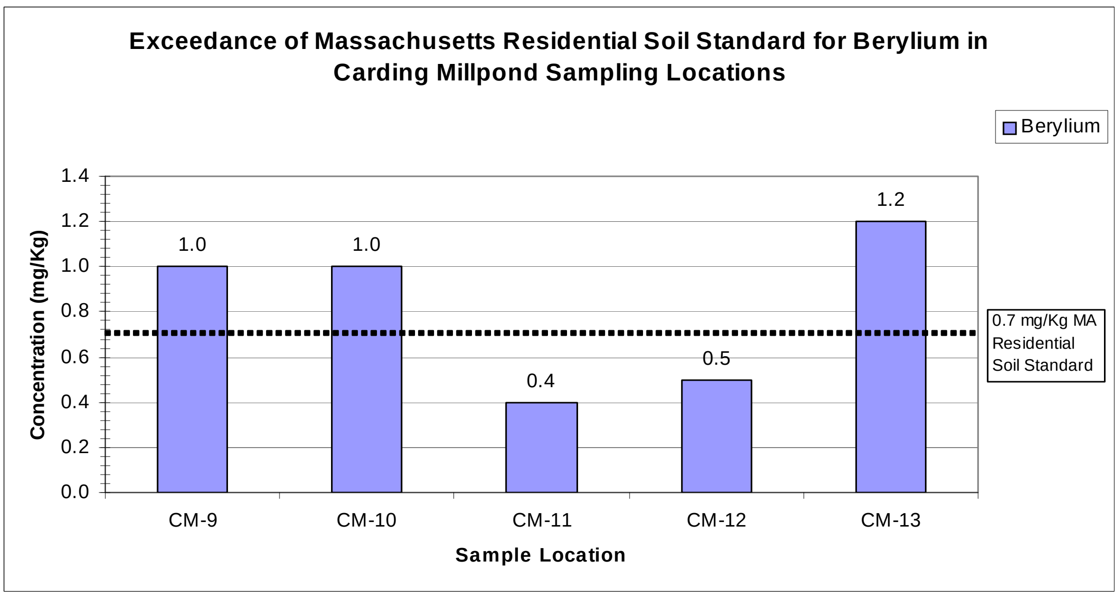

Exceedance of Massachusetts Residential Soil Standard for Chromium in Hager Pond Sampling Locations
Concentration (mg/Kg)
40
35
30
25
20
15
10
5
0
19.9
10.9
17.9
34
20.8
HP-01
HP-02
HP-03
HP-04
HP-05
Sample Location
30 mg/Kg MA Residential Soil Standard
Chromium

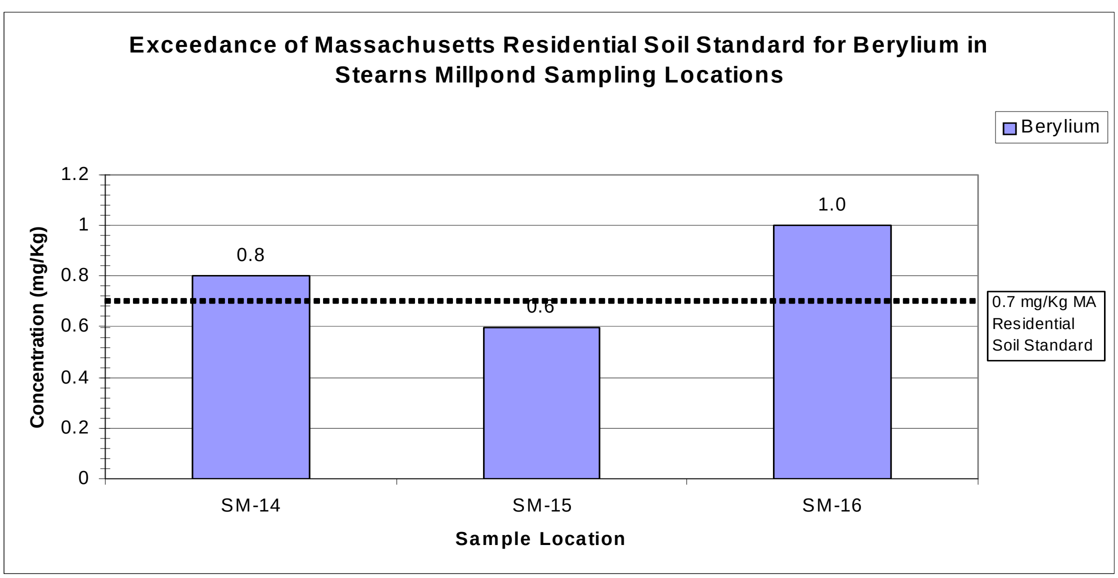

Exceedance of Massachusetts Residential Soil Standard for Lead in Hager Pond Sampling Locations
400
350
300
250
200
150
100
50
0
Concentration (mg/Kg)
120
33.3
41.7
339
149
300 mg/Kg MA Residential Soil Standard
Lead
HP-01
HP-02
HP-03
HP-04
HP-05
Sample Location

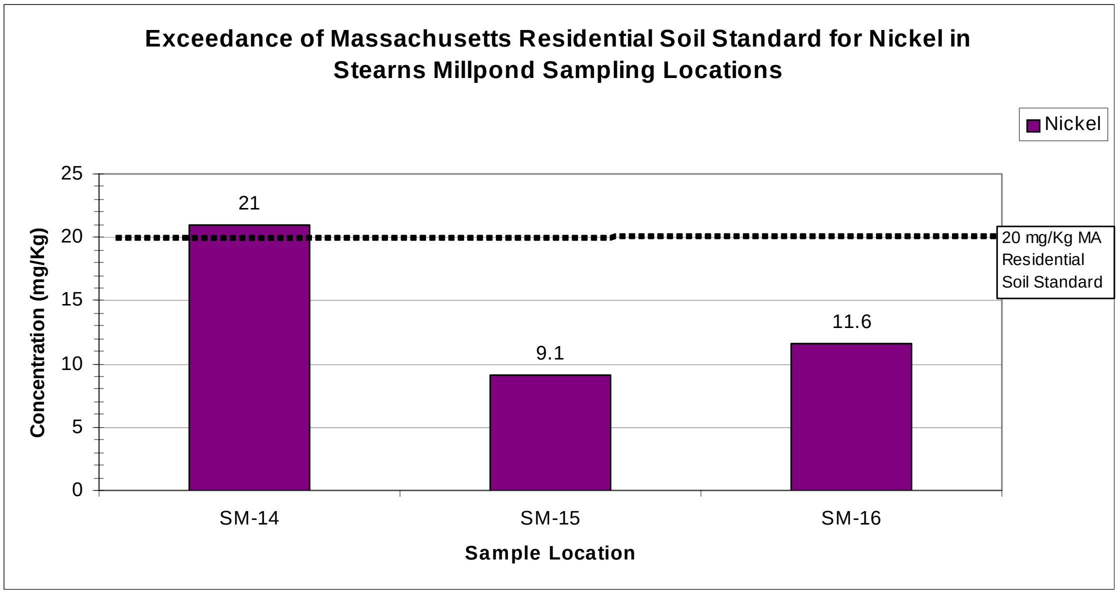

Exceedance of Massachusetts Residential Soil Standard for Berylium in Grist Millpond Sampling Locations
Berylium
1.2
1
0.8
0.6
0.4
0.2
0
Concentration (mg/Kg)
0.5
1
0.9
0.7 mg/Kg MA Residential Soil Standard
GM-06
GM-07
GM-08
Sample Location

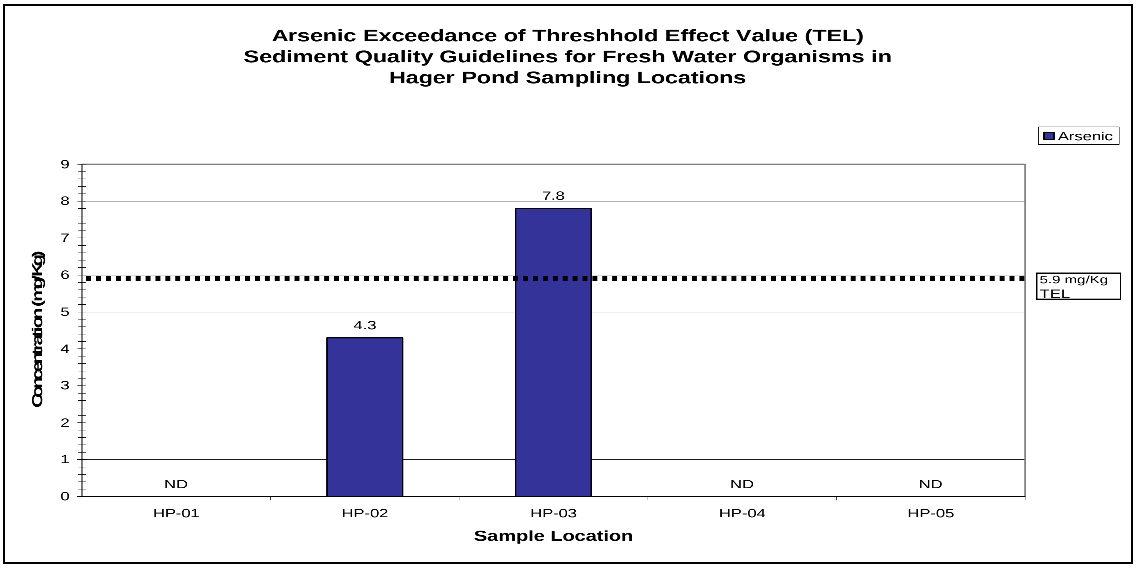

Exceedance of Massachusetts Residential Soil Standard for Cadmium in Grist Millpond Sampling Locations
Cadmium
4
3.5
3
2.5
2
1.5
1
0.5
0
Concentration (mg/Kg)
1
3.8
2.9
2 mg/Kg MA Residential Soil Standard
GM-06
GM-07
GM-08
Sample Location

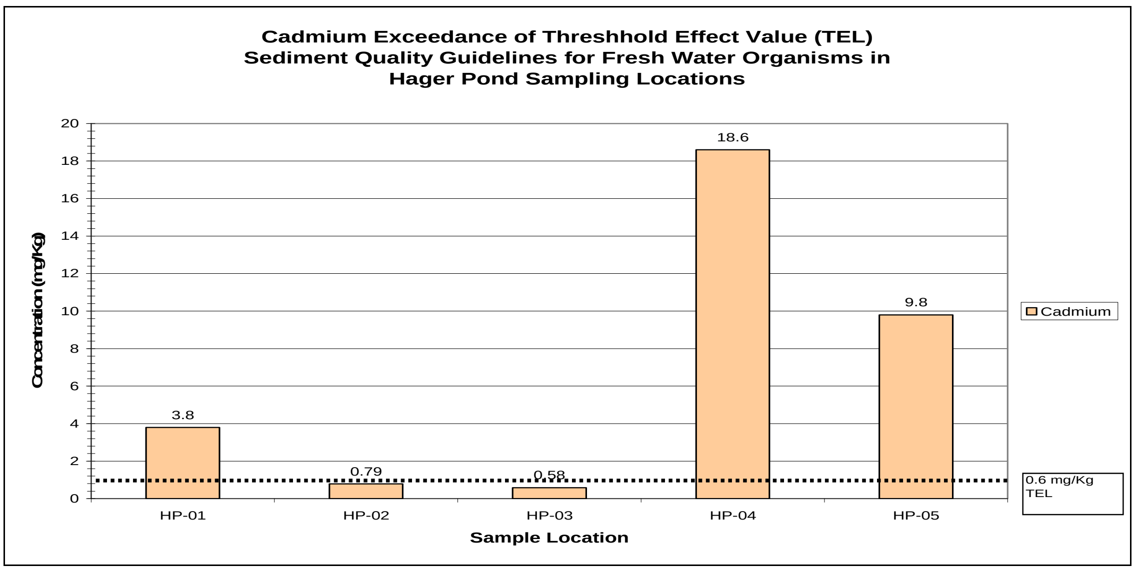

Exceedance of Massachusetts Residential Soil Standard for Berylium in Carding Millpond Sampling Locations
Berylium
Concentration (mg/Kg)
1.4
1.2
1.0
0.8
0.6
0.4
0.2
0.0
1.0
1.0
0.4
0.5
1.2
0.7 mg/Kg MA Residential Soil Standard
CM-9
CM-10
CM-11
CM-12
CM-13
Sample Location

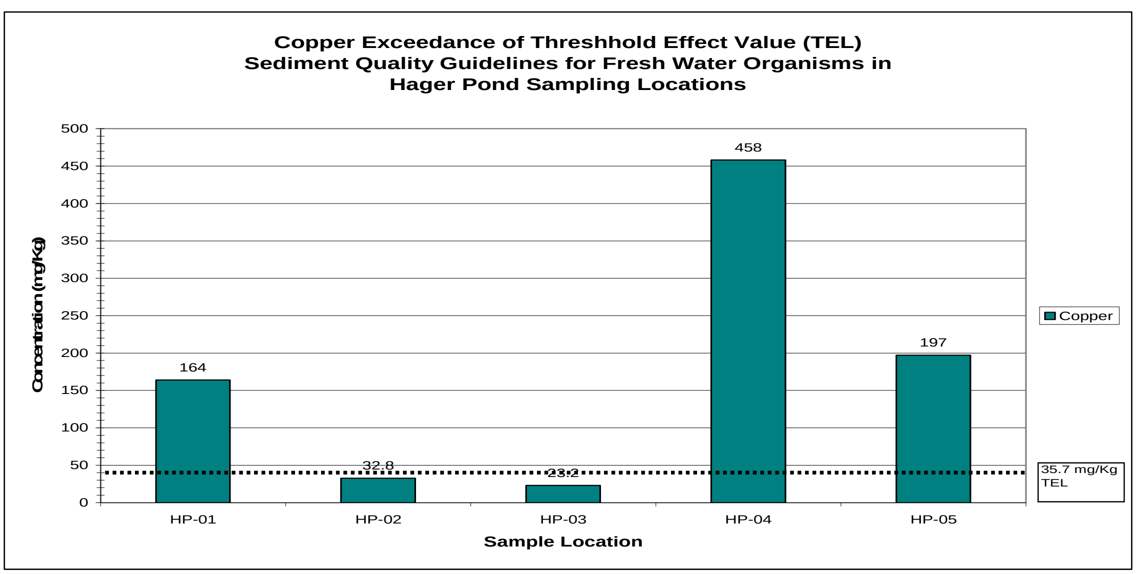

Exceedance of Massachusetts Residential Soil Standard for Berylium in Carding Millpond Sampling Locations
Berylium
Concentration (mg/Kg)
1.4
1.2
1.0
0.8
0.6
0.4
0.2
0.0
1.0
1.0
0.4
0.5
1.2
0.7 mg/Kg MA Residential Soil Standard
CM-9
CM-10
CM-11
CM-12
CM-13
Sample Location

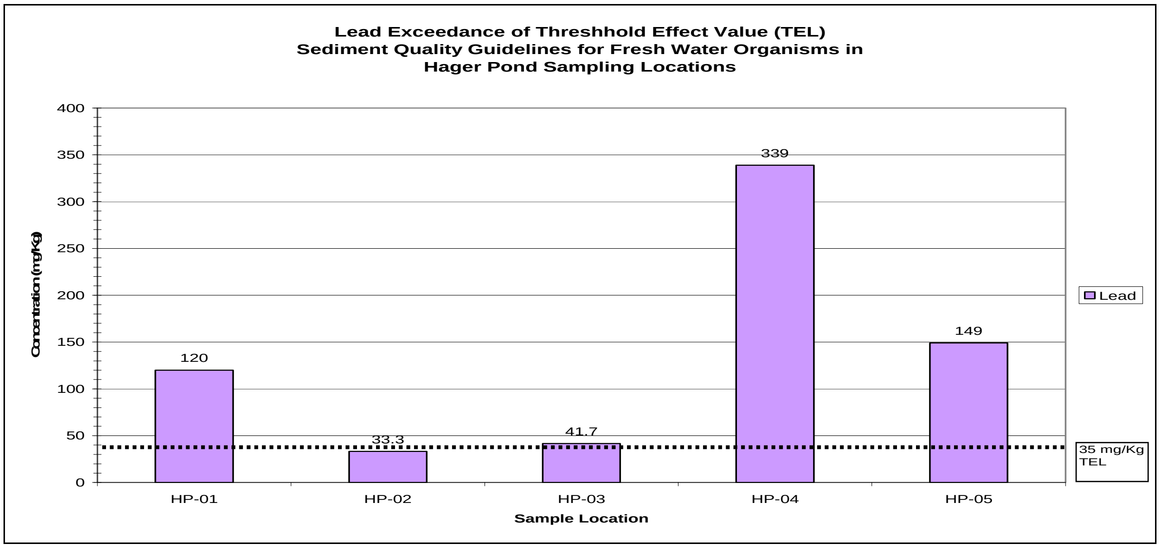

Exceedance of Massachusetts Residential Soil Standard for Berylium in Stearns Millpond Sampling Locations
Berylium
Concentration (mg/Kg)
1.2
1
0.8
0.6
0.4
0.2
0
0.8
0.6
1.0
0.7 mg/Kg MA Residential Soil Standard
SM-14
SM-15
SM-16
Sample Location

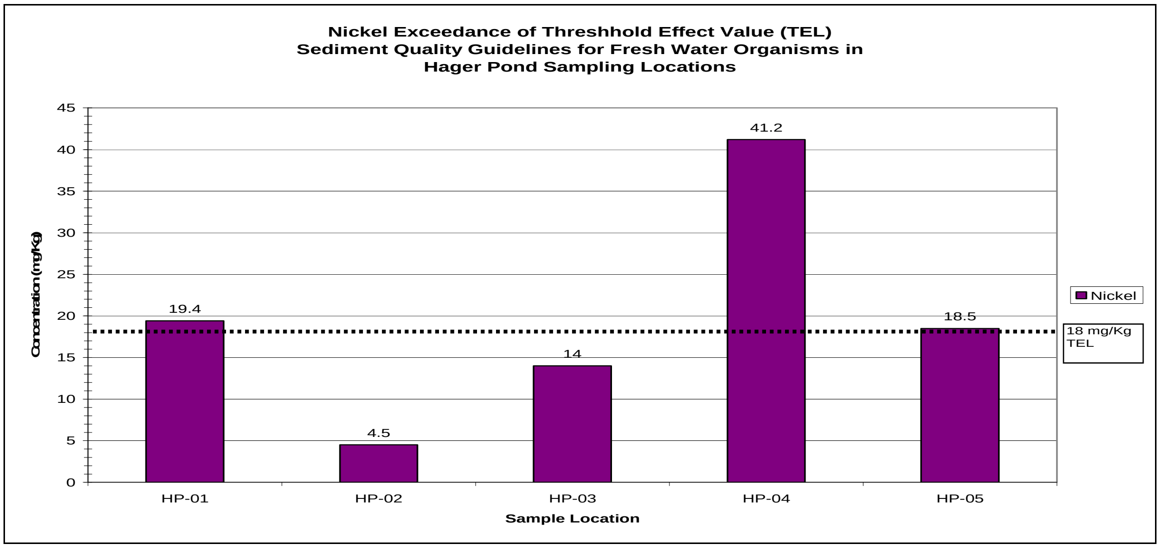

Exceedance of Massachusetts Residential Soil Standard for Nickel in Stearns Millpond Sampling Locations
Nickel
25
20
15
10
5
0
Concentration (mg/Kg)
21
9.1
11.6
20 mg/Kg MA Residential Soil Standard
SM-14
SM-15
SM-16
Sample Location

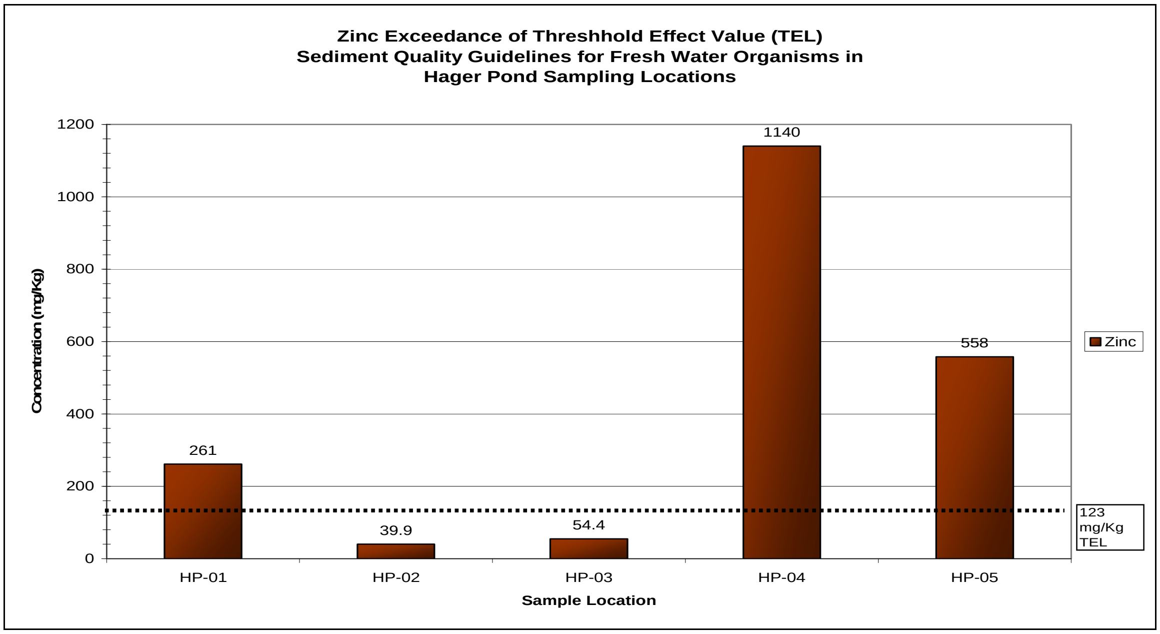

Arsenic Exceedance of Threshhold Effect Value (TEL)
Sediment Quality Guidelines for Fresh Water Organisms in
Hager Pond Sampling Locations
Arsenic
Concentration (mg/Kg)
0
1
2
3
4
5
6
7
8
9
ND
4.3
7.8
ND
ND
5.9 mg/Kg
TEL
HP-01
HP-02
HP-03
HP-04
HP-05
Sample Location

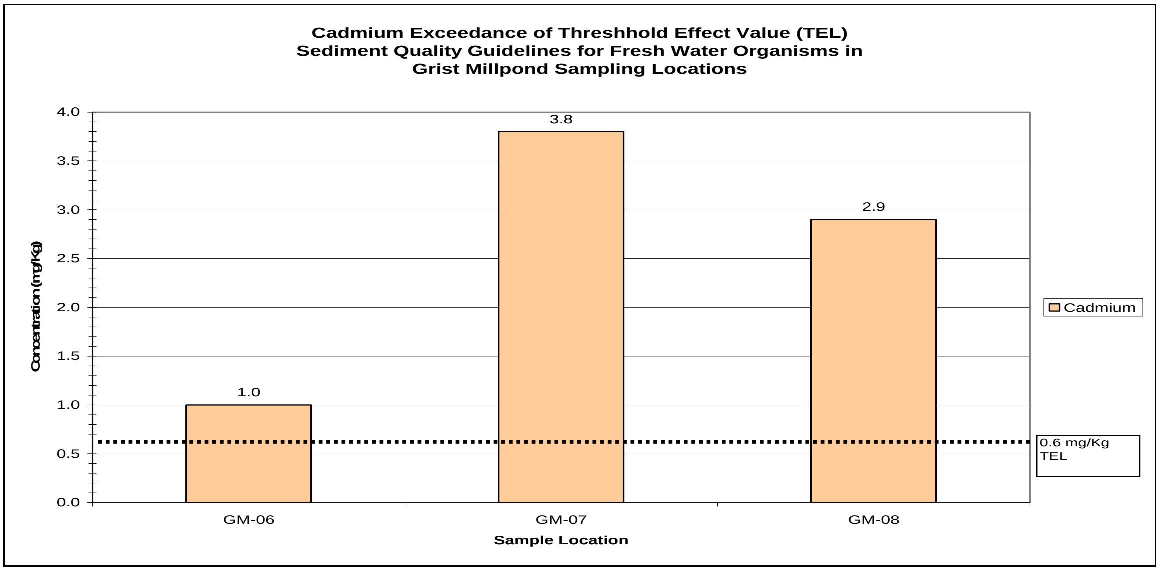

Cadmium Exceedance of Threshhold Effect Value (TEL)
Sediment Quality Guidelines for Fresh Water Organisms in
Hager Pond Sampling Locations
Concentration (mg/Kg)
0
2
4
6
8
10
12
14
16
18
20
3.8
0.79
0.58
18.6
9.8
Cadmium
0.6 mg/Kg
TEL
HP-01
HP-02
HP-03
HP-04
HP-05
Sample Location

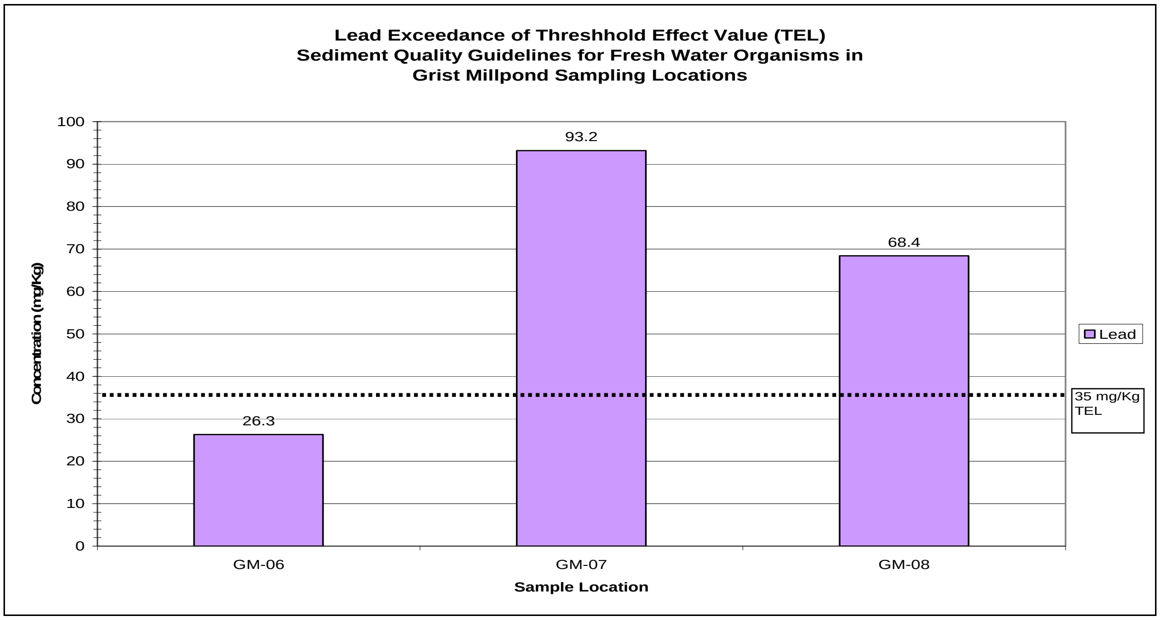

Copper Exceedance of Threshhold Effect Value (TEL)
Sediment Quality Guidelines for Fresh Water Organisms in
Hager Pond Sampling Locations
Concentration (mg/Kg)
0
50
100
150
200
250
300
350
400
450
500
164
32.8
23.2
458
197
Copper
35.7 mg/Kg
TEL
HP-01
HP-02
HP-03
HP-04
HP-05
Sample Location

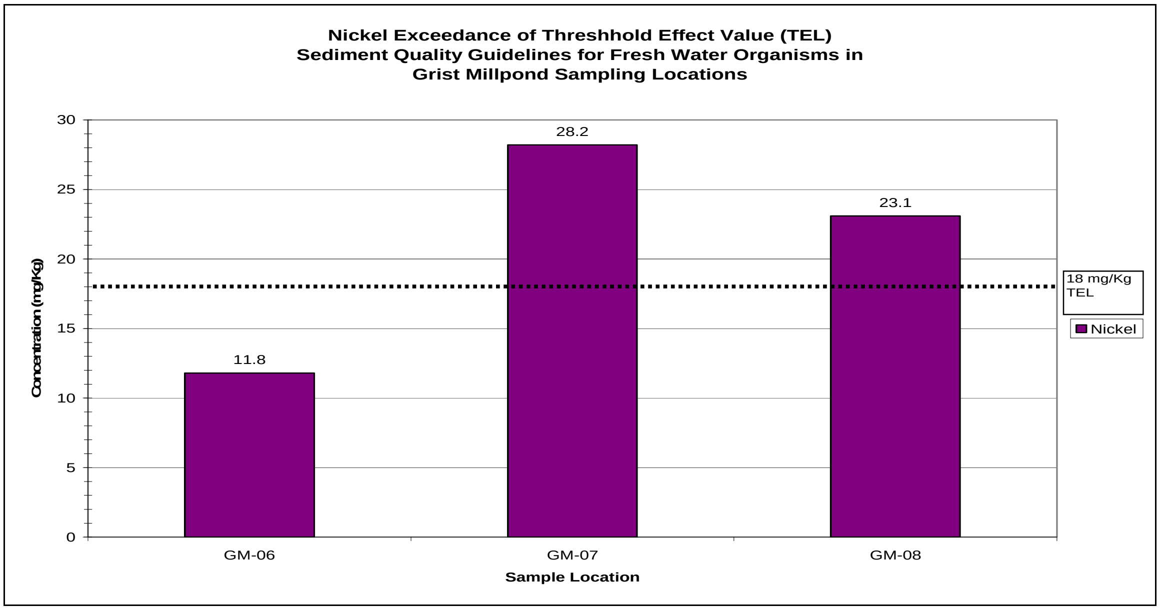

Lead Exceedance of Threshhold Effect Value (TEL)
Sediment Quality Guidelines for Fresh Water Organisms in
Hager Pond Sampling Locations
Concentration (mg/Kg)
400
350
300
250
200
150
100
50
0
120
33.3
41.7
339
149
Lead
35 mg/Kg TEL
HP-01
HP-02
HP-03
HP-04
HP-05
Sample Location

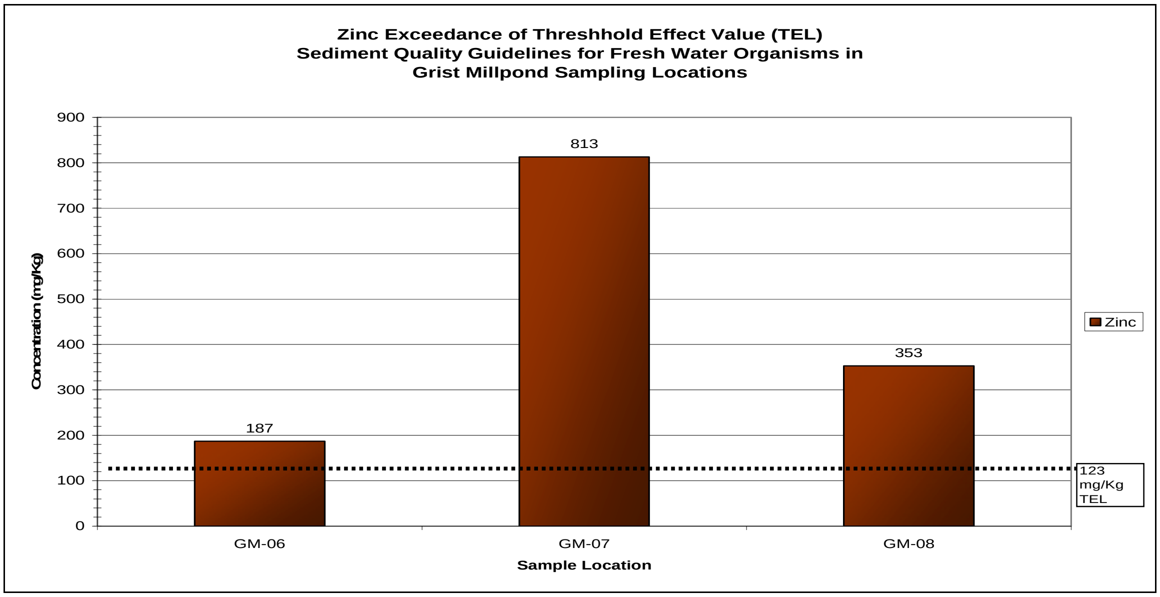

Nickel Exceedance of Threshhold Effect Value (TEL)
Sediment Quality Guidelines for Fresh Water Organisms in
Hager Pond Sampling Locations
Concentration (mg/Kg)
45
40
35
30
25
20
15
10
5
0
19.4
4.5
14
41.2
18.5
Nickel
18 mg/Kg TEL
HP-01
HP-02
HP-03
HP-04
HP-05
Sample Location

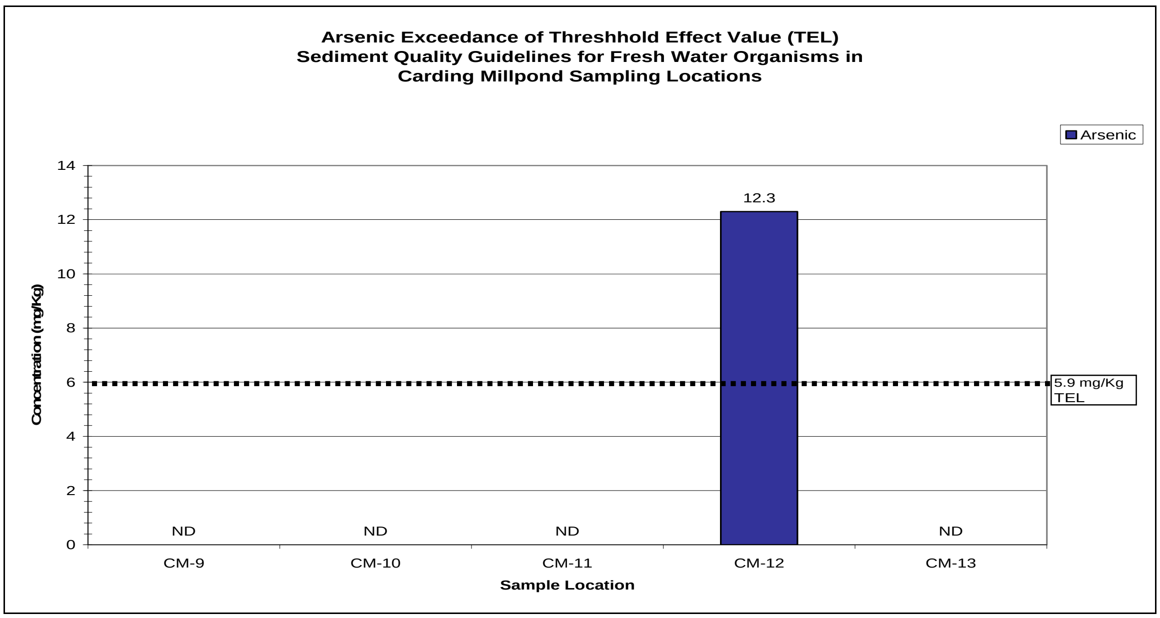

Zinc Exceedance of Threshhold Effect Value (TEL)
Sediment Quality Guidelines for Fresh Water Organisms in
Hager Pond Sampling Locations
Concentration (mg/Kg)
1200
1000
800
600
400
200
0
261
39.9
54.4
1140
558
Zinc
123 mg/Kg TEL
HP-01
HP-02
HP-03
HP-04
HP-05
Sample Location

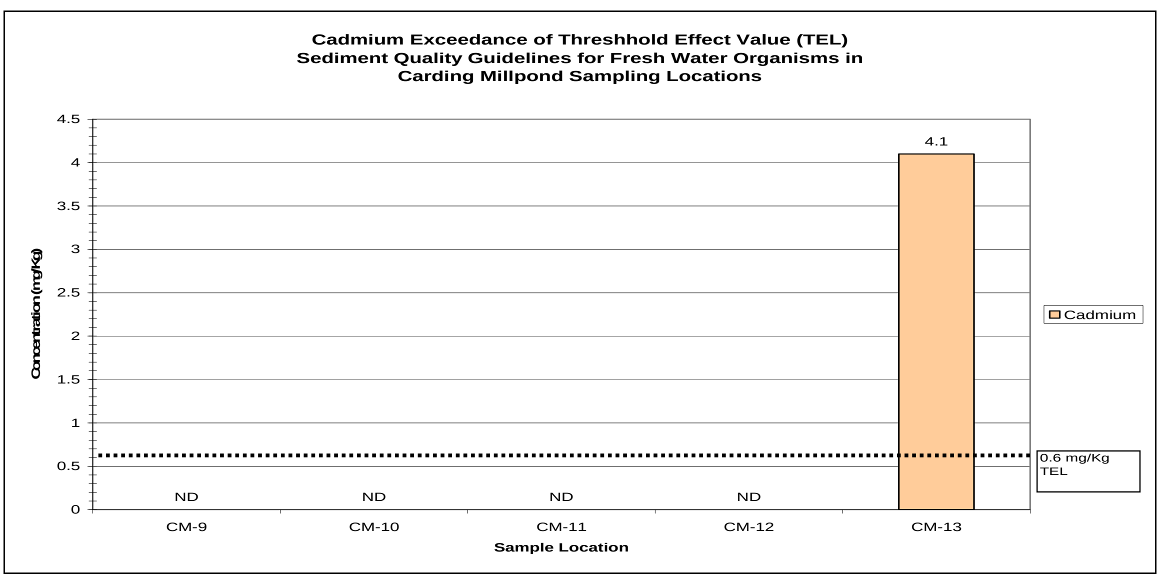

Cadmium Exceedance of Threshhold Effect Value (TEL)
Sediment Quality Guidelines for Fresh Water Organisms in
Grist Millpond Sampling Locations
Concentration (mg/Kg)
4.0
3.5
3.0
2.5
2.0
1.5
1.0
0.5
0.0
1.0
3.8
2.9
Cadmium
0.6 mg/Kg
TEL
GM-06
GM-07
GM-08
Sample Location

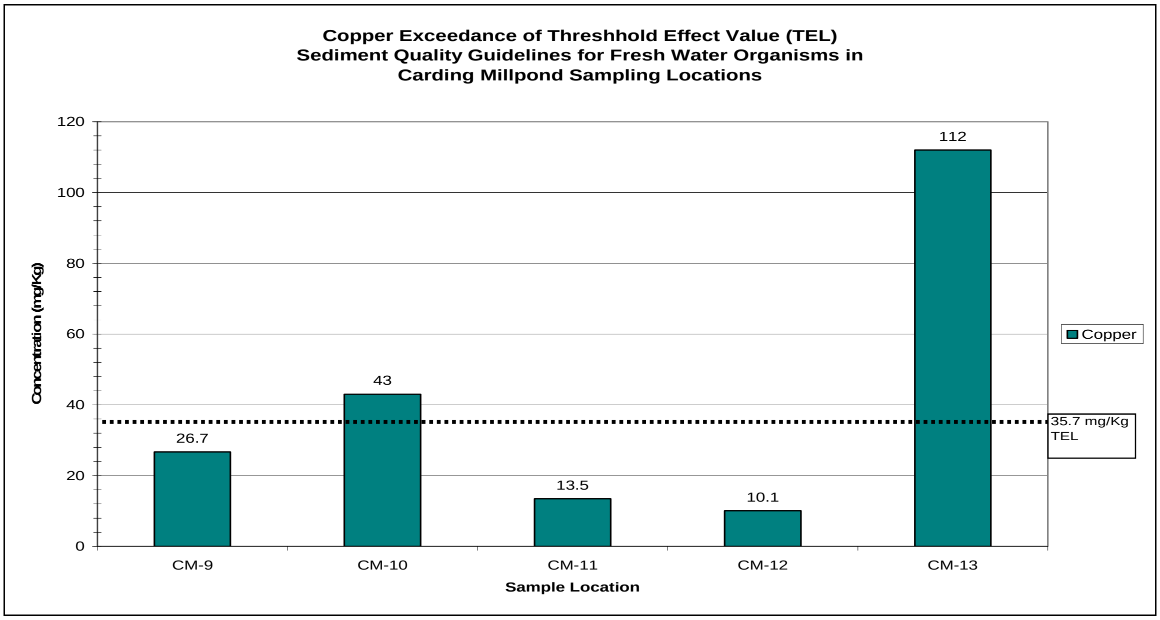

Lead Exceedance of Threshhold Effect Value (TEL)
Sediment Quality Guidelines for Fresh Water Organisms in
Grist Millpond Sampling Locations
Concentration (mg/Kg)
100
90
80
70
60
50
40
30
20
10
0
26.3
93.2
68.4
Lead
35 mg/Kg
TEL
GM-06
GM-07
GM-08
Sample Location


Nickel Exceedance of Threshhold Effect Value (TEL)
Sediment Quality Guidelines for Fresh Water Organisms in
Grist Millpond Sampling Locations
Concentration (mg/Kg)
30
25
20
15
10
5
0
11.8
28.2
23.1
18 mg/Kg
TEL
Nickel
GM-06
GM-07
GM-08
Sample Location

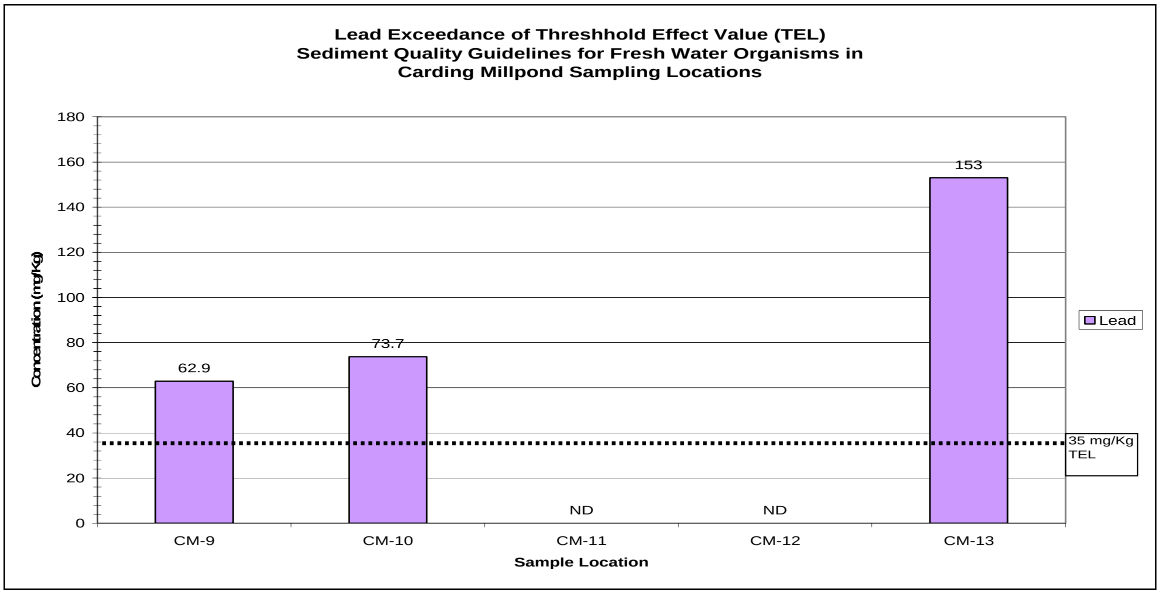

Zinc Exceedance of Threshhold Effect Value (TEL)
Sediment Quality Guidelines for Fresh Water Organisms in
Grist Millpond Sampling Locations
900
800
700
600
500
400
300
200
100
0
Concentration (mg/Kg)
187
813
353
Zinc
123 mg/Kg TEL
GM-06
GM-07
GM-08
Sample Location


Arsenic Exceedance of Threshhold Effect Value (TEL)
Sediment Quality Guidelines for Fresh Water Organisms in
Carding Millpond Sampling Locations
Arsenic
14
12
10
8
6
4
2
0
Concentration (mg/Kg)
12.3
5.9 mg/Kg TEL
ND
ND
ND
ND
CM-9
CM-10
CM-11
CM-12
CM-13
Sample Location

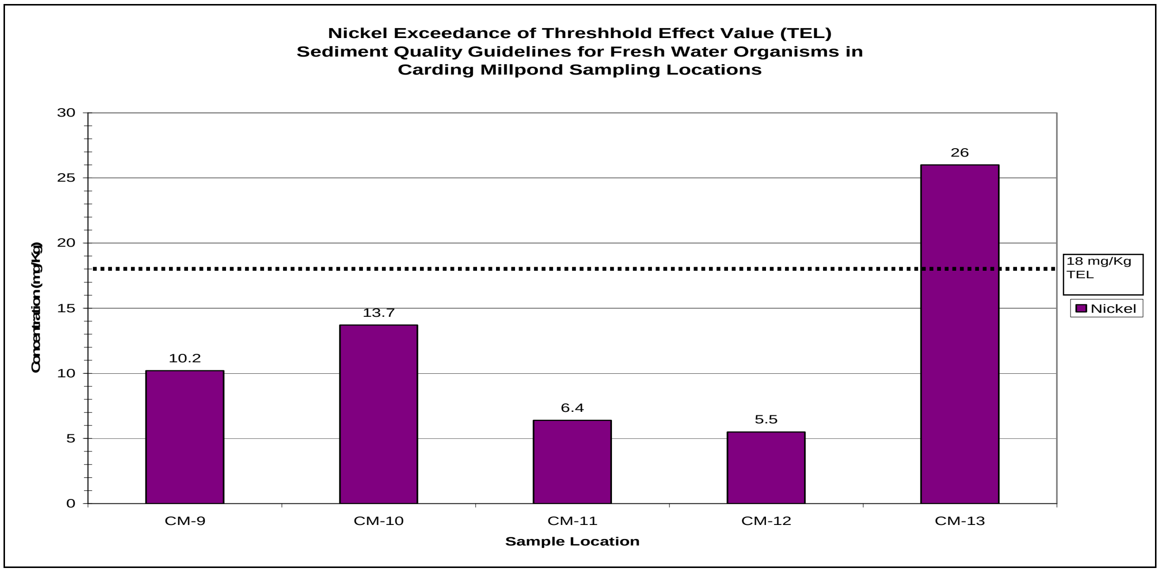

Cadmium Exceedance of Threshhold Effect Value (TEL)
Sediment Quality Guidelines for Fresh Water Organisms in
Carding Millpond Sampling Locations
4.5
4
3.5
3
2.5
2
1.5
1
0.5
0
Concentration (mg/Kg)
4.1
Cadmium
0.6 mg/Kg TEL
ND
ND
ND
ND
CM-9
CM-10
CM-11
CM-12
CM-13
Sample Location



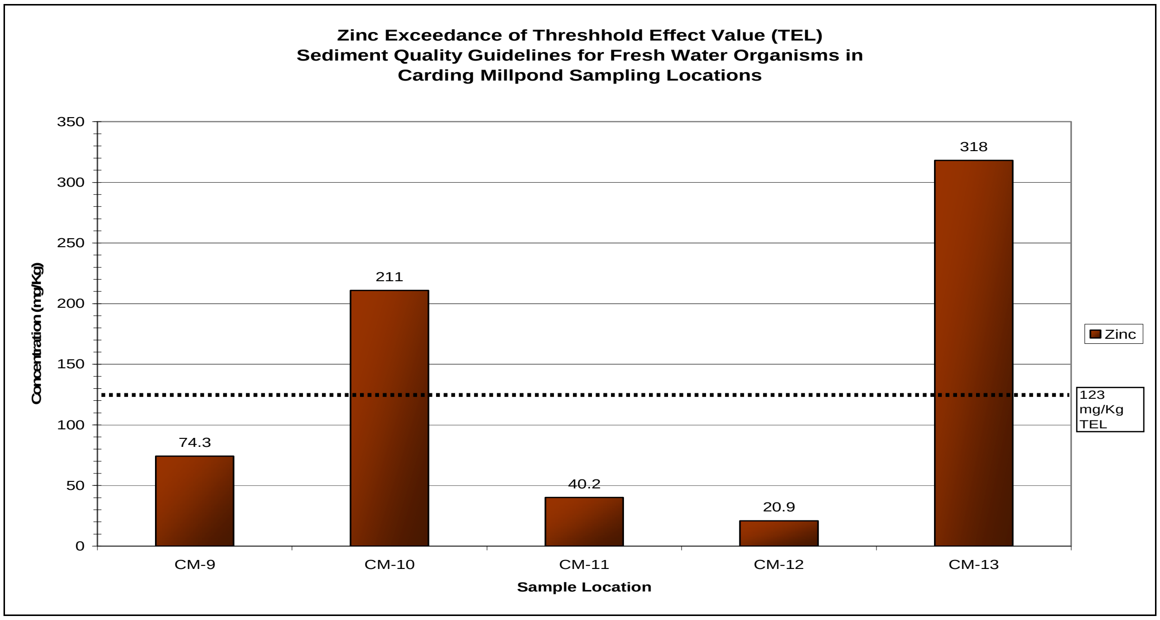
Copper Exceedance of Threshhold Effect Value (TEL)
Sediment Quality Guidelines for Fresh Water Organisms in
Carding Millpond Sampling Locations
Concentration (mg/Kg)
120
100
80
60
40
20
0
26.7
43
13.5
10.1
112
Copper
35.7 mg/Kg
TEL
CM-9
CM-10
CM-11
CM-12
CM-13
Sample Location

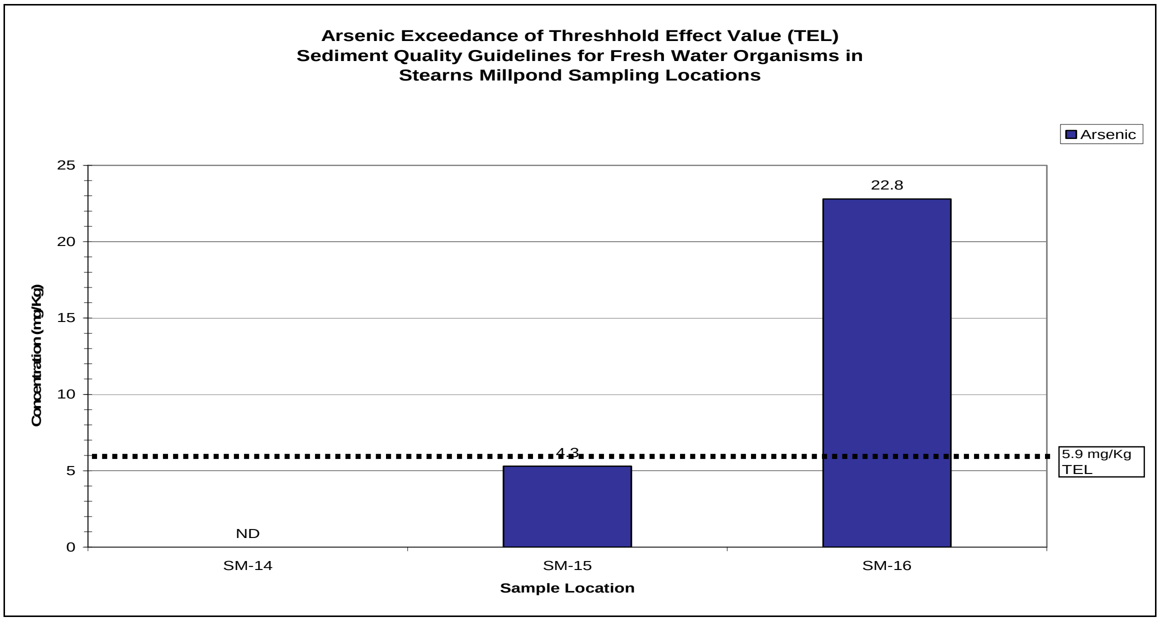


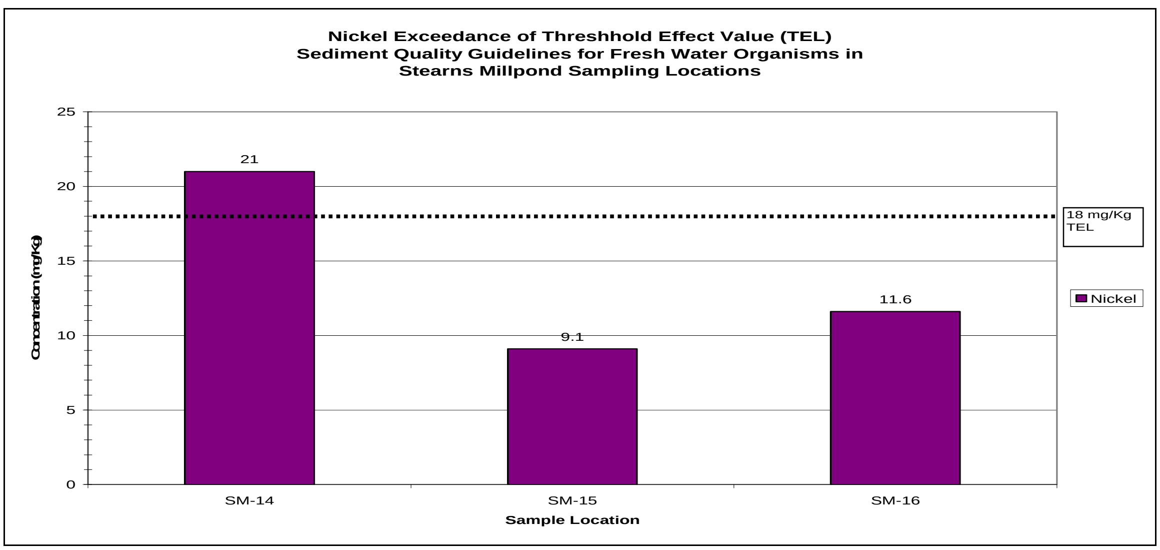
Lead Exceedance of Threshhold Effect Value (TEL)
Sediment Quality Guidelines for Fresh Water Organisms in
Carding Millpond Sampling Locations
Concentration (mg/Kg)
180
160
140
120
100
80
60
40
20
0
62.9
73.7
ND
ND
153
Lead
35 mg/Kg
TEL
CM-9
CM-10
CM-11
CM-12
CM-13
Sample Location



Nickel Exceedance of Threshhold Effect Value (TEL)
Sediment Quality Guidelines for Fresh Water Organisms in
Carding Millpond Sampling Locations
Concentration (mg/Kg)
30
25
20
15
10
5
0
10.2
13.7
6.4
5.5
26
18 mg/Kg
TEL
Nickel
CM-9
CM-10
CM-11
CM-12
CM-13
Sample Location


Zinc Exceedance of Threshhold Effect Value (TEL)
Sediment Quality Guidelines for Fresh Water Organisms in
Carding Millpond Sampling Locations
Concentration (mg/Kg)
350
300
250
200
150
100
50
0
74.3
211
40.2
20.9
318
CM-9
CM-10
CM-11
CM-12
CM-13
Sample Location
Zinc
123 mg/Kg TEL


Arsenic Exceedance of Threshhold Effect Value (TEL)
Sediment Quality Guidelines for Fresh Water Organisms in
Stearns Millpond Sampling Locations
Arsenic
Concentration (mg/Kg)
25
20
15
10
5
0
ND
4.3
22.8
SM-14
SM-15
SM-16
Sample Location
5.9 mg/Kg TEL


Nickel Exceedance of Threshhold Effect Value (TEL)
Sediment Quality Guidelines for Fresh Water Organisms in
Stearns Millpond Sampling Locations
Concentration (mg/Kg)
25
20
15
10
5
0
21
9.1
11.6
SM-14
SM-15
SM-16
Sample Location
18 mg/Kg TEL
Nickel

Appendix D – Natural Resources

NATURAL RESOURCES APPENDIX

A. INTRODUCTION

1. Description

Hop Brook is a small stream located in Marlborough, Massachusetts that is formed by runoff from Ward Hill, within the Concord River watershed in east central Massachusetts. The Concord River watershed lies within the Merrimack River basin which includes north and south central New Hampshire and Northeastern Massachusetts. Hop Brook flows a distance of approximately 12 miles to its confluence with the Sudbury River in Sudbury, Massachusetts. The Sudbury River flows an additional 10 miles to its confluence with the Assabet River in Concord, which together with the Sudbury River forms the Concord River. The Concord River flows an additional 16 miles to its confluence with the Merrimack River in Lowell, flowing about an additional 35 miles to the Atlantic Ocean in Newburyport, Massachusetts.

Hop Brook has been the subject of several water quality studies during recent years due to the excessive nutrients (phosphorus and nitrogen) that have entered the brook from the watershed. The Marlborough Wastewater Treatment Plant (MWWTP) discharges into Hop Brook near its headwaters, and it is believed that excess nutrients (phosphorus and nitrogen) from this discharge are primarily responsible for eutrophication at four downstream impoundments, resulting in excessive aquatic macrophytes and algal growth. Current upgrades to the MWWTP include improvements to its tertiary treatment to limit concentrations of phosphorus and nitrogen. The impact of this wastewater treatment plant is significant in that during periods of low flow (July-September) it is believed that at least 75% of the total stream volume in Hop Brook is comprised of effluent from this facility (ENSR Report, 2001).

The downstream impoundments affected by these excess nutrients lie within five miles of the headwaters in the communities of Marlborough and Sudbury and include (in order from upstream to downstream) Hager Pond, Grist Millpond, Carding Millpond and Stearns Millpond. In addition to the nutrients entering these impoundments from the MWWTP, existing cycling of nutrients from the sediments in these ponds, as well as other non-point sources may be contributing to the ongoing eutrophication problem. During the summer of 2006, field data and observations (meandering surveys) were collected in the section of Hop Brook that includes these four impoundments, in order to identify and assess alternatives for reducing internal phosphorus recycling from the sediments. This data consisted of Hydrolab field parameter recordings (pH, conductivity, dissolved oxygen, temperature, turbidity and % saturation) and natural history observations collected/recorded photographically during meandering surveys. Depth profiles were recorded with a Hummingbird fathometer and fish population data collected with backpack and boat mounted electro-shocking.

2. Riparian Habitat

As could be expected for a stream such as Hop Brook with three of the four historic dams in close proximity flowing through a suburban community in the midst of growth, the riparian areas are diverse and impacted by the highly eutrophic stream and the uplands. A study of watershed maps shows riparian areas that are very narrow surrounding much of Hager Pond, Grist Millpond and Stearns Millpond with more extensive riparian areas at the inflow into Carding Mills Pond. The riparian areas of greatest interest surrounding Hop Brook are between the discharge from Carding Millpond Dam and the inflow to Stearns Millpond. Northwest and southeast of Hop Brook in this area are two wetland complexes identified by MA Division of Fish and Wildlife as "Estimated Habitats of Rare Wildlife". The riparian area surrounding Hop Brook provides a connection between these two habitats where rare wildlife has been identified. There are several state listed species of amphibians/reptiles reported in this area. This habitat includes land managed by U.S. Fish and Wildlife Service between Carding and Stearns Millpond. There has been extensive housing development in this area just outside U.S. Fish and Wildlife Service property which has further limited the width of the riparian corridor. Riparian corridors are critical for large predators such as coyote and bobcats since they provide the access to sufficient niche to support a breeding population.

3. Fish

There was no fishery data available from the MA Division of Fish and Wildlife, since Hop Brook is not stocked. To document some fish data for the area of Hop Brook to be impacted by the alternatives of this study, portions of Hager and Carding Millponds and a section of Hop Brook proper was sampled by boat mounted and backpack electro-fishing. Because most areas of Hop Brook that were able to be easily sampled required access across private property only one section of Hop Brook just downstream of Carding Millpond was sampled. There was evidence that the four ponds provided recreational fishery both from the shore and small boats. There is a boat ramp at Carding Millpond. The results of fish sampling documented a well developed warm water fish community for Carding Millpond and a less well developed community at Hager Pond. Although not sampled because of the unavailability of a launch area for the sampling boat, Grist Millpond should also support a similar fish community since Grist Millpond was the deepest of the four ponds. Stearns Millpond is the most shallow pond and although not sampled, probably also supports a warm water fishery similar to Hager Pond.

Hop Brook possesses a warm water fishery, the stock most likely from the upstream ponds. It is unlikely any portion of Hop Brook within the project area supports a cold water fishery since the discharge of the Marlborough Wastewater Treatment Plant provides a significant volume of the flow of Hop Brook. There is one inflow to Grist Millpond that may be able to support native brook trout upstream of the inflow into Grist Millpond. The various alternatives of complete/partial dam removal will modify the fish community from lacustrine/pond community to a stream community. Although only one section of Hop Brook was sampled, the Hop Brook fish survey produced two lacustrine species, largemouth bass and bullhead. Both these species were young of the year, most likely produced in Carding Millpond. American eel was also sampled from this section of stream. With the removal of each downstream barrier, over time the lacustrine species (largemouth bass) will probably be replaced by lentic/lotic species (dace, fallfish, shiners, and smallmouth bass). The partial/complete removal of Grist Millpond Dam will interfere with the above described change in fish population from lacustrine to stream varieties. With the continued presence of Grist Millpond Dam it will remain an impediment to block the passage of these stream varieties of fish upstream into Hager Pond and beyond. If one of the objectives is unimpeded fish passage to the headwaters of Hop Brook, a fish ladder must be constructed at the Grist Millpond Dam with Alternatives 1-5. And in addition Alternative 1 will require a fish ladder on Stearns Millpond Dam and Carding Millpond Dam, Alternative 2 will require a fish ladder on Hager Millpond Dam, Alternative 3 will require a fish ladder on Stearns Millpond and Hager Pond, Alternative 4-6 will require similar but less extensive fish ladders since they reflect a partial dam removal. Since the spillway at Hager Pond is partially breached, the new ladder at Hager Pond will be a minimal structure.

4. Aquatic Invertebrates

The aquatic invertebrate data is limited to zooplankton richness and diversity in the impoundments collected as a portion of the "Nutrient Impact Evaluation of Hop Brook in Marlborough and Sudbury, MA" by ENSR in October 2000. Zooplankton studies completed in October1999 by ENSR showed low densities of zooplankton at all the impoundments with the exception of Hager Pond. Zooplankton density increased over the growth season at Hager Pond but remained fairly stable in Grist Millpond, Carding Millpond and Stearns Millpond. Rotifers, copepods and cladocerans were observed in almost all samples with low densities. The Hager Pond sample with the greatest density of zooplankton was dominated by cladocerans. Average body size for zooplankton community was low, especially during periods of low flow. Predation by young of the year fish or by being flushed from the ponds during high flow may be the cause of the small average size of these invertebrates since such an enriched environment would be expected to support a greater zooplankton community. Poor water quality conditions such as a low dissolved oxygen concentration especially at times with high BOD and COD may be causes for these low values.

There is no benthic invertebrate data available from the impoundments or from Hop Brook. As a portion of the field work conducted in this study it was observed that a significant area of the substrate of the inflow of Hager Pond downstream of the discharge of the MWWTP beginning at the downstream side of the culvert under Route 20 was covered with an unknown thickness of a finely divided material, probably alum, used in the flocculation process at the plant. Water depth in this area ranged from less than an inch to about two feet. This material effectively smothered rooted aquatic macrophyte growth and probably smothered the benthic invertebrate community as well. The substrate of most of the other Millponds was finely divided silt. This substrate tends to support a benthic invertebrate community limited to Dipteran species such as midge and black fly species. An exception to a substrate of finely divided silt, the inflow of Hop Brook into Stearns Millpond consisted of washed coarse sand and small rocks. This coarse sand substrate continued into Stearns Millpond for short distance where it resumed the silt character present in the other millponds. Hop Brook upstream of Hager Pond, between Hager and Grist Millpond, Grist Millpond and Carding Millpond, and Carding Millpond and Stearns Millpond was a mix of riffles and pools depending on the gradient of the flow. A qualitative examination of the undersides of rocks from the streambed of the riffle area revealed a diverse assemblage of stonefly, caddis fly and Dobson/alderflies. In the area of Hop Brook just downstream from Carding Millpond dam that was fish sampled, there was a dense growth of freshwater sponges. The many lightly colored sponge colonies were very conspicuous growing on the darkly colored stones in the streambed. This diverse assemblage of benthic invertebrates may be unique to this area. Freshwater sponges generally are considered to be an indicator of better than average water quality. This area of Hop Brook also supported a large population of crayfish.

5. Wetland and Riparian Vegetation

Within the study area, the most extensive wetland areas are:

a) south and east of Carding Millpond,
b) the area to the east and west of Hop Brook downstream of Carding Millpond from where Hop Brook flows under French Road to the inflow of Stearns Millpond,
c) the area upstream and adjacent to Grist Millpond,
d) Wetland complex just south of Hager Pond.

There are smaller wetlands such as a wetland complex incorporated in a recreational area at the Raytheon Plant located on the west shore of Hager Pond. Detail on each wetland is included in the discussion of specific portions of the study area.

Riparian areas that have the greatest importance in the study area are as stated above. They are adjacent to Hop Brook from the Dutton Road culvert downstream of the Carding Millpond dam discharge and they extend to the inflow of Hop Brook into Stearns Millpond. The riparian vegetation is characteristic of a series of diverse wetland communities. The riparian flora is typically associated with a wooded deciduous swamp dominated by red maple/high bush blueberry/winterberry, shrub swamp dominated by willow/alder/button bush, deep marsh dominated by tussock sedge and cattail and mixed wooded swamp consisting of red maple and slightly elevated areas with white pine and hemlock. There are several certified vernal pools in and adjacent to these riparian areas. It is important the riparian corridor remains since it is connected to two large parcels to the east and west of Hop Brook classified by MA Natural Heritage as “Estimated Habitats of Rare Wildlife”. The larger portion of these parcels is west of Hop Brook with much of this habitat owned by U.S. Fish and Wildlife property associated with the Assabet River and Oxbow National Wildlife Refuge. The riparian corridor provided by the wetland habitats associated with Hop Brook is critical for listed and other animals to access these large areas to the east and west. To estimate the impact on wetland resources of the mitigation Alternatives 1-6 on the various wetlands in the study area, a hydraulic model (HEC-RAS model) was prepared. Calculations of Channel Surface Water Elevation (CWSEL) in feet NGVD and Velocity Channel (VCH) in cfs were created with the HEC-RAS Model at several stations upstream and downstream of each impoundment.

The calculations were made with average August low flows and with 10 year average flows. A modeled area was calculated using a cross section narrow wetland channel just upstream of Stearns Millpond.

The models indicate Alternative 2, removal of Carding/Stearns Millpond dams, Alternative 3, removal of Carding Millpond dam, and Alternative 5 and 6 with a partial removal of the above dams, have impacts on CWSEL and VCH, and these changes are all about 0.5 ft. The other change was in the model upstream of Stearns Millpond in the riparian corridor which connects the State Listed “Estimated Habitats for Rare Wildlife”. Alternative 7, dredging sediment from all dams, also had a minor effect on CWSEL also about 0.5 ft. The overall effects of Alternatives 1-7 on CWSEL and VCH are minimal as calculated by the HEC-RAS Model. However since there is no extensive elevation data, the effects of the dam removal or notching on the wetlands upstream of the dams cannot be calculated. With dam removal the decline in water level will obviously impact wetlands acreage upstream of the impoundment as well as other peripheral fringing wetlands. There is insufficient data for a quantitative estimate of the wetlands lost with each of the Alternatives. Should this project continue, additional topographic survey data will be required to provide an accurate estimate for the impact of the various alternatives on the surrounding wetlands.

It is possible to provide a qualitative estimate of wetland loss with each of the Alternatives. With the removal of the Grist Millpond dam being ruled out as an Alternative, Carding Millpond possesses the largest wetland area that may be lost due to complete or partial dam removal. Another wetlands complex possibly affected by the partial/complete removal of Carding Millpond is an area just north and east of Carding Millpond, connected by a culvert under the cart road that traverses the north side of the pond. From a review of the U.S.G.S topographical sheets this inflow may provide water to a wetland complex north of French Road listed as “Estimated Habitats for Rare Wildlife” by MA Natural Heritage. Other wetland loss due to partial/complete dam removal may be two wetland complexes associated with the southern and western side of Hager Pond and the complex assemblage of wetland habitats upstream of the inflow of Stearns Millpond.

6. Invasive and Nuisance Species

The extensive distribution of filamentous green alga and aquatic macrophytes, both non-native/invasive and native floating and rooted species, have seriously impaired aquatic life, limited primary and secondary contact and the general aesthetics of the impoundments. The stated goal of this sediment study is to limit/remove these impairments from the study area. Invasive aquatic macrophytes include *Potamogeton crispis*, curly-leaf pondweed, and *Trapa natens*, waterchestnut. Also noted within the study area were isolated stands of the non-native *Phragmites australis*, the common reed and *Lythrum salicaria*, purple loosestrife. The *Phragmites* was not ubiquitous, present in large stands. For this project should any of the alternatives be selected that involved dam removal with the subsequent return of Hop Brook to a stabilized channel within the former channel, active measures should be employed to prevent the exposed areas of sediment from being overgrown with *Phragmites*. Without appropriate control measures, the areas of nutrient rich sediment exposed by the loss of the impoundments will be quickly overgrown by *Phragmites*.

Since Hop Brook in the study area is very eutrophic, native floating and rooted aquatic macrophytes such as *Lemna* (Duckweed) and Frog bit are a nuisance. These native varieties are individually less than a centimeter in diameter but with the high concentration phosphorus and nitrate/nitrite in the water and the sediment these small floating macrophytes become abundant forming a layer an inch or more in thickness across the entire surface area of each of the ponds. At Carding Millpond, windrows of the decomposing floating macrophyte were present throughout the spring/summer and fall. Duckweed and Frog bit were also visible into the winter. Another nuisance species is the microscopic green alga, *Hydrodictyon* (water net), which forms dense, green mats. Other native green alga species that become nuisance varieties in the presence of the unlimited nutrient supply contained and flowing through the study area are *Oedogonium* and *Nitella*.

To control the downstream discharge of this virulent crop of nuisance and invasive plant species, a silt curtain was deployed across the discharge/spillway of Carding Millpond. The aquatic macrophytes, especially water chestnut are present in large quantities requiring the used of mechanized aquatic weed harvesting several times over the summer months to limit the effects of accumulating decomposing plant material.

7. Wildlife

Hop Brook and the four millponds provide a green belt/riparian corridor through the industrial/commercial/ suburban congestion associated with Route 20, and the suburban development downstream of Route 20. This corridor connects to the Assabet and Concord Rivers and allows various animal species to utilize the isolated parcels of undeveloped conservation land/state forest. Research indicates smaller habitats are able to support greater numbers and diversity of animal species if there are connections with other similar habitats. The ability of various populations to exchange genetic information may encourage diversity within the species.

The area included in this proposed project contains many habitat magnets and more importantly is connected spatially and hydrologically to adjacent habitat. Habitat magnets are key landscape features that attract wildlife by providing niches (food, water, shelter, and breeding space).The area from the culvert under Dutton Road to the inflow into Stearns Millpond possesses greater habitat diversity than upstream areas. The habitat magnet hypothesis is supported in an informal study conducted by the Sudbury Conservation Commission on U.S. Fish and Wildlife property now a portion of the Assabet River National Wildlife Refuge, formally part of the Fort Devens Annex South. This property abuts west bank of Hop Brook between the culvert under Dutton Road and the inflow to Stearns Millpond. The numbers of amphibians and reptiles identified in this area were large, including several species listed as rare and of concern by MA Natural Heritage.

8. Rare Species Habitat

As expected for a riparian corridor with diverse habitats, there are several MA Natural Heritage species listed and located in the vicinity of the project site.

Table 1: Rare Species List

Scientific Name	**Common Name**	**State Status**
Ixobrychus exilis	Least Bittern	Endangered
Botaurus lentiginosus	American bittern	Endangered
Gallinula chloropus	Common Moorhen	Special Concern
Terrapene Carolina	Eastern Box Turtle	Special Concern
Gylptemys insulpta	Wood Turtle	Special Concern
Ambystoma laterale	Blue-spotted Salamander	Special Concern

When a similar request for a listing of federally listed and or proposed endangered or threatened species in relation to the area of Hop Brook included in this projected was made to the U.S. Fish and Wildlife Service, they determined there were no federally listed, proposed threatened, endangered species or critical habitat known to occur within the footprint of the project. They also determined a Biological Assessment or consultation under Section 7 of the Endangered Species Act was not required.

9. Restoration of Anadromous Fish

MA Fish and Wildlife and U.S. Fish and Wildlife Service have a common long term goal, that is the removal of dams which block the return of anadromous and catadromous species to most rivers where possible. This is especially relevant to Hop Brook. Hop Brook flows into the Sudbury River, which joins the Assabet River that flows into the Concord River which discharges into the Merrimack River. There are several dams in various state of disrepair on the Assabet, Concord River and on the Merrimack Rivers that presently block the return of anadromous fish species such as river herring and alewife. A sediment study similar to this study was recently completed on the Assabet River. Discussions with the U.S. Fish and Wildlife during the Assabet Study revealed their interest in restoring the Assabet River to an anadromous fishery. Although no discussions have occurred with either MA Fish and Wildlife and the U.S. Fish and Wildlife with regard to restoration of anadromous fishery on Hop Brook, the removal or breech of any or all of the four dams within the study area will be progress toward the goal of fishery restoration. Unfortunately the continued presence of the Grist Millpond Dam will block upstream passage of fish, although fish data indicates the American eel, a catadromous species, presently is able to pass over/around the Grist Millpond Dam. See below for a discussion of the American eel.

10. American Eel

American eel, *Anguilla rostrata,* was sampled at each of the fish sampling locations along Hop Brook, which indicates the species is able to access the entire length of Hop Brook including into the headwaters upstream of Hop Brook. American eel is a catadromous species. A catadromous species returns in a larval form to a freshwater habitat like Hop Brook and the various impoundments along Hop Brook where they grow to maturity and return to the ocean to breed. The eels in fresh water may spend as long as 40 years reaching several feet in length before emigrating back to the marine environment to breed.

In 2004 with data indicating declining populations, the Atlantic States Marine Fisheries Commission requested Endangered Species status be extended to the American eel. The U.S. Fish and Wildlife Service determined in 2005 that there was sufficient data indicating declining eel populations to examine the situation. However, after a more extensive study the U.S. Fish and Wildlife service determined the Endangered Species Act Protection for the American eel was not necessary. However, it was determined that that the declining American eel population in certain areas required special actions. These actions will be included in a future directive from the U.S. Fish and Wildlife Service. Although the present dams in their general state of disrepair does not impede American eel passage, the breaching or removal of the dams will improve the eel passage. Eel ladders should be constructed on any of the dams that remain, such as the Grist Millpond Dam.

11. Restoration Alternatives

After much discussion, the following were listed to be considered as alternatives for the possible long term solutions to the problems associated with effects of excess nutrients in Hop Brook and the four impoundments.

The alternatives are:

a) Removal of Hager Dam,
b) Removal of both Carding and Stearns Millpond Dams,
c) Removal of Carding Millpond Dam,
d) Partial removal/breach of Hager Pond Dam,
e) Partial removal/breach of Carding Millpond Dam,
f) Partial removal/breach of both Carding and Stearns Millpond Dams,
g) Partial removal/breach of Hager pond, Carding Millpond and Stearns Millpond Dams,
h) Sediment removal from behind all dams.

Any modification of Grist Millpond Dam was eliminated as an alternative since it is part of the Wayside Inn Historic District which is listed on the National Register and protected by MGL Chapter 184. This preservation restriction restricts or limits any alterations to the site including changes to the dam. Hence it was decided to not include the Grist Millpond Dam.

B. HAGER POND DAM

1. Description

Hager Pond Dam is located just downstream of the MWWTP discharge point. The pond comprises an area of approximately 30 acres. The dam is constructed of stone blocks and is approximately 20 feet high at the spillway and 200 ft wide. The surface of the dam is covered with large trees and water is present at the downstream base either due to leakage or a groundwater seep. Currently the spillway is breached, but maintains Hager Pond at its existing elevation.

At the inflow to the pond, there is a small PSS (Palustrine shrub/scrub) wetland composed primarily of willow. The inflow has created an area of about 5% of Hager Pond that is devoid of plant and animal life and is less than 0.5 ft deep. The substrate is a finely divided mixture of particulates. Most of the flow follows the historical channel only several feet from the north shore past the dam discharging through the remains of the breached spillway. There is probably a short water retention time in Hager Pond. The water depth in the channel is 4-5 ft, with all other recorded depths in Hager Pond two feet or less. Hager Pond is functioning as a nutrient retention basin, even though water retention time is short which explains why the plant production in Hager Pond is large but is less than in the downstream impoundments.

There are two wooded islands on Hager Pond. Most of the commercial development is on the north shore in close proximity to the channel. There are two very shallow, silt-choked embayments to the west; the adjacent Raytheon Plant has incorporated the western embayment into an extensive recreation area of trails, bridges, reflecting pools and picnic areas.

2. Natural Resources

Hager Pond supports a large biomass of aquatic bed vegetation both rooted and floating. During the July 14, 2006 site visit most of the littoral area (along the entire perimeter) was covered with an approximately 3 inch floating layer of duckweed, frog bit and filamentous alga. Numerous bubbles were observed trapped under this algal mat, presumably due to active photosynthesis under the midday sun. Fringing wetland areas were observed along the recreational complex associated with the Raytheon Plant. Field water quality parameters are as expected for a highly eutrophic, shallow pond. Physical water quality data for Hager Pond was collected during the day in the summer of 2006, and were generally within the ranges expected for a highly eutrophic shallow pond. Surface dissolved oxygen values were often in excess of 12 mg/L, well over 100% saturation and with pH values in excess of 9.0 units. This elevated pH is indicative of high level of photosynthesis, possibly an algae bloom, in the water column. These data are presented in Table 2. The ENSR Study, conducted in 2000, support these values, with dissolved oxygen during full sunlight of surface water ranging from 20.7 ppm (244.5% of oxygen saturation) to 12.3 ppm (123.1 % saturation)

With the highly organic substrate (BOD, COD), and the large amounts of plants/bacteria in the water column, the dissolved oxygen levels would be expected to plummet with the cessation of photosynthesis in darkness or reduced light. To show the effects of BOD during the day, a profile was recorded in the 4 foot channel. The surface dissolved oxygen was 14 mg/L, but at a 3 ft depth (one foot from bottom), the dissolved oxygen was 0.31 mg/L (Table 2). A value of 5 mg/L is considered the lower limit for the long-term survival of warm water fish. Diurnal field parameter recordings will verify this hypothesis.

Fish sampling found a warm water fish population of five species including large mouth bass. There was evidence of large mouth bass reproduction by the presence of young of the year and the use of Hager Pond by fisherpersons. American eel which is a species of interest to the USFWS, was collected in Hager Pond. This is interesting since the eel, a catadromous species, is able to pass all barriers from the ocean to the headwaters of Hop Brook. A listing of all fish species collected in Hager Pond is presented in Table 3. Hager Pond, due to its shallow depths and presumably high biological oxygen demand (BOD) presumably caused by large amounts of decomposing vegetation that would settle under the ice during the winter months is an ideal candidate for a fish kill especially under winter conditions.

3. Restoration Considerations

Alternatives considered to improve water quality for this pond are dam removal or dredging. Possible restoration considerations for this pond would be to either restore or rehabilitate the existing warm water lacustrine habitat created by the dam, or to remove the dam to restore historic or close to historic riverine conditions. In order to improve the existing lacustrine habitat, the large amounts of organic sediments would need to be removed around the perimeter and in throughout the main channel of the pond, in order to deepen it and reduce the silt and associated nutrient accumulation which exists there. In addition, deeper areas of the pond would need to be created and/or reconnected in order to establish or improve flushing which would reduce the potential for stagnation and anoxia in the deeper water. Whatever alternative is selected, it would be necessary to maintain the existing shallow habitat necessary for spawning, nursery and forage for warm water fish species. Additional native aquatic vegetation would need to be re-established in the littoral areas. In addition, the existing breached spillway would need to be repaired in order to maintain a sufficiently deep pool for over wintering of many of the warm water fish (i.e. 9 feet or more). If this dam were to remain in place a fish ladder, or minimally an eel way should be considered in order to allow improved passage of American eel (eel way) or to reconnect the stream and allow passage of anadromous or potamodramous fish.

If dam removal is considered, the resulting pond size would reduce, and the existing impounded area would revert back to riparian bank, scrub shrub, or emergent wetland, depending upon the hydrology of the surrounding area. In addition, the large amount of sediment which has accumulated behind the dam would need to be stabilized, by re-vegetation or by laying turf reinforcement mats, or removed. Hop Brook would return to its historic channel, if a new thalweg is created, which would eventually scour the substrate to its historic riverine configuration with rock/cobble and riffle pool sequences. However, due to the large amount of accumulated sediment it may be necessary to artificially re-create these stream characteristics. The riparian banks would be expected to eventually become forested, providing riparian canopy that would reduce warming. The existing warm water fish species would either move downstream to the next lower impoundment, or eventually be replaced by more fluvial species. The advantages would be restoration of historic stream habitat, which would provide habitat for stream dwelling species. Disadvantages of this alternative would be the loss of fringing scrub shrub and emergent wetlands, as well as loss of the existing warm water fishery. Included with the loss of the impoundment and associated warm water fishery would also be the eel rearing habitat, since there would be limited carrying capacity for this species in the free flowing sections of Hop Brook once the impoundment has been removed.

4. Recommended Additional Studies

A detailed wetland study may be necessary if the dam were to be removed, in order to document wetland loss and wetland hydrology in the without pool condition. In addition, monitoring of the dissolved oxygen levels near the bottom of the lake over time (i.e. possibly by deployment of continuous dissolved oxygen monitors) may help to determine diurnal fluctuations, to see if D.O. levels are being depleted in the lower water column.

C. GRIST MILLPOND DAM

1. Description

From Hager Pond, Hop Brook flows under Route 20, and within approximately 500 feet enters an extensive fringing wetland complex, bordering the inflow region of Grist Millpond. Grist Millpond is formed by impounding Hop Brook by the Grist Millpond Dam approximately 0.75 miles downstream of its discharge from Hager Pond. The Pond is approximately 0.5 miles long, and 0.25 miles wide comprising an approximate area of 80 acres. The Grist Millpond Dam, is located along Wayside Inn Road, and is constructed of stone block along the spillway. Additionally, the downstream end of Grist Millpond consists of an earthen dike which continues along the left side of the impoundment (looking downstream). During the August 2006 sampling, the dike appeared to have been recently breached by excessive flow, and was repaired by the placement of small cobbles along the breached area.

Grist Millpond is narrow and steep-sided with the greatest depth at the dam, approaching 7 feet. At the southeast side of the dam is a gated channel that supplies water to a waterwheel that is a part of the historic site of the Wayside Inn. There is a gate at the base of the dam where the amount of water in Hop Brook can be regulated by diverting amounts of flow to the Grist Millpond. Hop Brook in this entire area flows in a managed park like setting. Of the four dams, the Grist Millpond Dam is well maintained with no large trees growing on the dam riprap on the upstream face of the dam. There is one area where the dam surface may occasionally breach (noted above) which is filled with rock. This may occur when flows exceed the capacity of the gates.

2. Natural Resources

Extensive fringing wetlands consisting of wetland meadow/fen, Palustrine Shrub Scrub (PSS) and Palustrine Forested (PF) are located near the upstream section by the inflow of Hop Brook and surround Grist Millpond to the North. There is a perennial stream flowing from upland (underneath Rt. 20) into Grist Millpond. This stream may support a small coldwater fishery in its upstream areas. At the time of sampling, there was no surface flow in this stream, although an approximately 200 foot wide section of Palustrine Emergent (PEM) and PSS wetland were present along the edges of (and within) the stream bed. Species present in this wetlands area were alder, blueberry, nightshade, jewelweed, false nettle, tussock sedge, and sensitive fern along the margins, with skunk cabbage present in the streambed. Almost one half of Grist Millpond was limited to a shallow channel surrounded by an emergent wetland consisting of mostly cattails, with small amounts of *Phragmites.* There was also an extensive fringing wetland found along the north shore. All these wetlands would be vulnerable to a dam removal.

There was an abundance of rooted/floating macrophytes and filamentous alga in/on Grist Millpond. Duckweed was more abundant than at Hager Pond, and covered most of the downstream area along the shore particularly near the section of the formerly breached dam. Water chestnut was also present, but not abundant. Only the central deep channel was devoid of floating/rooted vegetation.

Temperature, dissolved oxygen concentration, conductivity, pH and turbidity are presented in Table 2. These values were similar to those collected from Hager Pond, with supersaturated surface dissolved oxygen concentrations (178.9% saturation; 13.5 mg/L) and elevated pH levels (9.22 units) measured at the downstream station near the dam. These levels are indicative of a high rate of photosynthesis in the water column resulting from the excessive aquatic plant growth present. During the July 26th sampling, the dissolved oxygen concentration dropped from the high surface level of approximately 14 mg/L to 2.5 mg/L between the 4 and 6 foot depths.

The water temperature of 29.64 ^{o} C in Grist Millpond was under relatively standard conditions, (i.e. barometric pressure and amounts of dissolved material in the water), the dissolved oxygen concentration for saturation would be approximately 7.6 mg/L (Standard Methods, 1992), and pH levels would most likely be in the range between 6 and 7 units (which is typical for many New England Lakes). The light reaction of photosynthesis involves the uptake of dissolved carbon dioxide from the water column, (or from the air if outside of the water) and release of oxygen into the water column. This uptake of the dissolved carbon dioxide reduces the concentration of carbonic acid in the water, with a resultant increase in pH (the water is becoming less acidic), while the release of oxygen into the water can cause oxygen super saturation. In many eutrophic lakes where there is active photosynthesis, during the summer months it is common to find pH levels approximately 2 or more units higher than what would normally occur in that same water body, accompanied by supersaturated dissolved oxygen concentrations. This has been observed at several U.S. Army Corps of Engineer flood control dams, including West Thompson Lake in Connecticut, which also experiences nutrient fueled algal blooms, being downstream from a Wastewater Treatment Plant similar to the case of Hop Brook. It should be mentioned that during photosynthesis, oxygen is consumed and the dissolved oxygen levels will decrease significantly to levels where fish would be stressed. It is presumed that this was occurring in the deeper levels of the water column on Grist Millpond on that sampling date.

Grist Millpond was not sampled for fish due to its inaccessibility. However, it would be expected that the same type of warm water fishery with the same limitations seen at Hager Pond would occur at Grist Millpond. The low dissolved oxygen concentration (2.5 mg/L) measured in the deeper sections of the pond are unsuitable for the growth and survival of most fish species (a concentration of 5 mg/L is considered the minimum D.O. level before stress would occur). Therefore, given that the deepest section is only 7 feet, and the low DO concentrations occurred at between 4 and 6 feet deep, only the upper 4 – 5 are useable for fish habitat during the summer months. Therefore, as with Hager Pond, the potential for a fish kill exists due to these low D.O. concentrations which could be exacerbated by a high BOD in the deeper layers. This could occur when the floating algae and plants die, sink to the bottom and decompose.

3. Restoration Considerations

Alternatives considered to improve water quality for this pond is dredging, as dam removal is not a feasible option. Restoration benefits on Grist Millpond would be similar to those described for Hager Pond, and would consist of either maintaining and improving the existing warm water/lacustrine habitat by keeping the dam in place (with provision of fish passage), or by dam removal (if that were ever to become an option) which would cause the loss of the upstream and fringing wetlands and a reversion to historic riverine habitat. The presence of eels in Hager Pond upstream from Grist Millpond indicates that they are moving through Grist Millpond and therefore would benefit from eel passage at the dam. In addition, providing some type of fish passage at each of the dams would benefit the existing fisheries by restoring connectivity to the river.

As noted for Hager Pond, if it is not feasible to remove the dam, then the pond should be dredged to deepen it and remove the nutrient rich sediment. In addition, certain shallow areas should be maintained to provide spawning and nursery habitat for warm water species. The existing steep sloping sides of this pond which form the historic river channel would limit the potential of this impoundment as warm water fish habitat. Therefore, in order to improve its potential it would be beneficial to create additional shallow areas for spawning and nursery of warm water species.

With dam removal it would be expected that some acres of the upstream and fringing wetlands would drain, and the resultant loss of the impoundment would eliminate much of the existing warm water fish habitat, replacing it with riverine habitat, and resulting change in dominant fish species. However, restoring historical stream habitat to this section of Hop Brook would have several advantages, one of them being the ability to have sustained high concentration of dissolve oxygen, due to the aeration that would occur with the swifter flowing water over rocky substrate.

Another alternative that could temporarily improve water quality conditions would be to seasonally open or close the flood gates at the dam to maximize the flushing in the pond by discharging water from the bottom during the summer, which would allow the bottom layers to mix from the inflow, rather than stagnate and becoming anoxic.

4. Recommended Additional Studies

If access could be provided, then additional fish sampling could be done to better document the existing resource and potential effects of dam removal. Additional winter or long term dissolved oxygen monitoring at various depth could also help to determine potential for winter fish survival. In addition, studies relating to various gate settings to determine if drawing off the bottom could improve water quality conditions in the pond.

D. CARDING MILLPOND DAM

1. Description

From the outflow of Grist Mill/Wayside Inn complex, Hop Brook flows under Wayside Inn Road, for a distance of approximately 1500 feet, to a wetland complex at the inflow of Carding Millpond which is directly tied to the water level in Carding Millpond. Hop Brook continues for approximately another 1500 feet through this wetland complex into Carding Millpond. Carding Millpond is approximately 2000 feet long (from the spillway to the upstream wetlands), and 1000 feet wide, and comprises a total area of approximately 41.4 acres. Two large forested islands are located within the pond, comprising areas of approximately 2.5 and 0.9 acres each. Maximum depth of the pond was approximately 5 feet adjacent to the island closest to the dam. Depths at the dam ranged from 2-3 feet.

There are two spillways over the dam, including an abandoned sluiceway which appears to have been the former millworks along its right side (downstream view). At the time of sampling a millwheel apparently in the process of being restored was on the ground adjacent to the outflow. The dam itself is in poor condition with leakage observed at the downstream base (see Figure 3, Appendix A (CARDING MILLPOND)). A cart path that provides access to the dam and former millworks extends east from Dutton Road and crosses over the spillway by a small bridge consisting of large stone slabs resting on steel I-beams. At the time of sampling the bridge appeared to be failing, with the stone slab closest to the pond showing signs of stress, bowing outward toward the pond. The access path after crossing the bridge continues along the north edge of the pond, obstructing the drainage of a wetland that extends to the northeast toward French Road. This wetland complex is also tied to levels in Carding Millpond.

2. Natural Resources

PEM wetlands are observed in the large complex on the southern side of the pond by the inflow of Hop Brook, with dominant species consisting of typha mixed with phragmites. Extensive PEM, PSS, and PFS wetlands also fringe the pond on its northern end between the pond perimeter and the access road. These wetlands appeared to be supported by the pond, and were in close proximity to residential property (houses), which surrounded almost the entire pond except to the north.

Corps personnel visited the Carding Millpond on August 10, August 17, November 7 and December 14, 2006. During the site visits in August, extensive floating rooted macrophytes and abundant filamentous algae growth was observed covering most of the pond, with the dominant rooted species being water chestnut. The large biomass of this species on the pond requires mechanical harvesting during the growing season in order to control it. Other rooted aquatic macrophytes included white and yellow water lilies present in the shallower areas along the shores of the two islands. Of the four impoundments, Carding Millpond had the most extensive duckweed/frog spit cover. Attempts to electro-fish Carding Millpond on August 17, 2006 (just after the mechanical water chestnut harvest), were unsuccessful due to an almost 4 inch thick layer of duckweed over the entire pond. This duckweed clogged the motor requiring the fish sampling to be delayed until December when frost would reduce the duckweed cover. Even the scheduled water quality sampling on that day could not be completed due to the duckweeds and was postponed until November 7, 2006.

Water quality data collected on November 7, 2006 are presented in Table 2. On this date, although much of the duckweed had died, it still covered areas of the shoreline, particularly on the northern side along the access road by the dam. It was observed that although the extensive submerged rooted vegetation had been reduced by frost, it was still present and actively growing, as well as large amounts of filamentous algae. At the inflow to the pond there was an 8 inch layer of filamentous algae growing up from the substrate. The dissolved oxygen concentration at that location was 13 mg/L (over 100% saturated) and pH was 9, at a temperature of 8^{o} C. These elevated dissolved oxygen and pH values may be indicative of a high rate of photosynthesis of this filamentous algal layer (as observed at Hager and Grist Millponds during the summer and explained in the section on Grist Millpond above). This can be interpreted as to the fact that even during the colder months, sufficient nutrients were present to support a large amount of algal growth. It should also be noted that most of this filamentous algae was coated with a layer of fine silt, and some had broken off forming floating mats with trapped air bubbles visible. The bottom substrate consisted of fine silt covering which appeared to be layers of dead vegetation. When disturbed, it would produce clouds of turbidity. Large amounts of Elodea were also present among the filamentous algae.

During the summer months it is presumed that low flow conditions, higher temperatures with higher BOD’s would result in a more septic anoxic aquatic environment near the bottom. However, on the November sampling date, dissolved oxygen concentration measured at the deepest area of the pond was 9 mg/L at a temperature of $7\ ^{o}$ C (less than saturated), indicating that although there was some oxygen demand in the lower water column, these lower temperatures would have reduced biological activity that would utilize oxygen.

Fisheries data collected on the December 17 sampling date are presented in Table 3. This sampling revealed the presence of a warm water fishery at Carding Millpond. A total of 7 species were represented including American eel, brown bullhead, bluegill, golden shiner, largemouth bass, pumpkinseed and yellow bullhead. The predominant sport fish was largemouth bass, but the most abundant non sport species was bluegill, followed by pumpkinseed. The largemouth bass collected from Carding Millpond were larger than those collected from Hager Pond, and the presence of many young of year indicated that there is natural largemouth bass reproduction. Most of these fish were collected in water depths ranging between 1-3 feet over the dense beds of elodea along the southeastern shore of the pond. Elodea beds can provide excellent nursery habitat for smaller fish, and in areas where this macrophyte was absent, relatively few fish were collected. It should be noted that American eel was also present in Carding Millpond, (similar to Grist Millpond and Hager Pond) indicating that they were passing through this area as larvae from the ocean.

3. Restoration Considerations

Alternatives considered to improve water quality for this pond are dam removal or dredging. Restoration alternatives similar to those described previously for Grist Millpond and Hager Pond could also be considered for Carding Millpond. However, the extensive cover of duckweed and mats of rooted aquatic vegetation with invasive water chestnut present at Carding Millpond necessitates control measures for this nuisance growth. During the summer 2007 sampling, it was observed that large amounts of duckweed had begun to die creating a septic odor near the shore. In addition, the extensive water chestnut growth made navigation even by non-motorized watercraft impossible. Continuation of the seasonal harvesting of water chestnut may help to control this invasive species. However, unless the nutrients responsible for sustaining the excessive duckweed growth are eliminated, there will still be problems with aquatic macrophytes growth in Carding Millpond. Dam removal may improve water quality by flushing nutrients through the free flowing brook, but there would be a loss of some acres of the PEM wetlands at the inflow, and some acres of the PSS wetlands on the Northern side along the access road. In addition, it will be necessary to either remove or stabilize the extremely fine sediment that has accumulated in the pond in order to prevent its discharge downstream (as noted in the previous sections for Grist Millpond and Hager Pond).

If dam removal is not feasible, then it would be necessary to repair the failing dam, and construct some form of fish passage, that would minimally pass eels (eel way), since their documented presence in the pond (from the November sampling) and the upstream ponds indicates their migration through and utilization of Carding Millpond. This would be expected to increase the numbers of eels passing into Carding Millpond, and to the upstream areas of Grist Millpond and Hager Pond as well. Dredging of the pond would still be recommended in order to remove the large amounts of extremely fine sediment which may be acting as nutrient source, and to deepen the pond to improve fish habitat. Ideally a fish ladder (that also incorporates eel passage) would be the best alternative. Since eels migrate through this pond, construction of an eel way would increase the number of eels that are able to pass upstream from the downstream area segments of Hop Brook.

4. Recommended Additional Studies

The extremely dense duckweed and water chestnut growth present in Carding Millpond which was noted even into the late fall and early winter, could create the potential for extremely low dissolved oxygen levels during winter under ice cover, due to the subsequent die off and decomposition. This could result in winter fish kill, which would be exacerbated by the shallow depths of the pond and would minimize the volume of the habitable water column. Therefore, it may be useful to measure dissolved oxygen and temperature data during the winter under ice cover to determine the extent of anoxia present in the pond.

E. HOP BROOK DOWNSTREAM FROM CARDING MILLPOND DAM

1. Description

An approximate 102 foot section of Hop Brook approximately 200 yards downstream from the spillway of the Carding Millpond Dam was sampled for fisheries on August 10, 2006. The section consisted of a straight rock lined channel that appeared to have been previously modified and armored for erosion control. Mean channel depth was approximately 2 feet, and the stream bottom consisted of small cobbles ranging from approximately 2 – 5 inches in diameter. The banks appeared to have been armored with boulders ranging from approximately 1-3 feet in diameter. The stream section sampled consisted of a long pool like run, with some slight riffles, although it did not actually fit the description of a natural riffle/pool combination due to a lack of visible natural control features. Apparently there was a downstream control (outside of the sampling area) which maintained the water level in the channel.

The water in this section of the brook was darkly stained. Physical water quality data collected at the time of sampling are presented in Table 2. and were within criteria suitable for survival of warm water fish, however the dissolved oxygen level 6.6 mg/L at a water temperature 24.14^{o} C indicated less than saturated dissolved oxygen concentration (79.3% saturated). This is significant, because the sampling location was immediately downstream from a turbulent flow from the dam discharge, where re-aeration would be expected. The fact that this turbulence did not re-saturate the water with dissolved oxygen suggests that either the water from Carding Millpond had a high oxygen demand, or the dissolved oxygen level of the discharge was so low that it could not fully saturate the water. The measured concentration of 6.6 mg/L however is still above the criterion of 5 mg/L considered the minimum concentration before fish become stressed.

2. Natural Resources

This section of Hop Brook was relatively unproductive and did not contain a typical lotic community. A total of 5 fish were collected from the entire stretch, which included 2 small yellow bullheads, a small largemouth bass and 2 American eel each measuring approximately 12 inches long each. The fact that eel were collected in the riverine section is consistent with their being present in Carding Millpond, immediately upstream as well as Grist Millpond and Hager Pond, and indicates their migration through Hop Brook around or over the dams and into the impoundments. American eel have the unique ability to climb wetted surfaces such as dam spillways as well as migrate around a wetted area of a dam in order to move upstream. This would explain their presence in Hop Brook and its impoundments upstream from numerous dams. However, climbing over dams is not the most effective way for this species to migrate, and many more would be likely to move if fish passage were provided.

A large number of fresh water sponges were observed on the rocks both in the riffle and in the pool sections of this stretch of the brook. Sponges are typically collected in areas with good water quality with sufficient dissolved oxygen concentrations, which the data seems to indicate, although the dissolved oxygen was below the saturation level. The Commonwealth of Massachusetts Division of Fisheries and Wildlife indicated that Hop Brook upstream and downstream of each of the four impoundments contained fallfish, white sucker, yellow perch and redfin pickerel in addition to the species collected in this survey. However, they did not collect largemouth bass and yellow bullhead. This supports the hypothesis that Hop Brook is a warm-water fishery. No fisheries data were available from the Commonwealth of Massachusetts Division of Fisheries and Wildlife for the four impoundments discussed in this study.

3. Restoration Considerations

Possible restoration alternatives for this section of the brook would be to create some meanders and additional pool and riffle habitat, by the placement of large boulders along the banks, and construction of rock weirs (J-weirs) or similar features in the stream. Artificial undercuts constructed of rock could also be added to the stream bank. The lack of fish productivity in this section is evidence of the lack of habitat. Creation of pool and riffle with resultant depositional areas and meanders would provide necessary resting and forage habitat for many stream dwelling fish species, while providing necessary substrate for aquatic invertebrates used as a food source for these fish species.

4. Recommended Additional Studies

If the above mentioned habitat restoration is considered, stream hydrology data would need to be collected. Once constructed, follow-up fisheries monitoring would be recommended to document any improvements in the fisheries.

F. HOP BROOK DOWNSTREAM OF FRENCH ROAD

1. Description

This section of the brook is located between French Road and the inflow to Stearns Millpond and extends for a distance of approximately 1.25 miles. French Road is located approximately 1000 feet downstream from Carding Millpond and Hop Brook Flows under it by means of a culvert. This section downstream of French Road to Stearns Millpond is a complex of many wetland habitats interspersed with smaller ponds, which consist of wet meadows that extend great distances from Hop Brook. Water level changes in Stearns Millpond may have an effect on some of these upstream areas along Hop Brook.

2. Natural Resources

The Commonwealth of Massachusetts Division of Fisheries and Wildlife Natural Heritage and Endangered Species Inventory has designated extensive plots of wetland and upland to the North and East of Hop Brook in this area as critical habitat for rare wildlife. Also, the U.S. Fish and Wildlife Service (USFWS) currently own and manage much of this area. The designated critical habitat noted above for rare wildlife is listed as priority Habitat 634 and Estimated Habitat 6033 as cited in MA Natural Heritage Atlas 11^{th} Edition. Species found in this area are all "Special Concern" and include the blue spotted salamander and eastern box turtle. These species and their habitat may be negatively affected by dredging activity and/ or the removal of at least Stearns Millpond Dam.

3. Restoration Considerations

The designated rare wildlife habitat in this area is currently protected and managed by the Commonwealth of Massachusetts and USFWS. If modifications to the dam at Stearns Millpond are made, or if dredging occurs, there should be appropriate coordination among these agencies to avoid any water level related impacts to these Priority and Estimated Habitats.

4. Recommended Additional Studies

Additional fisheries surveys of this area are recommended, to document what species are present in this section of the stream as it flows through the series of small ponds, wetlands and adjacent uplands.

G. STEARNS MILLPOND DAM

1. Description

Stearns Millpond is located approximately 1.25 miles downstream from Carding Millpond and is formed by a stone block dam at Hop Brook, approximately five miles upstream from its confluence with the Sudbury River. From its upstream section near the inflow of Hop Brook, Stearns Millpond extends a distance of approximately 0.75 miles, and has a mean width of approximately 500 feet. The inflow of the pond is located approximately 0.5 miles downstream from the Priority Habitat and USFWS Boundary noted above. In this upstream section of the pond, the inflow is characterized by highly scoured substrate of coarse sand and small pebbles indicative of a steeper gradient and higher flow rate. This was in sharp contrast to the upper reaches of the three upstream ponds described above, where the inflows were typically depositional with slower flows and fine silt and mud substrate. However, approximately 0.25 miles downstream from the inflow, the substrate in Stearns Millpond becomes the typical finely divided, rich, organic muck observed in the upstream impoundments.

The water depth of the pond ranges from approximately 1 to 4 feet deep with the deepest areas being in its center of the channel near mid pond, as well as the downstream section closest to the impoundment. However, outside of the channel (which includes most of the surface area of the pond) the mean water depth was approximately one foot. There is a persistent swift current through the narrow shallow millpond, as it slows in the summer with the result that Stearns Millpond becomes anoxic and septic (similar to the upstream impoundments) as temperatures and BOD increase.

2. Natural Resources

Water Quality data were collected on December 7, 2006. At that time there were only a few remnants of rooted aquatic vegetation present in the pond, since the sampling occurred following a heavy frost with a partial ice cover. However, there was still a cover of duckweed present on most of the unfrozen water surface with up to 12 inches of filamentous algae growing on the substrate. The Hop Brook Association reports that during summer conditions, Stearns Millpond is choked with rooted vegetation and duckweed and is "odiferous". In addition, water chestnut is routinely harvested from the water column. During the December sampling, Eoldea and nitella species were growing up from the substrate approximately 100 yards downstream from the inflow.

Water quality data are presented in Table 2. On the above said sampling date, dissolved oxygen concentrations measured greater than 11 mg/L at a temperature of approximately 4^{o} C, and pH levels ranged between 7-8 units at all the stations. As noted previously, elevated pH levels (with correspondingly high dissolved oxygen) can be the result of increased photosynthesis from algal or aquatic macrophytes growth. This was also noted in Carding Millpond, where increased photosynthesis was occurring on the November sampling.

Wetland habitat immediately surrounding the pond consists of a few small fringing areas of emergent and aquatic bed wetlands at the edge of the pond, being limited by the steeply sloping hillsides which border it and/or form the valley through which Hop Brook flows. These banks rapidly transition into upland habitat within a short distance from the water's edge becoming forested by red oak and white pine and comprise residential properties with houses, which surround the pond on both sides. Fish were not collected from Stearns Millpond due to the lack of boat access. However, it would be presumed that a warm water assemblage similar to those found in the two upstream ponds would be present, including American eel.

3. Restoration Considerations

Alternatives considered to improve water quality for this pond are dam removal or dredging. Similar to the upstream ponds, factors such as shallow depth, extremely fine silty sediment, and excessive amounts of duckweed reduce the ponds suitability as fish habitat. Removal of the sediments in order to deepen the pond and improve water quality may be one restoration alternative. This would create more deepwater habitat used for over wintering by bass species, as well as reduce the biological oxygen demand associated with the organic rich sediments currently in the pond. If the pond was deepened to native bed, then much of the rooted aquatic vegetation could also be eliminated, or significantly reduced. In addition, the sediments are presumed to be a source of nutrients which can contribute to the large amount of nuisance vegetation present in the pond.

If dam removal is considered, it would be necessary to determine its effect on the upstream wetlands and priority habitat, since these may be hydraulically dependant upon the water level of Stearns Millpond. However, this would restore historical stream flow in this area of Hop Brook, while reconnecting the brook and providing improved fish passage for American eel as well as other fish inhabiting Hop Brook.

4. Recommended Additional Studies

It is recommended that a hydrologic study of the upstream wetlands be conducted in order to determine their dependency upon the water level of Stearns Millpond. In addition, winter measurements of dissolved oxygen under the ice could help to determine the level of anoxia in the pond during the winter and the potential for a winter fish kill.

Table 2: Water Quality and Fish Data

Pond	Sampling Date	Station	Depth	pH	Conductivity	DO	Temp	Turbidity
				(Units)	(mS/cm)	(mg/L)	(Co)	(NTU)
Hager Pond	**7/14/2006**	HP1	0	8.07	0.864	7.69	26.67	6.7
		HP1	2	7.69	0.868	6.49	23.21	3.6
		HP1	4	9.49	0.872	4.15	22.96	110
		HP1	5					
	7/14/2006	HP2	0	7.59	0.81	7.58	25.49	6.8
	7/14/2006	HP3	0	7.48	868	4.23	23.21	2.1
Grist Millpond	**7/26/2006**	GR ML1	Too Shallow	No data				
	7/26/2006	GR ML2	1.5	7.75	0.792	6.83	25.45	15.8
	7/26/2006	GR	0	8.92	0.767	13.5	29.6	11.9

		ML3				6	4	
	7/26/2006	GR ML3	2	9.22	0.763	18.34	26	13
	7/26/2006	GR ML3	4	8.41	0.775	14.3	24.99	12.6
	7/26/2006	GR ML3	6	7.45	0.768	2.51	24.16	116
	7/26/2006	GR ML4	1.5	8.91	0.777	12.19	29.47	7.4
Hop Brook	**8/10/2006**	HB1	0.6	7.48	692	6.61	24.14	3.7
Hager Pond	**8/17/2006**	HP1	0	9.32	0.767	14	26.91	30
			2	9.15	0.772	12.1	24.69	8.8
			3	8.18	0.783	0.31	23.8	218
Carding Millpond	**11/7/2006**	CM1	0.5	8.04	0.617	8.63	6.85	5.6
			2	8.15	0.617	8.46	6.83	6.1
			4	8.17	0.617	8.37	6.82	5.9
			5	8.17	0.611	7.68	6.83	5999
Carding Millpond	**11/7/2006**	CM3	0.5	8.44	0.625	9.02	7.42	4.7
			2	8.41	0.625	8.93	7.39	5.2
			4	8.41	0.664	9.15	7.27	5.5
			5	8.46	0.626	9.02	7.27	5.4
Carding Millpond	**11/7/2006**	CM2	0.5	8.86	0.716	13.06	8.28	9.6
Stearns Millpond	**12/7/2006**	STM L1	0.5	7.23	0.465	11.63	4.74	6.1
	12/7/2006	STM L2	2	7.35	0.467	12.01	4.54	5.5

	12/7/2006	STM L3	0.5	7.41	0.466	11.72	4.26	3.3
			2	7.36	0.466	11.61	4.28	3.6
	12/7/2006	STM L4	0.5	7.33	0.465	11.25	4.48	3.5
			2	7.32	0.466	11.29	4.46	3.9
			3	6.98	0.424	0.18	5.04	5000
Carding Millpond	**12/14/2006**	CM4	0.5	7.37	0.69	10.23	4.51	6.4
			2	734	0.624	10.4	4.27	5.7
Key								
Station Locations								
HP1	Hager Pond, Site 1 near boat ramp, approximately 50 feet from shore							
HP2	Hager Pond Site 2, opposite end of pond , off northeast shore							
HP3	Hager Pond at outflow, approximately 50 feet from discharge at 1 foot below surface (in pond)							
GRML1	Grist Millpond, inflow stream on east side, near highway, not running at time of sampling, but associated wetland app. 200 feet wide							
GRML2	Inflow of Hop Brook to Grist Millpond							
GRML3	Grist Millpond, approximately 40 feet from dam, in water app. 7 feet deep							
GRML4	Grist Millpond, surface flow to Grist Mill							
CM1	Carding Millpond, mid lake on left of island, looking out from boat ramp							
CM2	Carding Millpond, on southeast side of pond near inflow in app. 1 foot of water							
CM3	Carding Millpond, west end of pond near boat ramp.							
STML1	Stearns Millpond approximately 100 yards downstream from inflow							
STML2	Stearns Millpond, approximately midway down lake, in 2 feet of water							
STML3	Stearns Millpond, approximately .75 downstream towards dam in 2 feet of water							
STML4	Stearns Millpond, closest to dam in approxmately 3-4 feet of water							

Units/Abbreviations								
units	pH units							
mS/cm	milli Siemens per centimeter							
mg/L	milligrams per liter							
(C^{o})	Degrees Celsius							
NTU	Nephelometric Turbidity Units							
DO	Dissolved Oxygen							
Temp	Temperature							
TL(CM)	Total Length in centimeters							
WT(GM)	Weight in Grams							
K	Condition Factor (length weight relationship)							

Table 3

2006 Fisheries Data						
Station	**Date**	**Location**	**Method**	**Species**	**TL (cm)**	**WT(G)**
Downstream from Carding MillPond Dam	**8/10/2006**		Back pack ES	YB	4.6	1.6
				YB	4.4	1.1
				LMB	5.6	2.4
				AE	30	
Carding Millpond	**12/14/2006**	**Site 1**	Boat Shock	AE	50.8	305
				BB	13.1	28.8
				BG	9	10.9
				BG	9.9	17.9
				BG	10.1	19.6
				BG	10.3	22.9
				BG	10.7	26.5
				BG	11.4	26.6
				BG	11.5	28.5
				BG	11.5	31.5
				BG	11.9	35.7
				BG	12.1	34.1
				BG	12.7	35
				BG	12.7	38
				BG	12.8	41.7
				BG	12.9	40.4
				BG	13	43.5
				BG	13	47.6
				BG	13.2	37
				BG	13.5	50.8
				BG	13.5	52.5
				BG	13.7	53.5
				BG	13.7	54
				BG	13.8	61.5
				BG	14.1	53.5
				BG	14.4	61.5
				BG	14.6	63.5
				BG	14.9	66.3
				BG	14.9	54.4

				BG	16.5	59.7
				BG	19.4	97.6
				BG	22.6	29
				GS	19.5	96.6
				GS	20.1	107.2
				LMB	6	3.1
				LMB	7.1	4.8
				LMB	7.6	6.1
				LMB	8.5	8.3
				LMB	13.1	57.5
				LMB	14	35.4
				LMB	18	
				LMB	19.6	103.6
				LMB	19.9	99
				LMB	20.1	110.7
				PG	12.5	42.5
				PS	8.9	16.1
				PS	9	12.7
				PS	9.2	22.3
Carding Millpond	**12/14/2006**			PS	9.4	19.7
				PS	10	20.2
				PS	10.7	25.2
				PS	12.4	41
				PS	12.6	43.9
				PS	12.7	49.3
				PS	14	41.4
				PS	14.1	67.8
				YB	12.5	24.3
				YB	21.6	140
				AE		
				BG		
				PS		
Hager Pond, Marlborough	**8/17/2006**	Sites 1 and 2	**Boat Shock**	AE	35.6	75.3
				AE	38.1	78.2
				BG	7.1	5.1
				BG	9	12.7
				BG	9.1	15.6

				BG	9.4	16.9
				BG	9.7	18.6
				BG	14.5	70.2
				BG	15.1	82.7
				BG	16.6	105
				BG	16.6	
				BG	17.2	120.3
				GS	4.9	1.3
				LMB	8.4	8.6
				LMB	17	67.2
				PS	7.4	8.6
				PS	7.7	8
				PS	9	15
				PS	9.8	19.8
				PS	9.8	21.8
				PS	10.5	25.8
				PS	11.9	41.3
				PS	12.9	23.9
				PS	13.2	58.7
				PS	15.2	82.3
Key						
Common Name	**Scientific Name**					
AE= American eel	*Anguilla rostrata*					
LMB= Largemouth bass	*Micropterus salmoides*					
BB= Brown Bullhead	*Amierus nebulosus*					
BG= Bluegill	*Lepomis Macrochirus*					
GS= Golden shiner	*notemigonus crysoleucas*					
PS= Pumpkinseed	*Lepomis gibbosus*					
WS= White sucker	*Catostomus commersoni*					
YB=Yellow bullhead	*Amierus natalis*					
YP=Yellow Perch	*Perca flavescens*					
Units/Abbreviations						
units	pH units					
mS/cm	milli Siemens per centimeter					

mg/L	milligrams per liter					
(C^o)	Degrees Celsius					
NTU	Nephelometric Turbidity Units					
DO	Dissolved Oxygen					
Temp	Temperature					
TL(CM)	Total Length in centimeters					
WT(GM)	Weight in Grams					
K	Condition Factor (length weight relationship)					

Appendix E – Cultural Resources

Hop Brook Sediment Study – Cultural Resources Evaluation

1. Preliminary Cultural Resources Identification

   In the Work Plan for the subject project, the task is to conduct cultural resources research for the project area to identify any potentially significant prehistoric and historic archaeological sites, and historic structures that might be affected by proposed alternatives. This consisted of identification of known cultural resources along Hop Brook, which might be impacted by dam or sediment removal. This task identified previously documented prehistoric archaeological sites, and historic sites along Hop Brook that may need to be considered during the development of alternatives for sediment removal.

2. Prehistoric Resources

   Massachusetts Historical Commission (MHC) Reconnaissance Survey reports for each town in which the Hop Brook traverses, note that these towns were known for aboriginal settlement and activity along rivers as well as ponds, and wetland areas. Sites were most often found on terraces overlooking water bodies. Identified sites represent all phases of New England prehistory from the PaleoIndian Period (12,500 – 10,000 BP [Before Present, 1950] to the Contact Period (450 – 300 BP/A.D. 1500 – 1620). These sites include short-term hunting or fishing stations or campsites, fish weirs, seasonal camps, and lithic production or repair sites.

   Sites representing the PaleoIndian Period in Massachusetts are rare. Only two sites in the Sudbury, Assabet, and Concord River drainages have been identified as possibly being from this period. A large flint knife from a find spot in Northborough was tentatively identified as a PaleoIndian artifact. A PaleoIndian period projectile point was recovered from the Dakin Farm Site (19 MD 94), a large multi-component site in Concord.

   Evidence of Early Archaic (10,000 to 7,500 BP) period sites in this area is rare. Single, bifurcate base projectile points, the most diagnostic stone tool artifact from this period, are not recorded for any sites within the Hop Brook drainage. River valley lowlands may have been the location for Early Archaic sites.

   A small number of sites from the Middle Archaic period (7,500 to 5,000 BP) have been located around the headwaters of the Sudbury and Assabet rivers. Middle Archaic sites are located in both lowland and upland sections adjacent to large rivers and small streams. Concentrations of prehistoric sites near falls, rapids, and at confluences of smaller tributaries with larger rivers would be expected for this period. Known sites in Westborough contain local (quartzite, argillite) and non-local (rhyolites and felsite) lithic materials.

Late and Transitional Archaic Period (5,000 to 2,500 BP) sites in New England are much more common than in previous periods. Modern environmental conditions were present and the wild resources available were the same as those observed by the early European settlers. A broad spectrum of resources was exploited during this period. Sites can be found in many diverse settings, including near falls, on the banks of large and small rivers and streams, on floodplain terraces, on lake bottom soils, and in upland locations. Artifact collections from the Sudbury and Assabet river drainages contain a large number of artifacts from this period. The Flagg Swamp Rockshelter in Marlborough dates to this period as well.

The time between the Transitional Archaic and Early Woodland (3,000 to 1,600 BP) Period has traditionally been considered an episode of changing resource utilization and adaptation where activity in the upland regions decreased while increasing in the coastal lowlands. Few sites dating to this period are known in the Marlborough or Sudbury vicinity.

Middle Woodland Period (1,600 to 1,000 BP) occupations have been identified in the Sudbury/Assabet river drainages at some sites that were previously exploited riverine wetlands during the Middle and Late Archaic Periods. Sites in Wayland, Westborough, and Marlborough all had Middle Woodland components. In general, however, this area appears to have been less intensively occupied during the Late Woodland (1,000 to 450 BP) Period.

The MHC Site files for prehistoric sites were checked to see where known sites for each town were located on Hop Brook in Marlborough and Sudbury. Nine sites were identified in the vicinity of Hop Brook in Marlborough, dating from possibly the Early to Late Archaic Periods (10,000 – 3,000 BP). Most of the sites were represented by a few stone flakes and burnt rock, representative of a pattern of wetland resource exploitation with short-term campsites common during the Late Archaic Period (5,000 – 3,000 BP). Several of these included small campsites as well as several loci of a larger site, and one tool-making site. One site (19 MD 203) had no specific information on site components but was noted as being located either near or on Grist Millpond. The Hager Pond Site, 19 MD 578 was identified during an intensive archaeological survey of the Raytheon Equipment Division Area in Marlborough. The site was a find spot of chipping debris (byproduct of repairing stone tools), and was probably a small camp occupied for exploiting resources of the nearby upland, wetland, and forest environment. The report noted that this find spot and the several other small sites in the general vicinity, suggest that the Hop Brook system was an important landscape feature for prehistoric groups in the Sudbury/Assabet River drainages.

Seven sites were identified in the vicinity of Hop Brook in the town of Sudbury. These sites date from the Late Archaic through the Late Woodland periods. Five of the sites were surface collected by vocational archaeologists or excavated by amateur archaeologists affiliated with the Massachusetts Archaeological Society during the early to mid-twentieth century. The remaining two sites were identified during the Intensive Archaeological Survey of the Sudbury Training Annex (Gallagher et al. 1986). The Sheffield Site, 19 MD 668, is a small, temporary, single occupation campsite from the Middle Woodland Period, which are rare in inland and upland Massachusetts. The Parmenter Site, 19 MD 669, was a small, single component, temporary campsite from an unknown temporal period, that consisted of quartz chipping debris associated with a hearth or pit feature. Both sites are typical of the prehistoric resources to be expected in the Hop Brook study area.

In summary, Hop Brook was moderately used by prehistoric groups for resource procurement, and seasonal or short-term settlement. The potential exists for other prehistoric sites to be identified in the floodplain, on terraces or surrounding wetlands adjacent to the river.

3. Historic Resources

During the Contact and Plantation Period (1500 to 1675 A.D.), there are documented Native American trails, reported burials and the establishment of a Praying Indian town called Ockomakamesit (present day Marlborough), with Native American fields on Ockoocangansett Hill. This was the fourth Christian Indian town established by Eliot. The Native American economy during this period depended on the cultivation of row crops and orchards, as well as fresh water fishing in the local rivers and streams.

Initial European settlement occurred c. 1658. The town of Marlborough was originally part of a 6 square mile tract of land known as the Sudbury Grant, which was given to petitioners from the town of Sudbury. It was incorporated as a separate town in 1660. The first saw mill in the area was built on Hop Brook, in South Sudbury in 1659 by brothers, Thomas and Peter Noyes. By 1670, there were 40 families settled in Marlborough and 20 families in Sudbury, most clustered around the Boston Post Road. Eight garrison houses were erected in Marlborough during this period as protection from Native Americans. The first meetinghouse was built in 1666.

The start of the Colonial Period (1676 to 1776) is marked by the destruction of both towns during King Philip's War (1675 - 1676). The garrison houses in Marlborough were the only structures left standing. The European population increased slowly again throughout the end of the seventeenth and beginning of the eighteenth centuries. In Marlborough, agriculture and cattle farming expanded to include beef and milk production and orchard owners produced cider and brandy for local use as well as export to Boston. Sudbury remained primarily agricultural as well. A second saw mill was in operation on Hop Brook (owned by a Peter King) in 1677.

During the Federal Period (1775 to 1830), Marlborough maintained a primarily agricultural economy. The only substantial waterpower available in the town was at Fentonville (now Hudson). Apples and cider were produced and a cottage industry in shoemaking began around 1815. Sudbury also had an agricultural economic base, with the exception of South Sudbury where there were brickyards, tanning vats, and a malt house, in addition to saw, grist, and fulling mills. During this period, three mills operated in relative isolation on Hop Brook in the southwest part of town.

The Early Industrial Period (1830 to 1870) saw the introduction of the railroad to Marlborough. Railroad access aided in the shipping of orchard products to Boston. Shoe production jumped from annual product valuation of $41,200 in 1837 to $2.3 million in 1865. Shoemaking by teams began in 1852, which coincided with the introduction of the sewing machine the same year. By 1860, there were 17 shoe shops in Marlborough, all run by steam, not waterpower. In Sudbury, during this period, most of the mills that began operation during the Federal Period remained in use, but were enlarged. In addition, there was a small cottage industry of straw braid production. Wadsworth Academy, a private school was established in 1857.

The population of Marlborough increased dramatically during the Late Industrial Period (1870 to 1915). There was a large foreign-born population, first Irish, then French Canadians, followed by Italians, who were encouraged to settle as strike breakers at the shoe manufactories. Shoe and boot making continued to grow rapidly. Mechanization and the growth of large factories had reduced the number of factories from 18 in 1875 to 8 in 1905. However, the annual production was valued at $6.6 million. In 1895, 78% of the population of Marlborough, were employed in shoemaking. In Sudbury, the population remained mostly unchanged during this period. The economic base remained primarily agricultural. The first greenhouse was erected in 1879, and between 1882 and 1889, 30 more greenhouses were established. Many of the small mills remained in operation, including a machinery manufacturer near the Massachusetts Central railroad in South Sudbury, and a nail manufacturer near the site of the present Wayside Inn Gristmill on Hop Brook.

During the Early Modern Period (1915 to 1940), the population of Marlborough remained relatively stable at around 16,000. Shoemaking apparently continued strong until the Depression. By this time, other manufacturers in Marlborough included paper boxes (Dennison factory, 1925), wire goods, shoe machinery, metal products, cosmetics, and textile soaps. Several large shoe factories remain in the city, including Frye and Rice and Hutchin's Middlesex Shoe Factory. Highway construction during the last 50 years, has brought additional, residential, commercial, and light industrial development to the city of Marlborough. In Sudbury, market gardening continued, as well as some industry along Hop Brook.

The historic inventories for both towns were examined at the MHC for the four dams being considered for possible removal. Some towns have very detailed, up to date inventories, while others have little or no information on the historic resources of the respective community. Two of the dams are listed in the MHC Historic Inventory in their respective towns, and one, the Grist Millpond Dam is part of a NR listed historic district.

Beginning upstream on Hop Brook, the first dam being investigated for removal is the Hager Pond dam, in Marlborough. Hager Pond is owned by the Ford Foundation while the dam is owned by two landowners abutting the pond. The Marlborough Wastewater Treatment Plant is directly upstream of the pond. The dam is stone and earthwork with concrete most likely added later with added space for flashboards. There is no visible evidence of an associated mill. Downstream, there is a stone arch culvert that is traversed by Boston Post Road. The culvert now has a corrugated pipe running through it. Hager Pond extends behind the Wayside Country Store, which may have been the site for any associated mill. It is hard to date this business as it has been enlarged and modified. Hop Brook had several early gristmills erected in Marlborough and Sudbury during the seventeenth century, but their exact location is not known. It appears that the dam may have been built in the nineteenth century with early twentieth century additions. Additional research is needed to determine whether removal of this dam would have an effect on historic properties, including archaeological resources.

The Grist Millpond and dam was owned by Henry Ford, then the Ford Foundation, but was given in trust to the Wayside Inn Corporation in 1946. The dam is part of the Wayside Inn Historic District. There are 14 properties included in the district, including the gristmill, Wayside Inn, Martha-Mary Chapel, the Redstone School, and several houses along the Boston Post Road. The district was expanded in 1973 and is roughly bounded by Wayside Inn and Dutton Roads, the B & M railroad track and Dudley Brook.

The Wayside Inn is believed to be the oldest operating inn in the country, with the first construction started by Samuel Howe, c. 1700. Samuel's son, David was granted a license for inn-keeping by the Concord Court in 1716 and kept Howe's Tavern until 1746. He added the two rooms now known as Longfellow's parlor and chamber, probably in 1716. Ezekial Howe, David's son, was landlord from 1746 to 1796 and renamed the inn The Red Horse. Ezekial added four rooms at the rear of the existing structure, including a ballroom, which in Henry Wadsworth Longfellow's "Tales of a Wayside Inn" was known as Hobgoblin Hall. Lyman Howe, was the fifth generation to operate the inn from 1830 to 1861. The inn was renamed as the Wayside Inn in 1863 (NR Nomination form: 1973).

The Wayside Inn was operated by various Howe heirs and tenants and gradually deteriorated, until 1923, when it was purchased by Henry Ford. Ford refurbished the inn and made it the center of a complex of buildings which, like those at his Greenfield Village, Dearborn, Michigan, were intended to keep Americans "in touch" with their past. The Redstone School, constructed in 1798, was moved to the inn district from Sterling, Massachusetts. The Grist Millpond was built in the 1920s near an earlier millrace. The Martha-Mary Chapel was also built by Henry Ford in 1939, and is one of six chapels that Ford had constructed from the same plans (NR Nomination form: 1973).

The Grist Millpond dam is part of the Historic District, but it appears to have been constructed sometime in the twentieth century. The spillway to the raceway, which provides water to the mill, is constructed of concrete and little stonework remains. It is possible that this dam is built on the site of an earlier dam and mill as Sudbury history describes a grist mill in operation on Hop Brook c. 1675, a sawmill built by 1659 by Thomas and Peter Noyes, and a nail factory near the present day grist mill, also on the Brook, all in South Sudbury.

The Wayside Inn Historic District is listed as protected by a Preservation Restriction. Owners of properties protected by a Preservation Restriction granted to a governmental body or qualified charitable corporation have a special responsibility to safeguard the historic integrity of their buildings or sites, and their settings. As defined by MGL Chapter 184, sections 31 – 33, a Preservation Restriction may restrict or limit any or all alterations to exterior or interior features, changes in site appearance, inappropriate uses, archaeological field investigations, or other uses or actions inappropriate to the preservation of an historic structure or site. Additional research is needed to determine whether removal or updating of this dam would be allowed under the existing Preservation Restriction.

The Carding Millpond and dam are located immediately downstream from the Grist Millpond. The town of Sudbury owns the dam and mill. The mill and dam appear to date to the mid to late nineteenth century. The dam has two sluiceways, and the metal waterwheel has been removed and is standing alongside the roadway to the site. The mill has a slate roof, and what appear to be original windows, doors, and hardware. Someone appeared to be living in the mill. There are three very large, new houses immediately downstream of the mill and dam. This dam is considered the most hazardous of the four in the study, but with its intact nineteenth century mill also appears to be one of the most historic. Additional research is needed to determine whether removal of this dam would have an effect on historic properties, including archaeological resources.

The Stearns Millpond dam is constructed of concrete and has two construction dates on the sluice gates, 1915 and 1934. There are remnants of concrete and fieldstone foundations surrounding the dam. However, this site is listed as a Historic Archaeological site (SUD-HA-9, Stearn's Mill) in the MHC Inventory. The first dam was built at this location in 1677, and the Stearn's Mill was built 39 years after the town was settled (early eighteenth century). During the

Revolution, the mill ground tons of saltpeter for the Colonial Army's gunpowder. In the Civil War, the mill turned out powder kegs for the Union Army. The mill made shell cases for the Korean conflict. There was a mill at this location for almost 300 years. Additional research is needed to determine whether removal of this dam would have an effect on historic properties, including archaeological resources, although its inclusion as an historic archaeological site in the state's inventory makes it likely that archaeological investigations will be needed.

4. Conclusions

Additional research is needed to determine if dam and sediment removal will affect historic properties. Currently, the Grist Millpond dam is the only dam in the study that is located within a historic district, which is listed on the NR. However, it is likely that the Stearns Millpond dam site may be eligible for the NR, and the integrity of the mill and dam at the Carding Millpond could make this site significant as well. In addition, once an alternative is selected, the location of staging or construction areas need to be researched for unknown prehistoric and/or historic period archaeological resources. Finally, consultation with the Massachusetts State Historic Preservation Officer (SHPO) and the Nipmuc and Wampanoag Tribal Historic Preservation Officers (THPOs) will need to be completed. If any dam (with the exception of the Grist Millpond dam which has a preservation restriction, so would be difficult to remove) is proposed for removal, then a determination of eligibility must be made and coordinated with the SHPO and THPOs. Any necessary staging areas should ideally utilize previously developed or disturbed upland areas, otherwise an intensive archaeological survey of the staging areas would need to be completed before use. If the dams are considered NR eligible, or are contributing elements of a historic district or archaeological site, then removal would constitute an adverse effect. If removal cannot be avoided, then mitigation in the form of photo and landscape documentation would be necessary and would need to be coordinated with the SHPO. Also, if archaeological sites are identified during the intensive archaeological survey of staging areas, then these sites would need to be avoided, or evaluated for NR significance. If the sites are determined NR eligible, then mitigation in the form of a data recovery would be necessary if site avoidance, or impact minimization is not viable. Another consideration is whether unknown prehistoric sites are on former brook terraces that are currently submerged under the impoundments. If dams are removed, then additional archaeological investigations might be needed for newly visible landforms. These adverse effects would require the preparation of a Memorandum of Agreement (MOA) between the agency funding the work, the SHPO, and the THPOs.

With all of these unknowns an accurate estimate for the cost of this work is unknown. A determination of effect just for dam removal, coordination with the SHPO and THPOs, and preparation of an MOA would cost approximately $8,000. Landscape documentation could cost between $5,000 and $10,000 per dam depending on associated structures. An accurate estimate for archaeological investigations cannot be made without knowing the acreage involved.

References

Leveillee, Alan, Mary Lynne Rainey 2001 Intensive (Locational) Archaeological Survey, Avalon Orchards Subdivision, Marlborough, Massachusetts. PAL Report No. 1171.

Massachusetts Historic Commission (MHC) Prehistoric Site Files

MHC
1980 Reconnaissance Survey Report, Marlborough, Massachusetts.

1980 Reconnaissance Survey Report, Sudbury, Massachusetts.

National Register of Historic Places
n.d. The Wayside Inn Historic District, Nomination Form

Appendix F – Real Estate Information

HOP BROOK SEDIMENT STUDY – REAL ESTATE INFORMATION
MARLBOROUGH AND SUDBURY, MASSACHUSETTS

1. PURPOSE: The purpose of the Hop Brook Sediment Study is to identify and assess alternatives for reducing internal phosphorus recycling from sediments through sediment removal, sediment treatment, or dam removal. This study is being done by the New England District Corps of Engineers under a Memorandum of Agreement with the Massachusetts Department of Environmental Protection (MADEP).

Hop Brook is classified as a Class B warm water fishery and designated as habitat for fish, other aquatic life and wildlife, and for primary and secondary contact recreation. Hop Brook, a tributary of the Sudbury River, played an important part in the development of industry in the area. Since the Sudbury River was not suitable for the siting of mills because of the broad wet meadows that surround it, at least seven mill sites were established along the 9.4 miles of hop Brook. The last of the mills operated on Stearns Mill Pond until the middle of the 20th century. Supplying water power for operation of the mills was a major function of Hop Brook for several centuries, as well as providing a supply of water to the farming population, their stock and crops. In earlier times, the brook also supplied abundant fish and excellent water quality. The Native American population used fishing weirs at numerous places on Hop Brook which is evidence of abundant fish and excellent water quality in earlier times.

Hop Brook experiences the chronic problem of excessive algae and aquatic weed growth during the summer season at the four impoundments: Hager Pond, located in Marlborough, MA, and Grist Millpond, Carding Millpond, and Stearns Millpond, in Sudbury, MA. This condition has existed for some time and past studies have shown the problem is a direct result of excessive levels of nutrients in the system, particularly in these slow moving impoundments. This causes excessive algae and plant growth. The nutrients come from both point and non-point sources of pollution. The Marlborough Easterly Wastewater Treatment Plant (MWWTP) is the only permitted point source in the watershed. Phosphorus and Nitrogen has been identified as the primary nutrient responsible for the excessive algae and aquatic weed growth.

This study will consider several options for reducing phosphorus concentrations in the impoundments. These options include further reduction of phosphorus concentrations in releases from the MWWTP, sediment dredging, dam removal or dam breachings.

2. PROJECT AREA DESCRIPTION: Hop Brook flows through the City of Marlborough and Town of Sudbury. Originally, farming communities, they have become more suburban with an increase in the number of single-family homes, roads, and commercial development.

The following real estate information was collected in the fall of 2005.

GRIST MILLPOND DAM, SUDBURY, MA

Location: Dam is located off Wayside Inn Road (off Route 20, aka The Boston Post Road), Sudbury (Assessor's Map L03, Lot 01).

The property was owned by Henry Ford, the Ford Foundation, between 1923 and 1945 , and then given in trust to the Wayside Inn Corporation, a private, non-profit educational historic trust which has been in existing since 1946. The parcel the dam is located on contains 32.09 acres and the deed is recorded in the Middlesex Registry, Book 6916, page 36. The Wayside Inn owns a total of 138.43 acres consisting of 8 contiguous lots, some with improvements (Map 03, Lot 1, 32.09 acres; Map 03, Lot 2, 65.15 acres; Map 02, Lot 9, 6.2 acres;
Map 02, Lot 10, 6.6 acres, L02, Lot 2, 21.5 acres; L02, Lot 3, .38 acres;
L02, Lot 4, 1.68 acres; and K 04, Lot 601, 4.83 acres).

Owner: The Wayside Inn Corp.
72 Wayside Inn Road
Sudbury, MA 01776

National Inventory of Dams: NID ID: MA01109
Record No.: 26131
County: Middlesex
Pond: Grist Millpond
Year Completed: 1800
Dam Type: REPG

The Wayside Inn Corp. owns a total of 110.04 acres of land comprised of the following: Map L03, Lot 1 consisting of 32.09 acres, Map 03, Lot 2 consisting of 65.15 acres, Map 02, Lot 09 consisting of 6.2 acres, and Map 02, Lot 10 consisting of 6.6 acres. The property is improved with plantings, a rose garden, and the following structures:

Grist Millpond – Henry Ford had this water-powered grist mill built as an educational replica a short distance downstream from the site of David How's early 1700's grist mill. It is currently used for grinding grains for use and sale at the Inn and is tended by the miller from April through November.

The Barn –This is the last remaining How Barn, probably built in the early 1800's. Historical records indicate the cultivation of hay, apples, Indian corn, rye, oats, and the raising of wine, sheep, cows, oxen and horses.

The Gate House – This was built by Edward Lemon, a former owner, around the turn of the century with many ancient timbers salvaged from colonial houses built elsewhere. It is presently the innkeeper's residence and not open to the public.

Ice House – This three-story building was built in the 1930's and was used for storage of ice cut from the adjacent Josephine Pond during the Henry Ford years.

Red Stone School – Built in 1798 in Sterling, Massachusetts, the Red Stone School is a good example of the early American one-room schoolhouse. The school was purchased by Henry Ford in 1926 and moved to its present location and was an active four-grade school from 1927 to 1951.

Martha-Mary Chapel – This non-denominational chapel, one of the six that Henry Ford had built in the U.S., was built in 1940 by Henry Ford in memory of his mother-in-law and mother. It served as a daily chapel for the Wayside Inn Boy's School, the Red Stone School House, and the Southwest School. It is now the site of many weddings and special events.

The Wayside Inn – Longfellow's Wayside Inn has been in operation since 1917, (archaeological research indicates that Native American used this site on Boston Post Road as far back as three thousand years ago). The original two-room house was built in 1707 by David How for his wife Hepzibah and the first two of his seven children. In 1716, he was granted a license to operate a "House of Public Entertainment" by the Massachusetts General Court. The house grew by seven additions to meet the changing needs of four generations of How's and later innkeepers.

Real estate summary: The property contains 110.04± acres with the above-listed improvements located in close proximity to each other, leaving plenty of land available for a construction staging area wherever it is needed.

CARDING MILLPOND DAM, SUDBURY, MA

Location: The property is located at 102 Dutton Road, Sudbury, MA 01776
Assessor's Map K03, Lot 0400. Middlesex Registry of Deeds
Book 19875, page 72, dated 6/13/1989.

Owner: The Town of Sudbury Conservation Commission
278 Old Sudbury Road
Sudbury, MA 01776

The property contains 43.01 acres of land with improvements, an old style building which was constructed about 1850. The 2,400 square foot building has a total of 4 rooms, 2 units, 1 full bath, 2 half baths, and 1 bedroom. The house appears to be in need of repairs with a couple of windows having cardboard or plywood in place of glass.

National Inventory of Dams: NID ID: MA00742
Record No.: 25827
County: Middlesex
River: Carding Millpond
Year Completed: 1930
Dam Type: REPG

Real estate summary: The property contains 43.1 acres of land improved with a one-story older structure, known as the Carding Mill Building, which appears to be in need of repairs. The town leases the building for residential use. Other than the area occupied by the building, driveway access (Cart Path), and the area where the pond is located, the remaining land is classified as Open Space and restricted by the deed, the land and pond are subject to the restrictions specified in the deed. There is sufficient land available for a construction staging area, if required in the future.

STEARNS MILLPOND DAM, SUDBURY, MA

Location: The property is located at 557 Dutton Road, Sudbury, MA 01776
Assessor's Map G05-Lot 0039, Middlesex Registry of Deeds
Book 831, page 27, dated 27 February 1973.

Current Owner: The Town of Sudbury Conservation Commission
278 Old Sudbury Road
Sudbury, MA 01776

Previous Owner: William L. smith and Janet M. Smith, trustees
Dovic Realty Trust, dated 2/13/1968
557 Dutton road
Sudbury, MA 01776

The property contains 2.73 acres of land improved with a 6-unit apartment building (the land was subdivided in 1996 into two lots, creating Lot 38 with 0.92 acres which is improved with a house, 555 Dutton Road, Sudbury).

National Inventory of Dams: NID ID: MA01132
Record No.: 26151
County: Middlesex
River: Stearns Millpond
Year Completed: 1900
Dam Type: REPG

Real estate summary: The 6-unit apartment unit is located on the northerly portion of the property. There are no other structures on the property, thus, the southerly portion could be utilized for a staging area, if required in the future.

HAGER POND DAM, MARLBOROUGH, MA

Location: The dam is located on Hager Pond (Assessor's Map 62, Lot 12 containing 33± acres) and between the following 2 parcels:

Assessor's Map 62, Lot 13 (Anthony P. Scerra Trustee)
Middlesex Registry of Deeds Book 13182, page 228, May 2, 1977 &
Assessor's Map 62, Lot 11 (Philip J. Bailey & Anne D. Fish)
Middlesex Registry of Deeds Book 24681, page 417, 28 June 1994.

Pond Owner: Hager Pond, which covers 33± acres of land, is owned by the Ford Foundation. The city of Marlborough has an assessed value of $477,700 on the pond, however, no taxes are due since it is owned by a charitable organization. The dam is owned by the following two landowners abutting the pond who own to the centerline of the stream.

Dam Owner: Anthony P Scerra Trustee (Lot 13)
AJ&S Realty Trust
126 Langelier Lane
Marlborough, MA 01752
This parcel contains 4.1 acres of land improved with a shopping center/mall having 11 businesses.

Philip J. Bailey and Anne D. Fish (Lot 11)
47 Hager Street
Marlborough, MA 01752
This parcel contains 3.37 acres of land improved with a single family, Cape Cod style house.

National Inventory of Dams: NID ID: MA00452
Record No.: 25593
County: Middlesex
River: Hager Pond
Year Completed: 1800
Dam Type: REPG

Real estate summary: The City of Marlborough owns 0.15 acres of land (Map 62, Lot 6B) adjacent to Route 20 which could be utilized for a construction staging area which was purchased by the city for the relocation of Hager Street.   If additional land is needed during construction, a portion of Map 62, Lot 6 (owned by Jennifer T. & Charles R. Landry, consisting of 1.85± acres and improved with a single family house) might be available.

3. RECOMMENDED PLAN: The alternative chosen will depend on the study results. The alternatives being considered include removing and/or breaching one or more dams; and removing/disposing of sediment in the impoundments.

The alternatives will consider the extent to which the project is expected to improve the aquatic habitat; likelihood that a dam could be removed; sediment disposal practicability (sediment to be placed in a landfill or confined disposal within the impoundments); and historic resource considerations.

4. OWNERSHIP: Hager Pond Dam is owned by two private property owners whose ownership goes to the centerline of the pond; Grist Millpond Dam is owned by a private non-profit educational trust; Carding and Stearns Millpond Dams are owned by the town of Sudbury.

5. RECOMMENDED ESTATES: It will be necessary to acquire temporary easements over land which can be used to access the various dam sites and for a contractor's staging area, both for dam removal and for dredging of the river. If the option is to remove the dam, it might also be necessary to acquire some of the property in fee.   However, the actual estates needed will be determined as the project progresses.

6. EXISTING FEDERAL PROJECTS: There are no current Federal projects in the subject project areas.

7. EXISTING FEDERAL OWNERSHIP: There are no federally owned lands in the subject project areas.

8. NAVIGATION SERVITUDE: Navigation servitude does not apply.

9. REAL ESTATE MAPPING: Detailed maps of the project areas will be provided after the study is completed and recommendations made.

10. INDUCED FLOODING: The project will not cause any flooding of other non-project lands.

11. BASELINE COST ESTIMATE: At this time, it is not feasible to estimate the real estate costs, since there are too many unknowns. A cost estimate will be provided in the future.

12. PUBLIC LAW 91-64 RELOCATIONS: It does not appear that there are any potential Public Law 91-646 relocations required in connection with this project, nor any residences or businesses which would be relocated under P.L. 91-646. When the project progresses further, the sponsor will be advised of P.L. 91-646 and the requirement to document expenses.

13. MINERAL AND/OR TIMBER ACTIVITY: There is no present or anticipated mineral or timber harvesting activity in the vicinity of this project.

14. ASSESSMENT OF NON-FEDERAL SPONSOR'S REAL ESTATE ACQUISITION CAPABILITIES: The sponsor must provide all lands, easements, rights of way, relocations and dredged or excavated material disposal areas (LERRD's) required for construction and maintenance of the project at no cost to the Federal Government.   The sponsor, the Commonwealth of Massachusetts Department of Environmental Protection, has the ability to acquire all the real estate needed for this project. The Assessment of Non-Federal Sponsor's Real Estate Acquisition Capability checklist will be included with the Real Estate Plan.

15. ZONING CHANGES: No zoning changes are proposed in lieu of, or to facilitate, real estate acquisitions.

16. ACQUISITION SCHEDULE: The following acquisition schedule will be established once the project move forward.

a. Forward maps to sponsor – date
b. Survey – date
c. Title – date
d. PCA Execution – date
e. Appraisals – date
f. Closings – date
g. Possession – date
h. LER Certification – date

17. FACILITIES AND UTILITIES RELOCATIONS: The proposed project will not require any utility and/or facility relocations.

18. HAZARDOUS, TOXIC, AND RADIOACTIVE WASTE: An Environmental Assessment and Finding of No Significant Impact will be completed on the project. The proposed project will not result in an adverse impact on the environment. Further assessment is not required.

19. LANDOWNERS SENTIMENT: There appears to be a broad base of support for this project from the public that uses Hop Brook for fishing, canoeing, walking near the river, or just enjoys being near the river as well as from other   Federal , State, and local agencies.

19. OTHER REAL ESTATE ISSUES: After recommendations are made as to the preferred alternative, the selected sites will have to be studied in detail since some of the sites are historical and some are located on privately owned land.

PHOTOGRAPHS TAKEN BY A. MARY DUNN
JANUARY 10, 2006

View of Hager Pond and Hager Pond Dam, Marlborough, MA

Grist Millpond Dam, Sudbury, MA

Looking at dam, standing on bridge over Carding Millpond Dam, Sudbury, MA

Carding Millpond, Sudbury, MA

Looking easterly while standing on bridge, Carding Millpond Dam

Looking northerly from ROW leading to Dutton Road. Wheel on upland appears to be in process of being repaired.

Stearns Millpond Dam, off Dutton Road, Sudbury, MA

Appendix G – Hydrologic and Hydraulic Analysis

Hydrologic and Hydraulic Analysis
Hop Brook
Marlborough and Sudbury, Massachusetts

1. Introduction.

This hydrologic and hydraulic analysis was conducted to provide an assessment of dam configuration alternatives within the Hop Brook watershed to determine the optimum channel configuration in order to help reduce internal phosphorus recycling from sediments. The dams on Hop Brook in Marlborough and Sudbury, MA provide sediment detention areas where the levels of phosphorus can accumulate to high levels resulting in unacceptable levels of plant growth. This study is being performed under a "Memorandum of Understanding" with the Massachusetts Department of Environmental Protection (MADEP).

The purpose of the study is to determine the best alternative to reduce nutrient loading in Hager Pond, Grist Millpond, Carding Millpond, and Stearns Millpond. Alternatives considered include dredging to remove nutrient loaded sediments, sediment treatment, and structural alternatives at the dams (removal, and partial removal). Analysis of the structural alternatives at the dams helps determine if lowering impoundment water levels and increasing channel velocities helps to achieve a more acceptable level of accumulated phosphorous in the sediments. This was accomplished using the Corps of Engineer's HEC-RAS standard step backwater model. The hydraulic analysis examined seven dam configuration alternatives for the four dams on the Hop Brook: existing conditions (no structural alterations), removal of Hager Pond Dam, removal of Carding Millpond and Stearns Millpond Dams, removal of Carding Millpond Dam, a partial breach of Hager Pond Dam, a partial breach of Carding Millpond Dam, a partial breach of Carding Millpond and Stearns Millpond Dams, a partial breach of Hager Pond, Carding Millpond, and Stearns Millpond Dams.

2. Description of Study Area.

a. General. The Hop Brook watershed is located in east-central Massachusetts and is formed by runoff from Ward Hill, within the Concord River watershed, a sub watershed of the Sudbury River. Hop Brook is located in Marlborough and Sudbury. Hop Brook flows a distance of approximately 12 miles to its confluence with the Sudbury River in Sudbury, Massachusetts. The Sudbury River flows an additional 10 miles to its confluence with the Assabet River in Concord, which together with the Sudbury River forms the Concord River. The Marlborough Wastewater Treatment Plant (MWWTP) discharges into Hop Brook near its headwaters, and it is believed that nutrients (phosphorus and nitrogen) from this discharge are primarily responsible for eutrophication at four downstream impoundments, resulting in excessive aquatic macrophytes and algal growth. The downstream impoundments affected by these excess nutrients lie within five miles of the headwaters of Hop Brook in the City of Marlborough and town of Sudbury. These include (in order from upstream to downstream) Hager Pond, Grist Millpond, Carding Millpond and Stearns Millpond. The study will focus primarily on these four impoundments:

The study area extends from just upstream of Hager Pond Dam in Marlborough, downstream along Hop Brook to where it enters Great Meadows Wildlife Refuge. The total length of the study reach is approximately 8.5 miles on Hop Brook within the city of Marlborough and town of Sudbury, MA. The drainage areas along the study reach increase from approximately 1.0 square mile just upstream of Hager Pond Dam to approximately 15.6 square miles at its confluence with Landham-Allowance Brook just upstream of the study limit. Significant tributaries to Hop Brook include Run Brook, Dudley Brook, and Landham-Allowance Brook with drainage areas of 0.6, 2.3, and 21.0 square miles, respectively. A map of the Hop Brook watershed and study reach is shown on Plate 1.

The Hop Brook watershed basin dominated by rural, forested areas with a moderate mix of development is characterized by rolling hills with some wetland areas in between the impoundments in the upper reaches and wide flat bordering vegetated wetlands in the lower reaches. Elevations in the basin vary from 116 +/- ft. NGVD at the most downstream study limit to 214 +/- ft. NGVD just upstream of Hager Pond Dam. Development in the Hop Brook floodplain is mainly residential with commercial and industrial near the main highways.

b. Dams. Following is a brief description of the four dams within the study reach in downstream order. This information was obtained from general inspection information reports completed by the Geotechnical Engineering Section as part of this study, and inspection reports provided by the State of Massachusetts Dam Safety Office.

(1) Hager Pond Dam. The dam, the most upstream in the study reach, is located approximately 8.5 miles upstream of the downstream study limit located within the Great Meadows Wildlife Refuge. The dam is currently in poor condition with concrete abutments in need of repair. The concrete and stone dam is approximately 14 feet high with a crest 225 feet long with an elevation of 223.3 feet NGVD at the top of the concrete abutments at the control structure.

(2) Grist Millpond Dam. The dam is located approximately 3,750 feet downstream of Hager Pond Dam. The dam is currently owned by the Wayside Inn and operated for recreational purposes. The earthen dam has an estimated structural height of about 15 feet and an estimated crest length of 400 feet with crest elevations ranging from 212 to 214 feet NGVD. The uncontrolled spillway is about 20 feet wide with a drop of approximately 2 feet from the crest of the dam. The dam is equipped with a 12-inch cast iron low-level outlet pipe at the downstream toe controlled by a structure consisting of a manhole and valve. The sluiceway to the Grist Millpond is on the right abutment of the dam. The channel is approximately 10 feet wide and 2 feet in depth The sluiceway has trash racks at the intake and a gated (to water wheel) and uncontrolled section about 10 feet wide at the Grist Millpond.

(3) Carding Millpond Dam. The dam is approximately 5,000 feet downstream of Grist Millpond Dam. The dam has a structural height of 15 feet and a crest length of 450 feet with a crest elevation at the spillways of 187.8 ft. NGVD. The dam is built adjacent to an existing historic wooden mill building. The dam has two spillways, one gated and the other uncontrolled. The combined width of the concrete and granite block spillways is about 60 feet.

(4) Stearns Millpond Dam. The dam is approximately 2.6 miles downstream of Carding Millpond Dam. The dam is constructed of earthfill with concrete abutment walls and a concrete spillway section. The embankment has a structural height of 10 feet and a crest length of approximately 300 feet with crest elevations ranging from 156.1 to 158.6 ft. NGVD. The left abutment of the dam has a 3 foot thick concrete wall about 20 feet in length and a 1 foot thick wall section along the side of the pond. The dam was part of an old powder mill used during the Civil War. The mill building has been removed from the site.

3. Streamflow.

a. General. There are no USGS river recording gages on Hop Brook. The August average daily flow was calculated from discharge records provided by the Marlborough WWTP. The flood flows were taken from the Hec-2 files used in the analysis for the Flood Insurance Studies for Marlborough and Sudbury, MA.

b. August Average Daily Flow. The August average daily flow was used in the HEC-RAS model to analyze any changes in water levels and velocities in the wetland areas for the different alternatives during a typical low flow period. The inflow into Hager Pond has been previously stated as being, "the discharge from the Marlborough WWTP in August is 80% of the total flow into Hager Pond". An August average daily flow was calculated using the Marlborough WWTP daily discharge records. Flows of higher magnitude were then analyzed to define the extent of changing water levels, and possible erosion, and scour problems in the study area due to the partial breach or dam removal alternatives.

c. Flood Flow. The following estimated peak flood flows were taken from FEMA's Marlborough and Sudbury, MA Flood Insurance Studies. These flows were used in HEC-RAS model and appear reasonable as compared to similar watersheds and were used to analyze the effects of the proposed alternatives under high flow conditions. Table 1 shows the flows at the upstream and downstream limits of the study.

Table 1
Flows
Hop Brook

	Peak Discharges (cfs)	**Peak Discharges (cfs)**
Flow Event	At D/S Limit	U/S Hager Pond Dam
Aug. Ave.	18	4
10YR	470	158
50YR	765	258
100YR	918	309
500YR	1300	435

4. Hydraulic Analysis.

a. General. The Corp's HEC-RAS computer program was used to model the hydraulic effects of dam removal/partial breach alternatives and to determine water elevations and velocities for the existing and proposed alternative conditions. Flows ranging from the August average daily flow up to the 500YR flood flow were modeled to provide a detailed profile of the Hop Brook for these different flow conditions. These results are used to determine if any of the proposed alternatives will decrease impoundment water levels and increase channel velocities to levels necessary to start to achieve acceptable levels of accumulated phosphorous in the sediments. The results of the analysis of proposed alternatives were compared to the existing conditions to define the effects on the river elevations and velocities at the impoundments and wetland areas of concern.

b. Dam Removal Alternatives. Seven dam removal alternatives were modeled as part of this study. A partial dam removal represents the smallest flow area (most restrictive channel without dam) to expect on the river and a complete removal represents the largest flow area (similar to pre-dam conditions). No structural alternatives for this hydraulic analysis were proposed for the Grist Millpond Dam. For this study a partial removal is considered as removal of 50% of the hydraulic height of the dam for the complete length. These parameters are reasonable for comparison of the alternatives. The seven alternatives are described below.

(1) Alternative 1: Removal of Hager Pond Dam. This alternative involves the removal of the concrete outlet works of the dam with a height of approximately 14 feet with a length of approximately 50 feet. Do nothing at Grist Mill, Carding Mill, and Stearns Mill Pond Dams.

(2) Alternative 2: Removal of Carding, and Stearns Millpond Dams. This alternative involves the removal of Carding and Stearns Millpond dams. The Carding Millpond dam is a earthen dam with a height of approximately 15 feet and a crest length of 450 feet. For this alternative only 250 feet of the total of 450 feet was assumed to be removed. Stearns Millpond dam is an earthfill dam with concrete abutment walls and a concrete spillway section. The embankment has a structural height of 10 feet and a crest length of approximately 300 feet. For this alternative only 126 feet of the total of 300 feet was assumed removed. Do nothing at Hager Pond, and Grist Millpond dams.

(3) Alternative 3: Removal of Carding Millpond Dam. This involves the removal of Carding Millpond Dam. The Carding Millpond dam is an earthen dam with a height of approximately 15 feet and a crest length of 450 feet. For this alternative only 250 feet of the total of 450 feet was assumed removed. Do nothing at Hager Pond, Grist Millpond, and Stearns Millpond dams.

(4) Alternative 4: Partial Removal of Hager Pond Dam. This involves the removal of approximately 7 feet of the hydraulic height of the dam for a length of approximately 50 feet. Do nothing at Grist, Carding, and Stearns Millpond dams.

(5) Alternative 5: Partial Removal of Carding Millpond Dam. This involves the removal of approximately 7.5 feet of the hydraulic height of the dam for a length of approximately 250 feet. Do nothing at Hager, Carding Millpond, and Stearns Millpond dams.

(6) Alternative 6: Partial Removal of Carding, and Stearns Millpond Dams. For Carding Millpond dam this involves the removal of approximately 7.5 feet of the hydraulic height of the dam for a length of approximately 250 feet. For Stearns Millpond dam this involves the removal of approximately 5.0 feet of the hydraulic height of the dam for a length of approximately 126 feet. Do nothing at Hager Pond, and Grist Millpond dams.

(7) Alternative 7: Partial Removal of Hager Pond, Carding Millpond, and Stearns Millpond Dams. For Hager Pond dam this involves the removal of approximately 7 feet of the hydraulic height of the dam for a length of approximately 50 feet. For Carding Millpond dam this involves the removal of approximately 7.5 feet of the hydraulic height of the dam for a length of approximately 250 feet. For Stearns Millpond dam this involves the removal of approximately 5.0 feet of the hydraulic height of the dam for a length of approximately 126 feet. Do nothing at Grist Millpond dam.

(8) Alternative 8: Dredging of Hager Pond, Grist Millpond, Carding Millpond and Stearns Millpond. This alternative looked into dredging the nutrient rich sediments from all four ponds: Hager Pond to a maximum depth of 4 ft, Grist Millpond to a maximum depth of 2 ft, Carding Millpond to a maximum depth of 2ft and Stearns Millpond to a maximum depth of 2 ft.

c. HEC-RAS Analysis. The Corps of Engineers HEC-RAS computer model was used to compute water surface profiles, from upstream of the confluence of Hop Brook and Sudbury River in the Great Meadows Wildlife Refuge upstream through the Town of Sudbury to just upstream of the Hager Pond Dam in Marlborough. It is a standard step method for calculating water surface elevations for steady gradually varied flows, based on river geometry and structures crossing the channel. Input for the model consists of channel geometry, hydraulic roughness coefficients, bridge and dam elevation data and structural geometry, and flow data.

Dimensions of the dams, bridges, and river channel cross sections through the study reach were obtained from the HEC-2 files for the Marlborough and Sudbury, MA FEMA Flood Insurance Studies. Supplemental survey was conducted in to better define existing conditions of the structure, channel, and surrounding topography at each of the dams, and at several wetlands located along the study reach. This new survey data was incorporated into the model to better define the existing conditions. Plate 1 shows the starting and ending limits of the 8.5 mile reach used for the HEC-RAS analysis.

5. Study Results. The HEC-RAS model was developed from just upstream of the confluence with the Sudbury River and extended to just upstream of Hager Pond dam. Starting water surface elevations and flows for the flood-flow analyses were taken from the profiles and information in the Sudbury Flood Insurance Study. Starting water surface elevations for the August average daily flow were calculated by the normal depth computation in the HEC-RAS model using the slope of the stream bottom. Profiles were computed from just upstream of the confluence to above Hager Pond dam. Computed elevations and velocities are presented in

Table 2 for three sections of the river that showed differences between existing conditions and the seven alternatives. The three sections that showed differences are; upstream of Hager Pond dam, an area upstream of Carding Millpond dam (river station 363.05 to river station 396.53), and an area upstream of Stearns Millpond dam (river station 227.1 to river station 287.55). The rest of the study reach showed no change in water surface elevations or velocities between existing conditions and the partial and complete removal alternatives. The information summarized in Table 2 is for August average daily flow, and FEMA's 10, 50, 100, and 500-year flood flows. Plates 1-18 present backwater profiles for the area upstream of Carding Millpond to downstream of Stearns Millpond dam, river stations 206.5 to 401.5. Alternatives 2, 3, 5, 6, and 7 were presented because they represent the most significant change in water surface elevations and channel velocities from the existing conditions.

Analyzed flows ranged from August average daily flow, 4 cfs, to the 500-year flood event of 890 cfs. Results from this range of flows defined the local flow characteristics needed to identify possible areas susceptible to scour and erosion due to velocity increases, and characterize the change of water surface profiles within the wetland areas for the seven alternatives. The velocities provide information needed in the planning and design for any needed stream bank protection. Velocity increases upstream and downstream of Carding Millpond and Stearns Millpond dams for 10 to 500-year flows ranged from 0.5-5 fps for the proposed Alternatives 2 and 3 (refer to Table 2).

6. Dredging Considerations.

a. General. In order to promote the long-term hydraulic and ecological soundness of the Carding and Stearns Millpond Dam removal, or partial removal projects, a two-foot-deep channel was proposed to be dredged in the future channel, with sloping banks and seeded as appropriate. It is expected that this new channel will need to pass the 1-to-2-year flood without its banks being overtopped. The channels were therefore examined to find appropriate widths to be excavated. The 2-year flood was chosen for this analysis.

b. Storm Sizes. The FEMA flood insurance study data adopted for the HEC-RAS model has provided flows for storms with average expected return periods of 10, 50, 100, and 500 years. At both Carding and Stearns Millponds, there is a strong relationship between the return period and the expected peak flow, of the form:

$$\text{Flow} = c\,(RP)^x$$

where Flow is in cfs
RP is the expected average return period
and c and x are constants determined from curve-fitting (best linear fit on a log-log plot).

Extending this relationship downward to smaller storm flows with smaller return periods for Carding Millpond leads to a 2-year flow of 108 cfs, and for Stearns Millpond to a 2-year flow of 222 cfs.

b. Results. Starting upstream and going down the thalweg/channel:

A Manning's n value of 0.035 was assumed for the channel (no change). Current bottom-of-channel was used to estimate slopes. Approximation: hydraulic mean depth taken as depth (good for a wide rectangular channel).

Channel to be 2 ft deep.

(1) Channel upstream of Carding Millpond (2-year flow is 108 cfs):
The Carding channel can carry the flow in a 16-ft-wide, 2-ft deep channel, both in the partial removal section (only 75 feet from Station 392.9 to 392.15) and in the rest (2,615 ft from 392.15 to 366.0).

The last 300 feet have an adverse slope and water will need to be conveyed subject to detailed site-specific modifications.

(2) Channel upstream of Stearns Millpond Dam (2-year flow is 222 cfs):

From Station 311.5 to 307.1, dist = 440 ft.
Ave width = 33 feet.

Bridge at Sta 307.05 will be subject to detailed attention.

From Station 307.0 to 298.0, dist = 900 ft.
Ave width = 110 feet.

Bridge at Sta 297.8 will be subject to detailed attention.

From Station 297.7 to 282.04, dist = 1,566 ft.
Ave width = 45 feet.

Bridge at Sta 282.01 will be subject to detailed attention.

From Station 282.0 to 261.1, dist = 2,090 ft.
Ave width = 43.4 feet.

End of thalweg in the case of a partial removal of Stearns Millpond Dam.

From Station 261.1 to 230.0, dist = 3,110 ft.
Ave width = 55.7 ft.

There is an adverse slope for 289 feet from Station 230.0 to the dam at station 227.11, and water will need to be conveyed subject to detailed site-specific modifications.

Table 2:

HEC-RAS Model Results

			Existing Cond.		Alternative 1[1]		Alternative 2[2]		Alternative 3[3]		Alternative 4[4]		Alternative 5[5]		Alternative 6[6]		Alternative 7[7]	
River Station	Flow Desc.	Flow (cfs)	CWSEL	VCH	CWSEL	VCH	CWSEL	VCH	CWSEL	VCH	CWSEL	VCH	CWSEL	VCH	CWSEL	VCH	CWSEL	VCH
206.5	Aug. Ave.	10	145.8	2.9	145.8	2.9	145.8	2.9	145.8	2.9	145.8	2.9	145.8	2.9	145.8	2.9	145.8	2.9
	10-YR	324	148.1	2.8	148.1	2.8	148.1	2.8	148.1	2.8	148.1	2.8	148.1	2.8	148.1	2.8	148.1	2.8
	50-YR	528	148.8	2.3	148.8	2.3	148.8	2.3	148.8	2.3	148.8	2.3	148.8	2.3	148.8	2.3	148.8	2.3
	100-YR	633	149.0	2.3	149.0	2.3	149.0	2.3	149.0	2.3	149.0	2.3	149.0	2.3	149.0	2.3	149.0	2.3
	500-YR	890	149.6	2.3	149.6	2.3	149.6	2.3	149.6	2.3	149.6	2.3	149.6	2.3	149.6	2.3	149.6	2.3
225.69	Aug. Ave.	10	148.3	0.3	148.3	0.3	148.3	0.3	148.3	0.3	148.3	0.3	148.3	0.3	148.3	0.3	148.3	0.3
	10-YR	324	150.4	2.0	150.4	2.0	150.4	2.0	150.4	2.0	150.4	2.0	150.4	2.0	150.4	2.0	150.4	2.0
	50-YR	528	150.9	2.4	150.9	2.4	150.9	2.4	150.9	2.4	150.9	2.4	150.9	2.4	150.9	2.4	150.9	2.4
	100-YR	633	151.2	2.6	151.2	2.6	151.2	2.6	151.2	2.6	151.2	2.6	151.2	2.6	151.2	2.6	151.2	2.6
	500-YR	890	151.7	3.0	151.7	3.0	151.7	3.0	151.7	3.0	151.7	3.0	151.7	3.0	151.7	3.0	151.7	3.0
226.05	Aug. Ave.	10	148.3	0.4	148.3	0.4	148.3	0.4	148.3	0.4	148.3	0.4	148.3	0.4	148.3	0.4	148.3	0.4
	10-YR	324	150.6	1.9	150.6	1.9	150.6	1.9	150.6	1.9	150.6	1.9	150.6	1.9	150.6	1.9	150.6	1.9
	50-YR	528	151.4	2.2	151.4	2.2	151.4	2.2	151.4	2.2	151.4	2.2	151.4	2.2	151.4	2.2	151.4	2.2
	100-YR	633	151.8	2.2	151.8	2.2	151.8	2.2	151.8	2.2	151.8	2.2	151.8	2.2	151.8	2.2	151.8	2.2
	500-YR	890	153.6	1.9	153.6	1.9	153.6	1.9	153.6	1.9	153.6	1.9	153.6	1.9	153.6	1.9	153.6	1.9
227.7	Aug. Ave.	10	155.8	0.2	155.8	0.2	155.8	0.2	155.8	0.2	155.8	0.2	155.8	0.2	155.8	0.2	155.8	0.2
	10-YR	324	157.9	1.2	157.9	1.2	156.1	4.6	157.9	1.2	157.9	1.2	157.9	1.2	157.0	1.9	157.0	1.9
	50-YR	528	158.6	1.5	158.6	1.5	156.4	5.4	158.6	1.5	158.6	1.5	158.6	1.5	157.3	2.5	157.3	2.5
	100-YR	633	158.7	1.6	158.7	1.6	156.5	5.7	158.7	1.6	158.7	1.6	158.7	1.6	157.5	2.7	157.5	2.7
	500-YR	890	158.9	2.1	158.9	2.1	156.7	6.4	158.9	2.1	158.9	2.1	158.9	2.1	157.9	3.3	157.9	3.3
258.0	Aug. Ave.	10	155.8	0.0	155.8	0.0	155.2	0.0	155.8	0.0	155.8	0.0	155.8	0.0	155.8	0.0	155.8	0.0
	10-YR	324	158.0	0.3	158.0	0.3	156.5	0.5	158.0	0.3	158.0	0.3	158.0	0.3	157.1	0.4	157.1	0.4
	50-YR	528	158.6	0.5	158.6	0.5	156.9	0.7	158.6	0.5	158.6	0.5	158.6	0.5	157.5	0.6	157.5	0.6
	100-YR	633	158.8	0.5	158.8	0.5	157.1	0.8	158.8	0.5	158.8	0.5	158.8	0.5	157.7	0.7	157.7	0.7
	500-YR	890	159.0	0.7	159.0	0.7	157.5	1.0	159.0	0.7	159.0	0.7	159.0	0.7	158.1	0.9	158.1	0.9
278.8	Aug. Ave.	10	155.8	0.3	155.8	0.3	155.3	0.4	155.8	0.3	155.8	0.3	155.8	0.3	155.8	0.3	155.8	0.3
	10-YR	324	158.3	1.5	158.3	1.5	157.8	2.0	158.3	1.5	158.3	1.5	158.3	1.5	159.0	1.7	159.0	1.7
	50-YR	528	159.0	1.7	159.0	1.7	158.5	2.2	159.0	1.7	159.0	1.7	159.0	1.7	158.6	2.1	158.6	2.1
	100-YR	633	159.2	1.9	159.2	1.9	158.8	2.2	159.2	1.9	159.2	1.9	159.2	1.9	158.9	2.2	158.9	2.2
	500-YR	890	159.6	2.2	159.6	2.2	159.5	2.4	159.6	2.2	159.6	2.2	159.6	2.2	159.5	2.4	159.5	2.4
283.0	Aug. Ave.	10	155.8	1.1	155.8	1.1	155.8	1.1	155.8	1.1	155.8	1.1	155.8	1.1	155.8	1.1	155.8	1.1
	10-YR	324	159.0	5.4	159.0	5.4	158.1	7.5	159.0	5.4	159.0	5.4	159.0	5.4	158.2	7.3	158.5	6.4
	50-YR	528	160.3	4.2	160.3	4.2	160.2	4.6	160.3	4.2	160.3	4.2	160.3	4.2	160.2	4.5	160.3	4.1
	100-YR	633	160.5	4.3	160.5	4.3	160.4	4.5	160.5	4.3	160.5	4.3	160.5	4.3	160.5	4.4	160.6	4.1
	500-YR	890	161.0	4.4	161.0	4.4	161.0	4.4	161.0	4.4	161.0	4.4	161.0	4.4	161.0	4.4	161.1	4.1
297.0	Aug. Ave.	10	157.9	0.9	157.9	0.9	157.9	0.9	157.9	0.9	157.9	0.9	157.9	0.9	157.9	0.9	157.9	0.9
	10-YR	324	160.8	1.4	160.8	1.4	160.8	1.4	160.8	1.4	160.8	1.4	160.8	1.4	160.8	1.4	160.8	1.4
	50-YR	528	161.1	1.7	161.1	1.7	161.1	1.7	161.1	1.7	161.1	1.7	161.1	1.7	161.1	1.7	161.1	1.7
	100-YR	633	161.3	1.8	161.3	1.8	161.3	1.8	161.3	1.8	161.3	1.8	161.3	1.8	161.3	1.8	161.3	1.8
	500-YR	890	161.7	1.9	161.7	1.9	161.7	1.9	161.7	1.9	161.7	1.9	161.7	1.9	161.7	1.9	161.8	1.8
299.0	Aug. Ave.	10	157.9	1.1	157.9	1.1	157.9	1.1	157.9	1.1	157.9	1.1	157.9	1.1	157.9	1.1	157.9	1.1
	10-YR	324	161.0	1.1	161.0	1.1	161.0	1.1	161.0	1.1	161.0	1.1	161.0	1.1	161.0	1.1	161.0	1.1
	50-YR	528	161.5	1.3	161.5	1.3	161.5	1.3	161.5	1.3	161.5	1.3	161.5	1.3	161.5	1.3	161.5	1.3
	100-YR	633	161.8	1.3	161.8	1.3	161.8	1.3	161.8	1.3	161.8	1.3	161.8	1.3	161.8	1.3	161.8	1.3
	500-YR	890	162.5	1.3	162.5	1.3	162.5	1.3	162.5	1.3	162.5	1.3	162.5	1.3	162.5	1.3	162.5	1.3

[1] Removal of Hager Pond Dam [2] Removal of Carding and Stearns Mill Pond Dams [3] Removal of Carding Mill Dam [4] Partial removal (50%) of Hager Pond Dam [5] Partial removal (50%) of Carding Mill Pond Dam
[6] Partial removal (50%) of Carding and Stearns Mill Pond Dams [7] Partial removal (50%) of Hager, Carding and Stearns Mill Pond Dams
* CWSEL - Channel Surface Water Elevation (ft. NGVD) ** VCH - Velocity Channel (cfs)

Any highlighted cells indicate a change from the Existing Conditions for the corresponding Alternative.

Table 2:
HEC-RAS Model Results

			Existing Cond.		Alternative 1[1]		Alternative 2[2]		Alternative 3[3]		Alternative 4[4]		Alternative 5[5]		Alternative 6[6]		Alternative 7[7]	
River Station	**Flow Desc.**	**Flow (cfs)**	CWSEL	VCH	CWSEL	VCH	CWSEL	VCH	CWSEL	VCH	CWSEL	VCH	CWSEL	VCH	CWSEL	VCH	CWSEL	VCH
	Aug. Ave.	4	160.4	1.1	160.4	1.1	160.4	1.1	160.4	1.1	160.4	1.1	160.4	1.1	160.4	1.1	160.4	1.1
	10-YR	158	162.6	1.9	162.6	1.9	162.6	1.9	162.6	1.9	162.6	1.9	162.6	1.9	162.6	1.9	162.6	1.9
336.5	50-YR	258	162.9	2.2	162.9	2.2	162.9	2.2	162.9	2.2	162.9	2.2	162.9	2.2	162.9	2.2	162.9	2.2
	100-YR	309	163.1	2.3	163.1	2.3	163.1	2.3	163.1	2.3	163.1	2.3	163.1	2.3	163.1	2.3	163.1	2.3
	500-YR	435	163.6	2.3	163.6	2.3	163.6	2.3	163.6	2.3	163.6	2.3	163.6	2.3	163.6	2.3	163.6	2.3
	Aug. Ave.	4	161.4	1.8	161.4	1.8	161.4	1.8	161.4	1.8	161.4	1.8	161.4	1.8	161.4	1.8	161.4	1.8
	10-YR	158	162.8	4.1	162.8	4.1	162.8	4.1	162.8	4.1	162.8	4.1	162.8	4.1	162.8	4.1	162.8	4.1
339.0	50-YR	258	163.2	4.2	163.2	4.2	163.2	4.2	163.2	4.2	163.2	4.2	163.2	4.2	163.2	4.2	163.2	4.2
	100-YR	309	163.4	4.3	163.4	4.3	163.4	4.3	163.4	4.3	163.4	4.3	163.4	4.3	163.4	4.3	163.4	4.3
	500-YR	435	163.7	4.3	163.7	4.3	163.7	4.3	163.7	4.3	163.7	4.3	163.7	4.3	163.7	4.3	163.7	4.3
	Aug. Ave.	4	163.7	0.3	163.7	0.3	163.7	0.3	163.7	0.3	163.7	0.3	163.7	0.3	163.7	0.3	163.7	0.3
	10-YR	158	166.8	1.1	166.8	1.1	166.8	1.1	166.8	1.1	166.8	1.1	166.8	1.1	166.8	1.1	166.8	1.1
343.6	50-YR	258	167.5	1.4	167.5	1.4	167.5	1.4	167.5	1.4	167.5	1.4	167.5	1.4	167.5	1.4	167.5	1.4
	100-YR	309	167.8	1.5	167.8	1.5	167.8	1.5	167.8	1.5	167.8	1.5	167.8	1.5	167.8	1.5	167.8	1.5
	500-YR	435	168.2	1.9	168.2	1.9	168.2	1.9	168.2	1.9	168.2	1.9	168.2	1.9	168.2	1.9	168.2	1.9
	Aug. Ave.	4	169.7	0.0	169.7	0.0	169.7	0.0	169.7	0.0	169.7	0.0	169.7	0.0	169.7	0.0	169.7	0.0
	10-YR	158	172.3	0.2	172.3	0.2	172.3	0.2	172.3	0.2	172.3	0.2	172.3	0.2	172.3	0.2	172.3	0.2
348.0	50-YR	258	173.4	0.2	173.4	0.2	173.4	0.2	173.4	0.2	173.4	0.2	173.4	0.2	173.4	0.2	173.4	0.2
	100-YR	309	173.9	0.2	173.9	0.2	173.9	0.2	173.9	0.2	173.9	0.2	173.9	0.2	173.9	0.2	173.9	0.2
	500-YR	435	176.3	0.2	176.3	0.2	176.3	0.2	176.3	0.2	176.3	0.2	176.3	0.2	176.3	0.2	176.3	0.2
	Aug. Ave.	4	169.7	1.2	169.7	1.2	169.7	1.2	169.7	1.2	169.7	1.2	169.7	1.2	169.7	1.2	169.7	1.2
	10-YR	158	172.6	3.5	172.6	3.5	172.6	3.5	172.6	3.5	172.6	3.5	172.6	3.5	172.6	3.5	172.6	3.5
352.0	50-YR	258	174.0	2.9	174.0	2.9	174.0	2.9	174.0	2.9	174.0	2.9	174.0	2.9	174.0	2.9	174.0	2.9
	100-YR	309	175.7	2.1	175.7	2.1	175.7	2.1	175.7	2.1	175.7	2.1	175.7	2.1	175.7	2.1	175.7	2.1
	500-YR	435	177.4	2.0	177.4	2.0	177.4	2.0	177.4	2.0	177.4	2.0	177.4	2.0	177.4	2.0	177.4	2.0
	Aug. Ave.	4	171.3	3.0	171.3	3.0	171.3	3.0	171.3	3.0	171.3	3.0	171.3	3.0	171.3	3.0	171.3	3.0
	10-YR	158	173.9	8.1	173.9	8.1	173.9	8.1	173.9	8.1	173.9	8.1	173.9	8.1	173.9	8.1	173.9	8.1
362.25	50-YR	258	174.7	9.2	174.7	9.2	174.7	9.2	174.7	9.2	174.7	9.2	174.7	9.2	174.7	9.2	174.7	9.2
	100-YR	309	175.1	9.6	175.1	9.6	175.1	9.6	175.1	9.6	175.1	9.6	175.1	9.6	175.1	9.6	175.1	9.6
	500-YR	435	177.1	7.4	177.1	7.4	177.1	7.4	177.1	7.4	177.1	7.4	177.1	7.4	177.1	7.4	177.1	7.4
	Aug. Ave.	4	183.1	0.1	183.1	0.1	181.1	2.2	181.1	2.2	183.1	0.1	183.1	0.1	183.1	0.1	183.1	0.1
	10-YR	158	186.0	0.6	186.0	0.6	182.4	5.7	182.4	5.7	186.0	0.6	185.4	0.7	185.4	0.7	185.4	0.7
363.45	50-YR	258	186.9	0.7	186.9	0.7	182.8	5.1	182.8	5.1	186.9	0.7	185.6	1.0	185.6	1.0	185.6	1.0
	100-YR	309	187.3	0.7	187.3	0.7	182.8	5.9	182.8	5.9	187.3	0.7	185.7	1.2	185.7	1.2	185.7	1.2
	500-YR	435	188.0	1.0	188.0	1.0	183.1	6.5	183.1	6.5	188.0	1.0	186.0	1.6	186.0	1.6	186.0	1.6
	Aug. Ave.	4	183.1	3.2	183.1	3.2	183.1	3.2	183.1	3.2	183.1	3.2	183.1	3.2	183.1	3.2	183.1	3.2
	10-YR	158	185.9	3.8	185.9	3.8	185.2	6.5	185.2	6.5	185.9	3.8	185.2	6.6	185.2	6.6	185.2	6.6
392.9	50-YR	258	186.9	3.4	186.9	3.4	185.7	7.4	185.7	7.4	186.9	3.4	185.7	7.4	185.7	7.4	185.7	7.4
	100-YR	309	187.3	2.9	187.3	2.9	185.9	7.8	185.9	7.8	187.3	2.9	185.9	7.8	185.9	7.8	185.9	7.8
	500-YR	435	188.0	2.9	188.0	2.9	186.5	7.8	186.5	7.8	188.0	2.9	186.5	7.8	186.5	7.8	186.5	7.8
	Aug. Ave.	4	185.3	3.0	185.3	3.0	185.3	3.0	185.3	3.0	185.3	3.0	185.3	3.0	185.3	3.0	185.3	3.0
	10-YR	158	187.6	7.9	187.6	7.9	187.6	7.9	187.6	7.9	187.6	7.9	187.6	7.9	187.6	7.9	187.6	7.9
397.5	50-YR	258	188.4	9.1	188.4	9.1	188.4	9.1	188.4	9.1	188.4	9.1	188.4	9.1	188.4	9.1	188.4	9.1
	100-YR	309	188.7	9.6	188.7	9.6	188.7	9.6	188.7	9.6	188.7	9.6	188.7	9.6	188.7	9.6	188.7	9.6
	500-YR	435	189.5	10.6	189.5	10.6	189.5	10.6	189.5	10.6	189.5	10.6	189.5	10.6	189.5	10.6	189.5	10.6

[1] Removal of Hager Pond Dam [2] Removal of Carding and Stearns Mill Pond Dams [3] Removal of Carding Mill Dam [4] Partial removal (50%) of Hager Pond Dam [5] Partial removal (50%) of Carding Mill Pond Dam
[6] Partial removal (50%) of Carding and Stearns Mill Pond Dams [7] Partial removal (50%) of Hager, Carding and Stearns Mill Pond Dams
* CWSEL - Channel Surface Water Elevation (ft. NGVD) ** VCH - Velocity Channel (cfs)

Any highlighted cells indicate a change from the Existing Conditions for the corresponding Alternative.

TABLE 3
HEC-RAS Model Results
Wetland Resource Areas

Wetland Resource Area U/S of Carding Mill Pond Dam and D/S of Grist Mill Pond Dam:

				Existing Cond.		Alternative 1[1]		Alternative 2[2]		Alternative 3[3]		Alternative 4[4]		Alternative 5[5]		Alternative 6[6]		Alternative 7[7]	
Station Desc.	River Station	Flow Desc.	Flow (cfs)	CWSEL*	VCH**	CWSEL	VCH	CWSEL	VCH	CWSEL	VCH	CWSEL	VCH	CWSEL	VCH	CWSEL	VCH	CWSEL	VCH
U/S of Carding Mill Pond	392.15	Aug. Ave.	4.0	183.1	0.2	183.1	0.2	182.6	0.3	182.6	0.3	183.1	0.2	183.1	0.2	183.1	0.2	183.1	0.2
		10 YR	158.0	186.0	0.4	186.0	0.4	183.9	2.1	183.9	2.1	186.0	0.4	185.4	0.5	185.4	0.5	185.4	0.5

Wetland Resource Area D/S of Carding Mill Pond Dam and U/S of Stearns Mill Pond Dam:

				Existing Cond.		Alternative 1[1]		Alternative 2[2]		Alternative 3[3]		Alternative 4[4]		Alternative 5[5]		Alternative 6[6]		Alternative 7[7]	
Station Desc.	River Station	Flow Desc.	Flow (cfs)	CWSEL*	VCH**	CWSEL	VCH	CWSEL	VCH	CWSEL	VCH	CWSEL	VCH	CWSEL	VCH	CWSEL	VCH	CWSEL	VCH
D/S of Dutton Road	334.59	Aug. Ave.	4.0	160.4	0.2	160.4	0.2	160.4	0.2	160.4	0.2	160.4	0.2	160.4	0.2	160.4	0.2	160.4	0.2
		10 YR	158.0	162.5	1.0	162.5	1.0	162.5	1.0	162.5	1.0	162.5	1.0	162.5	1.0	162.5	1.0	162.5	1.0
Wetland Cross Section	311.50	Aug. Ave.	4.0	158.7	1.2	158.7	1.2	158.7	1.2	158.7	1.2	158.7	1.2	158.7	1.2	158.7	1.2	158.7	1.2
		10 YR	158.0	161.4	2.0	161.4	2.0	161.4	2.0	161.4	2.0	161.4	2.0	161.4	2.0	161.4	2.0	161.4	2.0
U/S of Stearns Mill Pond	285.59	Aug. Ave.	4.0	155.9	0.5	155.9	0.5	155.8	0.6	155.9	0.5	155.9	0.5	155.9	0.5	155.9	0.5	155.9	0.5
		10 YR	158.0	159.6	0.8	159.6	0.8	159.2	1.1	159.6	0.8	159.6	0.8	159.6	0.8	159.2	1.1	159.3	1.0

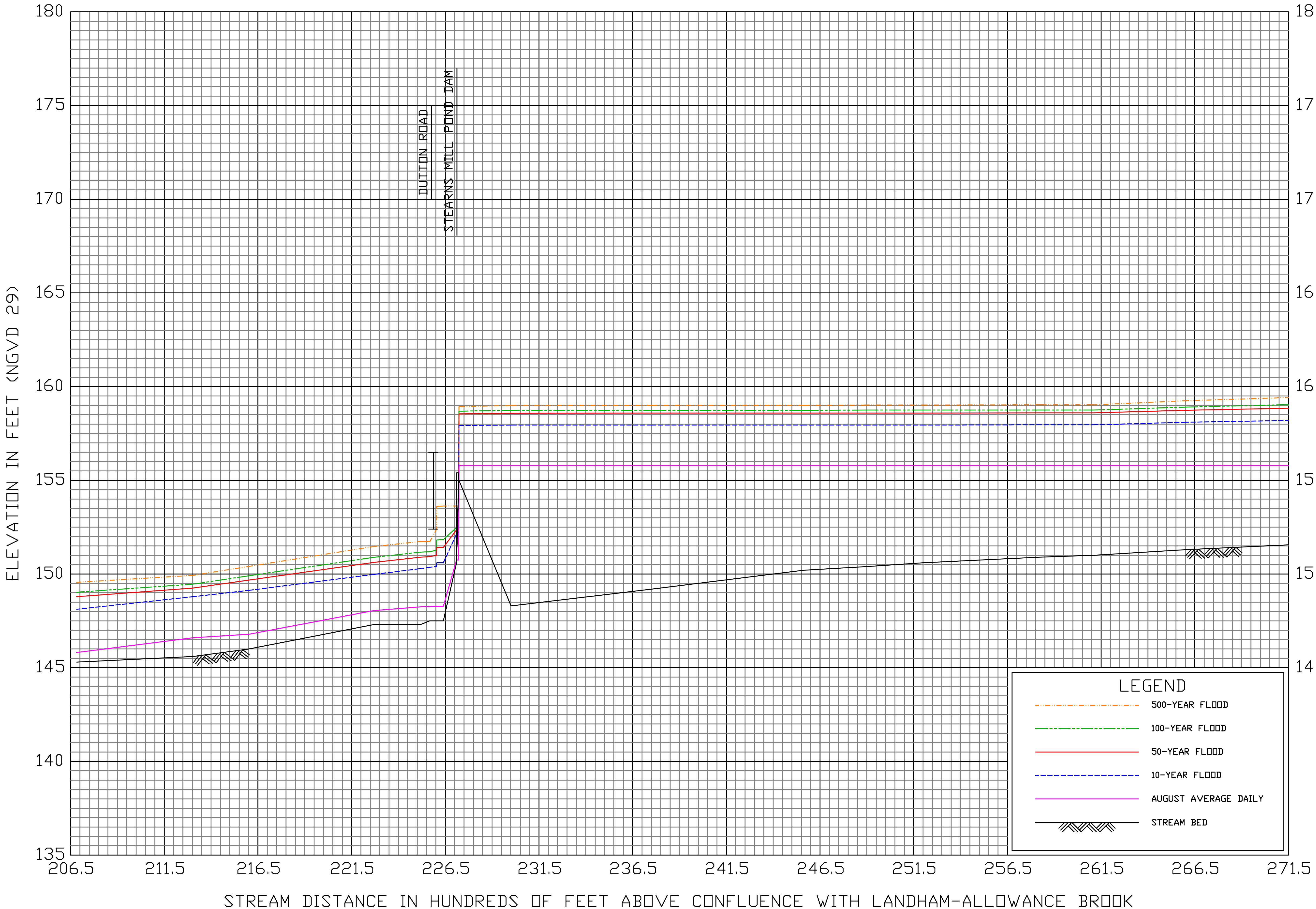
Wetland Resource Area D/S of Stearns Mill Pond Dam:

				Existing Cond.		Alternative 1[1]		Alternative 2[2]		Alternative 3[3]		Alternative 4[4]		Alternative 5[5]		Alternative 6[6]		Alternative 7[7]	
Station Desc.	River Station	Flow Desc.	Flow (cfs)	CWSEL*	VCH**	CWSEL	VCH	CWSEL	VCH	CWSEL	VCH	CWSEL	VCH	CWSEL	VCH	CWSEL	VCH	CWSEL	VCH
D/S of Stearns Mill Pond	194.78	Aug. Ave.	4.0	144.3	0.3	144.3	0.3	144.3	0.3	144.3	0.3	144.3	0.3	144.3	0.3	144.3	0.3	144.3	0.3
		10 YR	158.0	148.0	0.8	148.0	0.8	148.0	0.8	148.0	0.8	148.0	0.8	148.0	0.8	148.0	0.8	148.0	0.8

[1] Removal of Hager Pond Dam [2] Removal of Carding and Stearns Mill Pond Dams [3] Removal of Carding Mill Dam [4] Partial removal (50%) of Hager Pond Dam [5] Partial removal (50%) of Carding Mill Pond Dam
[6] Partial removal (50%) of Carding and Stearns Mill Pond Dams [7] Partial removal (50%) of Hager, Carding and Stearns Mill Pond Dams

***** CWSEL - Channel Surface Water Elevation (ft. NGVD) ****** VCH - Velocity Channel (cfs)

Any highlighted cells indicate a change from the Existing Conditions for the corresponding Alternative.



HEC-RAS RESULTS - EXISTING CONDITION PROFILES

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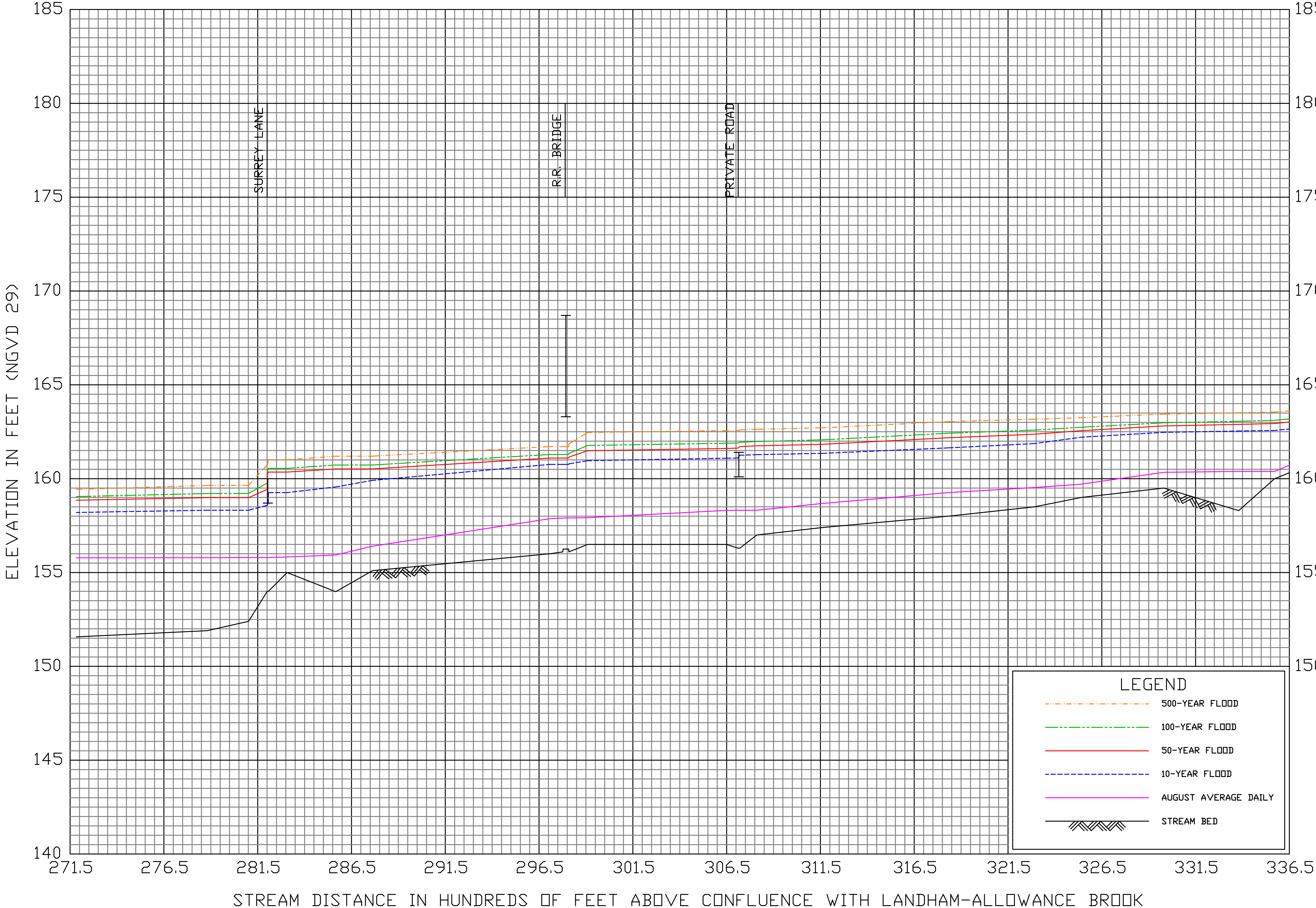
PLATE 1



HEC-RAS RESULTS - EXISTING CONDITION PROFILES

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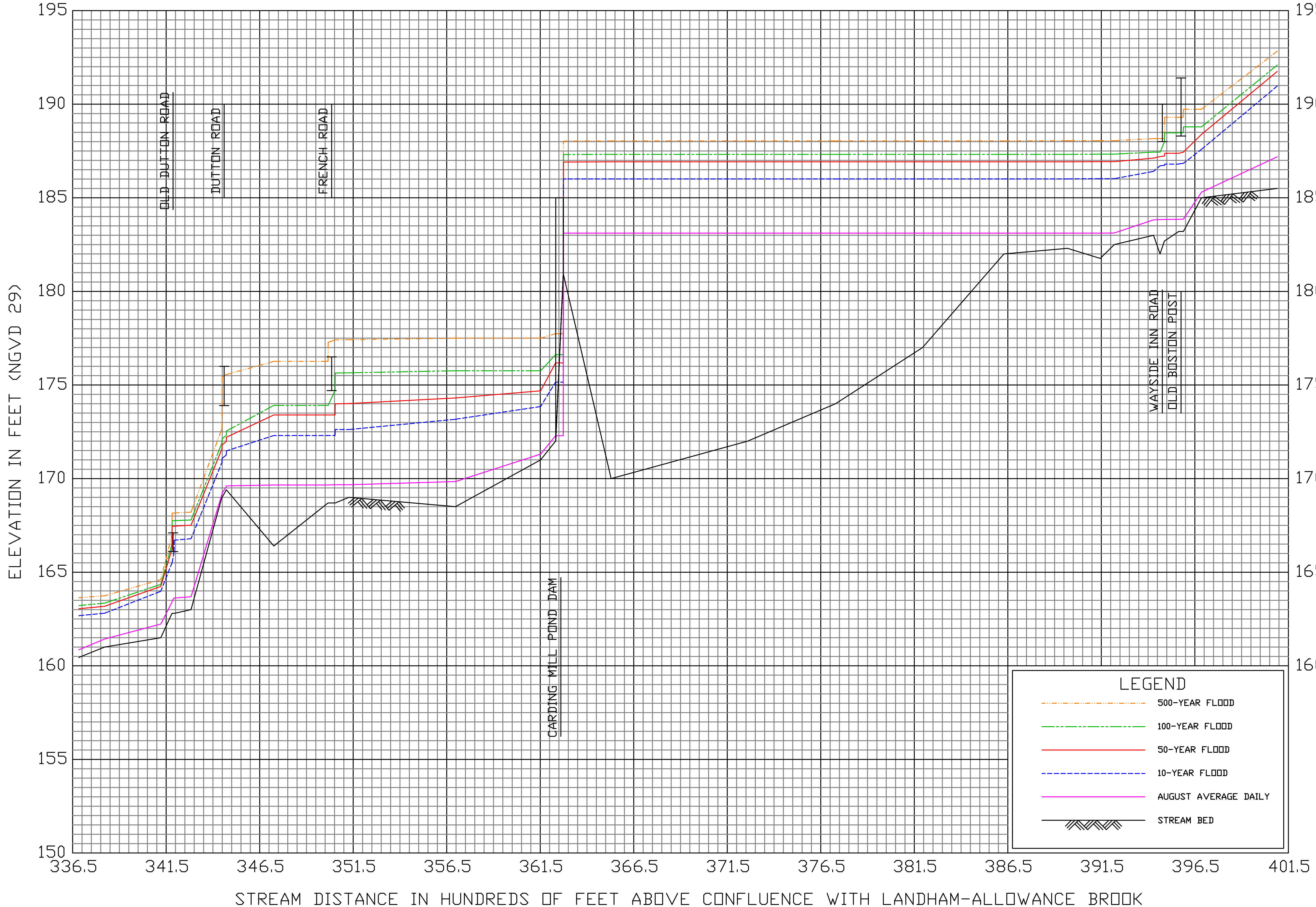
PLATE 2



HEC-RAS RESULTS - EXISTING CONDITION PROFILES

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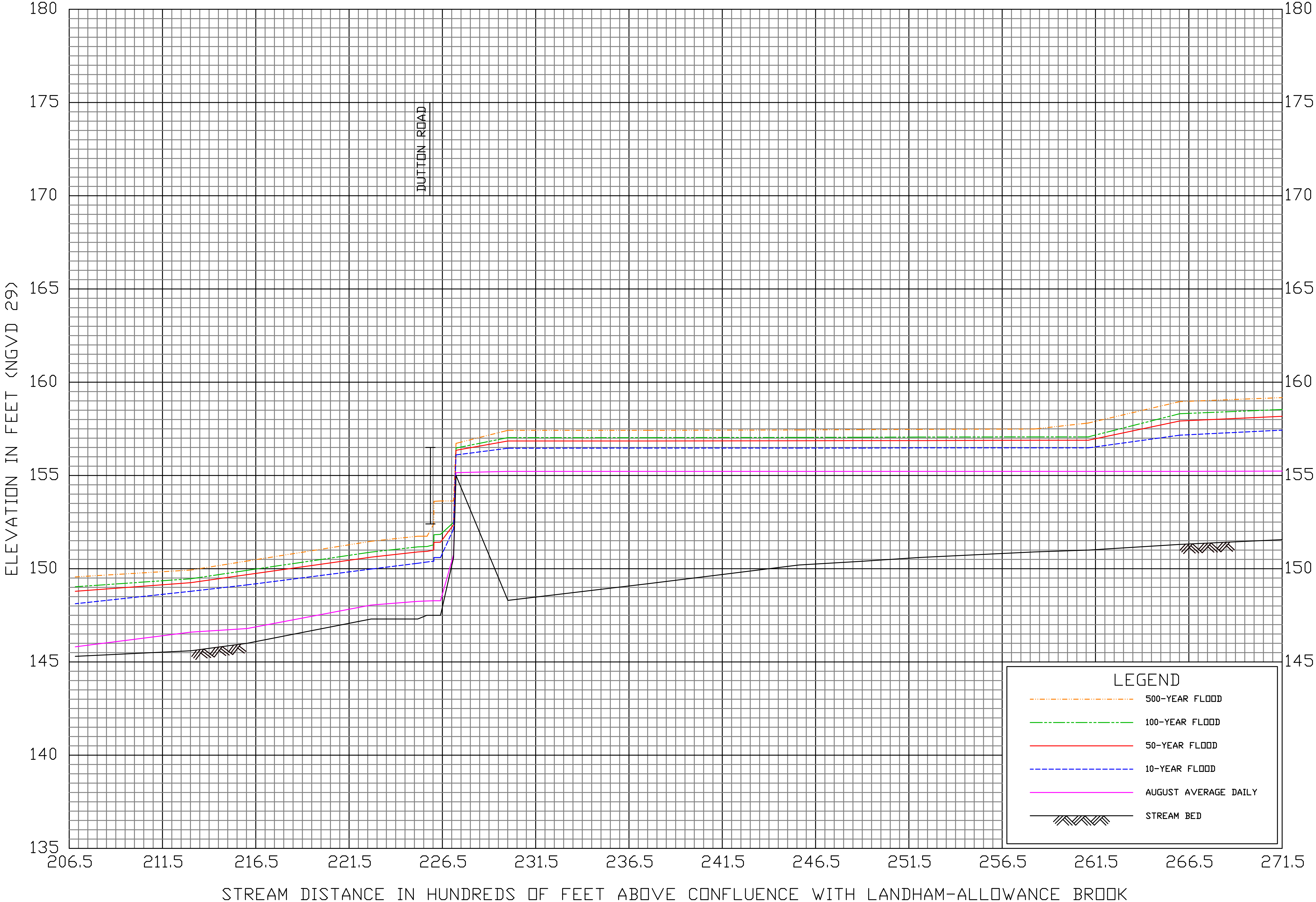
PLATE 3



HEC-RAS RESULTS - ALTERNATIVE 2 PROFILES

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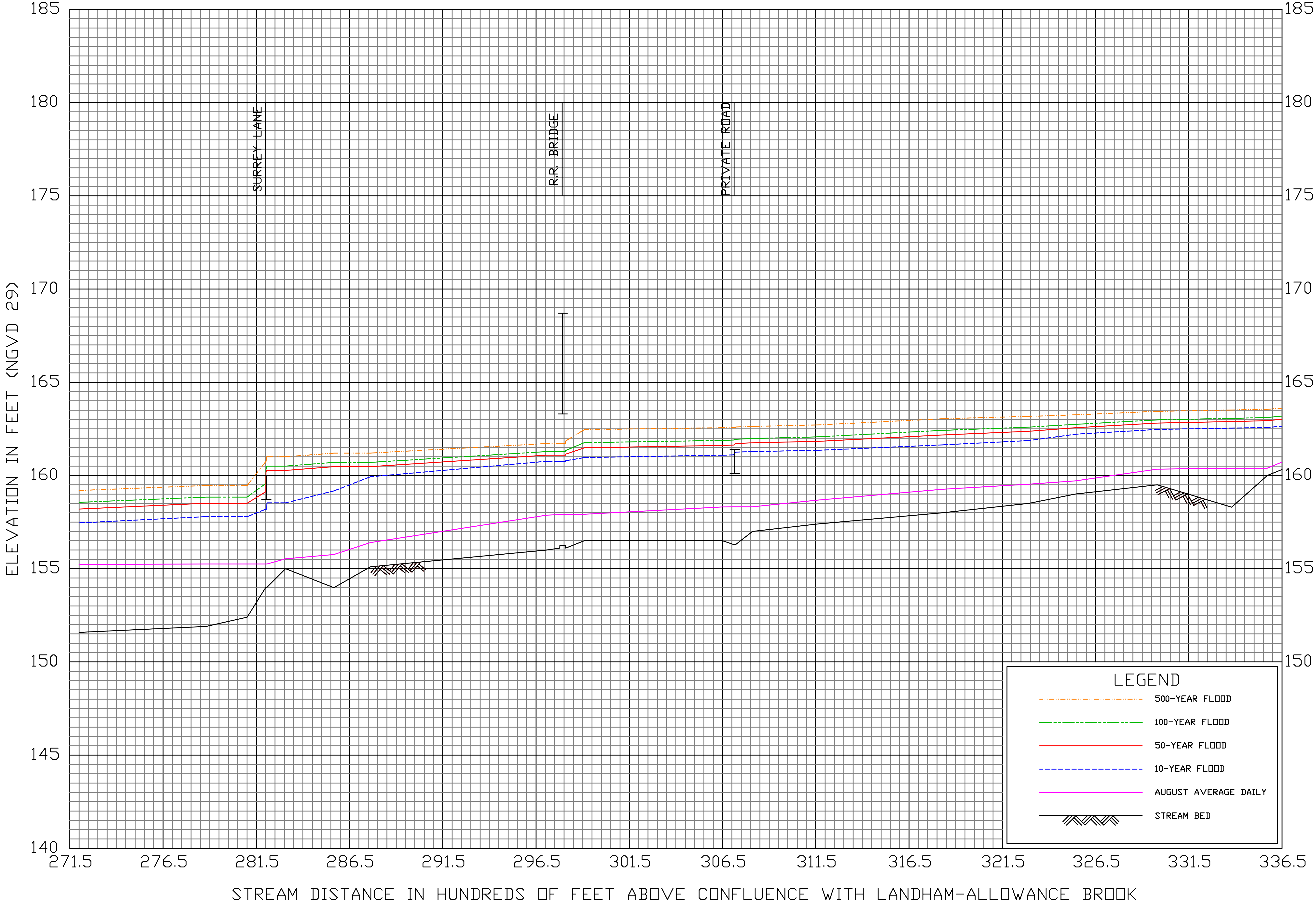
PLATE 4



HEC-RAS RESULTS - ALTERNATIVE 2 PROFILES

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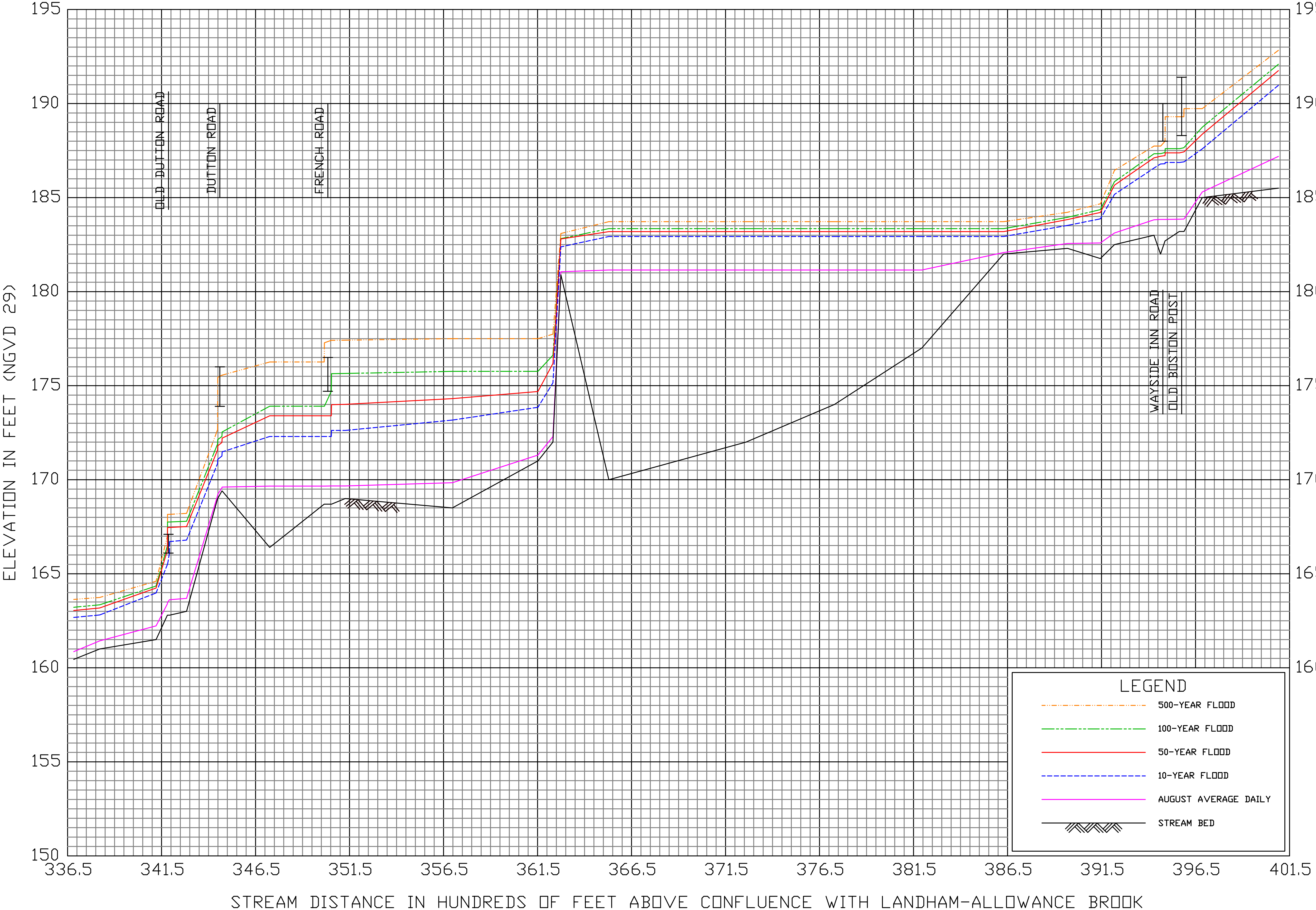
PLATE 5



HEC-RAS RESULTS - ALTERNATIVE 2 PROFILES

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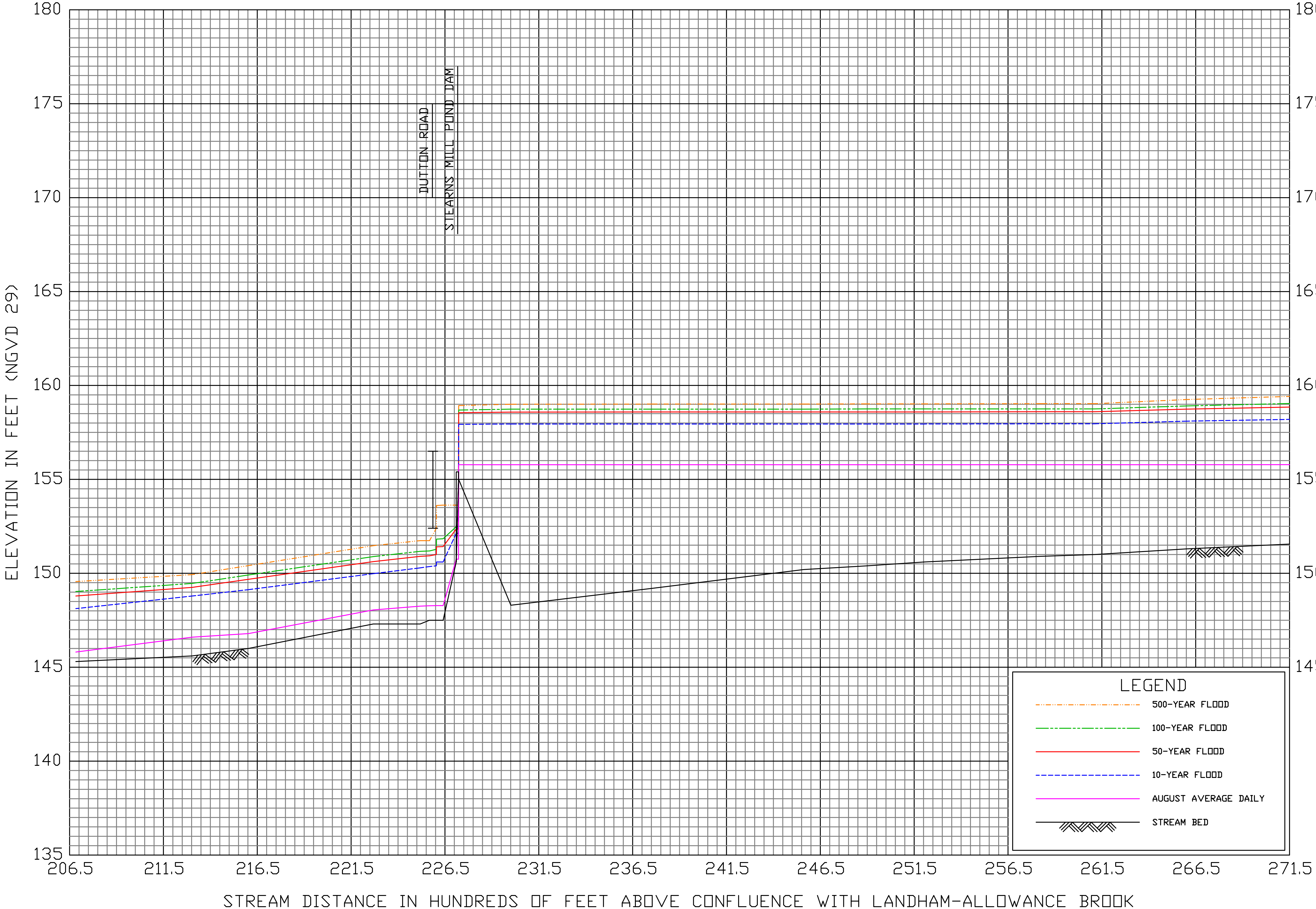
PLATE 6



HEC-RAS RESULTS - ALTERNATIVE 3 PROFILES

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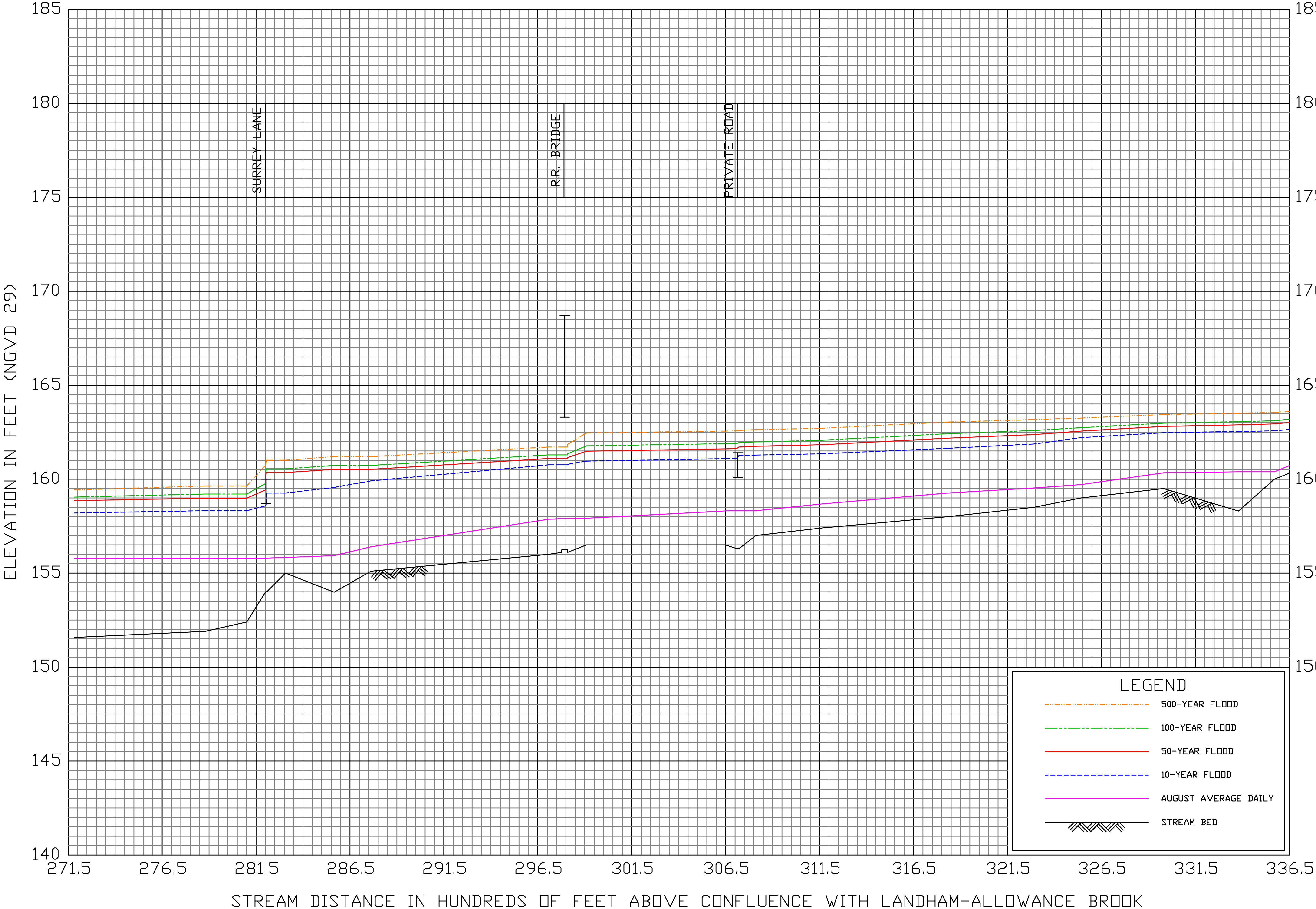
PLATE 7



HEC-RAS RESULTS - ALTERNATIVE 3 PROFILES

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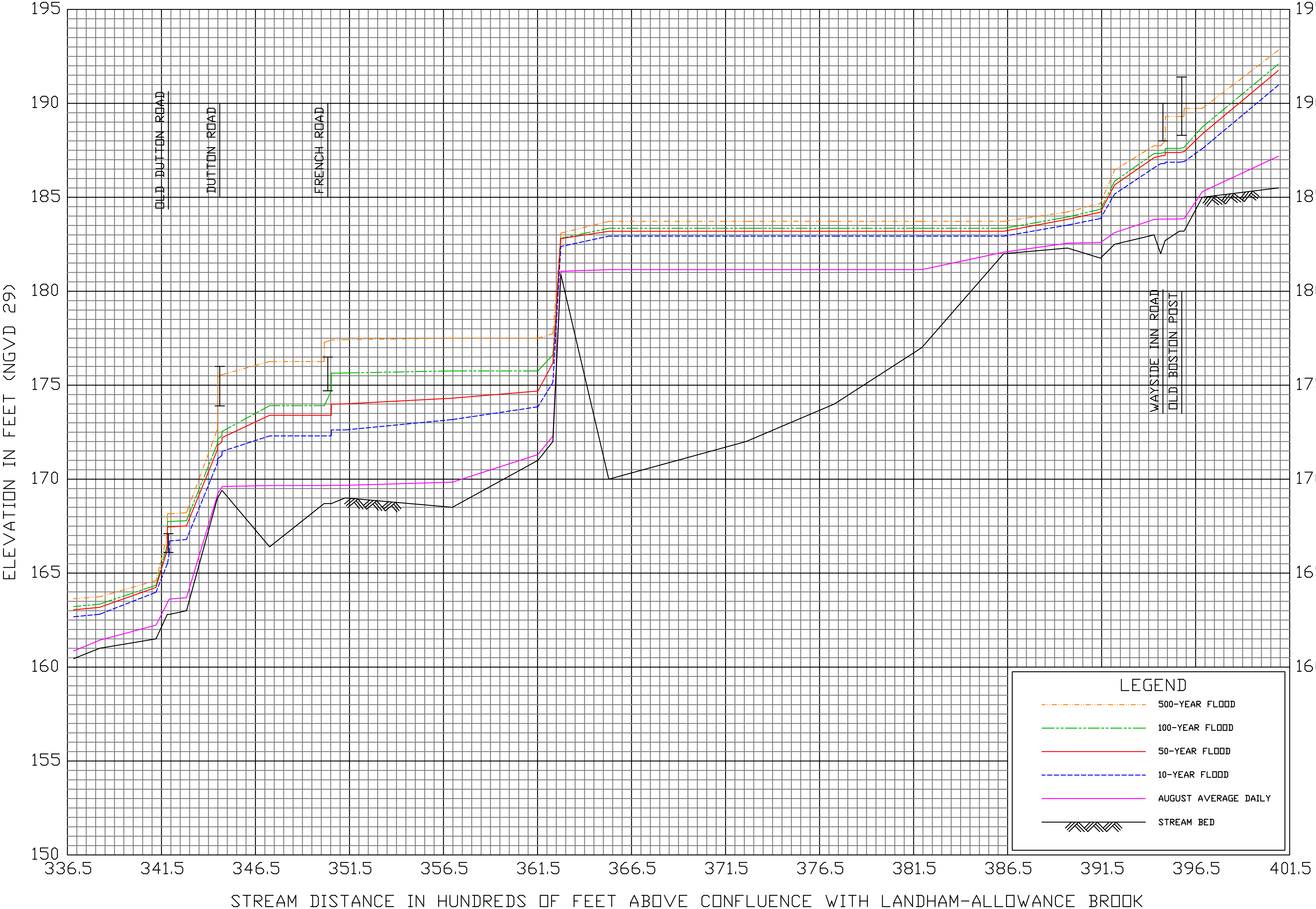
PLATE 8



HEC-RAS RESULTS - ALTERNATIVE 3 PROFILES

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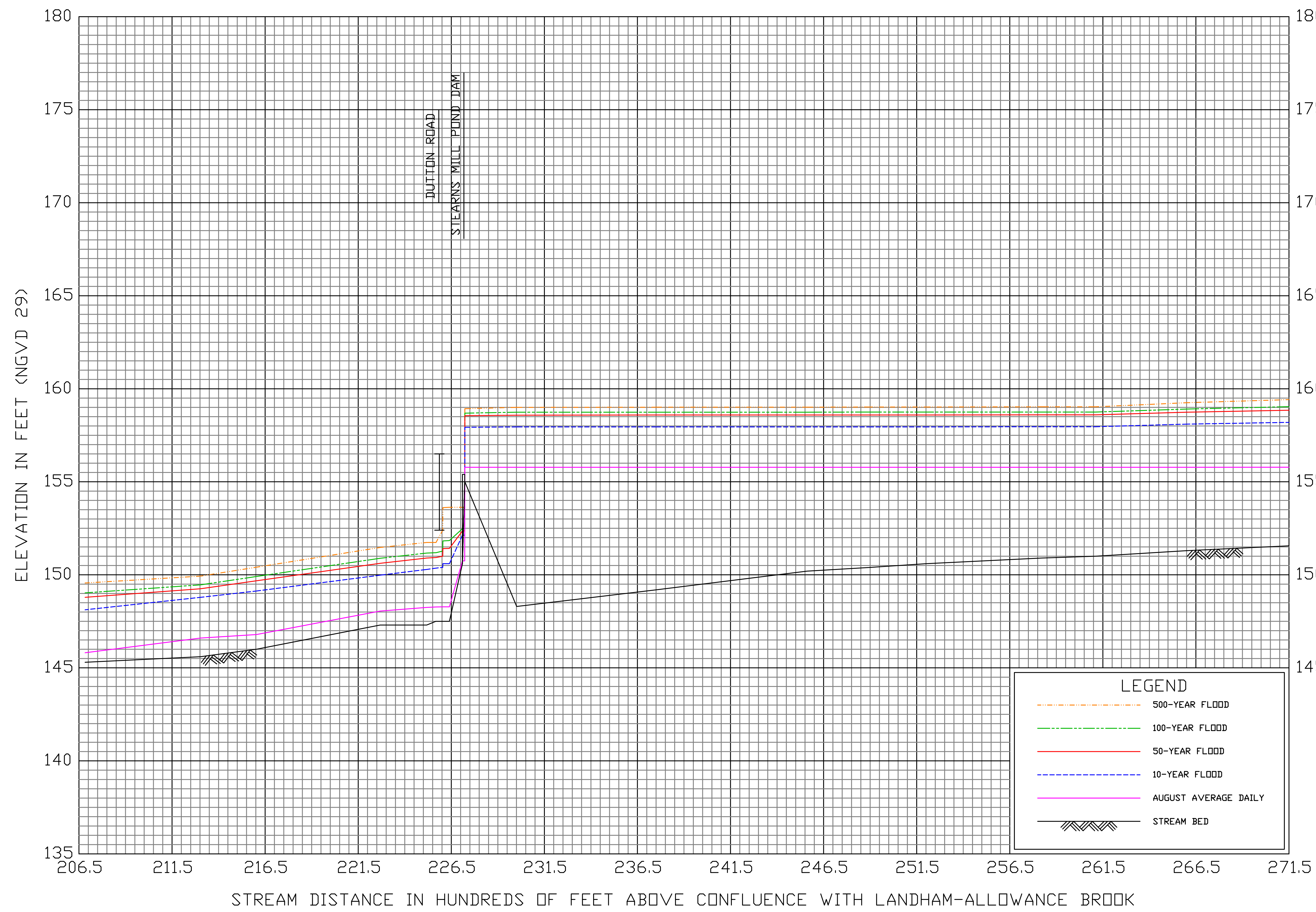
PLATE 9



HEC-RAS RESULTS - ALTERNATIVE 5 PROFILES

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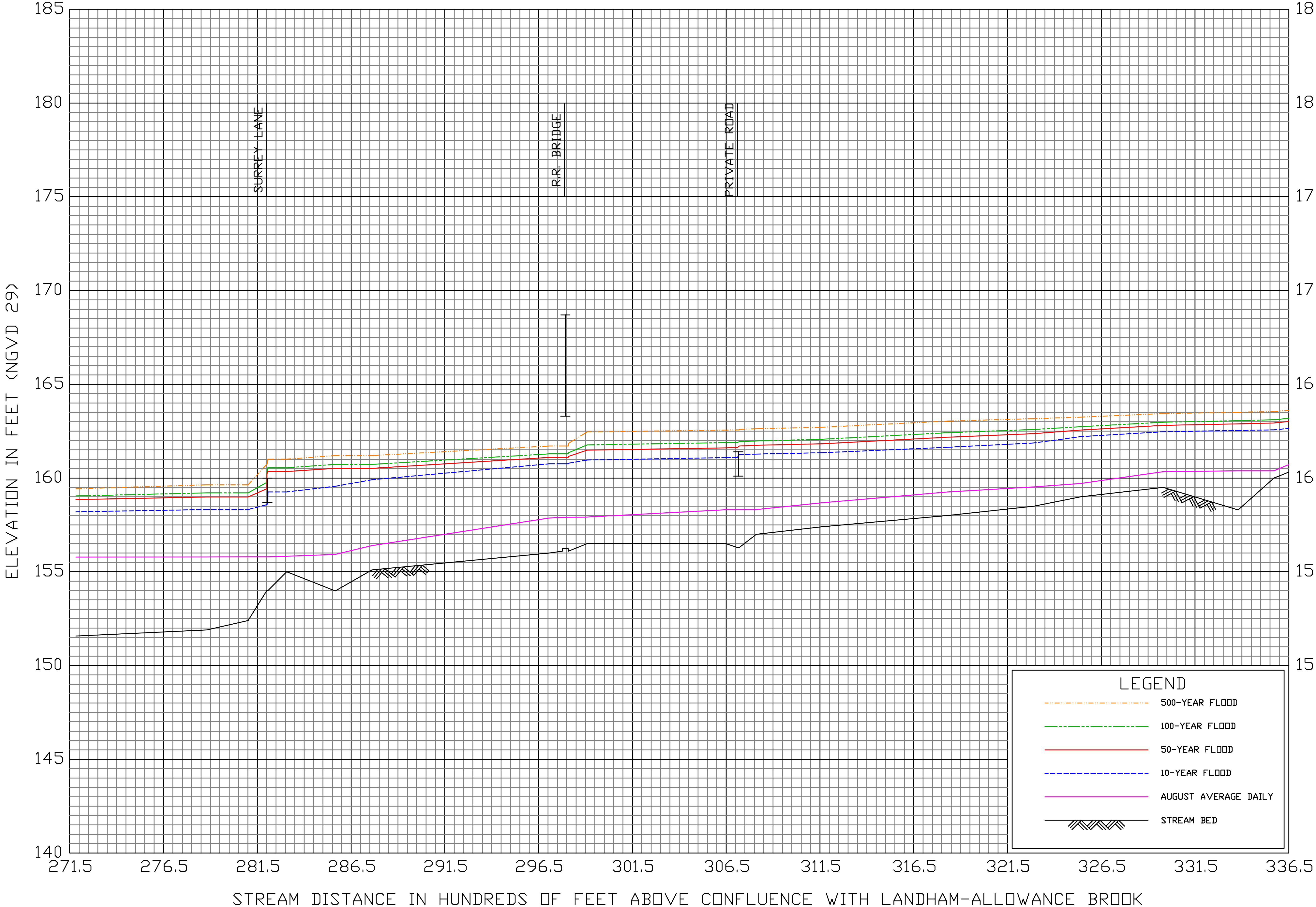
PLATE 10



HEC-RAS RESULTS - ALTERNATIVE 5 PROFILES

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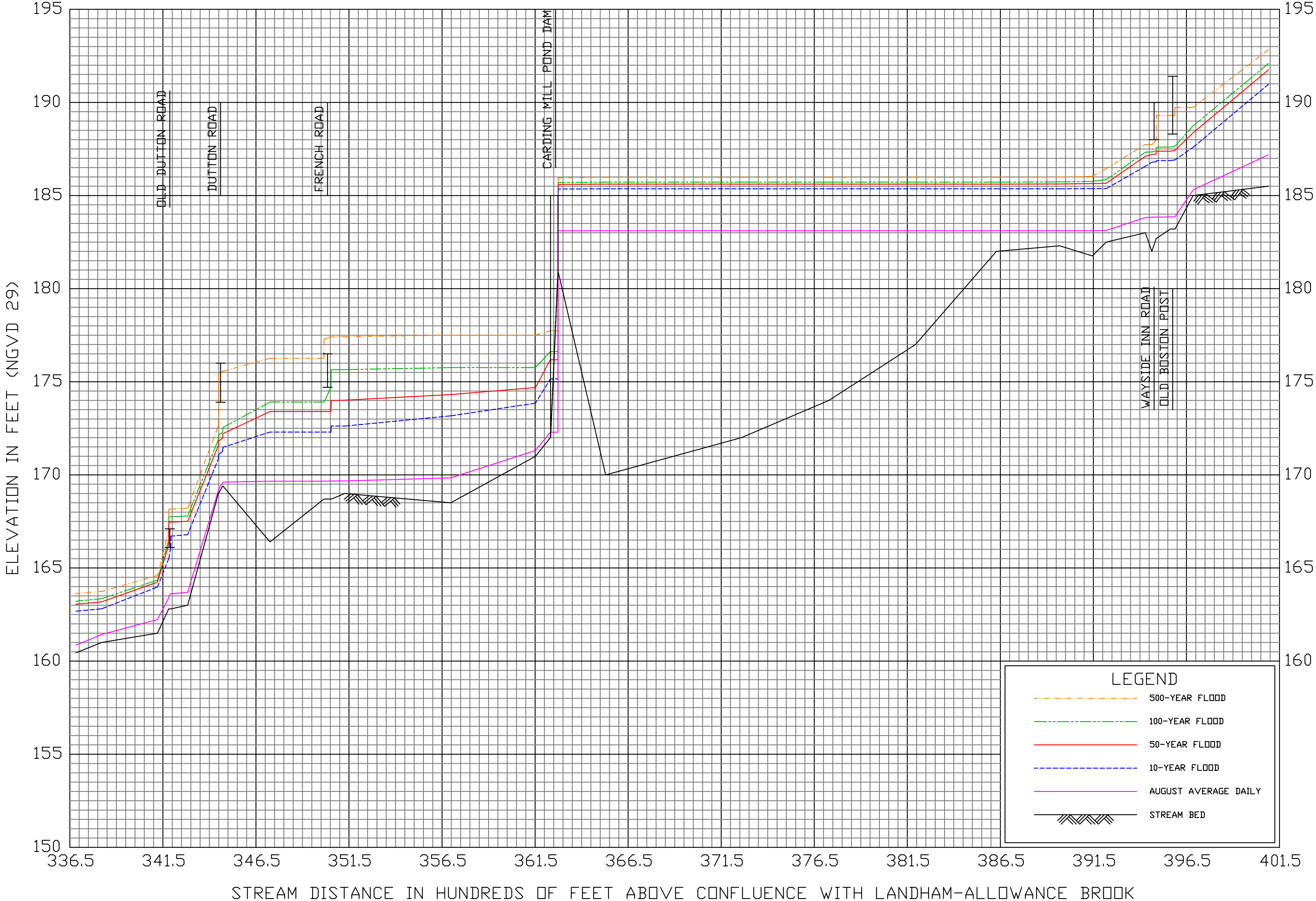
PLATE 11



HEC-RAS RESULTS - ALTERNATIVE 5 PROFILES

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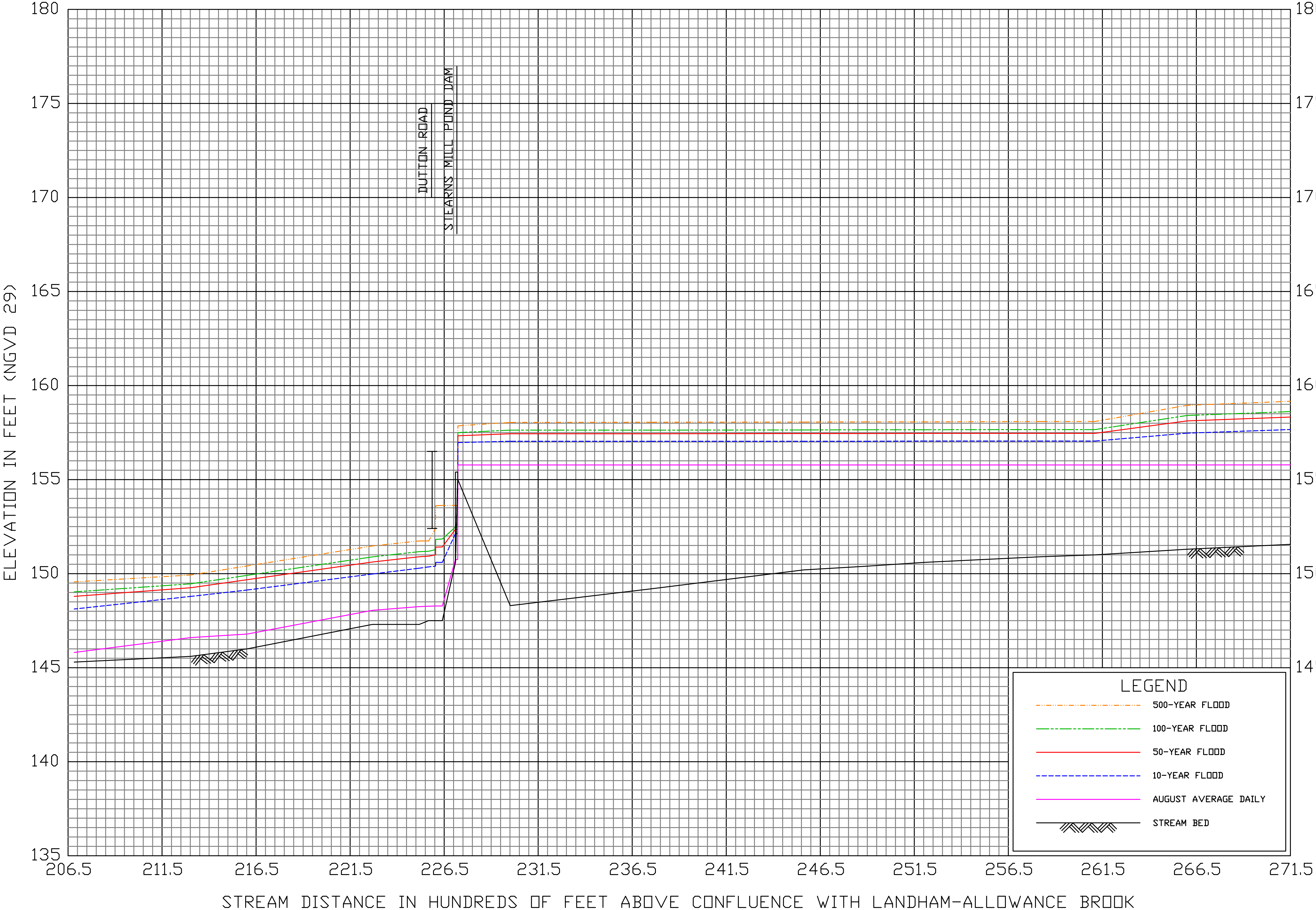
PLATE 12



HEC-RAS RESULTS - ALTERNATIVE 6 PROFILES

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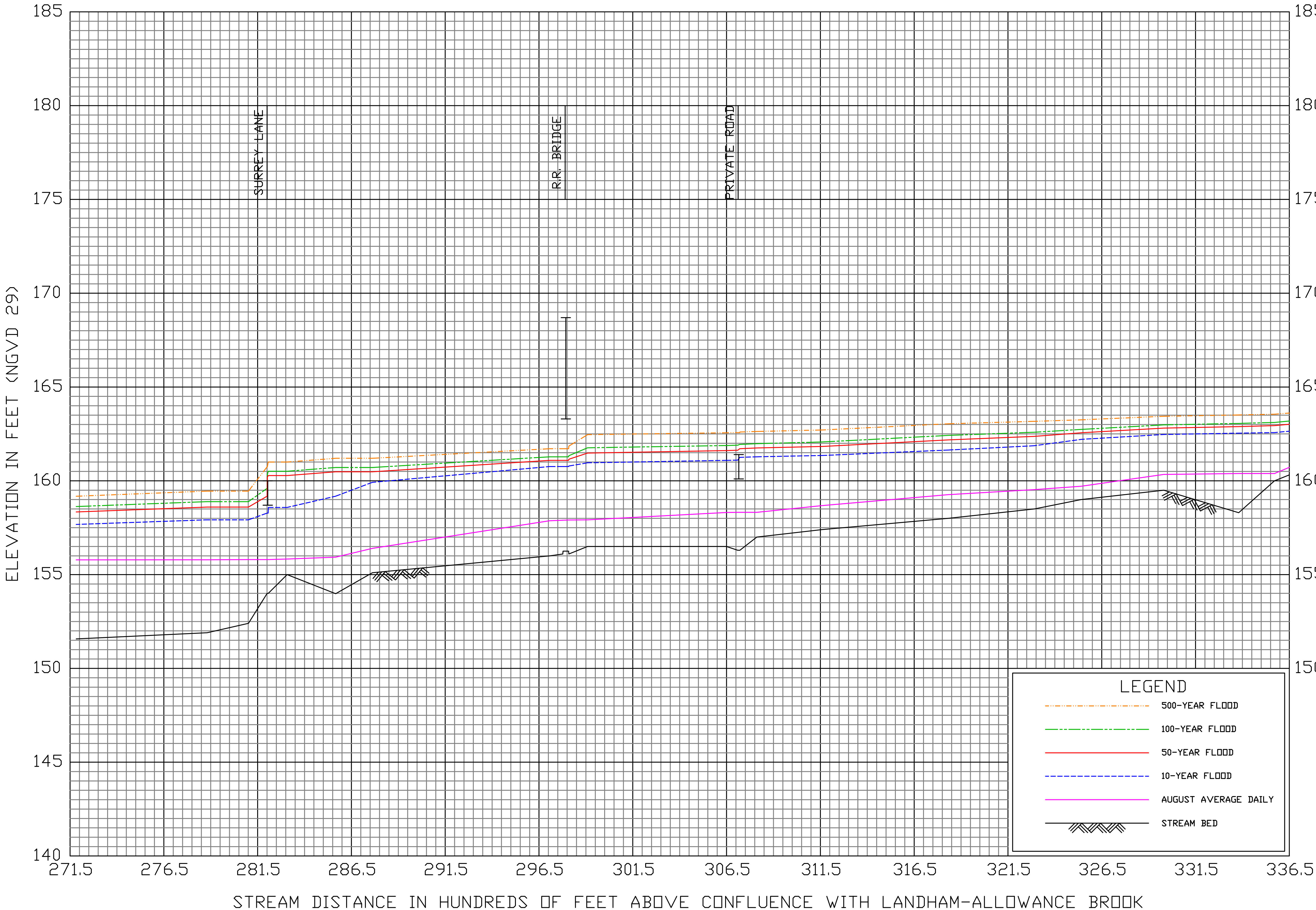
PLATE 13



HEC-RAS RESULTS - ALTERNATIVE 6 PROFILES

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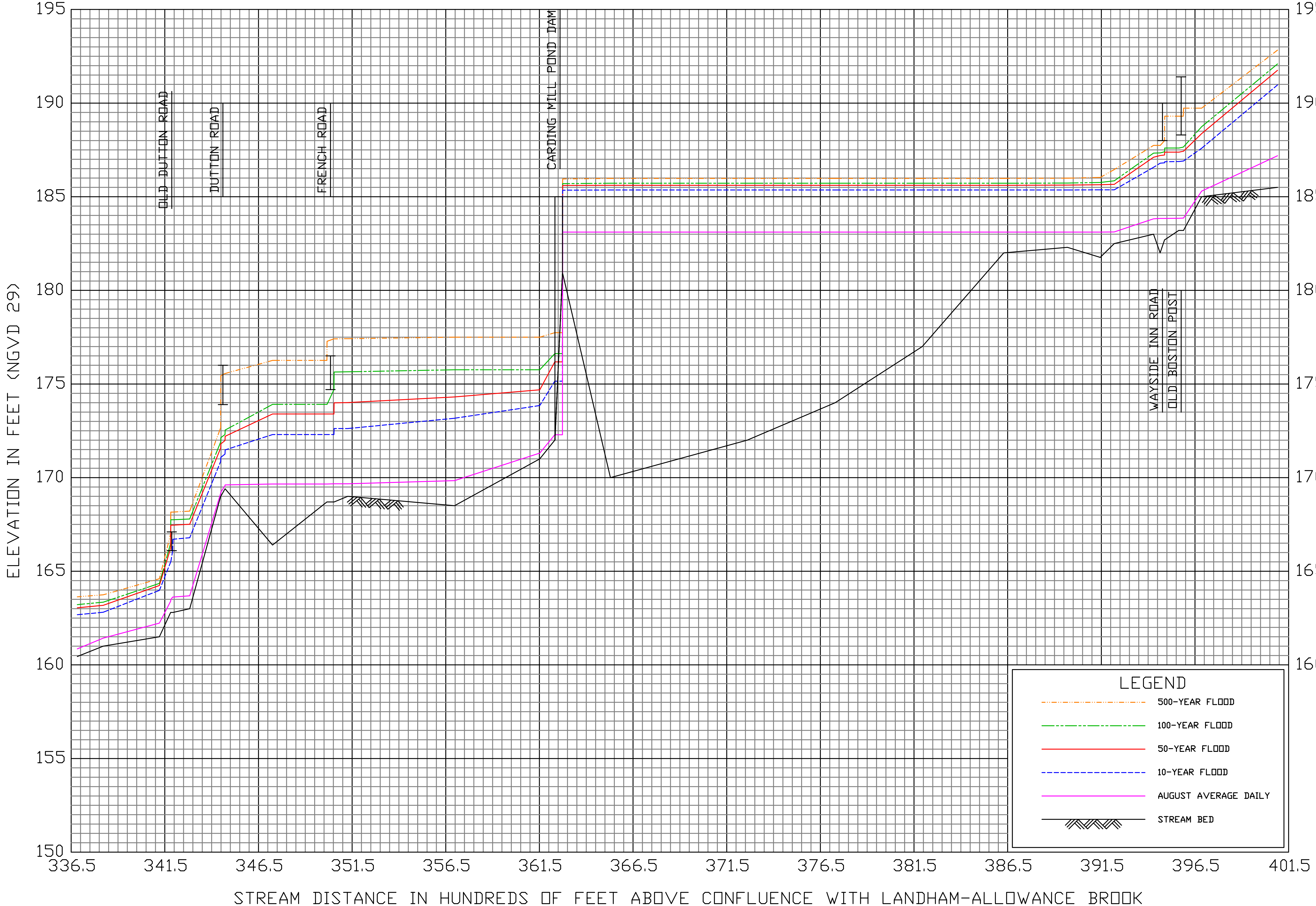
PLATE 14



HEC-RAS RESULTS - ALTERNATIVE 6 PROFILES

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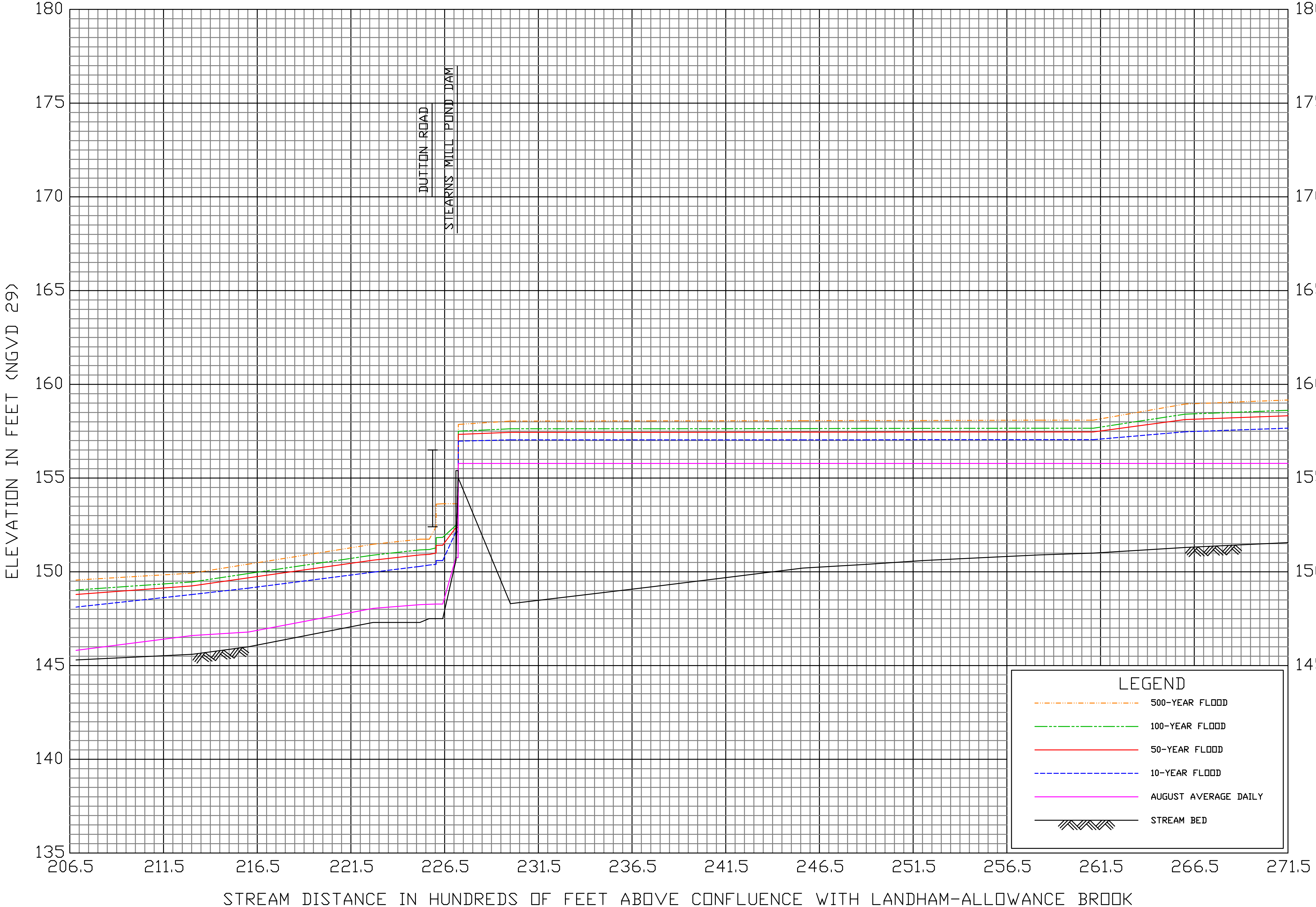
PLATE 15



HEC-RAS RESULTS - ALTERNATIVE 7 PROFILES

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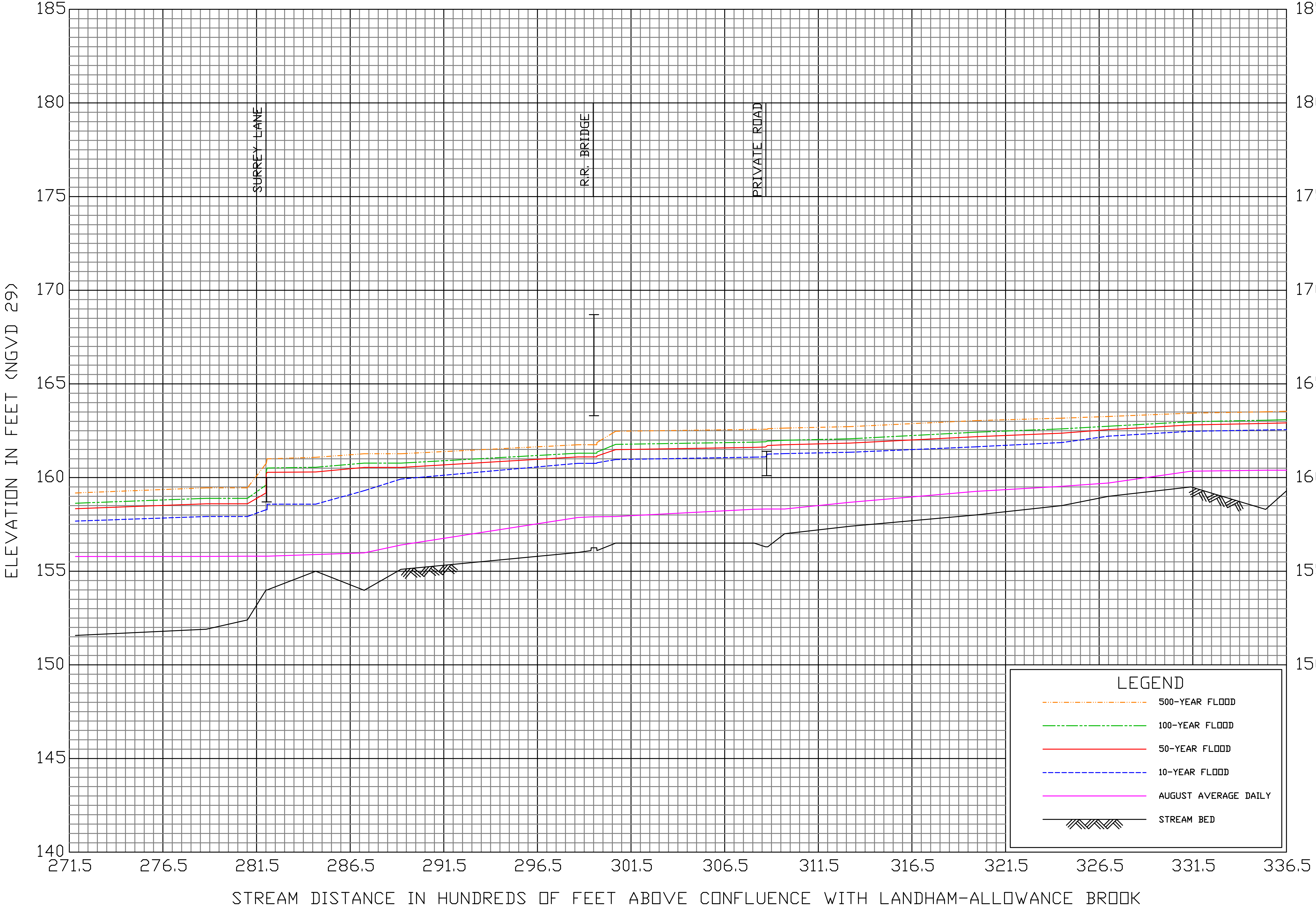
PLATE 16



HEC-RAS RESULTS - ALTERNATIVE 7 PROFILES

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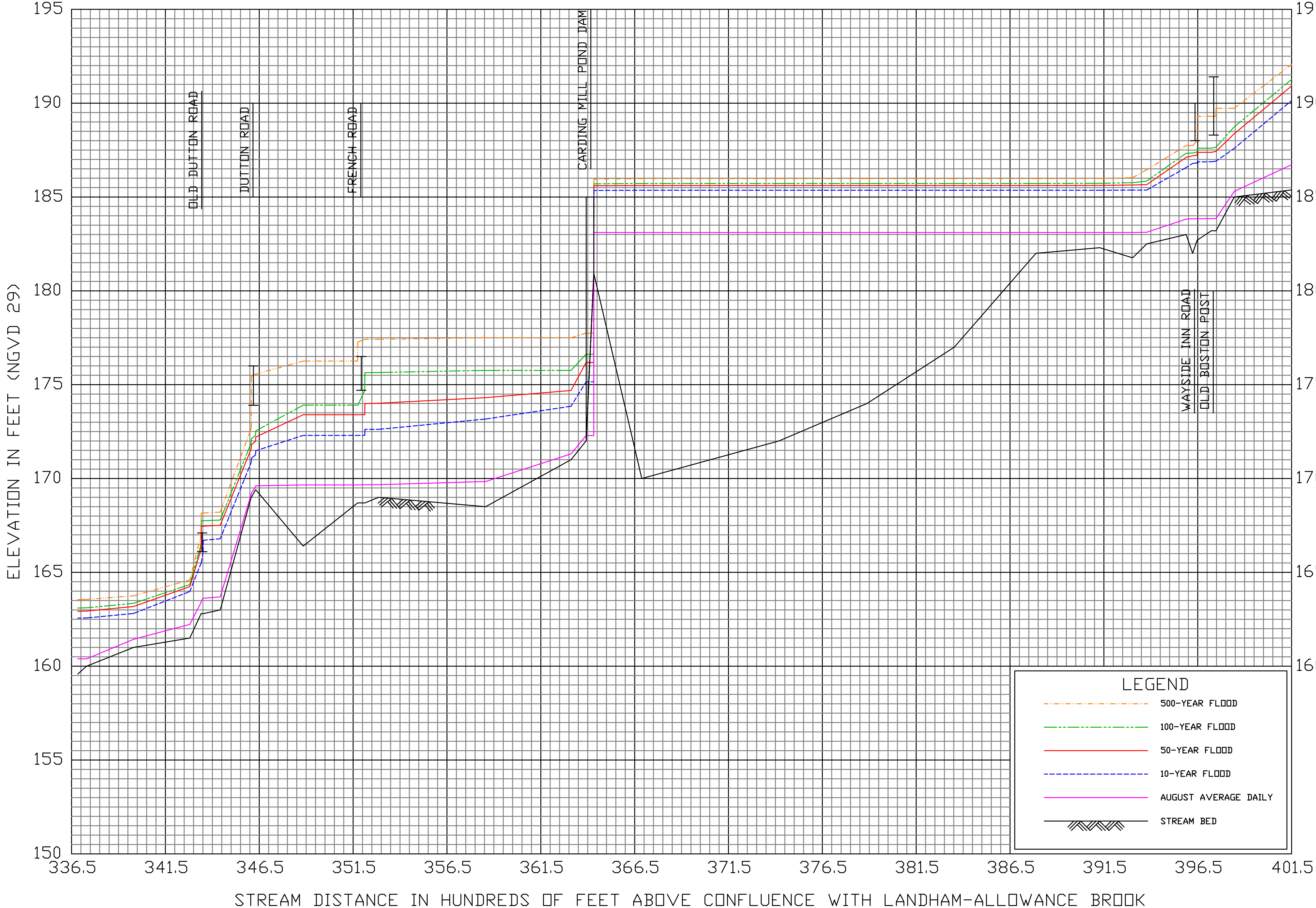
PLATE 17



HEC-RAS RESULTS - ALTERNATIVE 7 PROFILES

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PLATE 18

Appendix H – Additional Alternatives

Analysis of the additional options for:

1. **Converting Hager Pond into a free water surface constructed wetland system, and**
2. **By-passing (piping) the effluent water from the MWWTP directly to the Sudbury River.**

Under option 1, the Corps proposes to create a free-water-surface constructed wetland to further improve water quality of the treated wastewater from the MWWTP and under option 2, the Corps analyzed the effects of conveying flows from the treatment plant to the Sudbury River thus completely by-passing the Hop Brook riverine system.

Inflow to Hager Pond is taken as 6 cfs, derived as 150% of the average August outflow (4 cfs) from the Marlborough Wastewater treatment plant.

<u>Option 1: Create a "Free Water Surface" (FWS) Constructed Wetland</u>

This option would convey MWWTP effluent over a newly constructed wetland area (Free Water Surface wetland) in Hager Pond to be created from material that would be dredged from Hager Pond. The main objective of this FWS constructed wetlands is to absorb the nutrients from the MWWTP discharge. This new wetland would have three zones. The design involves a pipe and a chamber in which treated waste water is conveyed, flowing over a weir system into the first of three wetland zones, each separated by overflow weirs, until water discharges over the existing spillway weir at the end of Hager Pond. The modular nature of the chambers would facilitate maintenance and help control the migration of solid materials through the system.

FWS Wetland Design:
A "Free Water Surface" constructed wetland would have three zones, with water depths of approximately 2.5 ft, 4 ft, and 2.5 ft. The zones allow for floating and emergent plants in an aerobic zone (zone 1), submerged growth plants in a deeper zone (zone 2), and floating and emergent plants immediately upstream of the outlet (zone 3). Recommended retention times in the three zones, for maximum nitrogen removal, are as follows:

Zone 1: 1 to 2 days
Zone 2: 2 to 3 days
Zone 3: 2 days.

Hydraulic Design

Design Flow Quantity:
Although 4 cfs (80 million gallons per month) is the average August flow from the plant, the manifold would be sensibly sized as ‘a peak factor’ times the average daily flow. Treatment units within the MWWTP would have the effect of smoothing out the peaks from an expected peak factor value of 3, and so a peak of only 1.5 times the average flow is a reasonable design parameter for hydraulic purposes (i.e. a 6 cfs design inflow to the

pond system). For greater flows, a reduced water detention time would be tolerated in the three pools. The outlet pipe from the MWWTP will be split into two pipes and discharged into the Hager Pond from the south and south west sides of the pond as shown in Plate 1.

Inlet Pipe Diameter:
Assuming 6 cfs inflow is from a circular pipe flowing half-full at 3 fps, then a pipe diameter of 2.28 ft can be calculated (say 30-inch diameter). A manifold system would convey flows into the intake chamber, from which flow continues over a weir and into the first of the three treatment zones.

Inlet Weir:
The pipe discharges into a chamber of adequate length to incorporate a weir system designed to pass 6 cfs at one end of Zone 1. Assuming this occurs with a head of 2 inches over the weir crest, then the weir length can be calculated to be approximately 29 feet. For a head of 3 inches, the weir length would be approximately 16 feet. In the event of surges in the flow of MWWTP effluent, a subsidiary weir, normally dry, might be used to increase flow without excessive increase in water level.

The relatively small weir length requirement lends itself to a high aspect ratio, resulting in reduced "short-circuiting" and promoting "plug flow".

Winter month temperatures may lead to freezing at the surface. This should be further evaluated. If necessary, submerged passages from one zone to the next should be considered, as an alternative to weir overflows.

Treatment Zones:
The Zone 1 pond is typically designed to be an aerobic pond no more than 2.5 ft deep, with a retention time not exceeding 2 days. Floating and emergent plants are encouraged to be planted. Water discharged from the MWWTP is naturally warmer. However, during winter months in the New England environment, the shallow pool is likely to lose heat quickly, so peak storage of 1.5 days should be used for design purposes.

The Zone 2 pond is typically designed as a more aerobic "facultative" pond, with a depth of up to 4 feet. The retention time is expected to be 2 to 3 days. Submerged growth plants are encouraged. For the New England environment, a 2-day retention time should be used in design so as to promote the biological activity in a smaller pond at a slightly enhanced temperature during the cold winter months.

The Zone 3 pond is typically designed as an aerobic pond no more than 2.5 ft deep, with a retention time not exceeding 2 days. Floating and emergent plants are encouraged to be planted. A conceptual layout of these zones is shown in Plate 1.

The highest nitrogen treatment efficiencies should be expected in the warmer months with the lowest overall flows; the worst efficiencies are likely in the colder months, when total flows are greater. In this regard, the system should provide increased treatment when it is most required – the low flow period.

It is expected that the pond area available for this work is approximately the required area for the three-zone design. Flexibility in water level control (split-level weirs), the ability to remove modules of the design from the system for maintenance purposes (stop logs and emergency spillways for rapid drawdown; smaller ponds in parallel instead of larger ponds in series), and modules shaped to minimize short-circuiting, are therefore expected to be incorporated into the design. Detailed bathymetry of Hager Pond will dictate both dredging quantities and the layout design for the formal pond design.

The series of weir overflows between the zones would promote aeration, potentially increasing oxygenation of the water as it moves from one zone to the next. This potential advantage should be balanced against the possibility that the surface might freeze during winter months, and so submerged flows between the zones might need to be considered. The figures below are from the September 2000 EPA manual "Constructed Wetlands Treatment of Municipal Wastewaters" (EPA/625/R-99/010; http://www.epa.gov/nrmrl/pubs0199.html).

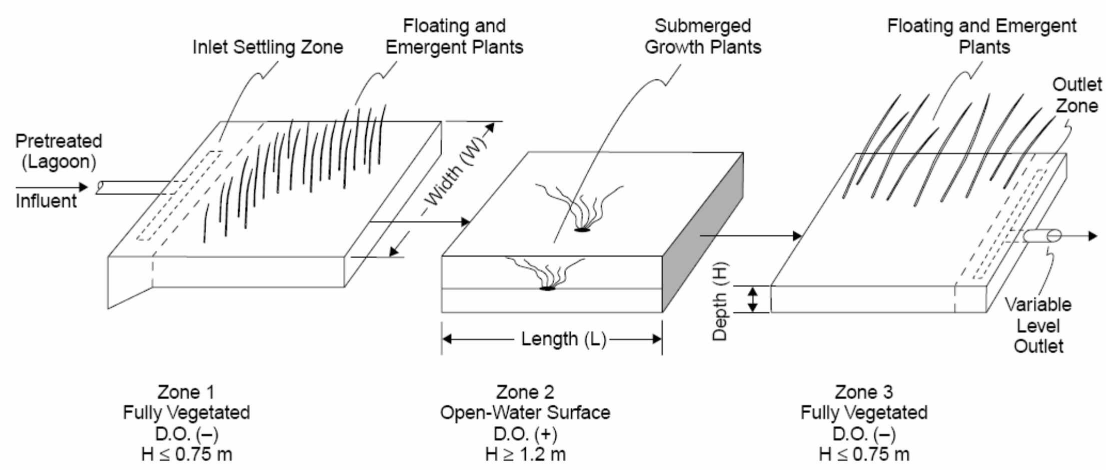


Figure 4-13. Elements of a free water surface (FWS) constructed wetland

(from EPA manual "Constructed Wetlands Treatment of Municipal Wastewaters")

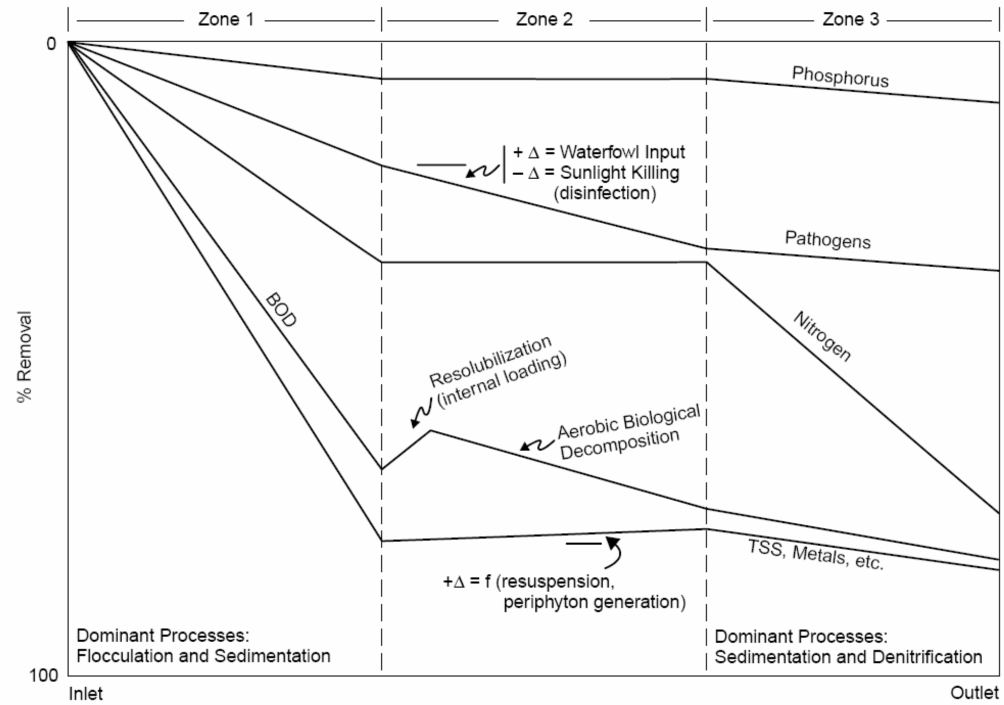


Figure 4-14. Generic removal of pollutants in 3-zone FWS system

(from EPA manual "Constructed Wetlands Treatment of Municipal Wastewaters")

The chart above shows that a typical three zone wetland treatment system has been proven to be effective in reducing Nitrogen in treated waste water by approximately 75%, and Phosphorus by about 10 %.

Table 4-7. Recommended Design Criteria for FWS Constructed Wetlands

Parameter	Design Criteria
Effluent Quality	BOD ≤ 20 or 30 mg/L TSS ≤ 20 or 30 mg/L
Pretreatment	Oxidation Ponds (lagoons)
Design Flows	Q_{max} (maximum monthly flow) and Q_{ave} (average flow)
Maximum BOD Loading (to entire system) to Meet:	20 mg/L: 45 kg/ha-d 30 mg/L: 60 kg/ha-d
Maximum TSS Loading (to entire system) to Meet:	20 mg/L: 30 kg/ha-d 30 mg/L: 50 kg/ha-d
Water Depth	0.6 - 0.9 m Fully vegetated zones 1.2 - 1.5m Open-water zones 1.0m Inlet settling zone (optional)
Minimum HRT (at Qmax) in Zone 1 (and 3)	2 days fully vegetated zone
Maximum HRT (at Qave) in Zone 2	2 - 3 days open-water zone (climate dependent)
Minimum Number of Cells	3 in each train
Minimum Number of Trains	2 (unless very small)
Basin Geometry (Aspect Ratio)	Optimum 3:1 tþ 5:1, but subject to site limitations AR > 10:1 may need to calculate backwater curves
Inlet Settling Zone Use	Where pretreatment fails to retain settleable particulates
Inlet	Uniform distribution across cell inlet zone
Outlet	Uniform collection across cell outlet zone
Outlet Weir Loading	≤200 m3/m-d
Vegetation	
Emergent -	Typha or Scirpus (native species preferred)
Submerged -	Potamogeton, Elodea, etc (see chapter 2).
Design Porosities	0.65 for dense emergents in fully vegetated zones 0.75 for less dense stand of emergents in same zones 1.0 for open-water zones
Cell Hydraulics	Each cell should be completely drainable Flexible intercell piping to allow for required maintenance Independent, single-function cells could maximize treatment

Details of the design should conform to the EPA design manual, bearing in mind that the wetland system proposed is not an entire treatment system but a polishing system for the existing treatment works.

Assuming a 5½-day retention time, the total pond volume in all zones is 6 cfs* 3600 sec/hr*24 hrs/day*5.5 days = 2,851,200 cubic feet or 65 acre-feet. If the average depth is 3 feet then the area required is 22 acres. Since the existing Hager Pond is approximately 31 acres, the communities will not need additional real estate for FWS wetlands creation. The possibility of a FWS constructed wetland system for treatment of the MWWTP effluent is a possibility. Maintenance considerations may dictate that two parallel treatment trains be designed as shown in Plate 1, since this would allow for one of the trains to be taken out of service as needed.

Flow control should allow for adaptations for changing inflow rates: possibly split-level overflow weirs could be used so that the durations of lower flows would not result in the various ponds experiencing extended retention times. The estimated construction cost for this option is approximately $2 Million.

Option 2: Convey Flows from the Marlborough WWTP to a point downstream of the Stearns Mill Pond

This alternative analyzed the effect on the Hop Brook system if the effluent from the MWWTP is directly piped from the treatment facility to the Sudbury River. The prime concern with this option is the possibility of inadequate flow into Hager Pond, and potentially the ponds drying up potentially exposing mud flats. The August average MWWTP discharge accounts for at least 4 cfs. Downstream of Hager Pond, the same concern exists for the other three ponds along Hop Brook. Base flow was derived from historical flow records (1941-2006) of USGS gage 01097000 (Assabet River at Maynard, MA). The drainage area for this gage is 116 square miles. The mean monthly discharge for August is 61 cfs. Base flow is calculated as 61 cfs/116 sq.mi. = 0.5 cfs for 1 square mile.

The entire basin area for **Hager Pond** is approximately 1 square mile, with an expected 0.5 cfs baseflow during dry weather events (August). The total evaporation during August can be expected to be 5 inches. This approximates to 4 mm/day or 0.0134 ft/day. With a 0.5 cfs baseflow, a pool of maximum area (0.5 cfs x 3600 sec/hr x 24 hrs/day)/0.0134 ft/day = 3,223,881 sq. ft = 74 acres can be maintained. Since the pond area is approximately 31 acres, there would still be a steady flow from Hager Pond to Hop Brook.

Grist Mill Pond has a reservoir area of approximately 29 acres and a contributing basin area (including the area contributing to Hager Pond) of approximately 3 square miles. Discounting upstream flows associated with Hager Pond, the basin area is 2 square miles. The August baseflow of 1.0 cfs will maintain a pool of approximately 148 acres. Since Grist Mill Pond, at 38 acres, is smaller than 148 acres, the pool can be maintained with a steady outflow from Grist Mill Pond to Hop Brook.

Carding Mill Pond has a reservoir area of approximately 50 acres and a contributing basin area (including the area contributing to Hager and Grist Mill Ponds) of approximately 10 square miles. Discounting upstream flows associated with Hager and Grist Mill Ponds, the basin area is 7 square miles. The August baseflow of 3.5 cfs will maintain a pool of approximate area 518 acres. Since Carding Mill Pond, at 50 acres, is smaller than 518 acres, the pool can be maintained with a steady outflow from Carding Mill Pond to Hop Brook.

Stearns Mill Pond has a reservoir area of approximately 30 acres and a contributing basin area (including the area contributing to Hager Pond, Grist Mill Pond, and Carding Mill Ponds) of approximately 15.6 square miles. Discounting upstream flows associated with Hager, Grist Mill, and Carding Mill Ponds, the basin area is 5.6 square miles. The

August baseflow of 2.8 cfs will maintain a pool of approximate area 414 acres. Since Stearns Mill Pond, at 30 acres, is smaller than 414 acres, the pool can be maintained with a steady outflow from Stearns Mill Pond into the Landham-Allowance Brook/Hop Brook confluence.

In summary, even when the WWTP effluent is removed from Hop Brook flow, the base inflow during a dry month at each reservoir is expected to exceed the evaporation from the pond surface, and the ponds would not dry up.

Pump station and piping requirements for Option 2

This solution requires piping the effluent wastewater approximately 6 miles alongside Route 20, with pumping as necessary. An approximate route along State Route 20 includes profile information as follows:

Start: EL. 69.0 m NGVD ~ EL 226.38 ft NGVD.
    3,780 ft distance.
Point 1: El. 78.5 m NGVD ~ EL 257.55 ft NGVD.
    7,730 ft distance along Rte 20.
Point 2: El. 53.8 m NGVD ~ EL 176.51 ft NGVD.
    1,755 ft distance along Rte 20.
Point 3: El. 57.0 m NGVD ~ EL 187.01 ft NGVD.
    3,884 ft distance along Rte 20.
Point 4: El. 42.7 m NGVD ~ EL 140.09 ft NGVD.
    2,600 ft distance
Point 5: El 42.7 m NGVD (same El. repeated; possible discharge point to Hop Brook) ~ EL 140.09 ft NGVD.
    11,865 ft distance
Point 6: El. 42.7 m NGVD (same El. repeated; final discharge point to Sudbury River). ~ EL 140.09 ft NGVD.

The total distance is 31,614 feet or 6.0 miles.

Assume that a pump station is situated at the start of the pipeline. The head imparted is adequate to overcome pipe losses and minor losses through the whole pipeline, a topographic difference of 9.5 m (31.2 ft) from the 'Start' to Point 1 (the highest point in the system) with an elevation 78.5 m (257.55 ft)

MWWTP effluent flow was summarized by month from 1992 to 2006. Taking the maximum monthly rate for each year, and averaging these peaks, it was found an average "wet" month has average flow of 8.05 cfs. Allow for an hourly peaking factor of 1.5 to get a maximum flow requirement of 12 cfs.

Note that the average daily flow from MWWTP over 2001 to 2006 was 5.6 cfs . For estimating design inflows into the MWWTP, the flow is multiplied by 2.5 for pump sizing purposes (for a municipality of 30,000 people) (See Design and Construction of Sanitary and Storm Sewers by ASCE and WPCF, 1969). This approach would lead to 14 cfs. However, 12 cfs is retained in the calculations here, because the 2.5 factor was intended to include contributing factors such as inflow and infiltration, which are not applicable to the effluent flows.

For simplicity, the Hazen-Williams formula with a C_{HW} of 100 (tabled values range from 100 to 150, but the number can be expected to reduce over time, approaching the lower value) was applied.

$V = 1.318\ C_{HW}\ R^{0.63}\ (h_l/L)^{0.54}$
V = velocity
C_{HW} = Hazen-Williams roughness coefficient
R = hydraulic radius (flow area divided by wetted perimeter)
h_l = Head loss
L = length of pipe

(The symbol S is often substituted for the ratio h_l/L.)

This equation has been incorporated into nomographs for ease of use, and the nomograph that was used for this analysis is reproduced below. It was taken from a standard hydraulics textbook, *Water Supply and Pollution Control* by Viessman and Hammer (4th edition).

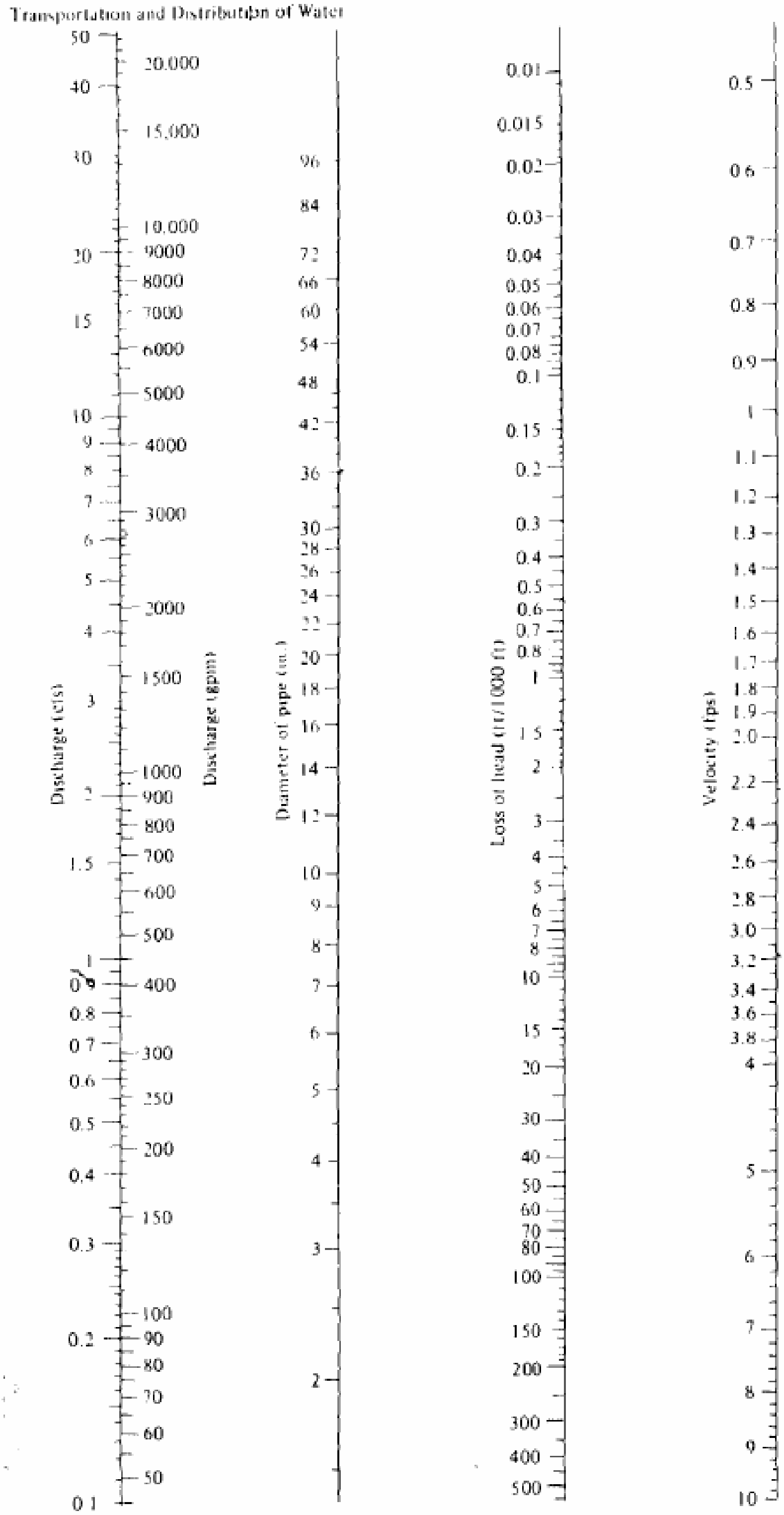


Figure 6.6 Nomograph for the Hazen–Williams formula with $C = 100$.

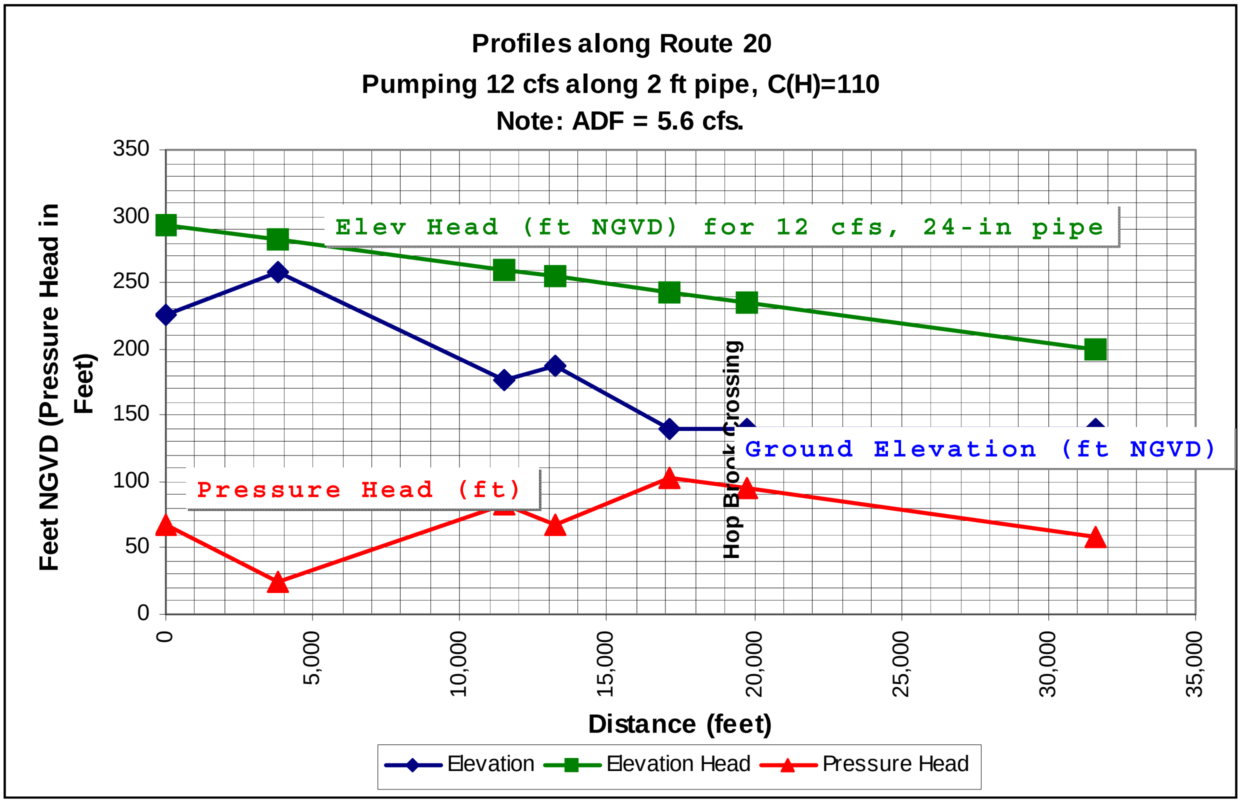
For a 12 cfs flow in a 2-ft diameter pipe, there is a friction head loss of 3 ft /1000 ft, or approximately 12 feet over the 3,780 ft up to the high point. The combination corresponds to a pipe velocity of 3.7 ft/second. In addition, there should be some residual head at this point to ensure that flow continues beyond this point (say 25 feet of head) and a maximum head of 270 feet at the high point.

Pumping head requirements:
Static head: (25 + 257.55 - 226.38) = 56 ft of head
Headloss up to the high point: 12 feet.
Total: 68 ft head (say 70 ft head, at flow 12 cfs, approximately 5,400 gpm).

To pump water flow at appropriately 70 ft head we need approximately 20 kW power. With electric and mechanical efficiencies assumed at 80% each, the pump station power requirement approaches 40 kW. Ordinarily, the power requirement is approximately half this amount (same head requirement, half the water requirement). Therefore for average power estimation purposes, the power is assumed to be 40 kW.

The sump volume for the pumps will influence the size of the station, but this should not be a substantial volume (a few minutes' flow at average rates as opposed to a few hours' flow). For 5 minutes, this would be 1200 cubic feet (say 7500 gallons).

Downstream of this point, there is positive pressure at all points along the pipe, with a maximum pressure of 100 ft head at 17,000 ft along the profile.



Pipe pressure requirements: 6 miles of 2-ft diameter pipe, for pressures up to 160 ft working head or 320 ft dynamic head (allowing for transient heads).

Control Valves: Valve chambers to include thrust blocks and 3-inch by-pass units. Maximum closure/opening rates to be set, subject to water hammer calculations. For this preliminary study, maximum possible pressures under static conditions are doubled to obtain rough estimates of transient pressures.

Washout (blow-off) valves to be located at low points in the design (clearly around 11,500 feet and where Route 20 crosses Hop Brook). Approximately 4 Washout Valves.

Pressure Release Valves (PRV) are air valves to be located at regular intervals (e.g., every 5,000 feet) and at high points in the system, such as at 3,780 ft and at 13,300 cfs, so as to avoid buildup of bubbles in the system (these would act as constrictions, not available for flow of water). Approximately 6 PRVs.

Pump Settings:
A set of three pumps is required at the pump station, such that 2 pumps can be used to pass the high flow of 12 cfs at 70 ft head, with one pump available as stand-by in case of mechanical breakdown. A single pump should be capable of pumping 4 cfs at 60 ft head,

with one not functioning and a third pump available in case of mechanical breakdown. Electrical power should be preferred over diesel of gasoline-powered units.

Electricity
The pump station will require up to 40 kW of power.

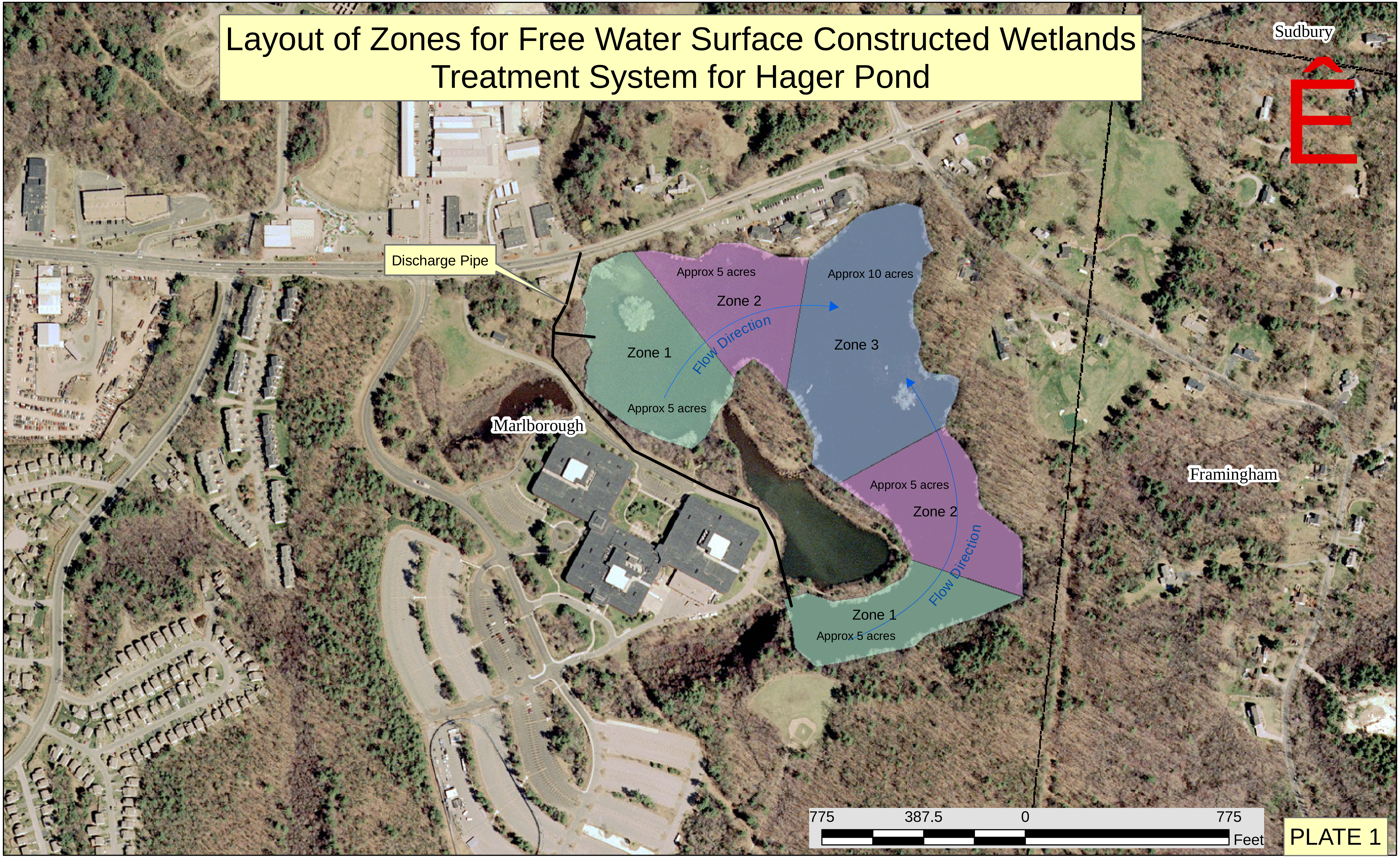
Power Failure Releases
In the event of pumping station failures, the pump station would be inoperable and flows would necessarily be diverted to Hager Pond.

The estimated construction cost for this option is approximately $4 Million.

Summary:

The two options are both technically feasible. Option 1 would involve creating a free-water-surface constructed wetland, which would take up all of the existing Hager Pond, with the advantage of confining nutrient removal efforts to the three modular zones (with emerging/submerged vegetation) subject to routine maintenance. This report has not dealt with permitting of newly constructed free water surface wetlands. EPA publication "Constructed Wetlands Treatment of Municipal Wastewaters" states under Section 1.7.2 that constructed treatment wetlands should not be constructed in the waters of the United States. However, it also states that "*If your constructed treatment wetland is constructed in an existing water of the U.S., it will remain a water of the U.S. unless an individual CWA section 404 permit is issued which explicitly authorizes it as an excluded waste treatment system designed to meet the requirements of the CWA. ... Once constructed, if your treatment wetland is a water of the U.S., you will need a NPDES permit for the discharge of pollutants ... into the wetland. ...*" It is recommended that prior to selecting this option, the communities seek guidance from State and Federal regulators on permit requirements such as discharge requirements, possible monitoring requirements etc.

Option 2 would involve trenching for a new pipeline to divert water from the Hager Pond to some location downstream of Stearns Mill Pond (e.g., pipe along Route 20, discharging into Hop Brook or into the Sudbury River). The ponds would not dry up in the summer, and they would no longer be subject to inflows from the Marlborough WWTP; the eventual receiving waters would be mildly warmed by the influent.


Layout of Zones for Free Water Surface Constructed Wetlands
Treatment System for Hager Pond
Discharge Pipe
Sudbury
Marlborough
Framingham
Zone 1
Approx 5 acres
Zone 2
Approx 5 acres
Zone 3
Approx 10 acres
Flow Direction
Approx 5 acres
Zone 2
Flow Direction
Zone 1
Approx 5 acres
775
387.5
0
775
Feet
PLATE 1