FEASIBILITY STUDY—NHDES DAM #071.03

Oyster River Dam at Mill Pond

Durham, New Hampshire

PREPARED FOR

Town of Durham
8 Newmarket Road
Durham, NH 03824
603.868.5571

PREPARED BY

vhb

2 Bedford Farms Drive
Suite 200
Bedford, NH 03110
603.391.3900

NOVEMBER 2020

IN PARTNERSHIP WITH

Pare Corporation

Weston & Sampson

Independent Archaeological Consultants

UNH Water Systems Analysis Group

FEASIBILITY STUDY – NHDES DAM #071.03

Oyster River Dam at Mill Pond

Durham, New Hampshire

PREPARED FOR

Town of Durham
8 Newmarket Road
Durham, NH 03824
603.868.5571

PREPARED BY

vhb

2 Bedford Farms Drive, Suite 200
Bedford, NH 03110
603.391.3900

IN ASSOCIATION WITH

Pare Corporation
Weston & Sampson
Independent Archaeological Consultants
UNH Water Systems Analysis Group

NOVEMBER 2020

Table of Contents

List of Tables

List of Figures

Appendices

Acronyms

ASTM	American Society of Testing and Materials
DO	Dissolved Oxygen
EQIP	Environmental Quality Incentives Program
gpm	Gallons per Minute
HEC-RAS	Hydraulic Engineering Center-River Analysis System
LAC	Local Advisory Committee
LCHIP	Land and Community Heritage Investment Program
MPM	Meyer-Peter Mueller Method
NHDES	New Hampshire Department of Environmental Services
NHDHR	New Hampshire Division of Historical Resources
NHDOT	New Hampshire Department of Transportation
NHFGD	New Hampshire Fish and Game Department
NHNHB	New Hampshire Natural Heritage Bureau
NHPA	National Historic Preservation Act
NMFS	National Marine Fisheries Service, NOAA
NIST	National Institute of Standards and Technology
NRCS	Natural Resource Conservation Service
NWI	National Wetlands Inventory
O&M	Operations and Maintenance
NOAA	National Oceanic and Atmospheric Administration
PAH	Polynuclear Aromatic Hydrocarbons
PCB	Polychlorinated Biphenyls
PEC	Probable Effect Concentration
PEL	Probable Effect Levels
PEC-HQ	Probable Effect Concentration - Hazard Quotient
SCS	Soil Conservation Service
TEC	Threshold Effect Concentration
TEC-HQ	Threshold Effect Concentration - Hazard Quotient
TEL	Threshold Effect Levels
TMDL	Total Maximum Daily Load
TOC	Total Organic Carbon
USACOE	US Army Corps of Engineers
USEPA	US Environmental Protection Agency
USFWS	US Fish and Wildlife Service
USGS	US Geological Survey
VOC	Volatile Organic Compounds

Executive Summary

ES-1 Background

The Oyster River Dam, also known as the Mill Pond Dam, is located on the Oyster River as it flows through the Town of Durham prior to its discharge into the Great Bay. Constructed in 1913, the dam is a concrete Ambursen-style dam consisting of a spillway, a set of gated outlets at the right abutment, and a fish ladder at the left abutment. It is approximately 140 feet long, with a maximum structural height of approximately 13 feet. Due to its age, engineering significance, and association with local history, the dam is listed on the NH Register of Historic Places.

The NHDES Dam Bureau has identified several safety deficiencies associated with the current dam, including concerns with its overall structural integrity and stability. The dam does not meet current NHDES dam safety standards which require such "low-hazard" dams to pass a 50-year storm event with at least one foot of freeboard between the water surface and the top of the dam abutments. The Town was notified of these problems in multiple Letters of Deficiency (LOD), most recently in February 2018.

The dam forms the 9.5-acre "Mill Pond," a surface water feature historically used for numerous recreational activities such as fishing, boating, and birdwatching. Over the years, water quality in the pond has declined and portions of the pond have filled with sediment, converting much of the former open water area to emergent wetland habitat.

To address these concerns, this feasibility study considered various alternatives including dam removal as well as various permanent modifications to the dam.

ES-2 Alternatives Considered

The project team developed a set of five preliminary alternatives to address the known structural deficiencies of the Oyster River Dam. The review considered the 2018 NHDES LOD, but also incorporated new data and modeling generated during this feasibility study. Based on an initial analysis that considered cost, constructability, and compliance with regulatory requirements, two alternatives were determined to have merit and were therefore advanced for detailed study.

Descriptions of Alternatives

- **Alternative 3 – Dam Stabilization:** This alternative would fill the interior spillway cells with reinforced concrete to create a mass concrete section. The concrete would be reinforced, and the dam would be anchored to the underlying bedrock. Additionally, repairs would be performed to address scour of the existing right training wall and undermining of the fish ladder downstream of the spillway.

  This alternative would retain the dam in essentially its current configuration, and therefore maintain the impoundment, with no measurable changes in water depths or surface area.

However, this alternative would not comply with NHDES Dam Safety regulations, and would there require the NHDES Dam Bureau to approve a waiver to regulate the dam as a "non-menace structure." Initial analysis and coordination with NHDES found that approval of such a waiver request would be contingent on the abutting property owner recognizing that dam failure would have a detrimental impact on its property and accepting the consequences associated with such an occurrence. NHDES would require that any such agreement would run with the land such that future property owners would also be bound.

Dam Stabilization would retain Mill Pond, but would not directly address the decreased depth and poor water quality in the pond. To do this, the project team developed a conceptual plan to remove approximately 11,000 cubic yards of sediment from the pond, which would convert approximately 2.4 acres of wetland to deepwater habitat. Because the Oyster River will continue to transport and deposit sediments, this pond restoration dredge would be an ongoing maintenance task that would need to be repeated in the future as the dredged areas are re-filled with new sediment. Based on a review of sequential historical aerial imagery, field observations, and professional experience in similar settings throughout the region, the dredge areas would likely refill over a period of 5-20 years.

Additionally, it is critical to note that coordination with NHDES and the US Army Corps of Engineers, both of whom would need to approve the dredge, indicates that obtaining a permit for a freshwater dredge of this size would be extremely difficult and perhaps impossible.

- **Alternative 5 – Dam Removal:** This alternative would consist of a four-part plan that includes the removal of the existing dam structure, abutment preservation, channel shaping, and upstream channel restoration. The main dam spillway and the adjacent fish ladder would be entirely removed, but the left and right abutments would be left in place to help stabilize the riverbank and mitigate historic impacts. The channel would be reshaped to have a roughly 42-foot bankfull width, incorporating a 12-foot wide low-flow channel, to provide fish passage under low flow conditions. The active restoration of the Oyster River channel upstream of the dam removal site is also recommended. This would involve channel shaping approximately 600 feet upstream of the location of the dam to stabilize the channel and remove approximately 3,000 cubic yards of sediment deposited in the center of the Mill Pond impoundment. This would minimize potential sediment impacts downstream, as well as improve the stability and ecological integrity of the upstream area following dam removal.

Cost Considerations

The initial investment required for each alternative would total an estimated $4,063,000 for Alternative 3 – Dam Stabilization compared to only $1,314,000 for Alternative 5 – Dam Removal (**Table ES-1**). These totals include construction work related to the dam itself, as well as the pond restoration dredge (Dam Stabilization) and active channel restoration (Dam Removal).

Table ES-1. Preliminary Cost Estimates, by Alternative

	Alt 3: Stabilization	Alt 5: Removal
Construction Components	**$485,000**	**$295,000**
General Construction Items	$77,000	$98,000
Spillway Stabilization	$327,000	N/A
Repair Scour and Undermining	$3,000	N/A
Gated Outlet Structure	$78,000	N/A
Spillway replacement	N/A	N/A
Raise Left abutment	N/A	N/A
Construct Auxiliary spillway	N/A	N/A
Construct Dike	N/A	N/A
Demolition of Dam	N/A	$197,000
Environmental Components	**$3,150,000**	**$711,000**
Pond Restoration Dredge (Option 1)	$3,150,000	N/A
Active Channel Restoration (Option 2)	N/A	$711,000
General Items	**$428,000**	**$308,000**
Bonds & Contingency	$128,000	$78,000
Engineering, Design, & Permitting	$180,000	$150,000
Construction Phase Services	$120,000	$80,000
Total Construction Phase Cost	**$4,063,000**[1]	**$1,314,000**[2]

Notes:
1 Including the cost of pond restoration
2 Including active channel restoration

In addition to the initial capital cost, the study estimated a 30-year life cycle cost, which accounts for operation and maintenance as well replacement costs. (**Table ES-2**) The total life cycle cost for Alternative 3 – Dam Stabilization would be $5,114,414 compared to $1,333,600 for Alternative 5 – Dam Removal.

Table ES-2. Life Cycle Cost Analysis (30 Year Analysis)

	Alt 3: Stabilization with Pond Dredge	Alt 5: Removal & Channel Restoration
Initial Capital Investment		
Discount Factor	1	1
Initial Capital Cost	$4,063,000	$1,314,000
Capital Replacement Cost		
Assumed Design Life (yrs)	50	N/A
Assumed CIP Cost Percentage	60%	0%
Discount Factor	0.412	0.412
Operations & Maintenance		
O&M Costs	$2,400	$1,000
Discount Factor	19.6	19.6
Total Present Cost	**$5,114,414**	**$1,333,600**

While cost estimates based on conceptual engineering are considered a reliable way of assessing the relative economic impact of each option, the actual cost can be expected to change as additional engineering is completed on the selected alternative or as the cost of energy or other factors change in the future.

ES-3 Impacts and Benefits

Flooding, Hydraulics, and Sediment Transport

There would be no change in river depths, widths or velocities downstream of the dam under any alternative.

The Oyster River Dam is a "run of the river" dam. The existing dam allows all the natural river flow to pass over the dam in a relatively consistent and steady flow; it does not significantly divert, store, or release water. Therefore, the water levels and velocities downstream of the dam would remain unchanged, except in the immediate vicinity of the dam. Tidal forces within the downstream portion of the Oyster River exert a much greater influence than the dam. This would remain unchanged under either the Dam Stabilization or Dam Removal alternative.

Dam Removal would substantially reduce the upstream depth and width of the Oyster River and Hamel Brook.

Dam removal would lower the hydraulic control of the river by approximately 9.6 feet. During typical conditions (median annual flow), the upstream surface water would decrease from about 19.7 acres to about 5.4 acres. The volume of water in the river volume would decrease from 77 ac-ft to 10 ac-ft. Dam removal would reduce the impoundment's surface average depth from about 3.3 feet to about 1.4 feet.

This effect would be significant at the dam (and particularly pronounced at Mill Pond), but would decrease upstream until the changes diminish to zero at the upper limit of the impoundment. Additionally, the change would be less pronounced under high flow conditions. If the dam were removed, the following changes are predicted to occur:

- **Mill Pond:** Under median flow conditions, Mill Pond would be eliminated. The average water depth in the river at Mill Pond would decrease from 2.2 to 0.5 feet, and the top width is expected to shrink from 514 to 32 feet. The predicted change will decrease as river flow increases and other factors, like the NH 108 bridge and natural channel and floodplain restrictions exert relatively more control. Dam removal would also allow the tide to influence the river in the area that is now Mill Pond, so tidal effects would raise and lower water levels in this reach throughout the day.
- **Middle Impoundment, Above Mill Pond:** The river's average depth is expected to decrease from 4.7 to 1.4 feet, while the maximum depth would decrease from 7.1 feet to 2.1 feet. Its width will decrease accordingly, from 91 to 41 feet. The significant reduction in both height and width indicates a decrease in cross-sectional flow area, and, therefore, an increase in average velocity, from 0.1 to 0.6 fps. Again, the proportional change from existing conditions is expected to decrease as river flows increase. The removal of the

dam will certainly change the hydraulics of the Oyster River in this area, but the scale of the changes in the Middle Impoundment are not as significant as they are predicted to be in Mill Pond, in large part because Middle Impoundment retains a more "riverine" and less "ponded" form in its present state.

- **Oyster River Mainstem:** Above its confluence with Hamel Brook, the Oyster River Mainstem reach would be relatively less affected than downstream areas, especially during higher flows. Under a median annual flow condition, the river's average depth is expected to decrease from 1.4 to 0.3 feet and its velocity is expected to increase accordingly, from 0.5 to 2.9 fps, similar to upstream reaches. However, during flow conditions expected during the 2-year storm event, dam removal would reduce the river's average depth from 2.7 to 2.0 feet and its width from 45 to 41.6 feet.
- **Hamel Brook:** Under median annual flow conditions, the top width of the impounded portion of Hamel Brook would decrease substantially - from about 135 feet to 18 feet as a result of the dam removal. The average depth would decrease from 3.4 feet to less than 1 foot. The significant reduction in flow area and the elimination of the backwater effect from Oyster River Dam would increase typical velocities to about 0.7 fps. As flow events become larger, the significance of dam removal on the brook's hydraulic character is reduced. The impacts of dam removal are mixed under 2-year flood conditions, with the average depth decreasing from 4.5 to 1.9 feet, but the top width only decreasing from 143 feet to 112 feet and the average velocity still only 0.2 fps, indicative of a largely backwatered reach.

Removal will restore tidal flow upstream of the dam.

If the dam were removed, tidal flows would return to the reach of the Oyster River upstream of the dam location. The upstream limits of tidal flows would depend on tide conditions as well as the adjustment of the river bed following dam removal as sediment transport is restored. Several feet of soft sediment have accumulated over the decades against the upstream side of the dam. If the dam were removed, that sediment would eventually be mobilized downstream by the free-flowing river, or by active channel restoration. As the river reformed its channel at a lower elevation, with that sediment displaced, the influence of tidal waters at high tide could extend further upstream, as much as 2,250 feet upstream of the dam's current location, extending into the middle impoundment reach near the confluence of the Oyster River and Hamel Brook. This would restore tidal habitats that were impacted by the original construction of the dam, as discussed further below. Based on predicted sea level rise, the head of tide could migrate even further upstream, potentially influencing the Hamel Brook reach over a period of decades as sea levels rise in response to climate change.

Removal of the dam will restore sediment transport to pre-dam conditions, mobilizing some accumulated sediment downstream.

In total, dam removal is expected to increase the sediment load to the tidal reach downstream of NH 108. Sediment transport model simulations suggest that sediment may be deposited in a relatively short reach, roughly located between the Three Chimneys Inn and Durham Landing. If deposited uniformly across the river in this area, the deposition of sediment from upstream could reach a depth of between 0.5 and 1.5 feet after 50 years.

However, tidal action will likely disseminate the sediment over a wider range, reducing the depth of deposition.

The potential effect of downstream sediment transport can be minimized by active channel restoration.

Under the Dam Removal Alternative, the active restoration of the Oyster River channel upstream of the dam removal site is recommended. This would involve channel shaping approximately 600 feet upstream of the location of the dam to stabilize the channel and remove approximately 3,000 cubic yards of sediment deposited in the center of the Mill Pond impoundment. Sediment transport modeling indicates that this sediment deposit is expected to become mobilized and re-deposited in the tidally-influenced reach downstream of the former dam location if it is left in place. An active channel restoration would minimize the potential for adverse downstream impacts, and improve the stability and ecological integrity of the upstream area following dam removal.

Sediments in the impoundment contain concentrations of PAHs and metals considered to have moderate to high potential for adverse effects to ecological receptors.

Sediment sampling results indicate that sediments throughout the study area are impacted by certain contaminants in concentrations that create concerns for aquatic organisms. PAHs and metals are commonly found in urban environments, and may be the result of anthropogenic or naturally occurring sources. Average PAH concentrations are slightly greater within and downgradient of Mill Pond, as compared to the upstream samples. There also appears to be more variability in the spatial trends for target metals, with greater concentrations of mercury and chromium observed within Mill Pond and/or downstream of the dam, compared to those further upstream. These results reinforce the benefits of an active channel restoration.

Contaminants in impounded sediments are unlikely to represent an additional or unacceptable risk to human health, but additional screening is warranted if these sediments are dredged.

Two PAH constituents were detected slightly above applicable NH Department of Environmental Services “S-1 standards” in samples located in the northeastern portion of Mill Pond and arsenic concentrations in many samples were slightly above the applicable S-1 standard. The relatively narrow range of arsenic concentrations and their consistent spatial distribution (exceedances of the S-1 standard in both upstream and downstream locations) suggest that these results are indicative of a naturally occurring background condition. Nevertheless, for the purposes of this screening level assessment, sediment analytical data exceeding the S-1 standards generally suggest additional assessment or risk mitigation may be warranted for sediments removed from Mill Pond through the Pond Restoration Dredge or Active Channel Restoration project components.

Infrastructure

Dam Removal would not adversely affect the downstream NH 108 Bridge or pedestrian bridge.

NHDOT Bridge No. 114/111 which carries NH 108/Newmarket Road over the Oyster River and the Town of Durham footbridge are scour-stable under existing conditions. Based on the hydraulic model results, neither of these two structures are likely to be adversely affected by implementation of any of the alternatives evaluated in this study.

Dam Removal would mitigate flooding of adjacent properties.

Dam Removal would drop the 50-year flood below the basement floor at 20 Newmarket Road and therefore reduce the risk of the building flooding. The 100-year flood elevation similarly drops, but due to tailwater from the NH 108 bridge remains above the basement flood elevation. However, it is lower than existing condition and therefore would reduce the magnitude of flooding for this event. Flood velocities near the building for all alternatives are less than 2 feet/second, which indicates low scour potential.

Water Quality

Dam Removal would substantially improve dissolved oxygen levels in the Oyster River.

This improvement of dissolved oxygen levels would possibly eliminate the existing dissolved oxygen impairment. The reduced surface water size, increased travel time and reduced solar thermal inputs will help to lower water temperatures, which would also improve dissolved oxygen conditions. The improved dissolved oxygen levels and lower water temperatures will positively affect habitat conditions for diadromous fish.

Dam Removal would reduce the amount of algae and aquatic plant biomass generated on an annual basis compared to the existing impoundment.

Algal and plant biomass growth can affect the nutrient dynamics and although the impoundment may temporarily retain nitrogen during the summer months, a potentially greater release of dissolved organic nitrogen could occur following plant die-off and the decomposition process. The decomposition of organic material also exerts a dissolved oxygen demand. Eliminating or reducing this biomass production would diminish the dissolved oxygen and nitrogen fluctuations produced under existing conditions.

Dam Removal would affect salinity levels in the current impoundment.

Increased salinity would result from the upstream migration of high tide levels after removing the dam, which will affect the distribution of vegetation species and aquatic organisms that prefer brackish conditions in tidally influenced areas.

Dam Stabilization would not improve water quality, except for temporary, minor benefits associated with the Pond Restoration Dredge option.

The pond restoration dredge associated with Dam Stabilization could improve water quality by lowering the potential dissolved oxygen demand and potential nutrient inputs from the nutrient-enriched bottom sediment and organic material that is removed. The magnitude of the overall improvement is difficult to predict but since the bottom sediments represent only one of many factors that exert a demand on lower dissolved oxygen levels. It seems unlikely that the current dissolved oxygen impairment could be eliminated, and any benefits would last only until new sediments are eventually deposited in the dredge areas.

Cultural Resources

Modification to the dam structure under the under Alternative 3 – Dam Stabilization is expected to be deemed a Section 106 "adverse effect" to the State Register-listed resource.

The dam is significant under Criterion C for its design and construction value, as an embodiment of the distinctive characteristics of an Ambursen dam-type and concrete slab and buttress method of construction. The characteristics that make it strongly representative of this type of dam include the evenly spaced downstream buttresses with hollow cells between, and the solid sloping reinforced concrete slab on the upstream side, with curved concrete spillway crest. Alternative 3 proposes to construct a "new" spillway within the confines of the existing spillway by pumping reinforced concrete within each of the spillway cells, which would alter the original design and construction, for which the resource derives its significance under Criterion C.

Dam removal would eliminate a State Register-listed resource, which would require substantial mitigation to offset.

Not only is the dam significant for its engineering and design under Criterion C, it is also significant under Criterion A. The dam played an important role in the local history of the Town of Durham. Its construction in the early twentieth century was part of a pattern of philanthropic activities and community planning and development that helped create the University of New Hampshire Campus and Downtown Durham. In addition, removal of the dam and restoration of the river channel would create a landscape that has not existed since the seventeenth century. The elimination of the dam would be an adverse effect under Section 106 of the National Historic Preservation Act, which would trigger a substantial mitigation effort.

The area surrounding the impoundment is sensitive for archaeological resources.

Dam removal may cause potential impacts to archaeological resources due to changes in sediment transport (erosion and aggradation) near potential archaeological sites along Hamel Brook and the Oyster River. In addition, removal of the dam may expose previously submerged sites, making any potential sites below the current waterline vulnerable to degradation.

Natural Resources

Dam Removal would eliminate the barrier to upstream fish passage and address the declining water quality in Mill Pond and the upstream impoundment.

These two effects would have a significant net benefit on fishery resources. This alternative involves restoring a more natural profile of the Oyster River at and immediately above the dam. This suggests that river herring will successfully ascend the restoration reach that would be exposed following dam removal, supporting a self-sustaining river herring run.

If the Pond Restoration Dredge is implemented as part of the Dam Stabilization alternative, approximately 2.4 acres of freshwater emergent and aquatic bed wetlands would be directly impacted.

These impacted areas would be converted from wetlands to open water habitat. This impact would reduce the structural diversity of the Mill Pond system, and would decrease plant and animal diversity on a local scale. Beneficial effects on dissolved oxygen levels and water temperatures would be associated with deepening the pond. However, given concerns regarding the sustainability of the pond dredge, obtaining regulatory approvals for this component of the project would be extremely difficult to impossible.

Dam removal would restore tidal wetlands in the lower portion of the study area.

Based on the existing bathymetry data, it appears that the upstream migration of tidal inflow following a possible dam removal would be confined primarily within the main river channel given that the main river within Mill Pond is confined within a submerged channel with top of bank limits that are generally at elevations of 6 to 8 feet (NAVD88). However, tidal action on adjacent wetland areas is also possible, especially as predicted sea level rise occurs over the next century, and the wetland community would shift towards salt water tolerant species. Based on the estimated high tide elevations and salinity changes, portions of the dewatered pond that have bottom elevations of 4.4 feet or less would likely be inundated or influenced by tidal waters on a daily basis. Occasionally, the brackish waters may extend as high as 5.4 feet or more based on the highest observable tide line. In general, the new tidally-influenced area within the potentially dewatered pond is anticipated to be contained within the eastern portion of the main river channel, based on the bathymetry data.

The area subject to tidal action on a daily basis would eventually acquire some of the characteristics of the portion of the Oyster River located immediately downstream of the dam, which is classified as a subtidal estuarine system with an unconsolidated bottom (E1UBL). Within this habitat type, brackish tidal water enters from the ocean, while the river carries nutrients, organic matter, and sediments to the downstream estuaries. These inputs combine to make estuaries extremely productive habitats with a great abundance of plants and animals. Outside of the immediate river channel, existing salt tolerant species observed downstream of the dam could provide a seed source for salt tolerant vegetation to become established in the new tidal influenced zone. The existing salt tolerant vegetation species include saltmeadow cordgrass (*Spartina patens*), prairie cordgrass (*Spartina pectinata*), blackgrass (*Alopecurus myosuroides*), and saltmarsh bulrush (*Scirpus robustus*).

1

Background

1.1 Introduction

The Oyster River Dam, also known as the Mill Pond Dam, is a highly visible historic structure which impounds the Oyster River to form the 9.5-acre "Mill Pond," a surface water feature located at the eastern gateway to Durham. The dam was originally constructed in 1913 and is currently owned and operated by the Town of Durham. **Figure 1.1-1** shows the location of the dam and the lower portion of the Oyster River watershed within Durham.

The NHDES Dam Bureau has identified safety deficiencies associated with the current dam, indicating concerns with the overall structural integrity and stability of the dam. Additionally, it does not meet current NHDES dam safety standards which require it to pass a 50-year storm event with at least one foot of freeboard between the water surface and the top of the dam abutments. Based on hydraulic modeling results, the dam abutments as currently configured would be overtopped by high-flow flood waters, which is an unsafe condition. While dams are designed to pass water over their "spillway," a dam can fail if the river flows rise to a level where they overtop the "abutments" or other parts of the dam. Dams can also fail by sliding or overturning if they are not properly designed, installed and maintained. In the case of the Oyster River Dam, NHDES has determined that the dam is appropriately classified as a "Low Hazard Structure" based upon the potential impacts that dam failure may have on adjacent or downstream properties.[1]

1 The NHDES Dam Safety Bureau has issued a number of letters relating to the dam, including "Letter of Deficiency DSP #18-010" dated February 12, 2018 which outlines a number of deficiencies associated with the dam, and requesting the Town of Durham to take certain actions to address these deficiencies. This letter and other relevant correspondence to and from NHDES can be found in **Appendix A**.

To address these concerns, the Town of Durham has considered various alternatives including the permanent modification of the dam as well as removing the dam entirely. This report is intended to provide an analysis of the summary of the costs, benefits and impacts associated with these alternatives. A considerable amount of previous research has been conducted, and further analysis has been completed as part of this study. While the text of this report provides much detail on the issues addressed, back up data and more detailed analyses can be found in **Appendices A** through **E**.

1.2 Purpose and Scope of this Study

The Town of Durham has studied options for addressing the Oyster River Dam safety issue for several years. This current study seeks to provide information on the alternative of removing the dam entirely as a means of eliminating the safety concern, and to examine retaining the dam to maintain the historic, iconic structure and the associated impoundment. Thus, the objectives and issues explored within this study are as follows:

- Determine the feasibility of removing the Oyster River Dam, including the engineering issues involved and the cost to remove the dam.
- Compare the costs of dam removal to other options such as modifying the dam.
- Determine the impacts and benefits of various alternatives on community issues and resources such as:
    - Flooding and Sediment Transport Effects, including the expected change in flooding conditions and the river's ability to carry sediment both above and below the dam site under the various alternatives including removal and modification options;
    - Infrastructure, including the possible effects on bridges, foundations and other structures located in or near the river;
    - Water Resources, such as the quality of the water in the river and the availability of water for public and private drinking water;
    - Cultural Resources, such as the historic character of the dam and its surroundings;
    - Recreational and Social Resources, including boating and other uses of the impoundment, and visual and aesthetic values and impacts; and
    - Natural Resources, such as the potential effect on fish passage and in stream aquatic habitat, wetlands and floodplain forests along the impoundment, wildlife habitat, and rare species.
- Provide this analysis in a clear to understand format so that the Town of Durham can make an informed decision about the best course of action to address the dam safety issues, hydraulic effects, and public and private infrastructure.

This study will supplement previous studies and is not meant to be the sole piece of information on which to base a final decision. This report is not intended to make a final recommendation regarding whether the dam should be modified or removed. Rather, the intent of this study is to provide detailed information to allow the Town to choose an alternative.

This study is intended to be comprehensive and address a multitude of issues including the costs, impacts and benefits associated with each alternative. Further information on the alternatives considered is provided in Chapter 2, and a discussion of impacts and benefits is provided in Chapter 3.

1.3 The Oyster River Watershed

The Oyster River's headwaters begin in southern Strafford County in the town of Barrington from which the river runs east through the towns of Lee, Madbury and Durham where it meets Great Bay. The dam's location is at the head of tide of the Oyster River, where the river changes from freshwater to saltwater. The Oyster River is a major tributary of the Great Bay, one of the largest, most ecologically significant estuaries on the east coast, with an area of approximately 6,000 acres.

The river provides diverse habitat for freshwater and anadromous fish species, which use the river and its tributaries for spawning and nursery habitat. Eighteen species of fish are known to use the river, including a mixture of warmwater, coldwater, and anadromous species. The Oyster River has one of the most diverse fish species assemblages in the state, including nine fish species of concern listed in New Hampshire's Wildlife Action Plan (NH Fish and Game Department, 2015). Of these important fish, the river is home to what was once New Hampshire's most productive river herring population, as well as the only known population of American brook lamprey in New Hampshire, which is listed by the state as endangered.

The Oyster River corridor also provides critical wildlife habitat to a wide variety of species that depend on the habitat connectivity provided by the river and large, unfragmented forest areas. This corridor allows for the movement of wildlife species, and its riparian habitats provide the most extensive contiguous habitat within the watershed. Between the Oyster River Dam in Durham and NH 125 in Lee, there are only nine river crossings and over 80 percent of the river has no development within 0.1 mile on either side.

The Oyster River and all its tributaries in Barrington, Durham, Lee, and Madbury from their sources to the crest of the Oyster River Reservoir dam are designated as Class A waters by the New Hampshire General Court. All other portions of the Oyster River downstream of the Oyster River Reservoir dam are designated as Class B.

In addition to the structural problems associated with the dam, the Oyster River has water quality issues related in part to stagnant water conditions in Mill Pond. (See Section 3.5 for a discussion of water quality.) As a result, the Oyster River is listed as impaired for low dissolved oxygen and pH for aquatic life on the NHDES's Section 303(d) Clean Water Act priority list of impaired water bodies.[2] In addition, the entire river is impaired for safe fish consumption due to increased mercury levels, and all portions of the river except for the Oyster River Reservoir are impaired for *E. coli*. The Oyster River serves as one of the main

[2] The Clean Water Act requires each state to submit a list of impaired waters to the US Environmental Protection Agency (USEPA) every two years. The document is typically called the "303(d) List," so named because it is a requirement of Section 303(d) of the CWA. The 303(d) List includes surface waters that are either impaired or threatened by a pollutant or pollutant(s), not expected to meet water quality standards within a reasonable time even after application of best available technology standards for point sources or best management practices for nonpoint sources, or require the development of a comprehensive water quality study (i.e., called a Total Maximum Daily Load or TMDL study) that is designed to meet water quality standards.

water supplies for Durham and the University of New Hampshire (UNH), with the water withdrawal and the water treatment plant being located at the upstream Oyster River Reservoir Dam.

The river's importance is made evident by the fact that the Oyster River was nominated as a "designated river" under NH Statute RSA 483:10 by the communities through which it flows. The Legislature approved the nomination for a 14-mile portion of the river from Hall Road in Barrington to the Oyster River Dam in Durham in 2011.[3]

This designation affords the river special protection through the New Hampshire Rivers Management and Protection Program (NHRMPP). Through this program, a management plan for the upper portion of the Oyster River was formulated and adopted by the river's Local Advisory Committee (LAC) in 2014. This designation carries specific regulatory protections under RSA 483:9-a and RSA 483:9-b, which include limitations on the construction of new dams and on certain channel alterations in certain segments. Other regulations include protection of in-stream flows and water quality.

1.4 Description of the Oyster River Dam at Mill Pond

1.4.1 Structural Description

The Oyster River Dam at Mill Pond is a concrete dam, approximately 140-foot long, with a maximum structural height of approximately 13 feet. The dam consists of three components:

- **Spillway:** The spillway structure for the dam is an approximately 100-foot wide reinforced concrete modified Ambursen type buttress dam. The spillway consists of a reinforced concrete shell supported by reinforced concrete ribs spaced approximately 12 feet on center beneath the crest. Flow over the spillway discharges into a bedrock plunge pool before discharging beneath the bridge carrying Newmarket Road (NH 108).
- **Gated Outlets:** The gated outlets are located at the right end of the dam and consists of two 4-foot wide timber gate-controlled bays. The gate operators consist of rack and pinion type operators with timber gate stems. The right[4] gate structure was previously used to supply the mill downstream with hydropower and is currently not utilized; the left gate structure is presently used as the low-level outlet. Flows from the low-level outlet enter the gate structure and outlet to the downstream channel where the masonry structure for the previous mill foundations are located.
- **Fishway:** A Denil (baffle) fishway is located at the left abutment of the dam. This structure was added by the NH Fish and Game Department (NHFGD) in 1975, in cooperation with the Town and the US Fish and Wildlife Service, to improve upstream fish passage for anadromous fish.

See **Figure 1.4-1** for a view of the dam looking upstream from the NH 108 bridge. **Figure 1.4-2** depicts a scaled drawing of the dam and its immediate vicinity.

3 The tidal portion of the river below the Oyster River Dam is not included in the designation.

4 In this report, "river right" and "river left" refer to the river as viewed when looking downstream.

1.4.2 History and Uses of the Dam

The Oyster River Dam was a gift to the town of Durham in 1913, constructed to replace a series of timber dams that had stood at the site since 1649. The Oyster River Dam is the oldest of seven known examples of an Ambursen-style dams in New Hampshire. The dam was renovated in the 1970s to address significant deterioration. At that time, the Town worked with the NHFGD to install a Denil fish ladder at the dam to create a means of upstream fish passage. Today, the river flowing over the Oyster River dam crest creates an iconic image for local residents and travelers entering Durham along NH 108. Residents also enjoy the aesthetic qualities and recreational opportunities provided by the pond and adjacent shoreline. These activities include picnicking, boating, kayaking, fishing, and bird watching in the spring, summer, and fall—as well as skating and cross-country skiing in the winter.

1.4.3 Current Condition of the Dam

Today, the dam is more than 100 years old and is showing clear signs of serious deterioration. Several town-sponsored engineering studies and inspections by the NHDES Dam Bureau over the last few decades document the poor condition of the dam. As part of this study, engineers from Pare Corporation completed a visual inspection of the dam in December 2019, intended to assess its condition and identify areas of vulnerability. A summary of the findings is presented in the following, and a detailed report of the inspection is included as **Appendix B**.

To properly assess and inspect the dam, a shallow drawdown of the impoundment occurred, which lowered the impoundment levels approximately 4-5 inches, to a point just below the spillway crest. In general, the overall condition of the dam was found to be Poor, with specific observations of the primary spillway broken down into three sections: spillway slab, training walls, and spillway cells. There were several deficiencies observed throughout the dam during the December 2019 inspection. These included:

- Concrete deterioration was found to have occurred along the spillway cells and ribs. More specifically, cracks and spalls were observed with evidence of water seepage, loss of the rib occurred between Cell 1 and Cell 2, delamination of the repaired concrete was noted, and debonded rebar was observed within multiple cells.
- Seepage at the downstream corner of the right abutment wall.
- Seepage through the downstream side of the gate structure.
- Inoperable right gate outlet.
- Concrete deterioration of the gate outlet structure in the form of delamination, cracking, and spalling.
- Insufficient capacity to pass the storm design freeboard at the dam, which could result in the potential for flooding during major storms.

Additional deficiencies such as the presence of scour and efflorescent staining were noted along multiple sections of the spillway slab and training walls. The multiple scour locations ranged from minor scours less than 1 inch deep to more major scours approximately

9 inches deep. The efflorescent staining was noted throughout all of the spillway cells, which typically indicates more severe deterioration.

Most of the deficiencies noted in previous inspections has continued to progress, and the deterioration is reaching a critical juncture. Not only has the seepage continued in multiple locations throughout the dam, but the area of section loss and deterioration between Cell 1 and Cell 2 has increased in size since 2018 and additional seepage through the outlet structure was observed for the first time. Despite of the issues noted within this report, the dam is still only classified as a Low hazard potential dam, based on the impacts dam failure would have on the adjacent and downstream properties, and because the height of the dam exceeds 6 feet and the storage capacity exceeds 50 acre-feet. However, the combination of both new and pre-existing deficiencies is cause for concern.

1.5 Public Involvement

During this study, the project team met with town committees, state and federal resource agencies, and the general public to solicit feedback and discuss questions and concerns about the project. At these meetings, the project team has provided updates about the scope of the project and its current status. Each of the municipal meetings has been broadcast on local public access television, and the recordings of the meetings have been posted to the Durham municipal website. As the project continues to progress, additional public information meetings are planned.

Table 1.5-1. Agency and Public Meetings

Date	Meeting Type
January 16, 2020	Public Information Meeting
February 24, 2020	Durham Conservation Commission
June 15, 2020	Town Council Briefing
July 6, 2020	Town Council Briefing
July 17, 2020	Resource Agency Briefing
August 6, 2020	Durham Heritage Commission
November 16, 2020	Town Council Briefing

2

Alternatives Considered

2.1 Introduction

The project team developed a set of engineering alternatives to address the known structural deficiencies of the Oyster River Dam. This review considered the 2018 Letter of Deficiency issued by the NH Department of Environmental Services (NHDES) Dam Bureau to the Town of Durham,[5] but also incorporated new data and modeling generated during the Feasibility Study. This new information included a recently completed dam inspection (Pare Corporation, 2020), as well as refined hydrological and hydraulic modeling.

Perhaps most importantly, the hydraulic modeling completed to date suggests that a waiver request to NHDES to treat the dam as Non-menace while maintaining a Low hazard classification may be viable.[6,7] This is important, because, if a waiver request is approved by NHDES, then viable alternatives would need only to preserve the existing spillway capacity, rather than increase the capacity to the design criteria for a Low-hazard dam (i.e., pass the 50-year storm with 1 foot of freeboard).

As such, the scope of the preliminary alternatives considered approaches assuming that the waiver could be issued. The list of alternatives discussed below includes options which would preserve the current spillway capacity (Alternative 1, 2, and 3), as well modify the site such that discharge capacity requirements are met (Alternatives 4 and 5). It should be noted that while issuance of a waiver from a regulatory standpoint appears possible, such approval is

[5] NHDES Letter of Deficiency, DSP #18-010, dated February 12, 2018.

[6] See Steve N. Doyon's letter to April Talon dated September 20, 2018, for a discussion of the dam hazard classification.

[7] For a report of the hydraulic modeling related to the non-menace waiver, see Weston & Sampson (2020) in **Appendix A**.

subject to NHDES review and approval and is anticipated to be contingent on conditions such as the execution of legal agreements between the dam owner and abutters.

As part of the alternatives screening scope of work, five distinct alternatives were considered including 1) No Action, 2) Repair, 3) Stabilization, 4) Redesign, and 5) Removal. Each of these alternatives are presented in detail in the sections below.

2.2 Alternative 1 – No Action

Under the No-Action Alternative, no work would be completed at the dam to address the identified regulatory or physical deficiencies, except for ongoing operations, maintenance, and inspections. If the non-menace waiver is approved, then the No Action Alternative would meet NHDES requirements for a non-menace dam. However, as previously documented, the condition of the concrete ribs supporting the spillway poses a short-term structural issue given the continued and progressive loss of concrete functioning to support the spillway slab. Furthermore, the No-Action Alternative would not address the current issues with poor water quality, aquatic habitat, or recreational resources. As such, No Action would serve to jeopardize the structural condition of the dam, potentially resulting in a sudden failure of a portion of the spillway and loss of the impoundment. Therefore, the No-Action Alternative is not considered an appropriate alternative and is not recommended.

2.3 Alternative 2 – Repair

Alternative 2 - Repair would implement improvements at the dam to address the immediately identified structural concerns. Conceptually, as shown on **Figure 2.3-1**, this alternative would include the following activities:

a. <u>Spillway Ribs</u>: Structurally reinforce the spillway ribs. Ribs may be reinforced through a variety of structural improvement measures including jacketing the ribs within a reinforced concrete shell, temporary spillway bracing and reconstruction of the deteriorated rib sections, and/or isolated concrete patch repairs. Extent and type of repair would be determined through subsequent evaluation and design.

b. <u>Right Training Wall Scour</u>: Remove deteriorated concrete in the area of scour; Replace with new reinforced concrete.

c. <u>Fish Ladder Undermining</u>: Fill the void beneath the fish ladder with flowable fill or other suitable fill material; provide a scour apron to prevent recurrence.

d. <u>Gated Outlet Stabilization</u>: Construct a new gravity section upstream of the existing gated outlet structure to provide an overall section meeting stability requirements. Complete concrete repair throughout the structure including removal of deteriorated concrete and replacement with new reinforced concrete.

e. <u>Gate Replacement</u>: Remove and dispose the existing gates; install new gates. Through recent operations, the left gate has sufficient capacity to drain the impoundment; as such, the right gate could be removed and the conduit through the gated outlet structure could be properly abandoned/filled.

f. Pond Restoration: This alternative could be combined with restoration of Mill Pond as discussed in Section 2.7.

This alternative is anticipated to address the immediate structural concerns noted along the dam. However, the scope of work is limited to addressing areas of significant concrete deterioration currently present at the dam. The scope of work does not include complete replacement of concrete components which have been shown through past studies to have been impacted by alkali-silica reaction (ASR) and other deterioration indicative of the age and poor condition of the concrete. As such, the effective design life of this approach may be limited.

2.4 Alternative 3 – Stabilization

Alternative 3 - Stabilization would provide a means by which to improve the long-term stability of the dam. For the purpose of alternatives screening, stabilization was considered to mean implementing measures that would limit changes to the existing structure while providing a structure designed for long term stability. Conceptually, as shown on **Figure 2.4-1**, Alternative 3 would include:

a. Spillway Stabilization: Essentially design and construct a "new" spillway within the confines of the existing spillway. This could be achieved through the installation of reinforced concrete within each of the spillway cells and around the rib walls to create a mass concrete section. Concrete reinforcement and anchors to the bedrock foundation would be provided, resulting in a spillway section that would be stable regardless of the presence of the existing spillway structure.

b. Gated Outlet Structure: Stabilization would include addressing stability and structural concerns at the gated outlet structure. In general, this work would take a form similar in nature and extent to the Repair alternative (See Items 2.3.d and 2.3.e above).

c. Pond Restoration: This alternative could be combined with restoration of Mill Pond as discussed in Section 2.7.

This alternative would also include the completion of additional repair work as discussed above including addressing scour of the existing right training wall and undermining of the fish ladder downstream of the spillway. The approach of designing and installing independent structures is anticipated to provide a long-term solution to the concerns for the existing dam.

2.5 Alternative 4 – Dam Redesign

Alternative 4 – Dam Redesign includes designing and implementing modifications to the dam to address known structural concerns, potential structure/long term stability concerns, and address all regulatory deficiencies. Alternative 4 would comply with applicable regulations for Low Hazard dams; receipt of a waiver to treat the dam as Non-menace would not be required to implement this alternative. As conceptually shown on **Figure 2.5-1**, the alternative includes:

a. Spillway Extension: Modifying the dam to provide sufficient capacity to accommodate the 50-year spillway design storm event with 1-foot of freeboard. Based upon hydrologic and hydraulic modeling completed during this feasibility study, the required modifications could include:
    1. Raising the design top of the dam approximately 1.85 feet while maintaining the current spillway crest elevation; modifications associated with raising the top of the dam would primarily include increasing the right abutment area and top of the fish ladder / left abutment such that they do not overtop during the spillway design flood event.
    2. Lowering the top of the gated outlet structure approximately 2 feet to effectively widen the spillway by 26 feet.
    3. Providing an auxiliary spillway extending into the right abutment at an elevation approximately 1.7 feet higher than the spillway crest.
    4. Constructing an approximately 50-foot long earthen berm/dike to tie the new system into the design top of dam elevation at the right abutment.
    5. Grading left of the fish ladder to meet design top of dam elevations.
b. Spillway Reconstruction: Reconstruction of the existing spillway to address structural concerns.
c. Gated Outlet Structure: Replacement of the gated outlet structure to address structural and stability concerns; providing a new low-level outlet.
d. Fish Ladder: Addressing other known concerns including undermining of the fish ladder at the left end of the spillway.
e. Pond Restoration: This alternative could be combined with restoration of Mill Pond as discussed in Section 2.7.

A number of variations of the spillway geometry modifications could be considered as part of final design to select the most beneficial layout.

Alternative 4 would provide a new dam which would meet applicable NHDES design requirements with an anticipated design life exceeding 50 years. During final design, considerations could be incorporated into the proposed structure to maintain the aesthetic character of the existing dam while providing a dam meeting current design standards.

2.6 Alternative 5 – Dam Removal

Alternative 5 – Dam Removal would remove the dam from the river. As shown on **Figure 2.6-1**, dam removal would include:

a. Dam Removal: Complete demolition and removal of the spillway structure and the fish ladder.
b. Abutment Preservation: Preservation of the gated outlet at the right abutment and the fish ladder forebay/left abutment concrete wall to protect the long-term stability of the abutments during high flow storm events and to mitigate historic impacts.

c. Channel Shaping: Creation of a reconstructed river channel through the former location of the dam, designed to simulate the geomorphology of a natural river with a channel slope consistent with the macro-scale longitudinal profile of the Oyster River in the vicinity of Mill Pond. The channel would have a roughly 42-foot bankfull width, incorporating a 12-foot wide low-flow channel centered on the thalweg, to provide fish passage under low flow conditions. Reshaping of the streambed or placement of stable streambed materials may be required to control the risk of erosion or to create conditions favorable to aquatic habitat or upstream fish passage once flow is returned to the full channel. While it is not anticipated that substantial grading would be required within the immediate vicinity of the dam, the amount and type of grading and channel stability structures (if needed) would be determined during the final design and permitting process if the dam removal alternative is selected. Areas beyond the limits of the channel disturbed by construction equipment would be restored to provide floodplain and habitat in the vicinity of the former dam.

d. Upstream Channel Restoration: In addition to the work involved in removing the dam and restoring the immediate vicinity of the dam site, Alternative 5 should include active restoration of the upstream channel of the Oyster River. This would address sediments deposited in the river channel due to the presence of the dam. More information on this recommended option is provided in Section 2.8.

2.7 Option 1 – Pond Restoration Dredging

In addition to the alternatives described above, the project team also developed a preliminary conceptual plan for restoring Mill Pond through dredging as a potential add-alternate in conjunction with Alternatives 2, 3 and 4. This effort was prompted by concerns expressed by the public regarding the declining quality of Mill Pond. Over the 107-year lifetime of the dam, accumulating sediments from the Oyster River have gradually filled in the pond, resulting in shallow water depths and excessive aquatic plant growth. Historic aerial images dating back as far as 1962 show evidence of sediment deposition in Mill Pond, with subsequent aerials showing increased aquatic plant growth.

A 2014 *Durham Ponds Assessment and Plan* identified dredging as a potential management option to improve water quality and support of designated uses in Mill Pond (DK Water Resource Consulting, 2014). The DK Assessment noted that dredging soft sediments would eliminate the substrate for plant growth and create open water areas free of aquatic plants for recreation and fishing, and identified potential dredging sites.

Building on the DK Assessment recommendations, the project team delineated three potential pond dredging locations and calculated quantities of sediment removal for a 6-foot targeted water depth. Quantities were calculated in AutoCAD based on 2008 Hydroterra bathymetric survey data for existing pond sediment elevations. Based on the concept plan shown in **Figure 2.7-1**, more than 11,000 cubic yards of sediment would be removed from the pond.

The project team prepared cost estimates for pond dredging at each location from these quantities incorporating unit costs from bid results from previous comparable projects and NHDOT weighted bid unit prices. The cost estimates include two potential methods:

- Mechanical dredging, where sediments are excavated and removed by traditional earth moving equipment "in the dry" after containing and dewatering the dredge areas behind temporary cofferdams, and
- Hydraulic dredging, where sediments are removed in-situ via a hydraulic vacuum system sending water-sediment slurry to geotubes for dewatering in a nearby staging area.

Because the Oyster River will continue to transport and deposit sediments, this pond restoration/dredging add-alternate should be considered as an ongoing maintenance task that would need to be repeated in the future as the dredged areas are re-filled with new sediment.

Additionally, it should be noted that the pond restoration dredging would require permits from the NHDES and the US Army Corps of Engineers (USACOE), as well as reviews by several additional state and federal resource agencies. Coordination with these agencies via an online meeting held on July 17, 2020 indicated that dredging of freshwater ponds of this scale are extremely rare; the resource agencies expressed significant concerns that would be very difficult to address. Therefore, the likelihood of obtaining such permits is considered to be poor.

2.8 Option 2 – Active Channel Restoration

Under the Dam Removal Alternative, the active restoration of the Oyster River channel upstream of the dam removal site is recommended. This would involve channel shaping approximately 600 feet upstream of the location of the dam to stabilize the channel and remove approximately 3,000 cubic yards of sediment deposited in the center of the Mill Pond impoundment (See **Figures 2.8-1** and **2.8-2**). Sediment transport modeling indicates that this sediment deposit is expected to become mobilized and re-deposited in the tidally-influenced reach downstream of the former dam location if it is left in place.[8] Although analysis of sediment samples from this deposit indicates similar composition to downstream reaches of the Oyster River, downstream transport of sediment is a concern due to the potential for impacts to downstream navigation and ecological resources. To avoid the potential for uncontrolled sediment release negatively impacting the downstream reach, and to improve the stability and ecological integrity of the upstream area following dam removal, it is recommended that Alternative 5 include this extended channel restoration through the upstream sediment deposit.

2.9 Cost Estimates

This section details the cost estimates for each of the alternatives considered and breaks down the costs by aspects of the proposed work.

[8] Sections 3.2 and 3.3 contains additional information on sediment transport modeling and the quality of the sediment in the Oyster River and suggests that an "active" channel restoration is the appropriate approach in this case.

2.9.1 Design, Permitting and Construction

To allow for comparison of the direct economic costs of the alternatives, preliminary Opinions of Probable Cost were prepared in 2020 dollars. The estimates are based on preliminary conceptual engineering only. Therefore, while they are considered accurate and appropriate for a feasibility study of this type, the actual cost associated with any of the alternatives may change as additional engineering is completed on the selected alternative. Nevertheless, the cost estimates are considered a reliable way of assessing the relative economic impact of each option.

The cost estimates provided in **Table 2.9-1** are an initial investment associated with the design, permitting and construction of each alternative. Details of the construction cost estimates are provided in **Appendix C**.

Table 2.9-1. Preliminary Opinion of Construction Phase Costs, by Alternative

	Alt 2: Repair	Alt 3: Stabilization	Alt 4: Redesign	Alt 5: Removal
Construction Components				
General Construction Items	$112,000	$77,000	$136,000	$98,000
Spillway Stabilization	$217,000	$327,000	N/A	N/A
Repair Scour and Undermining	$3,000	$3,000	N/A	N/A
Gated Outlet Structure	$115,000	$78,000	$124,000	N/A
Spillway replacement	N/A	N/A	$168,000	N/A
Raise Left abutment	N/A	N/A	$4,000	N/A
Construct Auxiliary spillway	N/A	N/A	$111,000	N/A
Construct Dike	N/A	N/A	$8,000	N/A
Demolition of Dam	N/A	N/A	N/A	$197,000
Environmental Components				
Pond Restoration Dredge (Option 1)	$3,150,000	$3,150,000	$3,150,000	N/A
Active Channel Restoration (Option 2)	N/A	N/A	N/A	$711,000
General Items				
Bonds & Contingency	$118,000	$128,000	$145,000	$78,000
Engineering, Design, & Permitting	$190,000	$180,000	$300,000	$150,000
Construction Phase Services	$120,000	$120,000	$150,000	$80,000
Total Construction Phase Cost	**$4,025,000**[1]	**$4,063,000**[1]	**$4,296,000**[1]	**$1,314,000**[2]

Notes:
1 Including the cost of pond restoration
2 Including active channel restoration

These construction estimates are based on several pieces of information including:

- An understanding of the dam and surroundings based on field survey, field visits and measurements;
- Preliminary conceptual design elements for each of the alternatives;

- Costs for similar projects in New Hampshire and other states;
- Commercial estimating databases such as RS Means, Site Work & Landscape Cost Data, 2020;
- Data from the NH Department of Transportation including their Weighted Average Unit Prices for 2019 Qtrs 1-4 accessed via the internet; and
- Recent vendor quotes for similar items, and experience with similar projects.

Engineering and permitting of the alternatives is included to cover the cost of the additional design work and regulatory permitting that would be required for each alternative. This includes permitting through NHDES and the USACOE, including coordination with their sister agencies. Construction monitoring is also included. This is the expected costs to the Town to oversee and manage the contractor during construction.

The cost for the Pond Restoration Dredging (Option 1), which could be included to supplement Alternatives 2, 3, and 4 would range from $2.96 million to $3.15 million, depending on the volume of dredge and method used.

The cost for the Active Channel Restoration (Option 2), recommended to be included with Alternative 5, would be approximately $711,000.

2.9.2 Operations, Maintenance and Capital Replacement Costs

Construction costs can be thought of as one-time expenditures, incurred during the initial stages of a project. However, a true estimate of the cost of an alternative must consider costs associated with its operation, maintenance and capital replacement. An analysis was conducted to estimate the total cost of each of these items over a period of 30 years in order to develop a better understanding of the true costs of each alternative. These types of costs, when considered with the initial construction of a project are often called "Life Cycle Costs."

The National Institute of Standards and Technology (NIST) Life Cycle Cost Manual Handbook 135 with the 2019 Supplement was used to determine the life cycle costs for the proposed alternatives (NIST, 1995). At this level of study, a simple method was utilized that accounts for initial investment, capital replacement, energy, and operation, maintenance, and repair. **Table 2.9-2** summarizes this analysis.

Operations and Maintenance (O&M) costs for the dam structure consists of gate operation/exercising, mowing and vegetation maintenance, debris removal, and other miscellaneous items. O&M includes routine activities but does not account for intermittent repairs or other minor repairs to address identified deficiencies.

The estimated yearly O&M cost estimate is $2,400 for Alternatives 2 through 4. Estimated O&M costs for Alternative 5 are $1,000 to account for post-dam removal maintenance (mowing, cleanup, etc.) of any publicly accessible areas created or restored as part of the dam removal program.

The present cost for each alternative was determined based on a 30-year analysis period, considering initial capital costs, assumed design life, and yearly O&M costs. Capital replacement costs were determined based on the assumed remaining design life at the end of the 30-year analysis period. Note that the costs in **Table 2.9-2** do not include environmental restoration components, allowing for a focused analysis on the infrastructure costs. However, **Table 2.9-3** includes both the Pond Restoration Dredging option and the Active Channel Restoration option within the life cycle costs of the relevant alternatives.

Table 2.9-2. Life Cycle Cost Analysis (30 Year Analysis w/o Environmental Components)

	Alt 2: Repair	Alt 3: Stabilization	Alt 4: Redesign	Alt 5: Removal
Initial Capital Investment				
Discount Factor	1	1	1	1
Initial Capital Cost	$875,000	$913,000	$1,146,000	$603,000
Capital Replacement Cost				
Assumed Design Life (yrs)	30	50	>50	N/A
Assumed CIP Cost Percentage	100%	60%	40%	0%
Discount Factor	0.412	0.412	0.412	0.412
Operations & Maintenance				
O&M Costs	$2,400	$2,400	$2,400	$1,000
Discount Factor	19.6	19.6	19.6	19.6
Total Present Cost	**$1,282,540**	**$1,185,734**	**$1,381,901**	**$622,600**

Table 2.9-3. Life Cycle Cost Analysis (30 Year Analysis with Environmental Components)

	Alt 2: Repair with Pond Dredge	Alt 3: Stabilization with Pond Dredge	Alt 4: Redesign with Pond Dredge	Alt 5: Removal & Channel Restoration
Initial Capital Investment				
Discount Factor	1	1	1	1
Initial Capital Cost	$4,025,000	$4,063,000	$4,296,000	$1,314,000
Capital Replacement Cost				
Assumed Design Life (yrs)	30	50	>50	N/A
Assumed CIP Cost Percentage	100%	60%	40%	0%
Discount Factor	0.412	0.412	0.412	0.412
Operations & Maintenance				
O&M Costs	$2,400	$2,400	$2,400	$1,000
Discount Factor	19.6	19.6	19.6	19.6
Total Present Cost	**$5,730,340**	**$5,114,414**	**$5,051,021**	**$1,333,600**

2.10 Potential Grant Funding Opportunities

Private and public grant funds may be available to offset the costs of the project. Available programs are discussed below.

It is unlikely that any of the funding sources below would cover 100% of the cost of any of the alternatives. All of the grant programs discussed here are competitive, and many require matching funds in one form or another. So, the most successful approach would seek awards under multiple grant programs. Further, it is very important to understand that many of these programs are in flux due to the status of state and federal budgets. Grant opportunities have generally become more constrained in the last few years, but opportunities still exist. While the discussion below is comprehensive, there may be other grant opportunities that are not listed here.

2.10.1 Potential Funding for Dam Repair/Stabilization

New Hampshire Land and Community Heritage Investment Program (LCHIP)

The LCHIP was established to conserve and preserve New Hampshire’s most important natural, cultural, and historical resources for the primary purposes of protecting and ensuring the perpetual contribution of these resources to the state's economy, environment, and overall quality of life. LCHIP makes matching grants to municipalities and publicly supported nonprofit corporations for the protection, restoration or rehabilitation of natural, cultural, or historic resources including archaeological sites, historic properties including buildings and structures, and historic and cultural lands and features. Matching funds are required, and the amount of matching funds must be equal to the LCHIP grant award amount. In 2019, LCHIP provided $3.5 million in matching funds to 33 projects. Rehabilitation of an historic dam would be eligible to apply for LCHIP funding, so long as the historic character of the dam is preserved.

National Preservation Loan Fund, National Trust for Historic Preservation

The National Preservation Loan Fund provides funding for establishing or expanding local and statewide preservation revolving funds, acquiring and/or rehabilitating historic buildings, sites, structures and districts, and preserving National Historic Landmarks. Eligible applicants are tax exempt nonprofit organizations; local, state, or regional governments; and for-profit organizations. Preference is given to nonprofit and public sector organizations. Eligible properties are local, state, or nationally designated historic resources; contributing resources in a certified local, state or national historic district; resources eligible for listing on a local, state, or national register; or locally recognized historic resources. Eligible projects involve the acquisition, stabilization, rehabilitation and/or restoration of historic properties in conformance with the Secretary of the Interior's Standards for the Treatment of Historic Properties. The loan amount is based on the type of project and use of funds, with a maximum loan amount of $50,000 and loan terms range from one to seven years. Grants generally start at $2,500 and range up to $5,000. The selection process is very competitive. The review process is generally completed within ten weeks of the application deadline, and applicants are notified via email once the review process is complete.

Society for Industrial Archeology, Industrial Heritage Preservation Grants Program

The Society for Industrial Archeology offers Industrial Heritage Preservation Grants from $1,000 to $3,000 for the study, documentation, recordation, and/or preservation of significant historic industrial sites, structures, and objects. Grants are open to qualified individuals, independent scholars, nonprofit organizations and academic institutions. Grant applicants must sponsor at least half the cost of a project through in-kind or cash expenditures. Grant recipients must agree to prepare a written summary of their project suitable for publication in either the SIA Newsletter and/or for Industrial Archeology, the Society's scholarly journal.

2.10.2 Potential Funding for Dam Removal

There are many sources of potential funding for dam removal; too many to list in detail. Those discussed below are most applicable to this project and most have provided funding for previous projects in NH.

National Oceanic and Atmospheric Administration Habitat Conservation Grants, Northeast Region

Through the Community-based Restoration Program, National Oceanic and Atmospheric Administration (NOAA) awards millions of dollars each year to national and regional partners and local grass roots organizations. Under competitive processes, projects are selected for funding based on technical merit, level of community involvement, cost-effectiveness and ecological benefits. Over the past decade, NOAA's Restoration Center has funded dozens of fish passage projects in the northeast. NOAA funds restoration projects that use a habitat-based approach to foster fish species recovery and increase fish production. Projects are funded primarily through cooperative agreements. Roughly $20 million could potentially be available over the next three years to maintain selected projects, dependent upon the level of funding made available by Congress. There is no statutory matching requirement for this funding, but NOAA considers matching contributions in its evaluation of grant applications.

NH Fish and Game - Fish Habitat Program

The NH Department of Fish and Game's Fish Habitat Program has funded several previous dam removal projects. A review of 2019 annual report from the program indicates that the program expended approximately $91,000 on three projects, one of which was related to dam reconstruction work, with expenditures ranging from $10,000 dollars to over $44,000. There is no match requirement, and these funds qualify as non-federal match for other grant programs.

NHDES Watershed Assistance Grants

The NHDES Watershed Assistance Section offers competitive grants to address nonpoint source pollution including changes in river flows or other impairments caused by dams. Grants may be available to assist with engineering and permitting for dam removal and deconstruction costs. Dam construction, repair or modification projects do not meet the eligibility criteria for this program. This is a federal funding source which requires non-federal matching funds for all projects and must equal at least 40% of the overall project budget, and indirect costs are not allowed to exceed 10%. Approximately $500,000 will be available for Watershed Assistance Grant projects during the 2021 fiscal year. Grant awards through this program typically range from $25,000 to $150,000, but final award levels are based on the annual amount of funding available through the program. Projects must implement existing watershed-based plans that meet the USEPA Watershed Plan Elements (a) through (i) criteria, or implement an USEPA and NHDES approved alternative plan. Although there is no minimum or maximum limit on project budgets and grant requests, NHDES typically selects five to eight projects each year. Prospective grantees should contact Watershed Assistance Section staff before submitting an application to discuss project eligibility, current grant requirements, funding levels, and grant proposal schedules. Funding for the Watershed Assistance Grants program is provided through Clean Water Act Section 319 funds from the US Environmental Protection Agency.

US Fish and Wildlife Service Fisheries and Habitat Restoration Grants

The US Fish and Wildlife Service (USFWS) has several grant programs which could be applied to dam removal. USFWS has a history of working in partnership with private landowners, conservation organizations, and state and federal agencies, to prioritize and provide funding for the removal or renovation of selected barriers in stream systems throughout New England. USFWS administers several grant programs, several of which could be applied to the dam removal. A few of the more promising programs would be:

- National Fish Passage Program
- National Fish Habitat Partnership
- Partners for Fish and Wildlife Program
- Coastal Impact Assistance Program
- National Coastal Wetland Conservation Grant

Each of these USFWS-administered programs has different application and match requirements. USFWS may offer assistance in identifying the most appropriate program(s) for the selected project and may assist in the development of a grant application.

Natural Resource Conservation Service - Environmental Quality Incentives Program

The federal 2018 Farm Bill was enacted on December 20, 2018, and typically includes funding for environmental conservation and restoration projects. While the Environmental Quality Incentives Program (EQIP) is a possible source of funding for dam removal projects, the program has limits on what entities are eligible for grants. The Natural Resource Conservation Service (NRCS) may enter into EQIP contracts with water management entities when they are supporting a water conservation or irrigation efficiency project. The 2018 Farm Bill requires a national 10 percent of mandatory program funding be targeted towards source water protection. States will identify priority source water protection areas (SWPA) and may offer increased incentives and higher payment rates for practices that address water quality and/or water quantity. EQIP is a voluntary program that provides financial and technical assistance to landowners for projects that improve water quality among other priorities. The EQIP program provides for a maximum grant of $350,000 and has no match requirement.

Trout Unlimited, Embrace a Stream Grant Program

Embrace-A-Stream is the recent grant program for funding Trout Unlimited's grassroots conservation efforts. Trout Unlimited (TU) funds local efforts to accomplish on-the-ground restoration of marine, estuarine, and freshwater habitats. Although all types of habitat improvement activities are eligible for funding, there is special emphasis involving fish passage projects, such as culvert removals and dam removals. TU local chapters and councils, as well as organizations working in partnership with TU local chapters and councils, are eligible for funding. Embrace-a-Stream is a matching grant program. Typical Embrace-A-Stream grants range can range up to $70,000 but are usually less than that. In 2019, a total of $100,000 was awarded to 29 chapters and councils, helping restore stream habitat, improving fish passage, and protecting water quality in 19 different states from coast to coast.

NH Charitable Foundation - Community Grants Program

The Community Grants Program is a broad, competitive program that responds to community needs within New Hampshire. While preference is given to operational support of community-based organizations, the Community Grant Program will consider project-specific proposals. However, in order to be eligible, applicants must be tax exempt under Section 501 (c)(3) of the Internal Revenue Code. Also, unrestricted grants are not available to municipal, county, or state government. Organizations that do not submit an audit or financial review, they are eligible for up to $30,000 over three years. If an organization completes an audit or financial review, they are eligible for up to $60,000 over three years. Public (state or municipal) agencies are eligible to apply, but an organization may receive only one grant per year through the Community Grants Program.

State Conservation Committee - Conservation "Moose Plate" Grant

The State Conservation Committee Conservation Grant Program is funded through the purchase of conservation license plates, known as "Moose Plates." The State of New Hampshire dedicates all funds raised through the purchase of Moose Plates to the promotion, protection and investment in New Hampshire's natural, historical and cultural resources. Applications are typically due on September 10th of each year in which funds are available, with awards announced in December. Municipalities are eligible applicants. For 2020, the program awarded almost $306,000 to 18 projects throughout NH, with awards ranging from $6,000 to $24,000.

2.11 Alternatives Brought Forward for Further Analysis

As described above, a total of five preliminary alternatives were developed during the early stage of this study. **Table 2.11-1** provides a summary of the key features of these alternatives.

Based on feedback from the Durham Town Council,[9] combined with considerations of cost, practicality, and compliance with regulatory requirements, the following alternatives were eliminated from further detailed evaluation in Chapter 3:

- *Alternative 1 – No Action* was eliminated from further consideration because it fails to address the significant dam safety deficiencies associated with the current dam condition and fails to comply with the outstanding NHDES Letter of Deficiency. The No Action Alternative would ignore the poor structural condition of the dam, potentially resulting in a sudden failure of the spillway and loss of the impoundment.
- *Alternative 2 – Dam Repair* was eliminated in part because it would require a dam safety waiver from the NHDES Dam Bureau. Further, the cost of this alternative is similar to other viable alternatives, but its design life span would be substantially less than others. For this reason, it was determined to be imprudent.
- *Alternative 4 – Dam Redesign* would extend the dam spillway significantly. It would maintain the impoundment and would fully address NHDES Dam Safety regulations without requiring any waivers. However, it was eliminated from consideration due to its substantial impacts on abutting properties, as well as the fact that it would be the costliest of the preliminary alternatives.

The two remaining alternatives - Alternatives 3 and 5 - were selected for further detailed analysis and discussion in Chapter 3, including consideration of impacts and benefits on the river, hydraulics, natural resources, social resources, cultural resources, water quality and supply, as well as other issues.

[9] The Town Council considered the preliminary alternatives and provided guidance to the consultant team during meetings on June 15 and July 6, 2020.

Table 2.11-1. Summary of Alternatives Considered

Alternative	Description	Life Cycle Cost[1]	Environmental Cost[2]	Address Dam Structural Deficiencies?	Require NHDES Non-Menace Waiver?	Recommended for Further Analysis?	Comments
Alternative 1 - No Action	Maintain status quo	N/A	N/A	No	N/A	No	Does not comply with NHDES dam safety rules. Not recommended or permittable.
Alternative 2 - Dam Repair	Address specific areas of substantial deterioration, reinforce spillway ribs	$1,282,540	$3,150,000	Yes	Yes	No	Limited design life, without substantial advantages over other alternatives.
Alternative 3 - Dam Stabilization	**Fill existing dam cells with concrete reinforcement and anchor to the bedrock**	**$1,185,734**	**$3,150,000**	**Yes**	**Yes**	**Yes**	**Achieves dam stability while maintaining the impoundment but depends on NHDES approval of non-menace waiver.**
Alternative 4 – Dam Redesign	Reconstruct the dam, extending the spillway onto adjacent property	$1,381,901	$3,150,000	Yes	No[3]	No	Would have significant impacts on adjacent properties due to increase spillway length required.
Alternative 5 - Dam Removal	**Remove dam entirely, restore upstream river channel**	**$622,600**	**$604,000**	**N/A**	**No**	**Yes**	**Potential grant opportunities**

Notes:

1. “Life Cycle Cost” includes dam infrastructure only, excluding environment restoration costs.
2. The “Environmental Cost” for Alternatives 2, 3, and 4 includes the initial capital costs of dredging of Mill Pond to restore its depth. For Alternative 5, this cost includes active restoration of a portion of the Oyster River channel upstream of the dam site.
3. Alternative 4 passes the 50-year spillway design flow with adequate freeboard and therefore fully complies with NHDES Dam Safety regulations.

3

Evaluation of Alternatives

3.1 Introduction

A variety of alternatives have been developed to address the goals of this project. This chapter includes information relative to the evaluation of each of the alternatives brought forward from Chapter 2 (i.e., Alternatives 3 and 5), including discussion of existing environmental conditions, method of analysis, and major conclusions:

- Alternative 3 – Dam Stabilization. The dam would be left largely intact but would be filled with concrete and anchored to the underlying bedrock which would ensure that the dam would remain stable. This alternative may be combined with the dredging of Mill Pond.
- Alternative 5 – Dam Removal. Under this scenario, the dam and fish ladder would be removed from the river, with the abutments left in place. This alternative would also include restoration of a portion of the Oyster River channel upstream of the dam to remove accumulated sediments.

The specifics of each of these alternatives is presented in Chapter 2.

The alternatives analysis includes consideration of environmental and cultural resources as well as analysis of the engineering constraints and project operations associated with each alternative. Although this feasibility study provides a full analysis of these constraints, it is important to note that each alternative has been designed only to a conceptual level. Quantitative analysis is presented where possible, while some analyses are of a more qualitative nature.

The main difference among alternatives relates to their potential effects on the size and depth of the dam impoundment. In examining the range of alternatives, it should be noted that they can be classified in one of two ways:

- Alternative 3 – Dam Stabilization would maintain the impoundment, similar to the existing condition.
- Alternative 5 – Dam Removal would substantially reduce the depth of water upstream of the dam site.

Thus, much of the discussion below is presented with this major distinction among the alternatives in mind. These two cases are sometimes referred to as the "dam in" and "dam out" scenarios.

The discussion below begins with a description of the hydrological and hydraulic analysis of the river as well as the fluvial geomorphic setting of the river. Once these analyses are understood, their results can be extrapolated to determine effects on environmental and cultural resources.

3.2 Hydrology, Hydraulics and Sediment Transport

A hydraulic model of the Oyster River and Hamel Brook, both upstream and downstream of the Oyster River dam, was used to evaluate the changes in water depth, width and velocity if the dam were to be removed or modified. The model was prepared using the USACOE's HEC-RAS program, Version 5.0.3, which performs hydraulic calculations in natural and man-made channels and performs flow routing and elementary sediment transport computations. The model can simulate depths and velocities for a single reach, a branched system, or a full network of channels.

The model incorporates two parts:

- <u>Hydrological Input</u>. The hydrological input to the model describes the volume of water that flows through the river system at various times. Flow changes with time and is a function of local climate/weather conditions. Flow is generally expressed as a volume of water that passes within a specific time period measured, such as "cubic feet per second" (cfs), and the range of flow conditions are also described in terms of "recurrence intervals." For instance, "100-year flow," indicates the flow level that would be expected to occur once in 100 years (or have a 1 percent chance of occurring in any given year).
- <u>Hydraulic Model (HEC-RAS)</u>. The hydraulic model performs engineering calculations that consider the properties of water and the shape of the channel. "Cross-sections" represent the shape of the channel in a specific location. The hydraulic model predicts the height and velocity of the water under various flows, as well as other parameters that help explain how the river will respond under the various alternatives.

The model can be used to help answer the following questions:

- How will flood conditions change in the Oyster River and Hamel Brook under different flow events if the dam is removed or modified?

- Could water velocities under dam out conditions scour existing infrastructure such as the NH 108 bridge?
- If the dam is removed, will water levels drop to an extent that recreational or natural resources might be affected?
- Will wells adjacent to the river be affected?
- Will water depths and velocities be sufficient for fish to pass through the project area if the dam is removed?
- Will changes in water velocities cause sediment to migrate downstream?
- Could changes in water levels and velocities affect archeological resources along the river?

These questions will be discussed later in this chapter. First, however, it is important to understand how the model was built and what its results demonstrate.

3.2.1 Hydrologic Study

In order to develop the flow inputs for the hydraulic model, two different approaches were taken:

- A "statistical" approach that relied on actual measurements of stream flows as recorded by the US Geological Survey (USGS) stream gage on the Oyster River immediately upstream of NH 155A; and
- A "watershed model" or "rainfall runoff model" which used information on the physical characteristics of the watershed combined with observed rainfall data to develop stream flows.

Both approaches are capable of producing good estimates of river flows and flood frequencies. Statistical analyses of actual flow measurements from a river gage is generally simpler and typically more accurate than other approaches. For some purposes, such as dam safety analyses, a rainfall-runoff model can produce additional information such as the timing of a flood (i.e., a "hydrograph" which shows how quickly flows would increase and subside). NHDES regulations, in fact, require the use of a rainfall-runoff model for dam permitting. Because the removal or modification of the dam would eventually require a permit from the Department, it was decided to use both methods to develop flow estimates. Using both approaches to develop independent estimates of river flows provides an additional level of confidence in the results.

3.2.1.1 US Geological Survey Gage Data Statistical Analysis

Flood Flows

Design flows were estimated by applying the Log Pearson Type III distribution to a record of peak stream flow (greatest discharge rate in a given water year, October 1 to September 30) for the Oyster River (USGS 01073000), which is shown in **Figure 3.2-1**.[10] While that gage has

[10] The Pearson distribution is a mathematical expression which converts observed flows to recurrence intervals. The Log-Pearson III is the USGS standard distribution for flood frequency analyses.

been recording streamflow data since December 1934, flood flows were evaluated based on data gathered during the water years 1970-2019. Streamflow data pre-1970 were not included in these analyses as New England rivers and streams experienced a marked step change in their flow regimes around that time.[11] It is considered best practice to evaluate design flow statistics with only post-1970 data when possible. This 50-year record of peak stream flow in the Oyster River was fit to the Log Pearson Type III distribution to yield the 1-, 2-, 5-, 10-, 25-, 50-, and 100-year design flows as shown in **Table 3.2-1**.

Table 3.2-1. Oyster River Dam Flood Flows from USGS Gage Data

	Design Flow (cubic feet per second)						
Location	**1-year**	**2-year**	**5-year**	**10-year**	**25-year**	**50-year[1]**	**100-year[1]**
Oyster River Dam	174	485	867	1,259	1,984	3,352	3,877

Notes:
1 See Section 3.2.1.2 for a discussion of the development of the 50- and 100-year flows used in the subsequent hydraulic modeling for this project.

Median/Fish Flows

In addition to the flows generated through the analyses described above, the annual median flow and seasonal "fish flows" were calculated from the USGS stream flow record of daily mean discharge recorded by the Oyster River gage from October 1970 through September 2019. Median annual flow was developed to analyze dam removal or dam modification impacts under "normal conditions." Several "fish flows" were also identified to facilitate the analysis of impacts to fish passage as the spring bioperiod represents a critical time period in the annual migration cycle for American Shad and other species. The fish flows considered are the April-June Q5, Q50, Q75, Q95, and Q98, which are the flows that are expected to be equaled or exceeded 5, 50, 75, 95, and 98% of the time, respectively, during the April-June period. **Table 3.2-2** shows these derived flows.

Table 3.2-2. Oyster River Dam Median Flow and "Fish Flows"

	Design Flow (cubic feet per second)						
Location	**Median Annual**	**April-June Q5**	**April-June Q50**	**April-June Q75**	**April-June Q95**	**April-June Q98**
Oyster River at Dam	17.9	140	30.7	14.6	4.87	3.39
Oyster River Mainstem[1]	14.6	114	25.1	11.9	3.98	2.76
Hamel Brook[2]	1.65	12.9	2.83	1.35	0.45	0.31

Notes:
1 Mainstem of the Oyster River, immediately downstream of the Oyster River Reservoir Dam.
2 Hamel Brook at its crossing under NH 108.

[11] This approach follows the recommendations in NOAA (2011).

3.2.1.2 Rainfall-Runoff Model

Because the modification or removal of Oyster River Dam would require a permit from the NHDES Dam Bureau, it is important that any analysis conducted as part of this project comply with their permitting rules. NHDES Dam Safety rules require design flows for dam safety purposes to be conducted in accordance with New Hampshire Administrative *Rule Env-Wr 403.05 – Hydrologic Investigations*. This rule requires the use of a watershed-based model, also known as a "rainfall-runoff" model, to develop design flows for dam safety analysis. As discussed in Section 3.2.1.2, NHDES Dam Safety rules require a low-hazard dam such as Oyster River Dam to pass the 50-year flow event with one-foot of freeboard without the need for manual operations. Therefore, the rainfall-runoff model was used to predict the 50-year flow for use in this analysis in order to comply with NHDES regulations.

A rainfall runoff model simulates the reaction of a watershed (in this case, the Oyster River watershed) to specific rainfall events and incorporates the following elements:

- The size of the drainage area;
- The shape of the drainage area;
- Antecedent moisture condition, i.e., amount of soil moisture in the watershed;
- Ground slopes;
- Soil types;
- Vegetation;
- Land use;
- Distribution of precipitation throughout the watershed; and
- Ponds, swamps, and other factors affecting the amount and rate of runoff.

The model was constructed using the HydroCAD Stormwater Modeling software, v.10.00, which generally employs the unit hydrograph methodology developed by the Soil Conservation Service (SCS) of the US Department of Agriculture. This methodology was developed to estimate the response of a watershed to specified rainfall depths and distributions based on a few defining watershed characteristics as listed above.

Watershed parameters were estimated from publicly available geospatial datasets and from field observations gathered during this and other recent projects for the Town of Durham. The rainfall-runoff model was subsequently used to estimate a range of design flows for Oyster River Dam, including the 50-year flood. The design rainfall depths, assumed to fall homogenously over the entire Oyster River watershed, were obtained for the approximate center of the Oyster River watershed from NOAA's Atlas 14 and are presented in **Table 3.2-3**.

Table 3.2-3. Design Rainfall Depths by Recurrence Interval, Oyster River Watershed

Recurrence Interval (years)	Rainfall Depth (in)
1	2.63
2	3.30
5	4.39
10	5.29
25	6.53
50	7.44
100	8.44

Source: NOAA Atlas 14

Simulations of the rainfall-runoff model, driven by the design rainfall depths identified in **Table 3.2-3**, were used to determine the shape of the runoff hydrographs and the peak runoff rates for multiple locations throughout the Oyster River-Hamel Brook system. The rainfall-runoff model was also useful in understanding how overflows from the Lamprey River impact large flood events in the Oyster River, an unusual issue but one that has been shown in past studies to significantly impact design flows at Oyster River Dam (Weston & Sampson, 2018).

During large flood events, the Lamprey River, which is impounded by Macallen Dam in Newmarket, backwaters to the point where it jumps its bank and overflows across NH 108 between downtown Durham and Newmarket, near the Durham Boat Company. Here floodwaters cross from the Lamprey River watershed into the headwaters of Hamel Brook and discharge down to the Oyster River and Mill Pond. To better understand how these overflows impact design flows at Oyster River Dam, the project team updated two hydrologic and hydraulic models of the Lamprey River and its watershed, which were developed by others, and reviewed and approved by the NHDES Dam Bureau for study of Macallen Dam. The project team worked in close coordination with the Dam Bureau while updating those models, a process which is summarized in a technical memorandum (Weston & Sampson, 2020). As a result of that work, it is understood that Lamprey River overflows begin to occur during flood events between the 25- and 50-year recurrence interval. As a result, the rainfall-runoff model of the Oyster River system includes a representation of those Lamprey River overflow hydrographs for simulations of the 50- and 100-year events. **Table 3.2-4** summarizes the design flows for Oyster River Dam based on the rainfall-runoff model.

Table 3.2-4 Oyster River Dam Flood Flows from Rainfall-Runoff Model

Location	Design Flow (cubic feet per second)						
	1-year	2-year	5-year	10-year	25-year	50-year	100-year
Oyster River Dam	589	923	1,518	2,029	2,795	3,352	3,877

Based, in part, on the design flows developed through statistical analyses of USGS streamflow data and on the results of a rainfall-runoff model, the project team developed a hydraulic model of the Oyster River and Hamel Brook to evaluate how dam removal or modification could impact water depth, width, velocity, and other hydraulic parameters within and downstream of the Oyster River Dam impoundment.

3.2.2 Development of a HEC-RAS Model

The HEC-RAS hydraulic model for this project includes 68 cross-sections,[12] shown in **Figure 3.2-2**, that extend from the toe of the Oyster River Reservoir Dam approximately 6,500 feet down the mainstem of the Oyster River to its confluence with Hamel Brook, where it continues an additional 2,600 feet to Oyster River Dam. The model also includes an approximately 6,800-foot reach of the tidally-controlled Oyster River from the toe of Oyster River Dam down to a point near the Durham Wastewater Treatment Facility. An approximately 6,200-foot reach of Hamel Brook was also incorporated into the model, beginning near the Durham Boat Company and extending to the brook's confluence with the Oyster River.[13]

The modeled Oyster River-Hamel Brook system includes a single dam, the Oyster River Dam, although there is a Class VI road across Hamel Brook that is effectively acting like a small dam and was modeled as such. The model also includes four bridge crossings of the Oyster River – Mill Road and the railroad embankment upstream of it, as well as NH 108 and a footbridge downstream of Mill Pond, and two bridge crossings of Hamel Brook – Longmarsh Road and NH 108.

The HEC-RAS model geometry was developed from multiple sources. The base geometry of the floodplain and valley walls is derived from LiDAR data (remote sensing technology that can measure the distance to a target by illuminating the target and measuring the backscattered light) covering the greater New Hampshire seacoast area. This data, downloaded from NH GRANIT, the state's geospatial clearinghouse, is part of the Coastal Basin dataset, which was flown during Winter 2010/Spring 2011 and Spring 2014.

The bathymetry of the Oyster River and Hamel Brook channels was incorporated into the HEC-RAS model geometry from five sources:

- A 2008 Hydroterra bathymetric survey, largely focused on Mill Pond and the area of the impoundment immediately upstream of the pond;
- A Fall 2019 survey effort conducted by the project team in support of this project, which supplemented the 2008 data, particularly in the immediate vicinity of Oyster River Dam and along Hamel Brook;

12 For a HEC-RAS model, a "cross-section" refers to a two-dimensional section formed by a plane cutting across the river channel at a right angle. The cross-section represents the shape of the river channel and the adjacent floodplain and upland at a specific location. By incorporating many of these cross-sections throughout the length of the river reach under study, a three-dimensional representation of the shape of the river is built which is used by the model to perform calculations.

13 While NHDES does not regulate the hydraulic modeling efforts in support of dam removal feasibility studies, the numerical model of the Mill Pond Dam and the channel and floodplain of the Oyster River and Hamel Brook were developed in compliance with both Env-Wr 502.07(a)(3) regarding dam breach analyses and Env-Wq 1503.09(f)(1)(a) regarding alteration of the 100-year floodplain.

- Limited spot measurements taken in November-December 2017 at select locations along the Oyster River mainstem by Weston & Sampson in support of the 2018 "Mill Pond Study";
- The current effective FEMA Flood Insurance Study hydraulic model geometry (ID 33017V0000B); and
- Digitized soundings from 1953 and 1954 NOAA smooth sheets 8093 and 8094 in the tidally-influenced portion of the Oyster River, obtained from the University of New Hampshire's Center for Coastal and Ocean Mapping Joint Hydrographic Center.

Geometries representative of the two dams and six bridges included in the HEC-RAS model were developed, where possible, from field data taken in Fall 2019 and November-December 2017. Where no survey data was available, these structures were modeled from the FEMA Flood Insurance Study geometry.

Model cross-sections were also manually modified to include ineffective flow areas, areas of each cross-section in which water may be temporarily or permanently stored but which do not convey water from upstream to downstream. These ineffective flow areas may occur during normal conditions, such as in the slack water behind or in front of a bridge abutment, or during flood conditions, such as in a low-lying field that is somewhat shielded by an upstream berm or natural high ground.

As with all numerical models, the HEC-RAS model developed for this project requires boundary conditions. Boundary conditions set the parameters against which HEC-RAS attempts to simulate the most reasonable water surface. The boundary conditions for this hydraulic model were defined for the most downstream cross-section on the Oyster River and the most upstream cross-sections on both the Oyster River and Hamel Brook. The most downstream cross-section is located well into the tidally-influenced portion of the Oyster River and was assigned an elevation value depending on the analysis being conducted. For instance, for evaluating flood conditions, the tide level was generally set to mean higher high water (MHHW), which is the average of the peak of the higher of the two high tides that occur daily. Similarly, for evaluating scour analyses or low flow conditions, the tide level was generally set to mean lower low water (MLLW). Still other analyses were conducted with the tide level set to mean sea level (MSL). All three tide levels were obtained from the Tide Datum page for NOAA's Fort Point (#8423898) tide gage in Portsmouth Harbor, the closest location with long-term data of high quality that references a known elevation datum. The boundary conditions of the most upstream cross-sections in both the Oyster River and Hamel Brook were defined with constant flow values determined from the statistical analyses and rainfall-runoff modeling efforts described above in Sections 3.2.1.

The HEC-RAS model is further defined by several additional variables, including expansion and contraction coefficients, channel and floodplain roughness coefficients, and coefficients of discharge for bridges and dams, among others. These variables were assigned initial values approximating the midpoint or the range of recommended values provided in the HEC-RAS Technical Manual. These variables were adjusted as needed based on the results of a CHECK-RAS analysis. The CHECK-RAS analysis, required by NH Administrative Rule Env Wq 1502.09, was conducted to ensure the appropriateness of model geometry and other input variables and to verify that the hydraulic assumptions made in the model appear to be justified and in accordance with the applicable FEMA requirements and compatible with assumptions and limitations of the HEC-RAS model platform.

Using the CHECK-RAS-verified model, the project team was able to reliably estimate a variety of hydraulic properties for each alternative and to evaluate their potential impacts.

3.2.3 Predicted Hydraulic Changes in the Oyster River Dam Impoundment

Several hydraulic parameters were calculated by the HEC-RAS model at each cross section and for a range of flow conditions. The hydraulic parameters included water level, channel depth, channel and overbank velocities, channel and overbank shear stresses, wetted top width, cross sectional area and slope of the energy grade line. Calculations for the reach upstream of the dam included total surface area and volume. All of these parameters may be important for understanding the potential effects of dam removal or modification. Velocity, for example, is important for understanding streambank erosion and sediment transport over time and during significant storm events. These analyses can also tell us about how conditions for fish passage would change. And, changes in total surface area and volume may similarly be important for understanding impacts to wetlands and anadromous fish spawning habitat.

3.2.3.1 General Hydraulic Model Findings

Tables 3.2-5 and **3.2-6** summarize the predicted changes in the impoundment volume and surface area, respectively, under Dam Stabilization and Dam Removal Alternatives, while **Table 3.2-7** summarizes the predicted change in average river depth within the impoundment. Additionally, **Figures 3.2-3** and **3.2-4** show the profile view of water elevations in the Oyster River under annual median and 50-year flood flow conditions. **Figures 3.2-5** and **3.2-6** show the aerial extent of flooding for Alternatives 3 and 5 under the median annual and 100-year flow conditions. The major conclusions that can be drawn from this analysis are discussed below.

- Under all flow conditions, there would be no change in the impoundment's surface area under Alternative 3 – Stabilization. This alternative would not make any significant change to the hydraulic characteristics of the dam or its operation. Therefore, the normal pool elevation and associated surface area are expected to remain consistent with the existing structure as represented by the existing condition. As shown in **Table 3.2-6**, however, Alternative 3 is shown to be associated with an increase in the impoundment volume of approximately 18%. This significant increase is a result of the incorporation of the Pond Restoration Dredging (Option 1) discussed in Section 2.6. The relative impact of the dredging decreases during higher flow conditions, with the volume increase being reduced to 10% during the 10-year flood and 6% during the 100-year flood. The impoundment's average depth, presented in **Table 3.2-7**, is also expected to increase as a result of the dredging, generally by 5 to 12% depending on river flows.
- For normal flows, there would be a substantial decrease in the impoundment under Alternative 5 – Dam Removal. The removal of Oyster River Dam would see the existing hydraulic control of the riverine impoundment, the crest of the dam's spillway at Elev. 10.85 feet, replaced by a reconstructed river channel with its thalweg or lowest point at

approximately El. 1.25 near the location of the existing dam. This 9.6-foot drop in the hydraulic control of the Oyster River would be accompanied by a substantial reduction in the impounded volume. As shown in **Tables 3.2-5** and **3.2-6**, during the median annual flow, the impounded volume would be expected to decrease from 77 ac-ft to 10 ac-ft if the dam were removed, a drop of 88%. Dam removal would reduce the impoundment's surface area as well, by approximately 72%, and its average depth, by approximately 59%.

- During flood flows, the dam exerts significantly less hydraulic control on its impoundment, as other factors – like the NH 108 bridge downstream or natural restrictions in the channel and floodplain – begin to exert more control. Therefore, reductions in the impoundment's size, as a result of dam removal, are expected to progressively decrease as river flows increase. For instance, while the impoundment volume decreases significantly as a result of dam removal (Alternative 5) under normal flow conditions or even during floods as large as the 10-year event, for very large storms, such as the 100-year event, dam removal is only expected to reduce the impoundment's surface area by 2% and its volume by 4%.

Table 3.2-5. Impoundment Surface Area by Alternative

					Percent Change Relative to Existing Condition	
Flow Condition	**River Flow (cfs)**	**Existing Condition (ac)**	**Alt 3 Stabilization with Dredging (ac)**	**Alt 5 Dam Removal (ac)**	**Alt 3 Stabilization with Dredging (%)**	**Alt 5 Dam Removal (%)**
Median Annual	34	19.7	20.1	5.4	2%	-72%
2-year	485	25.2	25.2	9.8	0%	-61%
10-year	1,259	27.5	27.5	14.5	0%	-47%
50-year	3,352	30.9	31.0	29.4	0%	-5%
100-year	3,877	32.0	32.0	31.4	0%	-2%

Table 3.2-6. Impoundment Volume by Alternative

					Percent Change Relative to Existing Condition	
Flow Condition	**River Flow (cfs)**	**Existing Condition (ac-ft)**	**Alt 3 Stabilization with Dredging (ac-ft)**	**Alt 5 Dam Removal (ac-ft)**	**Alt 3 Stabilization with Dredging (%)**	**Alt 5 Dam Removal (%)**
Median Annual	34	77	91	10	18%	-88%
2-year	485	106	120	33	13%	-69%
10-year	1259	141	154	61	10%	-57%
50-year	3352	202	216	167	7%	-18%
100-year	3877	222	236	213	6%	-4%

Table 3.2-7. Average Depth by Alternative

Flow Condition	River Flow (cfs)	Existing Condition (ft)	Alt 3 Stabilization with Dredging (ft)	Alt 5 Dam Removal (ft)	Percent Change Relative to Existing Condition: Alt 3 Stabilization with Dredging (%)	Percent Change Relative to Existing Condition: Alt 5 Dam Removal (%)
Median Annual	34	3.3	3.7	1.4	12%	-59%
2-year	485	4.4	4.7	3.1	8%	-30%
10-year	1259	6.0	6.3	5.8	5%	-3%
50-year	3352	3.7	4.0	2.5	10%	-31%
100-year	3877	5.6	5.9	4.9	6%	-14%

3.2.3.2 Predicted Changes at Specific Reaches

Like many run-of-river dams on shallowly sloped coast rivers, the Oyster River Dam impounds the Oyster River-Hamel Brook system and its tributaries for several miles upstream. The removal or modification of Oyster River Dam has the potential to impact water levels, velocities, and other characteristics for the full length of the impoundment. The project team utilized the HEC-RAS hydraulic model of the Oyster River-Hamel Brook system to predict what, where, and when those impacts may occur.

The hydraulic impacts of dam removal or dam modification are predicted to be greatest immediately upstream of the dam and diminish moving away from the dam. However, different reaches of the Oyster River-Hamel Brook system will experience these changes differently. The hydraulic model results indicate that the type and magnitude of changes in the hydraulic characteristics of the Oyster River Dam impoundment divide the Oyster River-Hamel Brook system into five distinct sections, including:

- Oyster River, Tidal (downstream of Oyster River Dam);
- Oyster River, Mill Pond;
- Oyster River, Middle Impoundment (Mill Pond to Hamel Brook confluence);
- Oyster River, Mainstem (Oyster River Reservoir Dam to Hamel Brook confluence); and
- Hamel Brook.

Results of the hydraulic model for each of these reaches is provided in **Tables 3.2-8** through **3.2-12**, and each is discussed in more detail below.

Oyster River: Tidal

The Oyster River is tidally influenced for a length of approximately 2.9 miles from the downstream face of Oyster River Dam down to its discharge into Little Bay. Most of this reach is characterized by a broad, shallowly sloped channel with very fine sediments and extensive salt marshes in its low-lying floodplains. The current in this reach is completely controlled by the tides. On the banks of this reach of the Oyster River are the Durham Wastewater Treatment Facility; Jackson’s Landing with its public boat launch and UNH Boathouse; and the scenic park at Durham Landing. One length of the tidally influenced

Oyster River that is markedly different from the rest is the approximately 110-foot length of river between the dam and the NH 108 bridge crossing just downstream. This short section is characterized by a steep rocky channel with high banks, generally 5-10 feet tall, often lined with dry set or mortared stone, which limit the river's access to its floodplain under some flow conditions.

Alternative 3 – Stabilization, would have no impact on the hydraulics of the Oyster River's tidal reach. In contrast, Alternative 5 – Dam Removal is expected to have modest impacts to the river's hydraulics in the short 110-foot reach upstream of NH 108, but those changes are not expected to propagate any further downstream. These modest changes are the result of proposed changes to the river channel and floodplain in this area that would accompany the removal of the dam. These changes would be necessary to create a stable river channel that approximates natural conditions.

The reach of the Oyster River between Oyster River Dam and the NH 108 bridge crossing is typified by the area immediately upstream of the bridge. As shown in **Table 3.2-8**, the top width of the river and the depth of water in the channel change very little as a result of dam removal during lower flows, such as the median annual flow and the 2-year flood event. The average velocity in the channel during these lower flow events do increase somewhat. For instance, during "normal conditions" typified by the median annual flow, the average velocity is expected to increase from 3.2 to 3.4 feet per second (fps). The increase is more dramatic for the 2-year storm event, with velocities increase from 2.0 to 3.5 fps. The reason for the increase, despite the same top width and depth is that during these smaller flows, the river is contained within the channel, and the shape of the channel was assumed to be rehabilitated to a more stable form during any dam removal effort, a form that has a smaller cross-sectional area.

During larger flood events, like the 50- and 100-year storms, the top width of the river remains the same across all alternatives, but as **Table 3.2-8** indicates, the depth of water in the channel is expected to increase as a result of dam removal. However, it is important to note that this increased depth of flow does not indicate higher flood levels, but rather a lower channel thalweg as part of the rehabilitated channel design. *In summary, the hydraulic change in the tidally influenced reach of the Oyster River are expected to be negligible as a under Alternative 5 and essentially absent as a result of Alternative 3 - Dam Stabilization or downstream of the NH 108 crossing under any alternative or flow condition.*

Oyster River, Mill Pond

In sharp contrast to the short rocky channel downstream of Oyster River Dam, the reach of the Oyster River immediately upstream of the dam, Mill Pond, is predicted to experience substantial changes in both river depths and velocities if the dam were removed. Mill Pond is the widest part of the impoundment, and although it contains the deepest point, as visible in **Figure 3.2-3**, sediment has been deposited in the pond over the many decades since the dam's construction. This influx of sediment has created a mound of sediment immediately upstream of the dam such that the channel bottom rises as it approaches the dam. A significant amount of sediment has also been deposited along both sides of the pond. This reach of the impounded Oyster River, known as Mill Pond, is wide and shallow relative to other reaches of the impoundment upstream.

While *Alternative 3 – Dam Stabilization* would not impact the hydraulic characteristics of the pond, the pond restoration dredge (Option 1) that may be incorporated into that alternative would have an impact. As described above in Section 2.6, more than 11,000 cubic yards of material would be removed from Mill Pond. As highlighted in **Table 3.2-9**, while the top width of the pond would not change as a result, the average depth is expected to change significantly. For instance, under a median annual flow condition, the average depth of the pond would increase from 2.2 to 3.7 feet. The relative change decreases as the flow condition increases; however, even during the 100-year flood, the average depth is still expected to increase from 6.2 to 7.5 feet. As a result of the greater cross-sectional area through the pond, average velocities are expected to decrease, although somewhat less substantially. For instance, during the 50-year storm, the average velocity of the Oyster River moving through Mill Pond is expected to decrease from 1.0 to 0.8 fps.

The hydraulics of the pond are also expected to change significantly under *Alternative 5 – Dam Removal*. Under "normal conditions" typified by the median flow, the average depth of the pond reach is expected to decrease from 2.2 to 0.5 feet, and the top width is expected to shrink from 514 to 32 feet. Naturally, with the removal of the dam which impounds the pond, velocities will increase accordingly, from less than 0.1 to 2.3 fps under median flow conditions. The significance of the predicted changes to all three hydraulic characteristics – depth, width, and velocity – will decrease as river flow increases and other factors, like the NH 108 bridge and natural channel and floodplain restrictions exert relatively more control. For instance, during the 50-year storm, the river depth is expected to decrease from 5.7 to 4.4 feet while the width decreases from 721 to 697 feet and velocities increase from 1.0 to 1.3 fps.

One important observation to make from **Table 3.2-9** is that the decreases in average depth noted for *Alternative 5 – Dam Removal* are not attributed to changes in the channel as in the area between the dam and NH 108, but instead indicate lower flood levels. During the 50-year storm, the dam's regulatory design event, the peak water level is expected to drop 1.3 feet, and during the 100-year flood, it is expected to drop 0.4 feet.

While the discussion above has focused on potential changes in Mill Pond during mean tide conditions, dam removal under Alternative 5 will also impact the inland reach of tidal waters during periods of high tide. Based on data collected at NOAA's Fort Point (#8423898) tide gage in Portsmouth Harbor, the closest location with long-term data of high quality that references a known elevation datum, Mean Higher High Water, the average highest of the two high tides that occur each day, reaches El. 4.39 ft. NAVD88. Under Alternative 1 and 3, the influence of high tide ends at the downstream face of Oyster River Dam. As shown in **Figures 3.2-7** and **3.2-8**, if the dam were removed, high tide would reach approximately 550 feet further upstream into Mill Pond. As will be discussed further in Section 3.3, several feet of soft sediment have accumulated over the decades against the upstream side of the dam. If the dam were removed, that sediment would be mobilized downstream by the free-flowing river. As the river reformed its channel at a lower elevation, with that sediment displaced, the influence of tidal waters at high tide would extend further upstream, as much as 2,250 feet upstream of the dam's current location, well into the Middle Impoundment reach.

Sea level rise in response to climate change may extend tidal influence even further upstream. Data published by Wake, *et al*. (2019) and the NH Coastal Flood Risk Science and Technical Advisory Panel (2019) indicates that there is a 67% probability that relative sea levels in coastal NH will rise between 1.0 foot and 2.9 feet by the year 2100, and a 5% chance that the rise will be as much as 3.8 feet.[14] Under these scenarios, much of the area occupied by Mill Pond would be subject to tidal flow, and tidal influence would extend upstream to include much of the currently impounded area of Hamel Brook.

Oyster River, Middle Impoundment

The "Middle Impoundment," extends from the upstream end of Mill Pond to the confluence of the Oyster River and Hamel Brook, running parallel with Mill Pond Road. This reach of river is very consistent in its width and depth, and it is, on average, the deepest portion of the impoundment.

As Alternative 3 is not expected to modify the hydraulic performance of Oyster River Dam and the proposed restorative dredging is limited to Mill Pond, hydraulically, Alternative 3 will have no impact on the Middle Impoundment reach of the Oyster River.

In contrast, Alternative 5 is expected to have a substantial impact on the river's average depth, its width, and its velocities in this area under all flow conditions. As shown in **Table 3.2-10**, under a median annual flow condition, for instance, the river's average depth is expected to decrease from 4.7 to 1.4 feet, while the maximum depth would decrease from 7.1 feet to 2.1 feet. Its width will decrease accordingly, from 91 to 41 feet across. The significant reduction in both height and width indicates a decrease in cross-sectional flow area, and, therefore, a significant increase in average velocity, from 0.1 to 0.6 fps. Again, the proportional change from existing conditions is expected to decrease as river flows increase. For instance, during the 50-year storm, the river depth is expected to decrease from 8.8 to 7.8 feet, the river's top width is expected to decrease by only 5 feet, from a width of 120 feet to 115 feet, and its average velocity is expected to increase rather modestly from 3.6 to 4.1 feet per second. Peak flood levels during the 50- and 100-year storms are expected to be reduced by 1.1 and 0.2 feet, respectively.

The removal of the dam will certainly change the hydraulics of the Oyster River in this area, but the scale of the changes in the Middle Impoundment are not as significant as they are predicted to be in Mill Pond, in large part because Middle Impoundment retains a more "riverine" and less "ponded" form in its present state. As the following sections will discuss, this pattern continues upstream. The further upstream from Oyster River Dam, the smaller its hydraulic influence reaches, and the more "riverine" the current character of the river channel and floodplain would remain. Therefore, the scale of the hydraulic changes related to dam removal generally decrease, approaching zero at the limits of the dam's current impoundment.

[14] These relative sea level rise projects are based on the RCP 4.5 global greenhouse gas concentration scenario, whereby carbon emissions begin to stabilize and then slowly decline after 2050, with a corresponding global temperatures rise of 2.4ºC (4.3ºF) (likely range 1.7 - 3.2ºC) by 2100, compared to 1850-1900. See Moss, *et al.* (2010) for further description.

Oyster River, Mainstem

The Mainstem of the Oyster River flows from north to south upstream from the confluence of Hamel Brook. The limit of the Oyster River Dam impoundment is located approximately 1,500 feet upstream of the confluence, very close to the municipal pump station located near the intersection of Oyster River Road and Thompson Lane. This portion of the impoundment is noticeably narrower and shallower than Middle Impoundment, and, as **Figure 3.2-3** shows, the channel is steeper.

Hydraulically, Alternative 3 is not expected to have any impact on the Mainstem reach of the Oyster River. In contrast, Alternative 5 is expected to impact on the river's average depth, width, and velocity in this area. Although, as expected, those impacts, highlighted in **Table 3.2-11**, are progressively smaller than those expected for Mill Pond or the Middle Impoundment reaches. And in fact, where dam removal-induced changes to river hydraulics in those downstream reaches were significantly decreased during very large floods, like the 50- and 100-year storm events, the Mainstem impoundment sees a sharp reduction in removal-induced changes for floods as small as the 2-year event.

For instance, under a median annual flow condition, the river's average depth is expected to decrease from 1.4 to 0.3 feet and its velocity is expected to increase accordingly, from 0.5 to 2.9 fps. However, during flow conditions expected during the 2-year storm event, dam removal would reduce the river's average depth from 2.7 to 2.0 feet and its width from 45 to 41.6 feet. The expected change in velocity is similarly modest, increasing from 3.8 to 5.1 fps. Upstream of the limit of the impoundment, near Oyster River Road and Thompson Lane, the HEC-RAS hydraulic model confirms that dam removal would have no discernable impact on the hydraulics of the Oyster River.

Hamel Brook

Hamel Brook is unusually complex. The brook's headwaters drain an area consisting predominantly of farmland and forest bordered roughly by NH 108, Palmer Drive, Willey Road, and Cutts Road. Through its tributaries, Longmarsh Brook and Bedford Brook, it also drains an area of forest and wetland along the east side of NH 108, extending upstream roughly to 181 Newmarket Road. At least two culverts beneath NH 108 connect Hamel Brook and its tributaries to tributaries of the Lamprey River on the west side of the highway.

Upstream of NH 108, Hamel Brook is quite flat and impounded by Longmarsh Road, a former Class VI road that now acts effectively as a dam, and other smaller, natural restrictions. Crossing under NH 108, a clear channel emerges, roughly 10 feet across and 2 feet deep. This channel is noticeably steeper than upstream tributaries and runs approximately 800 feet before reaching the limit of the Oyster River Dam impoundment. The channel bottom continues to drop steadily in elevation for another 800 feet or so into the impoundment before flattening out between El. 5 and 6 feet NAVD88. In total, Hamel Brook is impounded by Oyster River Dam for approximately 2,400 feet above its confluence with the Oyster River.

One other noteworthy aspect of the Hamel Brook reach is the presence of an overflow channel to the left of the main channel, approximately 180 feet downstream of where the brook crosses under NH 108. While dry under normal flow conditions and during small storm events, when water levels in the steep section of Hamel Brook reach approximately 1.5 feet in height, the river jumps its left bank and discharges down a rock-lined secondary channel, roughly 15 feet wide at its base. The downstream end of the secondary or overflow channel discharges into the far southern limit of the Oyster River Dam impoundment. The hydraulic model results presented in **Table 3.2-12** focus on the impounded portion of Hamel Brook.

Hydraulically, Alternative 3 would not any impact on Hamel Brook. In contrast, Alternative 5 is expected to impact the brook’s average depth, width, and velocity. For instance, under ”normal conditions” typified by the median annual flow, the top width of the impounded portion of Hamel Brook is reduced from 135 to 18 feet as a result of the dam removal. The average depth decreases from 3.4 feet to 0.2 feet. The significant reduction in flow area and the elimination of the backwater effect from Oyster River Dam results in an increase in average velocity from negligible under existing conditions to 0.7 fps.

As flow events become larger, the significance of dam removal on the brook’s hydraulic character is reduced. The impacts of dam removal are mixed under 2-year flood conditions, with the average depth decreasing from 4.5 to 1.9 feet, but the top width only decreasing from 143 feet to 112 feet and the average velocity still only 0.2 fps, indicative of a largely backwatered reach. As with the Oyster River Mainstem, however, the impacts of dam removal on the brook’s hydraulics are relatively modest during the 50- and 100-year floods. For instance, during the 50-year event, the brook’s top width decreases from 161 to 157 feet as a result of dam removal, while the average velocity increases from 1.5 to 1.6 fps. The brook’s average depth changes somewhat more, decreasing from 8.0 to 7.2 feet, indicating that dam removal decreases the peak flood level by approximately 0.8 feet.

Table 3.2-8. Hydraulic Model Results - Oyster River: Tidal

	Existing Condition				Alternative 3 Stabilization with Dredging				Alternative 5 Dam Removal			
River Flow	Max. Depth (ft)	Avg. Depth (ft)	Top Width (ft)	Avg. Velocity (ft/s)	Max. Depth (ft)	Avg. Depth (ft)	Top Width (ft)	Avg. Velocity (ft/s)	Max. Depth (ft)	Avg. Depth (ft)	Top Width (ft)	Avg. Velocity (ft/s)
Median Annual	0.3	0.3	34	3.2	0.3	0.3	34	3.2	0.9	0.3	31	3.4
Q2	3.7	2.8	88	2.0	3.7	2.8	88	2.0	3.6	2.8	87	3.5
Q50	12.2	10.2	130	3.0	12.2	10.2	130	3.0	12.2	11.4	130	3.7
Q100	13.7	11.6	139	3.0	13.7	11.6	139	3.0	13.6	12.9	139	3.6

Table 3.2-9. Hydraulic Model Results - Oyster River: Mill Pond

	Existing Condition				Alternative 3 Stabilization with Dredging				Alternative 5 Dam Removal			
River Flow	Max. Depth (ft)	Avg. Depth (ft)	Top Width (ft)	Avg. Velocity (ft/s)	Max. Depth (ft)	Avg. Depth (ft)	Top Width (ft)	Avg. Velocity (ft/s)	Max. Depth (ft)	Avg. Depth (ft)	Top Width (ft)	Avg. Velocity (ft/s)
Median Annual	6.1	2.2	514	0.0	6.1	3.7	519	0.0	0.9	0.5	32	2.3
Q2	7.1	3.0	661	0.3	7.1	4.4	661	0.2	2.8	1.3	97	3.8
Q50	9.8	5.7	721	1.0	9.8	7.1	721	0.8	8.6	4.4	697	1.3
Q100	10.3	6.2	727	1.0	10.3	7.5	727	0.9	10.0	5.8	723	1.1

Table 3.2-10. Hydraulic Model Results - Oyster River: Middle Impoundment

	Existing Condition				Alternative 3 Stabilization with Dredging				Alternative 5 Dam Removal			
River Flow	Max. Depth (ft)	Avg. Depth (ft)	Top Width (ft)	Avg. Velocity (ft/s)	Max. Depth (ft)	Avg. Depth (ft)	Top Width (ft)	Avg. Velocity (ft/s)	Max. Depth (ft)	Avg. Depth (ft)	Top Width (ft)	Avg. Velocity (ft/s)
Median Annual	7.1	4.7	91	0.1	7.1	4.7	91	0.1	2.1	1.4	41	0.6
Q2	8.2	5.8	103	1.0	8.2	5.8	103	1.0	4.7	3.1	59	2.4
Q50	11.1	8.8	120	3.6	11.1	8.7	120	3.6	10.1	7.8	115	4.1
Q100	11.6	9.1	122	4.7	11.5	9.2	122	4.7	11.3	8.9	120	4.8

Table 3.2-11. Hydraulic Model Results - Oyster River: Mainstem

	Existing Condition				Alternative 3 Stabilization with Dredging				Alternative 5 Dam Removal			
River Flow	Max. Depth (ft)	Avg. Depth (ft)	Top Width (ft)	Avg. Velocity (ft/s)	Max. Depth (ft)	Avg. Depth (ft)	Top Width (ft)	Avg. Velocity (ft/s)	Max. Depth (ft)	Avg. Depth (ft)	Top Width (ft)	Avg. Velocity (ft/s)
Median Annual	1.4	1.4	39	0.5	1.4	1.4	39	0.5	0.3	0.3	36.5	2.9
Q2	2.7	2.7	45	3.8	2.7	2.7	45	3.8	2.1	2.0	41.6	5.1
Q50	6.3	6.2	86	8.5	6.3	6.2	86	8.5	5.8	5.7	83.0	9.4
Q100	7.1	7.1	93	9.9	7.1	7.0	93	9.9	7.0	6.9	91.8	10.1

Table 3.2-12. Hydraulic Model Results – Hamel Brook

	Existing Condition				Alternative 3 Stabilization with Dredging				Alternative 5 Dam Removal			
River Flow	Max. Depth (ft)	Avg. Depth (ft)	Top Width (ft)	Avg. Velocity (ft/s)	Max. Depth (ft)	Avg. Depth (ft)	Top Width (ft)	Avg. Velocity (ft/s)	Max. Depth (ft)	Avg. Depth (ft)	Top Width (ft)	Avg. Velocity (ft/s)
Median Annual	5.1	3.4	135	0.0	5.1	3.4	135	0.0	0.5	0.2	18	0.7
Q2	6.3	4.5	143	0.1	6.3	4.5	143	0.1	3.3	1.9	112	0.2
Q50	9.7	8.0	161	1.5	9.7	8.0	161	1.5	8.9	7.2	157	1.6
Q100	10.4	8.7	165	2.0	10.4	8.7	165	2.0	10.2	8.5	164	2.0

3.2.4 Predicted Changes in Sediment Transport

Rivers move sediment along with water. Sediment transport is a naturally occurring, continuous process in all streams. Typically, streams are in dynamic equilibrium between sediment deposition and scour, usually resulting in a stable channel configuration. Local changes in this equilibrium can result from, among other things, high flow events, erosion from adjacent upland sources, or changes to the hydraulic characteristics of a river reach due to new or modified infrastructure (e.g., a bridge or culvert). Changes in land use and increases in impervious cover associated with increased urbanization in a watershed can affect how quickly stormwater runs off within the watershed, which can also affect stream equilibrium.

Just as rivers move sediment in addition to water, dams impound sediment just as they impound water. Thus, it can be assumed that some amount of sediment migration would accompany dam removal or, possibly, pond restoration dredging.

Sediment sampling in the Oyster River and Hamel Brook indicates sedimentation of relatively uniform silt and/or fine sand size particles is occurring within the impoundment. See **Table 3.2-13** and **Figure 3.2-9** for the location of 25 sampling stations where sediment data was collected in 2009, December 2017, December 2019 and July 2020. These sampling stations were established in accordance with the *NHDES Policy on the Evaluation of Sediment Quality for Dam Removals* (NHDES, 2016a).[15] The particle size distributions determined from sediment samples collected at the 25 sampling locations represent the conditions above, within, and below the impoundment. Inspection of topographic maps of the Oyster River, in combination with an understanding of the regional physiography and stream channel patterns, guided the sediment transport and management assessment.

To better understand how Alternatives 3 and 5 might impact sediment accumulation and degradation patterns within and below the impoundment, hydraulic and sediment transport characteristics were evaluated for several flow conditions. The "bankfull discharge" is the flow that determines much of the shape of a river channel when a stream system is at equilibrium. Larger flows above bankfull have similar channel forming functions but are generally stabilized in overbank conditions where vegetative stabilization, thick boundary layer, and high roughness play a large role. For a large variety of rivers throughout North America, bankfull flow has been shown to correspond with a discharge that has a recurrence interval of approximately 1.5 to 1.8 years in the annual flood series (Dunne and Leopold, 1978).

While the concept of the bankfull discharge has limitations in an urbanized watershed that is impounded (i.e., not in equilibrium) it is still useful to look at the predicted sediment transport conditions for the flow approximating the bankfull discharge. The bankfull discharge is often inferred from field measurements, but for the purposes of this study, we use the 2-year flow as an approximation to understand the effects of dam removal and the potential Pond Restoration Dredging (as incorporated into Alternative 3).

15 More information on sediment sampling can be found in Section 3.3, with detailed data in **Appendix D**.

In addition to evaluating sediment transport trends at the 2-year recurrence interval (Q_2), the project team also evaluated trends during the Q_{10} and Q_{100}. Trends in sediment transport were also evaluated for annual median flow to evaluate "normal conditions" as well as over an extended, 50-year period to evaluate potential long-term trends. Sediment transport analyses were performed for the Oyster River-Hamel Brook system using the HEC-RAS model results that were developed for the project.

Table 3.2-13. Sediment Sampling Descriptions

Sample ID	Location Description	Sediment Sample Depth (ft)	General Sediment Description
HMB-1	Hamel Brook, near upstream limit of impoundment	0-0.8	Sand with silt
SED-1	Oyster River Mainstem, 780' upstream of confluence	0-3.0	Gray clayey silt
SED-2	Mill Pond, 780' upstream of dam	0-4.0	Gray clayey silt
SED-3	Mill Pond, 650' upstream of dam	0-4.0	Gray brown clayey silt
SED-4	Mill Pond, 650' upstream of dam	0-4.0	Black gray clayey silt
SED-5	Mill Pond, 480' upstream of dam	0-2.0	Gray silty clay
SED-6	Mill Pond, 480' upstream of dam	0-2.0	Gray brown clayey silt
SED-7	Mill Pond, 20' upstream of dam	0-3.0	Gray clayey silt
SED-8	Mill Pond, 20' upstream of dam	0-2.5	Gray brown clayey silt
SED-9	Mill Pond, 120' upstream of dam	0-1.5	Gray brown clayey silt
SED-10	Mill Pond, 540' upstream of dam	0-3.5	Gray brown clayey silt
SED-11	Mill Pond, 780' upstream of dam	0-2.0	Gray brown clayey silt
SED-13	Hamel Brook, 1,500' upstream of confluence	0-1.3[1]	–
SED-14	Hamel Brook, 680' upstream of confluence	0-1.8	–
SED-15	Mill Pond, 530' upstream of dam	0-2.5	–
SED-16	Mill Pond, 80' upstream of dam	0-3.3[1]	–
SED-17	Oyster River (Tidal), 450' downstream of NH 108	0-0.9	–
SED-18	Oyster River (Tidal), 1,030' downstream of NH 108	0-1.0	–
SP-1	Mill Pond, 60' upstream of dam	0-3.3	Grayish brown silt with sand
SP-2	Mill Pond, 600' upstream of dam	0-2.4	Grayish brown silty sand
SP-3	Mill Pond, 860' upstream of dam	0-3.4	Dark grayish brown sandy silt
SP-4	Middle Impoundment, 620' downstream of confluence	0-2.2	Dark grayish brown silt with sand
SP-5	Oyster River Mainstem, 850' upstream of confluence	0-2.5	Dark grayish brown silty sand
SP-6	Oyster River Mainstem, 1,400' down from Mill Pond Rd.	0-0.3	Grayish brown sand with silt
SP-8	Oyster River Mainstem, 770' upstream of railroad	0-0.4	Grayish brown sand with silt

Note:
1 Sediment depth not measured at sample location; depth value estimated from nearest sediment thickness data.

3.2.4.1 Channel and Particle Stability

Based on the particle size distribution of the samples obtained and model-derived hydraulic parameters, particle stability analyses were performed. Stability analyses results are consistent with field observations that indicate that sedimentation of fines is occurring within the backwater, disrupting sediment transport continuity, resulting in channel aggradation in the impoundment above Oyster River Dam. Particle stability was determined by shear stress assessment in accordance with ASCE Manual 54 and EM 1110-2-1418. Shear stress (τ) is a function of the slope of the energy grade line, approximated as the water surface slope and the hydraulic radius, which is similar to the depth of flow. The Shield's parameter was used to determine the particle size that will experience incipient motion at various key locations along the river (Simons et al, 1982).

The incipient diameter is the diameter at which individual particles subjected to a shear stress begin to move. While sediment transport is a very complex phenomenon, changes in shear stress from one cross-section to another, or from one condition to another (e.g., dam repair vs. dam removed), may predict changes in sediment transport and channel maintenance processes.

For a given shear stress, the corresponding incipient diameter of the substrate can be classified using any of several soil classification systems. For this sediment transport analyses, the Wentworth sediment grade scale was used. The soil gradations for this scale are shown in **Table 3.2-14**.

By comparing the incipient diameters between existing condition and the conditions predicted for *Alternative 3 – Stabilization* and *Alternative 5 – Dam Removal*, inferences can be drawn regarding the potential for erosion and deposition. Large calculated increases in the incipient diameters between scenarios may be predictive of changes in substrate size and channel geometry. For example, if the calculated incipient diameter at a cross-section goes from fine gravel to cobbles after dam removal, there may be significant scouring of bed material, and perhaps streambank erosion, at this section. This may also indicate a morphological change at this section from a shallow pool or run to a riffle.

Table 3.2-14. Wentworth Sediment Grade Scale

Sediment Type	Diameter (mm)	Diameter (inches)
Fines (Silt, Clay)	< 0.062	< 0.0025
Fine Sand	0.062 - 0.250	0.0025 – 0.01
Medium Sand	0.250 – 0.500	0.01 – 0.02
Coarse Sand	0.500 – 2.00	0.02 – 0.079
Fine Gravel	2.00 – 8	0.079 – 0.31
Coarse Gravel	8 – 64	0.31 – 2.50
Cobbles	64 - 256	2.50 – 10.1
Boulders	> 256	> 10.1

3.2.4.2 Incipient Diameter Calculation Results

Three incipient diameter calculations were conducted to evaluate particle stability methods, including Shields (1936), Leopold, Wolman, and Miller (1964), and Colorado. The stable particle size was calculated for the existing condition, *Alternative 3 – Stabilization*, and *Alternative 5 – Dam Removal*. **Table 3.2-15** below illustrates the calculated stable particle sizes for both the bankfull flow (Q_2), and the 10-year recurrence interval flood (Q_{10}) for the three alternatives evaluated at each of ten sampling locations.

Table 3.2-15, through its presentation of results for three different methods of calculation for the stable particle size, presents a range of particle sizes that would be considered stable. In general, the Leopold, Wolman and Miller method (LWM) predicted the low end of the stable particle size and the Colorado Method predicted the larger end of the stable particle size. Although both the 2-year recurrence interval (Q_2) and 10-year recurrence interval (Q_{10}) flow events are presented, the hydraulic modeling efforts support the idea that the Q_2 flows may be the channel forming events. For some of the larger flows, like the Q_{10}, while significant transport can be expected, the increasing depth of water limits the tractive force as the energy dissipates into the floodplain and out of the main channel of the river.

The results suggest that some sediment movement would be expected in the impoundment following dam removal, specifically in areas characterized by the sediment samples taken at location SED-7 immediately upstream of the existing dam; locations SED-5 and SED-2 within Mill Pond; SP-4 within the Middle Impoundment between Mill Pond and the confluence of the Oyster River and Hamel Brook; SP-5 within the impounded portion of the Oyster River Mainstem; and HMB-1 in the impounded portion of Hamel Brook. Unfortunately, shear stresses predicted by the HEC-RAS model in the vicinity of SED-13 in Hamel Brook are so low that it is not possible to estimate the stable particle size under Q2 or Q10 conditions. However, given the stable particle size results for HMB-1, which is in a very similar environment, sediment movement would be expected near SED-13 as well.

As expected, the relative increase in the stable particle size is greatest in Mill Pond and then generally decreases upstream into the farther reaches of the impoundment where the influence of Oyster River Dam is weakest. Locations upstream and downstream of the impoundment show no change. The stable particle size calculated for the SP-6 location near Mill Pond Road on the Oyster River Mainstem is shown not to vary under any alternative, confirmation that it is located upstream of the influence of the Oyster River Dam impoundment. Stable particle sizes were also shown not to vary at the SED-17 location near Durham's Landing in the tidal portion of the Oyster River. However, in that case the size of sediment mobilizing from that area may not be expected to change as a result of dam removal, but additional sediment transport analyses described in Section 3.2.4.4 describe how dam removal may release upstream sediment *into* the that area.

One final observation to make from **Table 3.2-15** is that there is no difference in the stable particle sizes between Alternatives 1 and 3 for any of the three locations within Mill Pond despite the inclusion of restoration dredging into the geometry of Alternative 3 simulations. This finding indicates that if changes in shear stresses in the pond would occur as a result of the dredging, they are small enough so as not to overcome the powerful influence of the backwater created by the dam. That is not to say that sediment will not move into or within

Table 3.2-15. Incipient Motion – Stable Particle Size Analysis

Sample Location	Alternative	Q_2 Ds (mm) Shields	Q_2 Ds (mm) Colorado	Q_2 Ds (mm) LWM	Q_2 Ds Sediment Grade Class Range Minimum	Q_2 Ds Sediment Grade Class Range Maximum	Q_{10} Ds (mm) Shields	Q_{10} Ds (mm) Colorado	Q_{10} Ds (mm) LWM	Q_{10} Ds Sediment Grade Class Range Minimum	Q_{10} Ds Sediment Grade Class Range Maximum
SED-17 Oyster River Tidal	1 - No Action	<0.01	<0.01	<0.01	N/A[1]	N/A[1]	2.79	11.53	2.02	Very Fine Pebbles	Medium Pebbles
	3 - Stabilization	<0.01	<0.01	<0.01	N/A[1]	N/A[1]	2.79	11.53	2.02	Very Fine Pebbles	Medium Pebbles
	5 - Dam Removal	<0.01	<0.01	<0.01	N/A[1]	N/A[1]	2.79	11.53	2.02	Very Fine Pebbles	Medium Pebbles
SED-7 Oyster River Dam	1 - No Action	0.93	5.14	0.64	Coarse Sand	Fine Pebbles	2.79	11.53	2.02	Very Fine Pebbles	Medium Pebbles
	3 - Stabilization	0.93	5.14	0.64	Coarse Sand	Fine Pebbles	2.79	11.53	2.02	Very Fine Pebbles	Medium Pebbles
	5 - Dam Removal	31.56	68.75	25.33	Coarse Pebbles	Cobbles	44.56	88.60	36.29	Very Coarse Pebbles	Cobbles
SED-5 Mill Pond	1 - No Action	<0.01	<0.01	<0.01	N/A[1]	N/A[1]	0.93	5.14	0.64	Coarse Sand	Fine Pebbles
	3 - Stabilization	<0.01	<0.01	<0.01	N/A[1]	N/A[1]	0.93	5.14	0.64	Coarse Sand	Fine Pebbles
	5 - Dam Removal	62.20	113.23	51.37	Very Coarse Pebbles	Cobbles	94.69	154.25	79.59	Cobbles	Cobbles
SED-2 Mill Pond	1 - No Action	<0.01	<0.01	<0.01	N/A[1]	N/A[1]	0.93	5.14	0.64	Coarse Sand	Fine Pebbles
	3 - Stabilization	<0.01	<0.01	<0.01	N/A[1]	N/A[1]	0.93	5.14	0.64	Coarse Sand	Fine Pebbles
	5 - Dam Removal	0.93	5.14	0.64	Coarse Sand	Fine Pebbles	2.79	11.53	2.02	Very Fine Pebbles	Medium Pebbles
SP-4 Middle Impoundment	1 - No Action	0.93	5.14	0.64	Coarse Sand	Fine Pebbles	4.64	16.79	3.44	Very Fine Pebbles	Coarse Pebbles
	3 - Stabilization	0.93	5.14	0.64	Coarse Sand	Fine Pebbles	5.57	19.20	4.16	Fine Pebbles	Coarse Pebbles
	5 - Dam Removal	5.57	19.20	4.16	Fine Pebbles	Coarse Pebbles	13.00	35.80	10.05	Medium Pebbles	Very Coarse Pebbles
SP-5 Oyster River Mainstem	1 - No Action	5.57	19.20	4.16	Fine Pebbles	Coarse Pebbles	19.50	48.24	15.33	Medium Pebbles	Very Coarse Pebbles
	3 - Stabilization	5.57	19.20	4.16	Fine Pebbles	Coarse Pebbles	19.50	48.24	15.33	Medium Pebbles	Very Coarse Pebbles
	5 - Dam Removal	35.28	74.62	28.45	Coarse Pebbles	Cobbles	53.85	101.84	44.20	Very Coarse Pebbles	Cobbles

Table 3.2-15. Incipient Motion – Stable Particle Size Analysis (Continued)

Sample Location	Alternative	Q2					Q10				
		Ds (mm)			Ds Sediment Grade Class Range		Ds (mm)			Ds Sediment Grade Class Range	
		Shields	Colorado	LWM	Minimum	Maximum	Shields	Colorado	LWM	Minimum	Maximum
SP-6 Oyster River Mainstem	1 - No Action	5.57	19.20	4.16	Fine Pebbles	Coarse Pebbles	13.93	37.66	10.80	Medium Pebbles	Very Coarse Pebbles
	3 - Stabilization	5.57	19.20	4.16	Fine Pebbles	Coarse Pebbles	13.93	37.66	10.80	Medium Pebbles	Very Coarse Pebbles
	5 - Dam Removal	5.57	19.20	4.16	Fine Pebbles	Coarse Pebbles	13.93	37.66	10.80	Medium Pebbles	Very Coarse Pebbles
SED-13 Hamel Impoundment	1 - No Action	<0.01	<0.01	<0.01	N/A[1]	N/A[1]	<0.01	<0.01	<0.01	N/A[1]	N/A[1]
	3 - Stabilization	<0.01	<0.01	<0.01	N/A[1]	N/A[1]	<0.01	<0.01	<0.01	N/A[1]	N/A[1]
	5 - Dam Removal	<0.01	<0.01	<0.01	N/A[1]	N/A[1]	<0.01	<0.01	<0.01	N/A[1]	N/A[1]
HMB-1 Hamel Overflow	1 - No Action	<0.01	<0.01	<0.01	N/A[1]	N/A[1]	<0.01	<0.01	<0.01	N/A[1]	N/A[1]
	3 - Stabilization	<0.01	<0.01	<0.01	N/A[1]	N/A[1]	<0.01	<0.01	<0.01	N/A[1]	N/A[1]
	5 - Dam Removal	0.93	5.14	0.64	Coarse Sand	Fine Pebbles	60.34	110.74	49.77	Very Coarse Pebbles	Cobbles

Note:

1 HEC-RAS model simulation results indicate a Shear Stress of <0.01 lbs/ft^2, which is presented as 0.00 in the model output. Stable particle sizes could therefore not be calculated using empirical formulas but if calculated would be very small.

Mill Pond under Alternative 3, just that sediment movement rates are not expected to vary significantly from the existing condition. The volume of sediment movement is explored further in the following sub-section.

3.2.4.3 Estimated Volume of Sediment Subject to Downstream Migration

The project team evaluated the potential movement of sediment within the Oyster River-Hamel Brook system under existing conditions, *Alternative 3 – Stabilization*, and *Alternative 5 – Dam Removal* under a variety of flow conditions through a series of sediment transport simulations conducted with the HEC-RAS model. Sediment transport simulations were conducted for a variety of flow conditions ranging from a normal flow to very high flows and from short duration events to very long duration time series to establish a full understanding of the ramifications of dam removal or restoration dredging of Mill Pond.

The HEC-RAS model uses "Quasi-Unsteady State" flow routing for sediment transport simulations. Quasi-unsteady state simulations consist of several steady-state simulations run in sequence, in which one simulation's output becomes the next simulation's input. This type of simulation is required for sediment transport analysis, as bed erosion or deposition may change the channel shape, in turn affecting erosion or deposition rates elsewhere in the modeled river system. Analyzing these changes throughout the river system and over time requires an iterative, quasi-unsteady state approach.

To conduct these simulations, the project team augmented the HEC-RAS model to include additional sediment depth and bed gradation input data required for sediment transport simulation. While the initial geometry files that contain the cross-section, bridge, and dam geometry that represent each of the alternatives were unmodified, the project team prepared a separate "sediment data" file to represent sediment depth and bed gradation information. It is this sediment data file that the simulations modify during their iterative calculation process.

The project team prepared the HEC-RAS sediment data file based on information obtained during the various sediment sampling efforts that have been conducted in and near the Oyster River Dam impoundment since 2009. In addition to collecting sediment samples for particle size distribution analysis, the project team also documented the depth of sediment at each of the 25 sample sites as noted in **Table 3.2-13**.

Field measurements and visual observations made during the various site visits to the Oyster River Dam impoundment and other locations further upstream and downstream suggest that sediment depth varies considerably both laterally across the impoundment as well as longitudinally along the length of both the Oyster River and Hamel Brook. However, given the significant number of samples taken, as well as additional soft sediment depth probes taken in 2009 and 2017 that are not shown in **Figure 3.2-9**, the project team has been able to develop a reasonable representation of the movable sediment that has been deposited in the Oyster River Dam impoundment over the dam's history.

The project team incorporated these observations and inferences into the HEC-RAS sediment data file. Cross-sections near known sediment depth data points were assigned those field-measured sediment depths. For cross-sections further away from field measurement locations, the modeled sediment depths were interpolated from the nearest upstream and downstream point data.

The HEC-RAS sediment data file also requires information regarding bed gradations. The 25 known bed gradations derived from the 2009, 2017, and 2019-2020 sampling efforts were applied to the model cross-section nearest to each sampling location. For intermediate cross-sections located between sampling locations, bed gradations were assigned by linearly interpolating along the channel centerline using an interpolation tool built into HEC-RAS. Cross-sections on the Oyster River upstream of SP-8 or downstream of SED-18 were assigned sediment depth and bed gradation data representative of SP-8 and SED-18, respectively.

The area that is least understood, from an existing sediment perspective, is Hamel Brook upstream of NH 108. However, given that this area is well above the limit of the Oyster River Dam impoundment, there should be no difference in sediment transport behavior in that area between alternatives. For the sake of fully developing the HEC-RAS model's "sediment data" file, this area was represented based on visual observations made during various site visits and from sediment profile data taken from data taken at SP-6 and -8, which are located above the impoundment on the Oyster River Mainstem.

In addition to augmenting the HEC-RAS model geometry by developing a sediment data file to supplement the existing geometry files, the project team prepared a total of five additional flow files with which to "drive" the sediment transport simulations. Just as the quasi-unsteady state sediment transport simulations require additional bed geometry information, they also require more refined flow data. During a quasi-unsteady state simulation, streamflow in the modeled cross-sections is constant within each individual steady-state simulation but can vary between those steady-state simulations.

The five flow events incorporated into the HEC-RAS model included three flood events (i.e. 2-, 10-, and 100-year events), a year-long simulation of the median annual flow, and an extended, 50-year simulation. The storm events were assumed to take place over 24 hours and sediment transport volumes were evaluated over a period of 72 hours to allow the majority of the storm-generated runoff time to discharge through the watershed. The flow files used to define the three flood events were developed so that the simulated stream flow entering the impoundment and discharging to the tidally influenced Oyster River varied over the 72-hour simulation period. The inflow hydrographs used to define those three flood events were taken from the HydroCAD rainfall-runoff model of the Oyster River watershed, described in Section 3.2.1.2. Note that the 100-year storm event simulation included overflows from the Lamprey River into Hamel Brook.

In contrast to simulations of the three flood events, in which each hour of the 72-hour quasi-unsteady state simulations was assigned a different inflow value, the year-long simulation of median annual flow conditions was defined with the same flow at each computational timestep. Little sediment movement was expected under these constant, low- to normal-flow conditions, but the simulation was useful in establishing an understanding of baseline conditions.

The fifth and final analysis was an extended period simulation intended to mimic the streamflow and sediment movement that may have historically occurred in the Oyster River between October 1, 1969 and September 30, 2019. The 50-year period was broken down into month-long computational time steps. The streamflow values used to drive each time step were the calculated monthly average values from the USGS streamflow gage. While using average monthly flows may blunt some of the very large flood flows that occurred during that period, computer processing times would not reasonably allow for significantly smaller time steps. Regardless, the 50-year simulation does a good job of representing some of the long-term trends in sediment movement.

Sediment transport rates are difficult to estimate accurately and consistently in naturally occurring setting. Numerous methodologies are routinely used to estimate transport rates, none of which is appropriate for all geomorphologic and hydrologic settings. Therefore, the project team prepared sediment transport simulations using three different methodologies generally suited to the conditions of the Oyster River Dam impoundment. Given that the Dam impoundment is composed primarily of unconsolidated silt- and sand-sized or larger particles, bedload transport equations are generally applicable to the prediction of sediment transport loads.

The project team selected three such bedload transport equations that are available through the HEC-RAS modeling platform: Meyer-Peter Mueller (1948), Toffaleti (1968), and Wilcock (2001). As noted in the HEC-RAS "Hydraulic Reference Manual," the Meyer-Peter Mueller (MPM) method was one of the earliest developed but remains one of the most widely used methods. The MPM method is based on the simple comparison of available shear stress on the bed and the shear stress required to move various particle sizes. While this method was developed primarily for relatively uniform gravel substrates, it is routinely used for finer substrates with the caveat that it may tend to under predict the transported load. In contrast, Toffaleti was developed from studies of sand-sized particles. This method breaks the water column into vertical zones and calculates the concentration of sediment in each zone. It is considered especially applicable to large rivers in which the importance of shear velocity decreases. The Wilcock method was developed relatively recently for graded beds of sand and gravel, based on the assumption that sediment transport is primarily dependent on the material in direct contact with flow. This method includes a "hiding function" accounting for how larger particles will shield smaller particles, reducing their transport rates.

Using the sediment data file, additional flow files, and sediment transport methods described above, the project team evaluated the potential total net volume of sediment transported to and from each of the five reaches identified in Section 3.2.3.2 as well as the total volume of sediment that may be discharged downstream of the NH 108 crossing and into the tidally influenced Oyster River. These analyses were conducted for Alternatives 3 and 5 for each of the five flow conditions described above (i.e. annual median, three flood events, and an extended period) through a series of HEC-RAS simulations. In total the project team conducted 45 sediment transport simulations, one for every combination of the three alternatives, five flow conditions, and three transport methodologies. The results of those simulations are presented in **Tables 3.2-16** through **3.2-20** below.

In reviewing the preliminary model output, it became apparent that the Toffaleti method was not providing sufficiently reliable estimates of sediment transport and that the MPM and Wilcock methods were producing very similar results. Therefore, the summary tables and subsequent interpretation of the results focus on the Meyer-Peter-Mueller simulations.

Table 3.2-16. Total Sediment Volume Transported by Reach for the Median Annual Flow Simulation

Design Event	Alternative		Total Volume Discharged Downstream of NH 108	Oyster River: Dam to NH 108	Oyster River: Mill Pond	Oyster River: Middle Impoundment	Oyster River: Mainstem	Hamel Brook
			Total Sediment Volume (cubic feet) Transported from Reach (+ = lost, - = gained)					
Median Annual	***No Action***	Total	-965	965	0	0	0	0
	Stabilization with Dredging	Total	-965	965	0	0	0	0
		Change	**0**	**0**	**0**	**0**	**0**	**0**
	Dam Removal	Total	-4,956	-1,391	5,166	-6,610	6,253	1,538
		Change	**-3,991**	**-2,356**	**5,166**	**-6,610**	**6,253**	**1,538**

Table 3.2-17. Total Sediment Volume Transported by Reach for the 2-year Flood Event

Design Event	Alternative		Total Volume Discharged Downstream of NH 108	Oyster River: Dam to NH 108	Oyster River: Mill Pond	Oyster River: Middle Impoundment	Oyster River: Mainstem	Hamel Brook
			Total Sediment Volume (cubic feet) Transported from Reach (+ = lost, - = gained)					
2-year Flood	***No Action***	Total	-2,031	2,018	-1	-2,797	2,811	0
	Stabilization with Dredging	Total	-2,031	2,018	-1	-2,813	2,828	0
		Change	**0**	**0**	**0**	**-16**	**17**	**0**
	Dam Removal	Total	-21,887	199	21,320	-13,316	13,683	0
		Change	**-19,856**	**-1,819**	**21,319**	**-10,519**	**10,872**	**0**

Table 3.2-18. Total Sediment Volume Transported by Reach for the 10-year Flood Event

Design Event	Alternative		Total Volume Discharged Downstream of NH 108	Oyster River				Hamel Brook
				Dam to NH 108	Mill Pond	Middle Impoundment	Mainstem	
			Total Sediment Volume (cubic feet) Transported from Reach (+ = lost, - = gained)					
10-year Flood	***No Action***	Total	-2,193	2,036	-352	-12,759	13,616	0
	Stabilization with Dredging	Total	-2,178	2,036	-372	-12,825	13,687	0
		Change	**15**	**0**	**-20**	**-66**	**71**	**0**
	Dam Removal	Total	23,880	-58	21,366	-27,878	30,795	2
		Change	**-26,073**	**-2,094**	**21,718**	**-15,119**	**17,179**	**2**

Table 3.2-19. Total Sediment Volume Transported by Reach for the 100-year Flood Event

Design Event	Alternative		Total Volume Discharged Downstream of NH 108	Oyster River				Hamel Brook
				Dam to NH 108	Mill Pond	Middle Impoundment	Mainstem	
			Total Sediment Volume (cubic feet) Transported from Reach (+ = lost, - = gained)					
100-year Flood	***No Action***	Total	26,182	1,884	860	-6,587	10,366	130
	Stabilization with Dredging	Total	26,254	1,877	786	-6,605	10,392	131
		Change	**72**	**-7**	**-74**	**-18**	**26**	**1**
	Dam Removal	Total	8,206	-1,235	21,066	-8,892	13,427	265
		Change	**-17,976**	**-3,119**	**20,206**	**-2,305**	**3,061**	**135**

Table 3.2-20. Total Sediment Volume Transported by Reach for the Extended Period Simulation

Design Event	Alternative		Total Volume Discharged Downstream of NH 108	Oyster River				Hamel Brook
				Dam to NH 108	Mill Pond	Middle Impoundment	Mainstem	
			Total Sediment Volume (cubic feet) Transported from Reach (+ = lost, - = gained)					
Water Year 1970 (1 year)	***No Action***	Total	-1,864	1,864	0	-55,208	55,208	0
	Stabilization with Dredging	Total	-1,864	1,864	0	-55,270	55,270	0
		Change	**0**	**0**	**0**	**-62**	**62**	**0**
	Dam Removal	Total	-77,606	1,494	18,614	-37,135	97,621	0
		Change	**-75,742**	**-370**	**18,614**	**18,073**	**42,413**	**0**
Water Years 1970-1971 (2 years)	***No Action***	Total	-1,878	1,878	0	-58,274	58,273	0
	Stabilization with Dredging	Total	-1,878	1,878	0	-58,317	58,317	0
		Change	**0**	**0**	**0**	**-43**	**44**	**0**
	Dam Removal	Total	-100,322	501	3,200	-21,506	117,278	849
		Change	**-98,444**	**-1377**	**3,200**	**36,768**	**59,005**	**849**
Water Years 1970-1974 (5 years)	***No Action***	Total	-1,879	1,879	0	-64,416	64,415	0
	Stabilization with Dredging	Total	-1,879	1,879	0	-64,452	64,452	0
		Change	**0**	**0**	**0**	**-36**	**37**	**0**
	Dam Removal	Total	-157,242	765	-15,060	34,192	131,669	5,675
		Change	**-155,363**	**-1,114**	**-15,060**	**98,608**	**67,254**	**5,675**
Water Years 1970-2019 (50 years)	***No Action***	Total	-1,938	1,938	-501	-82,263	82,812	0
	Stabilization with Dredging	Total	-1,986	1,938	-505	-82,221	82,775	0
		Change	**-48**	**0**	**-4**	**42**	**-37**	**0**
	Dam Removal	Total	-264,182	-370	63,481	60,949	132,454	7,669
		Change	**-262,244**	**-2,308**	**63,982**	**143,212**	**49,642**	**7,669**

Existing Conditions (Alternative 1 – No Action)

Under existing conditions, model simulation results indicate relatively little sediment movement within Mill Pond or Middle Impoundment, but there is a flow of sediment from the Oyster River Mainstem into the Middle Impoundment during all flow conditions except the annual median flow simulation. For instance, in the first year of the extended period simulation, approximately 55,000 ft^3 of sediment was lost from Oyster River Mainstem only to be deposited in the Middle Impoundment. That such significant sediment movement occurs so early on in the extended period simulation, within the first few months in fact, indicates an instability or a vulnerability of the model to overestimate sediment transport in the lowest 2,000 feet or so of the Oyster River Mainstem reach. A similar but significantly smaller instability appears to be occurring in the vicinity of the NH 108 crossing of the Oyster River. For instance, during the year-long median flow simulation, 965 ft^3 of sediment is mobilized and migrates from immediately upstream to immediately downstream of the highway bridge. These instabilities or vulnerabilities do not invalidate the sediment model output, but they do highlight the need to compare simulation output for Alternatives 3 and 5 against the baseline existing condition results.

In contrast to the likely overestimated movement of sediment from the Oyster River Mainstem into the Middle Impoundment, relatively little sediment is shown to be entering the impoundment from Hamel Brook, except during very large events like the 100-year flood. This finding is relatively consistent with the large diameter material observed in the steep, rocky reach of Hamel Brook between the impoundment and NH 108.

Alternative 3 – Stabilization with Dredging

Based on the long history of sediment accumulation in Mill Pond, simulations of Alternative 3, which incorporate dredging of the pond, were expected to show some movement of sediment from Middle Impoundment into Mill Pond, particularly in the extended period simulation. Such sediment movement would indicate that the material removed by the dredge would slowly be replaced. However, as shown in the summary tables above, Mill Pond supposedly receives only very modest inflows of sediment. Even during the 2-year flood event, model output indicates Mill Pond experiences no net gain or loss of sediment.

These results are likely occurring for many reasons. Among those reasons are limitations of the sediment transport functions that are supported by HEC-RAS, like MPM, with regard to very small particle sizes. Also, the bed gradations incorporated into the model are based on laboratory sieve analyses, which did not evaluate in detail the size distribution of particles less than 0.075 mm. The model does not include local sources of sediment to Mill Pond such as road sand from nearby roadways and parking lots that discharge to College Brook. But perhaps the most significant source of sediment accumulation in Mill Pond is the growth and decay of organics within the pond. Visual observations made during numerous site visits confirm that parts of the pond appear to be steadily accumulating a layer of organic material.

Therefore, despite the model simulation results summarized in the tables above, it is the project team's opinion, based on a review of sequential historical aerial imagery, field observations made during, and professional experience in similar settings throughout the region, that if dredging were to take place in Mill Pond, as incorporated into Alternative 3, sediment would refill those dredged volumes over a period of 5-20 years.

Alternative 5 – Dam Removal

As illustrated by the model results summarized in **Tables 3.2-16** through **3.2-20**, if Oyster River Dam were removed, sediment would immediately begin to mobilize from the pond and other upstream areas of the impoundment. The extended period simulation results are particularly instructive in understanding sediment movement trends throughout the Oyster River-Hamel Brook system over time with the dam removed.

As shown in **Table 3.2-20**, in the first year, the Mainstem of the Oyster River loses a considerable amount of sediment, approximately 42,400 ft^3 or 77% more than under existing conditions. In contrast, Hamel Brook loses none. While some of the sediment coming into the impoundment from the Oyster River mainstem is surely deposited in the Middle Impoundment, the Middle Impoundment loses sediment of its own and experiences a net loss of over 18,000 ft^3 or 33% more than under existing conditions. Mill Pond also experiences a net loss of sediment during the first year, losing approximately 18,700 ft^3, much of which comes from the wedge of soft sediment that has accumulated immediately upstream of the dam as shown in **Figure 2.8-2**. In total, removal of the dam may cause more than 76,000 ft^3 of sediment to mobilize downstream.

In the second year of the extended period simulation, the Oyster River Mainstem and Middle Impoundment continue to lose significant volumes of sediment, and Hamel Brook has even started contributing sediment flow to downstream reaches. Mill Pond, on the other hand, has started gaining sediment again. The first year's net loss of more than 18,000 ft^3 of sediment from Mill Pond was surely influenced by the mobilization of the soft sediment wedge behind the dam. In the second year, with the wedge largely gone, Mill Pond actually experiences a significant net gain in sediment as it receives some of the sediment mobilized from upstream reaches. Much of this sediment would transit through the former pond reach, with an additional 22,700 ft^3 of sediment being deposited downstream of NH 108 for a total net deposition of more than 98,000 ft^3.

By the fifth year of the extended period simulation, the removal of Oyster River Dam continues to have an impact on sediment movement within the Oyster River-Hamel Brook system as that system works towards a stable, natural, riverine configuration. By the five-year mark, Hamel Brook has finally contributed sediment, with a net loss of nearly 5,700 ft^3 of sediment, all of it originating from the formerly impounded lower reaches of the brook. The lag experienced by Hamel Brook is likely due to the fact that, presently, the bottom of the impoundment is relatively flat, well up into the lower reaches of Hamel Brook. When the dam is removed, the backwater affect is immediately eliminated, but water levels and velocities are still somewhat controlled by the flat grade of the channel bottom in the Middle Impoundment. It takes a few years for the channel to restore a slope sufficient for the lower reaches of Hamel Brook to begin to experience the more natural, riverine flow conditions required to mobilize sediment of its own. That is why the 5-year results for Hamel Brook show sediment movement, but the 100-year simulation shows none; the 72-hour simulation period is not enough time for Hamel Brook to return to natural, riverine flow conditions, even with the dam out.

In sharp contrast to Hamel Brook, after five years, the Oyster River Mainstem has largely reached an equilibrium, having discharged approximately 67,200 ft^3 of sediment downstream. And, in fact, as **Table 3.2-20** shows, that reach will discharge very little additional sediment in the following 45 years. The Middle Impoundment, on the other hand continues to experience a net loss of sediment after five years (and beyond).

Model results indicate that at the 5-year mark, the former Mill Pond reach continues to be a sediment sink with a net gain of more than 15,000 ft^3 of sediment over those five years. The sediment is not deposited uniformly throughout the reach, however. Instead, the net accumulation of sediment is expected to fill an existing scour hole at the upstream end of the pond. While the scour hole appears likely to take some time to refill with sediment, the 50-year results presented in **Table 3.2-20** suggest that ultimately the former Mill Pond area would lose nearly 64,000 ft^3 of sediment over 50 years.

In total, dam removal is expected to cause increase the sediment load to the tidal reach beyond NH 108 by more than 155,000 ft^3 in five years and by more than 262,000 ft^3 in 50 years. The sediment transport simulations suggest that sediment may be deposited in a relatively short reach, roughly located between the Three Chimneys Inn and Durham Landing. If deposited uniformly across the river in this area, the deposition of sediment from upstream could reach a depth of between 0.5 and 1.5 feet after 50 years. In practice, tidal action, which cannot realistically be modeled with a 1-month computational time step, will disseminate the accumulated sediment over a wider range, reducing the height of deposition.

3.3 Sediment Quality

As discussed in Section 3.2, rivers transport not only water, but also sediment. Due to the history of industrial uses and urbanization adjacent to New England rivers, contaminated sediments are sometimes found in these surface water bodies. Because the removal of the Oyster River Dam (Alternative 5) has the potential to mobilize sediment from within the impoundment and redeposit it in downstream areas including the tidal reach beyond NH 108, it is important to understand whether the mobilization/redeposition of this material could pose a risk to the downstream aquatic and benthic environment. Key risk factors include the relative amount of sediment likely to be transported by dam removal (discussed in Section 3.2), and the level of chemical contamination associated with the sediments. In addition, for alternatives involving pond restoration and/or sediment dredging, consideration must be given to potential human health risks associated with contaminated sediment/material handling and disposal.

Therefore, a screening-level assessment of sediment quality in the vicinity of the Oyster River Dam was completed as part of this feasibility study. The assessment, which is summarized in the remainder of this section, was conducted in general accordance with the protocols and procedures outlined in applicable NHDES guidance (NHDES, 2005; NHDES, 2016b). Additional information is available in the June 2020 Sediment Sampling and Analysis Plan

(SAP), which was prepared by VHB to inform and guide the supplemental data collection effort implemented in support of this study.[16]

3.3.1 Due Diligence Review

Consistent with NHDES guidance, VHB reviewed existing sediment data and publicly available environmental information for the study area. Key findings from this review, which are summarized in the following sections, were considered in the development of the supplemental sediment data collection effort. Additional details of the due diligence review are provided in Section 2.2 of the SAP (**Appendix D.1**).

3.3.1.1 NHDES Environmental Database Search

VHB conducted a review of NHDES' searchable online environmental database ("OneStop") to identify contaminant sources with the potential to significantly impact sediment quality within the dam impoundment. The database was queried to identify State regulated sites located inside the dam watershed within one mile of the dam (i.e., area of interest).

The query results indicated that multiple NHDES regulated sites, including registered storage tank sites, hazardous waste generators, and remediation sites are located within the area of interest. However, the presence of storage tank and hazardous waste generated facilities, in and of themselves, is not indicative of a release of contaminants to the environment. In addition, the status for most remediation sites identified in the search area was identified as "closed", indicating that any associated contaminant release had been mitigated to the satisfaction of NHDES. Further review of available database records for the active remediations sites indicated that these sites were unlikely to have significantly impacted sediment quality within the impoundment given the location and/or nature of the releases.

3.3.1.2 Bathymetric Survey and Sediment Sampling Study

VHB previously conducted a bathymetric survey and sediment sampling study of Mill Pond (VHB, 2009). As part of the 2009 study, 12 sediment samples (identified as SED1 through SED12) were collected from depths up to 3 to 5 feet below the river bottom and submitted for laboratory analysis of various chemical contaminants including polychlorinated biphenyls (PCBs), pesticides, metals, polycyclic aromatic hydrocarbons (PAHs), and volatile organic compounds (VOCs). As shown on **Figure 3.2-9**, 10 samples were collected within Mill Pond, one sample was collected upstream of the pond (SED1), and one sample (composite) was collected downstream of the dam (SED 12).

The analytical results from the study indicated concentrations of PCBs, pesticides, and VOCs were below the laboratory reporting levels in all samples. However, multiple PAH compounds, were detected in eight of the 12 sediment samples. The concentrations of some PAHs exceeded ecological screening criteria selected for the study.[17] The PAH concentrations

[16] A draft of the SAP was provided to NHDES for review and comment prior to field implementation. A copy of the SAP is provided in **Appendix D.1**.

[17] The 2009 study compared the observed parameter levels to the 1999 NOAA Ecological Risk Screening Threshold Effect Concentrations (TECs) established for various parameters, which represent the lowest concentrations where aquatic organisms might be at risk of adverse effects from long-term exposure to contaminant levels in freshwater sediments.

were generally similar throughout the impoundment, although slightly higher concentrations tended to be associated with samples collected in the off-channel, depositional areas just outside the main channel. PAHs are commonly associated with urban stormwater runoff and have been linked to driveway sealants and other pavement treatment products.

Various metals including arsenic, cadmium, chromium, lead, and mercury were also detected in the sediment samples above the selected ecological screening criteria. Much like the PAHs, the detected metal concentrations were generally consistent across the sampling locations. Two of the most commonly detected metals included arsenic and mercury. It is well documented that arsenic is a naturally occurring component of sediment and bedrock within New Hampshire and may be indicative of a background condition. Mercury is typically attributed to atmospheric deposition associated with emissions from major coal-fired power plants located primarily in the Midwest states.

3.3.1.3 UNH Sediment Study

In 2019, a student at the University of New Hampshire (UNH) completed a research project, which involved the characterization of sediment samples from two local dam impoundments (Mill Pond and Sawyer Mill Pond in Dover, NH) (Miller, 2019). As part of the study, surficial and core sediment samples were analyzed for grain size distribution and mercury content. Research findings reportedly indicate that relatively homogenous, fine-grained sediment is located throughout the impoundment. Elevated levels of mercury (i.e., greater than the NOAA 1999 Upper Effects Threshold) were reported at multiple locations within the impoundment, particularly at depths equal to or greater than 20 centimeters (about 8 inches). It was also reported that depositional areas adjacent to the main channel were more likely to contain fine-grained sediment, and therefore be associated with mercury contamination. In addition to air pollution from regional sources and possible upstream industrial sites, the former UNH waste incinerator, which closed in the 1980s, was identified as a possible local historical source of mercury contamination. A copy of the study analytical data summary is appended to the June 2020 SAP (**Appendix D.1** of this report).

3.3.2 Supplemental Sediment Sampling and Analysis Program

In consideration of the due diligence review findings, VHB conducted supplemental sedimental sampling and analysis to address certain spatial data gaps and to verify that the existing data are representative of current sediment quality. As noted previously, the proposed supplemental data collection effort was outlined in the June 2020 SAP (**Appendix D.1**) for NHDES review and comment; key elements of the sampling and analysis program are presented in the following sections.

3.3.2.1 Supplemental Sampling Locations

While the sample locations from the 2009 study provided broad spatial coverage of the impoundment area, limited data were available for the upper limits of the Hamel Brook channel and farther downstream of the dam where the channel widens out into a more estuarine environment. In addition, a significant amount of time had passed since the existing sediment data had been obtained. Therefore, the project team recommended the collection and analysis of sediment samples from six additional locations as detailed in

Table 3.3-1; the relative locations of the supplemental sediment samples and the 2009 samples are shown on **Figure 3.2-9**.

Table 3.3-1. Supplemental Sediment Sampling Scheme

Sample ID	Sample Location Description	Rationale
SED-13	Hamel Brook upstream near impoundment limits	Address spatial data gap upstream of 2009 sample with elevated levels of PAHs
SED-14	Hamel Brook upstream between SED-13 and SED-1	Address spatial data gap upstream of 2009 sample with elevated levels of PAHs
SED-15	Main river channel upstream of dam (targeting previous sample locations SED-3)	Confirm existing data is representative of current conditions; supplement existing impoundment data
SED-16; SED-16MS; SED-16MSD; SED-FD; SED-EB[1]	Main river channel upstream of dam (targeting previous sample locations SED-7 or SED-8)	Confirm existing data is representative of current conditions; supplement existing impoundment data
SED-17 A-E; SED-18 A-E[2]	Downstream of dam in tidal estuary	Supplement existing downstream data

Notes:

1 Field quality control samples were collected from this sampling location; MS - matrix spike; MSD - matrix spike duplicate; FD – field duplicate; EB – equipment blank.

2 Composite samples were collected at these locations, each comprising 5 sediment cores located along a transect perpendicular to the direction of flow (see Section 3.3.3.2 for field sampling methods).

3.3.2.2 Field Sampling

The supplemental field sampling activities were conducted on June 23, 2020. Consistent with the 2009 study (VHB, 2009), the supplemental sediment samples were collected over the water, using hand and gravity coring techniques (Wildco® Hand Corer). The samples collected upstream of the dam were retrieved at distinct locations, with the sampling equipment being manually advanced through the soft sediments into the more dense material below (i.e., generally to depths of 1.5 to 2.5 feet below the sediment surface); up to two cores were advanced at these locations in order to retrieve sufficient material for recommended laboratory analyses. Consistent with the 2009 study, the downstream samples were composited from multiple sediment cores collected from the top 1 to 1.5-foot interval along transects perpendicular to the stream channel at the selected locations (see **Figure 3.2-9**).

Once collected, the core sample(s) were visually observed for sediment texture, color, or debris content. All core samples for a given location were transferred to a clean, stainless-steel bowl and mixed using a stainless-steel spoon or spatula. The homogenized sediment material was then immediately transferred into clean, unused, laboratory-supplied sample containers. The containers were packed in coolers with bagged ice and delivered directly to the analytical laboratory under standard chain-of-custody protocols. Field documentation, including field sampling forms, is provided in **Appendix D.2**.

3.3.2.3 Target Analytes and Laboratory Analytical Methods

The supplemental sediment samples were submitted to Absolute Resource Associates, LLC, a New Hampshire Environmental Laboratory Accreditation Program-accredited laboratory located in Portsmouth, NH for chemical analysis of the target analytes listed in **Table 3.3-2**; the laboratory analytical methods and rationale for recommending each test are also provided in this table.

Table 3.3-2. Supplemental Sediment Analysis Scheme

Analyte Group	Analytical Method	Rationale
RCRA 8 list of metals	EPA method 6020; EPA method 7471 (mercury only)	Previous detections/exceedances of ecological screening levels
Polychlorinated biphenyls (PCBs)	EPA method 8082	Confirm previous non-detections given persistent, bioaccumulative and/or toxic properties
Polycyclic aromatic hydrocarbons (PAHs)	EPA method 8270	Previous detections/exceedances of ecological screening levels
Organochlorine pesticides	EPA method 8081	Confirm previous non-detections given persistent, bioaccumulative and/or toxic properties
Total Phosphate	EPA method 365.3	Downstream water quality impairment (see Section 3.5 for additional discussion)
Total Nitrogen	EPA method 350.1	Downstream water quality impairment (see Section 3.5 for additional discussion)

Notes:

1 RCRA 8 list of metals include: arsenic (As), barium (Ba), cadmium (Cd), chromium (Cr), lead (Pb), mercury (Hg), selenium (Se), and silver (Ag).

2 The sediment samples were also be analyzed for total organic carbon (TOC) by EPA method 9060 and grain size by American Society of Testing and Materials (ASTM) method D-422.

Because volatile organic compounds (VOCs) were not detected in the previous study, and are not generally considered as persistent, bioaccumulative or toxic in aquatic environments as other organic compounds such as PCBs or pesticides (NHDES, 2005), additional VOC testing was not considered necessary in the supplemental sampling program. Similarly, testing for per- and polyfluoroalkyl substances (PFAS) was not recommended since the due diligence review did not identify potential source(s) of these constituents in the vicinity of the study area.

3.3.3 Sediment Quality Results

The analytical results from both the 2009 study and the 2020 supplemental sediment sampling program are provided in **Appendix D.3** (see **Table D.3-1**); a copy of the laboratory analytical report for the supplemental samples is provided in **Appendix D.4**.

As noted previously, the alternatives considered in this study necessitated consideration of both ecological and human health risks associated with chemically impacted sediments. Because initial review of the data indicated that the supplemental sample results were similar to those from the 2009 study, data from both efforts were considered in the screening-level risk assessments. Key findings from these assessments are summarized in the following sections.

3.3.3.1 Ecological Screening Assessment

Consistent with NHDES guidance (NHDES, 2005), the sediment sample analytical results were compared to NHDES recommended threshold effect concentrations (TECs) and probable effect concentrations (PECs) to evaluate whether the sediment quality may pose a risk to aquatic and benthic organisms. As noted in the NHDES guidance:

› TECs represent the estimated chemical concentration threshold below which adverse effects on ecological receptors are unlikely; and
› PECs represent the estimated chemical concentration threshold above which adverse effects on ecological receptors is likely.

TEC and PEC thresholds for both fresh water and marine sediments were considered in this analysis since the environment downstream of the dam is tidally influenced. The NHDES recommended screening thresholds were obtained from NHDES (2016).[18] We note that for the marine sediments, the threshold effect concentrations and probable effect concentrations are expressed as threshold effect levels (TELs) and probable effect levels (PELs) but generally represent the same type of risk thresholds. For purposes of this discussion, the terms TEC and PEC are used generically to represent both freshwater and marine screening threshold levels.

Following NHDES guidance, hazard quotients (HQs) were calculated for all detected constituents in each sample by dividing the constituent concentration by the screening threshold value (i.e., either the TEC or PEC). A HQ calculated with a TEC (HQ-TEC) of 1 or greater indicates the possibility that exposure to the sediment may adversely affect ecological receptors. An HQ calculated with a PEC (HQ-PEC) of 1 or greater indicates the likelihood that exposure to the sediment will adversely affect ecological receptors. Based on the calculated HQs, each constituent was assigned a risk classification as follows:

› HQ-TEC<1 was qualified as low risk;
› HQ-TEC>1 was qualified as moderate risk; and
› HQ-PEC>1 was qualified as high risk.

The calculated HQs and assigned risk classifications for fresh water and marine screening thresholds are provided in **Appendix D.3** (see **Table D.3-2**), and the ecological screening results is summarized in **Table 3.3-3** below. As shown in the tables, all sediment samples contained concentrations of PAHs and/or metals considered to have moderate to high potential for adverse effects to ecological receptors. These screening results suggest that sediments throughout the study area are impacted by these contaminants. As noted previously, PAHs and metals are commonly found in urban environments, and may be the result of anthropogenic or naturally occurring sources.

[18] NHDES Memorandum from Matt Wood to Gregg Comstock, PE entitled *"Updated TEC and PEC sediment thresholds"* dated January 8, 2016 was provided to VHB by Mr. William Thomas, NHDES River Restoration Coordinator, via email on April 17, 2020.

Table 3.3-3. Summary of Findings - Ecological Screening Assessment of Sediment Sample Analytical Results

Upstream Samples

Sample ID	SED1	SED-13	SED-14
Date	10/31/09	6/23/20	6/23/20
PAHs		Low	Mod
Pesticides	ND	ND	ND
PCBs	ND	ND	ND
Metals	High	High	High
VOCs	ND	NA	NA

Mill Pond Samples

Sample ID	SED2	SED3	SED4	SED5	SED6	SED7	SED8	SED9	SED10a	SED10b	SED11a	SED11b	SED-15	SED-16	SED-DP
Date	10/30/09	10/31/09	10/31/09	10/31/09	10/31/09	10/31/09	10/31/09	10/31/09	11/2/09	11/2/09	11/2/09	11/2/09	6/23/20	6/23/20	6/23/20
PAHs	High	High	High	ND	High	High	High	ND	High	High	ND	ND	High	High	High
Pesticides	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	High
PCBs	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND
Metals	High	Mod	High	High	High	High	High	High	High	High	High	High	High	High	High
VOCs	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	NA	NA	NA

Downstream Samples

Sample ID	SED12	SED-17	SED-18
Date	11/2/09	6/23/20	6/23/20
PAHs	ND	Mod	High
Pesticides	ND	ND	ND
PCBs	ND	ND	ND
Metals	High	Mod	Mod
VOCs	ND	NA	NA

Key:

Low	Results for one or more target analyte in group indicates low risk of adverse effects to ecological receptors.
Mod	Results for one or more target analyte in group indicates moderate risk of adverse effects to ecological receptors.
High	Results for one or more target analyte in group indicates high risk of adverse effects to ecological receptors.
NA	Target analytes not analyzed.
ND	Target analytes not detected.

While overall the sample results are similar across the study area, further review of the analytical data does indicate some slight variability by target analyte and/or sample location. As shown in the box and whisker plots provided in **Figure 3.3-1** below, concentrations of target PAHs are relatively consistent across the study area, with the overall range of reported concentrations for a given analyte generally within an order of magnitude. However, average PAH concentrations are slightly greater within and downgradient of Mill Pond, as compared to the upstream samples.

Similarly, the overall range of reported concentrations for metal constituents are generally within the same order of magnitude. However, there does appear to be more variability in the spatial trends for target metals. For example, average concentrations of arsenic and lead are similar across the study area; whereas greater concentrations of mercury and chromium were observed within Mill Pond and/or downstream of the dam, compared those further upstream.

3.3.3.2 Human Health Screening Assessment

If sediments are removed from Mill Pond as part of a restoration alternative, they become classified as soils and are then subject to review in accordance with NHDES Contaminated Sites Risk Characterization and Management Policy (RCMP). The RCMP provides a process to determine if detected contaminant concentrations constitute a direct contact risk to humans or a potential risk to groundwater quality. Therefore, to preliminarily assess the sediment quality conditions in Mill Pond relative to these risks, the 2009 and 2020 analytical results were compared to the current RCMP Method 1 Soil Category S-1 Direct Contact Risk-based Concentrations ("S-1 standards").[19] The results of this comparison are detailed in **Appendix D.3** (see **Table D.3-3**) and summarized below in **Table 3.3-4**.

In general, detected concentrations of target analytes exceeded the S-1 standards in relatively few instances. Two PAH constituents (benzo(a)pyrene and benzo(b)fluoranthene) were detected slightly above applicable S-1 standards in samples SED2 (benzo(b)fluoranthene only) and SED3, which were located in the northeastern portion of Mill Pond. In this setting and at these concentrations, VHB does not consider these results to be indicative of a regulated "release" subject to the NHDES Contaminated Site Management regulations.

Similarly, most arsenic concentrations were slightly above the applicable S-1 standard of 11 milligrams per kilogram (mg/kg). The S-1 standard (SRS) for arsenic is based on typical background concentrations found in soils in the State of New Hampshire (SHA, 1998). The relatively narrow range of arsenic concentrations reported just above and below the S-1 standard and consistent spatial distribution (exceedances of the S-1 standard in both upstream and downstream locations) are indicative of a naturally occurring background condition. Nevertheless, for the purposes of this screening level assessment, sediment analytical data exceeding the S-1 standards generally suggest additional assessment and/or risk mitigation may be warranted should excavated/dredging of sediments be proposed as part of the selected alternative.

19 The NHDES S-1 standards are based upon sensitive uses of property and accessible soils, either currently or in the reasonably foreseeable future, and are equivalent to the Soil Remediation Standards (SRSs) established in the New Hampshire Code of Administrative Rules Chapter Env-Or 600, Contaminated Site Management.

Table 3.3-4. Summary of Findings - Human Health Screening Assessment of Sediment Sample Analytical Results

Upstream Samples			
Sample ID	SED1	SED-13	SED-14
Date	10/31/09	6/23/20	6/23/20
PAHs			
Pesticides	ND	ND	ND
PCBs	ND	ND	ND
Metals			
VOCs	ND	NA	NA

Mill Pond Samples															
Sample ID	SED2	SED3	SED4	SED5	SED6	SED7	SED8	SED9	SED10a	SED10b	SED11a	SED11b	SED-15	SED-16	SED-DP
Date	10/30/09	10/31/09	10/31/09	10/31/09	10/31/09	10/31/09	10/31/09	10/31/09	11/2/09	11/2/09	11/2/09	11/2/09	6/23/20	6/23/20	6/23/20
PAHs				ND				ND			ND	ND			
Pesticides	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	"J"
PCBs	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND
Metals															
VOCs	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	NA	NA	NA

Downstream Samples			
Sample ID	SED12	SED-17	SED-18
Date	11/2/09	6/23/20	6/23/20
PAHs	ND		
Pesticides	ND	ND	ND
PCBs	ND	ND	ND
Metals			
VOCs	ND	NA	NA

Key:

(shaded)	Detected concentration exceeds NHDES S-1/SRS for at least one target analyte within group.
NA	Target analytes not analyzed.
ND	Target analytes not detected.
"J"	Estimated result (in duplicate sample only).

As discussed above, implementation of Alternative 5 (dam removal) would result in substantial dewatering of the Hamel Brook reach (see **Figure 3.2-6**). As a result, sediments which are currently submerged would become exposed at the surface. To assess the potential for adverse human health impacts resulting from increased exposure to previously submerged sediments, VHB compared the sediment sample concentrations reported for samples collected from within the Hamel Brook reach (i.e., samples SED1, SED13, and SED14) to New Hampshire Department of Environmental Services (NHDES) Contaminated Sites Risk Characterization and Management Policy (RCMP) soil category S-1 standards (S-1 Standards). The S-1 Standards are derived based on a residential exposure scenario whereby potential receptors of all ages may be exposed as the result of normal everyday activities. While appropriate for screening-level assessment purposes, residential exposure assumptions (e.g., frequency and duration of exposures) are likely more conservative than the actual exposure scenarios typical of visitor and/or recreational use of the Hamel Brook reach.

This comparative assessment, summarized in **Table 3.3-5** below, indicates that the reported concentration of arsenic in sample SED1 (12 milligrams per kilogram or mg/kg) slightly exceeds the S-1 standard for that constituent of 11 mg/kg. The S-1 standard for arsenic is based on typical background concentrations found in soils in the State of New Hampshire (SHA, 1998). Considering the larger sediment quality dataset for the study (i.e., including samples collected from within Mill Pond and further downstream of the dam), the average detected concentration of arsenic is 12 mg/kg, with the range of reported concentration between 7 and 17 mg/kg. As noted above, the relatively narrow range of arsenic concentrations (reported just above or below the S-1 standard) and relatively consistent spatial distribution (exceedances of the S-1 Standard in both upstream and downstream locations) are indicative of a naturally occurring background condition; therefore, newly exposed sediments are unlikely to represent an additional or unacceptable risk to human health.

Table 3.3-5. Summary of Findings - Human Health Screening Assessment of Upstream Sediment Sample Analytical Results

	Upstream Samples		
Sample ID	**SED 1**	**SED-13**	**SED-14**
Date	**10/31/09**	**6/23/20**	**6/23/20**
PAHs			
Pesticides	ND	ND	ND
PCBs	ND	ND	ND
Arsenic			
Other Metals			
VOCs	ND	NA	NA

Key:

(shaded)	Detected concentration exceeds NHDES S-1/SRS for at least one target analyte within group.
NA	Target analytes not analyzed.
ND	Target analytes not detected.
"J"	Estimated result (in duplicate sample only).

3.4 Infrastructure

Within the immediate vicinity of Oyster River Dam and the Mill Pond impoundment there are multiple private residences, retaining walls, roads, and bridges. Two bridges cross the Oyster River immediately downstream of the dam: the Newmarket Road (NH 108) bridge and a pedestrian footbridge. Stone masonry retaining walls line the banks of the river around both bridges. Two houses on Newmarket Road are located adjacent to the dam, one behind each dam abutment; there are approximately six additional houses on Mill Pond Road and Laurel Lane located within 100 feet of the upstream Mill Pond impoundment. Each of these structures is potentially influenced by river hydraulics in some way and the possible impacts that could result from the modification or removal of the dam are discussed in this section. The discussion is focused on structures located close enough to the river's edge and the dam such that they could potentially be affected by the modification or removal of the dam removal. The structures with potential for being affected are further discussed below.

The HEC-RAS model (Section 3.2) was employed to simulate hydraulic conditions in the river channel that would dictate hydraulic loading on existing structures resulting from implementation of the project alternatives. The HEC-RAS model output provides water surface elevations for the 2-year, 10-year, 50-year, and 100-year flood events as well as the median annual flow regimes. The results of the model provided water surface elevation, water depths and average water velocities at key locations for each of the alternatives discussed herein. These data were used to estimate potential scour relative to existing structure foundations for each alternative, as well as comparisons of the current scour conditions versus conditions associated with the implementation of dam removal or modification. Additionally, the resulting water surface elevations for each alternative were compared to the existing structure elevations obtained from the drawings.

In general, with alternatives that preserve the dam (Alternative 3), water surface elevations and velocities in the vicinity of the dam would remain unchanged from existing conditions. Under Alternative 5 (Dam Removal), the water surface elevations would be lower and the velocities would be higher than existing conditions. Farther up the impoundment away from the dam the effects are reduced and are relatively minor.

When the river is not experiencing flood events, the water surface elevations and velocities associated with *Alternative 3 – Dam Stabilization* would remain essentially unchanged from the Existing Condition. *Alternative 5 - Dam Removal* would result in lower water surface elevations and higher velocities at the dam location for the 100-year flood: decreasing from 15.0 to 14.7 ft and increasing from 3.4 to 3.8 ft/sec, respectively. These changes are relatively minor due to the dominant backwater effect from the Newmarket Road bridge at this location. The increased velocities, coupled with the lower water depths, may create scouring conditions. Scour is defined as erosion of streambed or bank material caused by flowing water, usually being localized. The major concern of scour is the decrease in foundation stability that could lead to structure damage and/or failure.

It is assumed that the structures are sufficient to resist the current loadings, as they have been doing for many years; hence, the focus of this discussion is to compare the current conditions to those associated with the proposed alternatives.

3.4.1 Bridges, Walls and Foundations

The New Hampshire Department of Transportation (NHDOT) Bridge No. 114/111 carries Newmarket Road (NH 108) over the Oyster River in Durham, New Hampshire. The bridge is located approximately 700 ft south of the Durham Town Hall and approximately 90 feet downstream of the Oyster River Dam (NHDES #071.03). The current bridge structure was built in 1991 to replace an earlier bridge; as-built plans dated March 24, 1992 are available from NHDOT. The single-span bridge consists of a shallow concrete arch superstructure supported by concrete abutments and footings with stone masonry facing around abutment walls, wingwalls, and bridge fascia. The bridge has a span of 25 feet and width of 45.3 ft. Boring logs and from record plans indicate consistent bedrock at elevations ranging from -0.8 to 0.0 ft below the bridge footprint; bedrock cores characterize bedrock as medium- to coarse-grained gray and gray-green diorite. Plans show 5.5-ft wide, 3.0-ft thick concrete spread footings set directly on this bedrock, with bottom of footing elevations -3.7 ft at the south abutment and -2.7 ft at the north abutment. The riverbed elevation between the abutments is shown on the plans to range from elevation -1.0 to 0.0 ft under the bridge. The embankment sections north and south of the bridge are lined with riprap except for the southwest section that consists of a granite block wall embankment section.

The Town of Durham footbridge carries a pedestrian walkway connecting the Town Landing and General Sullivan parks. This bridge is located approximately 60 feet downstream of the Newmarket Road bridge. The current bridge structure was constructed in 1991; as-built plans are not available from the Town of Durham. The single-span bridge consists of a shallow laminated timber arch with timber deck supported by concrete abutments and footings. The bridge has a span of 63 feet and width of 6 ft. No borings are available but exposed bedrock outcrops are visible in the channel upstream and downstream of the bridge. Abutment footing elevations are unknown, but they are set behind the stone masonry walls comprising the river banks. The riverbed elevation between the abutments is shown on the plans to range from elevation -1.0 to 0.0 ft under the bridge. The embankment sections north and south of the bridge are lined with riprap except for the southwest section that consists of a granite block wall embankment section.

Between the two bridges and extending approximately 100 feet downstream of the footbridge, both channel banks are armored by stone masonry retaining walls.

A field evaluation of bridges, walls and foundations in the impoundment was performed in August 2020. During the field visit, staff accessed bridge footings, reviewed bridge plans, took channel dropline measurements, collected photographic documentation, and observed river channel conditions around the bridges.

The Newmarket Road bridge is in generally good condition with isolated areas of minor deficiencies. The bridge is inspected every two years by the NHDOT, with the most recent bridge inspection report from 2018; additional detail pertaining to the current bridge condition can be located within those reports. The concrete footings appear to be in fair condition, with no observed evidence of channel degradation or scour relative to the 1992 as-built plans.

The pedestrian bridge is generally in good condition. Channel bed elevations range from -0.3 to -4.0 ft below the bridge; the channel bed is characterized by aggradation of gravel and cobble deposits along the left side of the channel with the thalweg on the right side. Large boulders and bedrock outcrops are visible across the channel between the pedestrian and Newmarket Road bridges. The stone masonry retaining walls along both banks are in good condition and do not show evidence of scour.

Both bridges are considered to be scour-stable under existing conditions based on foundations anchored to bedrock and no history of scour in light of the flood history of the Oyster River. Hydraulic modeling indicates that hydraulics at both bridges would be unchanged from existing conditions under any of the alternatives evaluated. Although some sediment aggradation in the channel may occur under the Dam Removal Alternative, any accumulated sediments would be scoured away under flood flows due to the contracted channel through the bridges and would not be expected to reduce the hydraulic capacity of the bridges. Conversely, no further channel degradation at these bridges is anticipated. Due to the upstream Oyster River Dam blocking downstream sediment transport, all fine material in the channel at the bridges has been scoured away and the remaining bed consists of exposed bedrock outcrops and large boulder armoring. Empirically, field measurements indicate no substantial change in channel bathymetry compared to record plans.

There are two residential structures in the immediate vicinity of the Oyster River Dam: 14 Newmarket Road (above the left bank, approximately 80 feet upstream of the dam) and 20 Newmarket Road (above the right bank, approximately 40 feet downstream of the dam). Further upstream, there are additional structures between 50 and 100 feet behind the channel: four behind the left channel bank along Mill Pond Road and two behind the right channel bank along Laurel Lane.

20 Newmarket Road is set back approximately 50 feet from the bank of the Oyster River, with a basement floor elevation at 14.3 feet. Hydraulic modeling predicts that when the Oyster River flood stage overtops the right abutment, a portion of river flow bypasses the dam and flows across the lawn of 20 Newmarket Road; when flood stage upstream of the dam exceeds 14.3 feet, it results in basement flooding of the structure. This prediction was confirmed during the Mother's Day Flood of 2006 when floodwater reached the basement of 20 Newmarket Road.

14 Newmarket Road is set back approximately 50 feet from the bank of Mill Pond, with a basement floor elevation at 18.9 feet, 8 feet above the dam spillway crest. This building foundation is set above the estimated flood elevation under all evaluated scenarios, and the left bank of the river below the structure is stable. Similarly, the residences along Mill Pond Road and Laurel Lane are located above the floodplain and are assumed to be stable.

Based on the hydraulic model results and their locations, these structures are not likely to be adversely affected by implementation of any of the alternatives evaluated in this study. At 20 Newmarket Road, Alternative 5 - Dam Removal would drop the Q50 flood elevation below the basement floor elevation and therefore reduces the risk of building flooding. The Q100 flood elevation similarly drops, but due to tailwater from the Newmarket Road bridge remains above the basement flood elevation; however, it is lower than existing conditions and therefore would reduce the magnitude of flooding for this event. Flood velocities near the building for all alternative are below 2 ft/sec, which indicates low scour potential. All other residences are located above predicted flood elevations for all alternatives and therefore would not be impacted.

3.4.2 Surface Water Withdrawals

VHB consulted various online databases and resources to determine if any surface water withdrawal locations are present in or adjacent to the Oyster River Dam impoundment. The databases used include NHDOT OneStop Data Mapper, NH GRANITView, and NH Coastal Viewer, and the National Water Information System, as well as the Durham Department of Public Works. After consultation with these resources, only one surface water intake was identified – the UNH campus water intake located at the upstream Oyster River Reservoir Dam.[20] Because this intake is in a reach of the Oyster River situated well above the impoundment, it will not be affected by either the modification or removal of the Dam.

3.4.3 Wells

Using existing geologic information, maps, and well drilling logs, VHB developed a conceptual hydrogeological model of the site to evaluate the potential for modification or removal of the dam to result impact the yield of public or private wells.

3.4.3.1 Existing Groundwater Conditions and Conceptual Site Model

VHB defined a Well Study Area based on topography, a conservative inferred zone of groundwater influence from the impoundment, and locations of water supply wells mapped within and beyond the vicinity of the inferred zone of influence (refer to **Figures 3.4-1** through **3.4-3**). Existing groundwater conditions within the Well Study Area were inferred from bedrock and surficial geologic mapping and available well reports.

The surficial geology of the Well Study Area originated from the last glacial period and the subsequent melt of the glaciers, which occurred less than 14,000 years ago (Goldthwait et al., 1951). Subsequent deglaciation of the Durham area was accompanied by marine inundation where glacial ice was in contact with the ocean resulting in the deposition of glacioestuarine silts and clays (USGS, 1990). According to the New Hampshire Geological Survey (NHGS, 2005a), surficial geology surrounding the impoundment is mapped as the silt clay facies of the Presumpscot formation (map code Qpc, **Figure 3.4-2**). This facies consists of variably thick (up to 75 feet) clayey silt to silty clay, locally containing silt and fine sand beds. The Presumpscot formation overlies older surficial deposits such as stratified glacial and gravel and till (map code Qt). In general, fine-grained materials such as these silts and clays do not transmit water freely (USGS, 1990).

Outward from the impoundment, surficial geology is mapped as glacial till (map code Qt) and thin till/glacial till with bedrock exposures (map code Qtt). Glacial till is material directly deposited by the ice sheet and is described by NHGS as a non-sorted to poorly sorted mixture of clay, silt, sand, pebbles, cobbles, and boulders. The dominant grain size is silt to

[20] These databases generally only register water users that withdraw more than 20,000 gallons of water per day. However, field inspections and consultation with local officials did not identify any known smaller private intakes or dry hydrants anywhere within the impoundment area.

small pebbles, and locally contains small irregular masses of sand and gravel. The thickness of till material varies but generally is less than 20 ft. Glacial till is generally dense and contains large portions of fine-grained materials, and does not readily transmit water.

According to the NHDES water well inventory, no nearby water supply wells are installed in the overburden materials, and overburden thickness ranges from 2 to 38 feet based on reported depths to bedrock (see more information in Sections 3.4.3.2 and 3.4.3.2). No stratified drift aquifers are mapped in the Well Study Area (USGS, 1990), indicating overburden materials here do not likely provide substantial amounts of water. In addition, the till aquifer generally is considered to be a minor source of groundwater because of its low transmissivity (USGS, 1990).

According to the NHGS (2005b), bedrock geology in the Well Study Area consists entirely of the Exeter Diorite formation (map code De9), which includes associated intrusive rocks of southeastern New Hampshire: pyroxene and pyroxene-hornblende diorite and gabbro, along with minor granodiorite and granite. Wells in the Study Area are installed to depths ranging from 85 to 523 feet below ground surface (53 to 496 feet below sea level) with reported yields ranging from 3 to 30 gallons per minute. Flow of water in bedrock aquifers is controlled by networks of interconnected fractures within the rock.

In summary, the surficial geology around the impoundment consist of silts, clays, and tills which have low transmissivity and hydraulic conductivity, meaning that they do not readily transmit water. These materials do not form productive aquifers, do not support known water supply wells in the Study Area, and they limit the hydrogeologic connectivity between the surface and the underlying bedrock aquifer.

The productive groundwater source in the Well Study Area that supports water supply wells is the bedrock aquifer. The bedrock aquifer is recharged with water from precipitation and snowmelt in the higher-elevation terrain where the surficial materials are thinner and bedrock is exposed. Groundwater flows from the higher-elevation recharge zones through the bedrock towards the low elevations around the impoundment and the Great Bay.

3.4.3.2 Municipal/Public Wells

VHB reviewed information available online for municipal and public wells and water systems within and adjacent to the Well Study Area to characterize public water supplies and to evaluate potential impacts of the project. One public transient non-community (TNC) well is mapped in the Study Area. According to the NHDES database, the system is inactive but the source is active. The TNC system served the Riverside Day Camp with a population of 30. The well is installed in bedrock at a total depth of 85 feet and has a reported safe yield of 3 gallons per minute (gpm).

The University of New Hampshire - Durham Water system is a jointly operated water system that is supplied by reservoirs on the Lamprey River and the Oyster River (both upstream of the project impoundment), the Spruce Hole Well, and the gravel packed Lee Well (Durham Public Works Department, 2020 Water Quality Report). The reservoirs and surface water intakes are upstream from the Mill Pond Impoundment where they would not be affected by changes in the dam or the impoundment water-level. The Spruce Hole and Lee Wells are located outside the Well Study Area, several miles away from and hydrogeologically isolated from the impoundment.

3.4.3.3 Private Wells

The area to the west/northwest of the impoundment is serviced by the UNH-Durham municipal water supply system discussed above (**Figures 3.4-1** through **3.4-3**), so few private/domestic wells are mapped in that area. Private wells are primarily located to the east of the impoundment that is not serviced by the municipal distribution system. In total, 16 domestic wells are mapped within the Study Area, all of which are reportedly installed in bedrock. VHB reviewed available construction details for these wells, which are summarized in **Table 3.4-1** below.

Table 3.4-1. Well Construction Information: Private/Domestic Wells Within Study Area

Well ID	Overburden Description	Depth to Bedrock (ft bgs)	Total Well Depth (ft bgs)	Yield (gpm)
8037	Till	2	113	12
8202	Till	6	301	12
8320	Gravel	5	465	6
8648	Clay	4	220	15
31408	Till	3	523	10
41638	Clay	8	280	20
41751	Clay	38	340	6
41756	Gravel	13	320	3
54194	Clay	13	280	30
8201	Clay	3	140	15
8203	Sand	2	423	7.5
8314	Clay	7	120	12
29645	Sand, gravel, clay	26	500	0.5
31206	Sand, gravel	9	360	5.5
41641	Sand	3	420	3
58391	Till	18	500	45
31206	Till	2	113	12
Minimum		**2**	**113**	**0.5**
Maximum		**38**	**523**	**45**
Average		**10**	**332**	**12.7**

Notes:
1 Ft bgs = feet below ground surface
2 gpm = gallons per minute
3 Source = NHDES Water Well Inventory

In summary, the private wells identified within the Study Area obtain water from the deep bedrock aquifer, which is hydrogeologically isolated from the impoundment by low-permeability surficial layers of clay, silt, and till, therefore, no impact to private wells are expected as a result of either *Alternative 3 – Dam Stabilization* or *Alternative 5 – Dam Removal*.

3.4.3.4 Water Supply Conclusions

Based on review of online databases and conceptual hydrogeological model, public and private water sources within the Study Area consist of wells that obtain water from the deep bedrock aquifer. The surficial geologic materials that are in contact with the impoundment consist of low-permeability silts, clays, and glacial tills that do not readily transmit water and do not support known water supplies. A portion of the Study Area is also supplied by the municipal water system, which obtains its water from sources that are hydrologically isolated from the dam and impoundment.

VHB concludes that the impoundment is not a significant source of recharge to the bedrock aquifer, and that Alternative 5 (dam removal and the resulting reduction of the existing impoundment) will not affect groundwater levels in the bedrock aquifer that supplies the Study Area wells. Thus, private and municipal water supplies will not be affected.

3.5 Water Quality

Water quality conditions in the Oyster River both upstream and downstream of the Oyster River Dam are impaired and do not fully support the existing designated uses. These designated uses include aquatic life integrity and primary recreation, and the impairments are largely due to low dissolved oxygen levels and elevated bacteria levels, respectively. Excessive algae and aquatic plant growth are concerns both upstream and downstream of the dam and are believed to be linked to an abundance of nutrient inputs. In freshwater bodies, like Mill Pond, phosphorus is typically the limiting nutrient where increased availability often leads to excessive growth (also known as eutrophic conditions). In marine or estuarine waters downstream of the dam, nitrogen is often the limiting nutrient.

The state 303(d) list indicates that both the downstream, estuarine river segment is nitrogen impaired as is Mill Pond itself due to excessive algal productively as measured by chlorophyll *a* levels.[21] Excessive plant and algal growth contribute to lower dissolved oxygen levels caused by an oxygen demand during the decomposition of the plant biomass following seasonal die-off. With respect to dissolved oxygen, NH Administrative Rule Env-Wq 1703.07(b) states that Class B waters shall, except as naturally occurs, maintain a minimum dissolved oxygen concentration of 5 mg/L and at least 75% dissolved oxygen saturation based on a daily average. Water bodies not meeting these standards would be considered impaired and not fully supportive of the designated use of maintaining aquatic life integrity.

Dissolved oxygen levels in Mill Pond are often below acceptable thresholds considered necessary to support the more sensitive aquatic life.

[21] Chlorophyll *a* is the photosynthetic pigment found in freshwater algae and is used as an indicator of the relative abundance of algae.

Although the Oyster River is considered to support a diverse fish population, including nine fish species of concern listed in New Hampshire's Wildlife Action Plan, the potential for warm water temperatures and low dissolved oxygen levels within the impoundment behind the dam could limit the spatial and temporal extent of suitable habitat and spawning conditions for more sensitive fish species. A previous report indicated that optimal water temperatures for spawning is between 11ºC and 22.8ºC for blueback herring and similarly, between 11 ºC and 24ºC for alewives (Greene et al., 2009).

3.5.1 Existing Conditions

Extensive water quality data has been collected in the Mill Pond and its tributaries as part of several recent studies and monitoring efforts geared toward assessing the causes and extent of declining water quality conditions. In 2013, the Durham Pond Limnological Study found that total phosphorus (TP) concentrations in Mill Pond generally ranged between 0.40 and 0.60 mg/L which is two to three times higher than a generally accepted threshold of 0.20 mg/L, where algal blooms are known to become more prevalent in New England lakes and ponds. College Brook had even higher TP levels - much higher than those observed in the Oyster River upstream, suggesting that inputs from College Brook likely have a major influence on the downstream TP levels. Using predictive modeling, the study found that the elevated TP levels were mostly attributable to stormwater runoff from developed land areas in the upstream watershed; nutrient releases from bottom sediments and decaying organic detritus are also contributors but to a lesser extent. The study recommended various watershed and in-lake source control measures including possible dredging of a portion of the nutrient-rich sediments to limit future aquatic plant growth. The fact that much of the pond area has relatively shallow water depths of 3 feet or less is likely also to be a major contributing factor to the extent of aquatic plant growth in Mill Pond.

The UNH Water Systems Analysis Group (WSAG), led by Dr. Wilfred Wollheim, have collected continuous water quality and grab sampling data at the Oyster River Dam since 2015 focusing primarily on the nitrogen dynamics within the pond. As mentioned above, nitrogen is a key pollutant of interest for the downstream estuarine waters since the downstream waters are listed as impaired due to elevated nitrogen levels. Excessive nitrogen inputs in estuarine waters are generally considered to produce the same excessive plant growth and low dissolved oxygen levels as excessive phosphorus levels in freshwater bodies.

In collaboration with the WSAG team, this data has been used to assess the influence that the Oyster River Dam may have on existing nitrogen levels and, specifically, whether or not the impoundment acts as a nitrogen sink due to possible denitrification processes under low dissolved oxygen (DO) conditions or if excess nitrogen is potentially released under certain conditions at other times of the year. This information is essential to assessing how the proposed alternatives may change the nitrogen dynamics and the downstream water quality under more free flowing conditions if the dam was removed or modified.

3.5.1.1 Dissolved Oxygen

As shown in **Table 3.5-1**, the WSAG data shows that approximately 60% to 80% of the days from June through September in 4 of the last 7 years (2014, '15. '17 and '18), had at least one dissolved oxygen (DO) measurement below the 5 mg/L standard for Class B waters. During these same years, an even higher percentage of days had %DO saturation below 75%. **Figure 3.5-1** presents the full data set of continuous %DO saturation readings for the period of record. The darker shaded areas show the duration or period of time when the %DO saturation readings were below the 75% standard, which occurred mostly during the summer months.

The DO measurements were taken approximately 3 feet below the water surface at the Oyster River Dam, which suggests that in certain years relatively large portions of the pond volume may have critically low DO concentrations and provide habitat conditions that only allow the most tolerant aquatic species to survive or utilize the pond during these periods.

Table 3.5-1. Dissolved Oxygen at Mill Pond[1]

	June 1-September 30		
Year	**% of Days DO < 5 mg/L[2]**	**% of Days DO Saturation < 75%**	**Completeness of Record (%)**
2013[3]	40	56	59
2014	70	80	98
2015	79	93	99
2016	19	19	16
2017	80	90	100
2018	62	74	75
2019	21	62	32

Notes:
1 Data provided by the UNH Water Analysis Systems Group.
2 The percentage of days is based on 122 days for the full 4-months or # of days with available data.
3 Monitoring in 2013 did not begin until mid-June in 2013.

Figure 3.5-2 shows a comparison of the continuous %DO saturation data collected at upstream and downstream locations in the Oyster River from July 2017 to July 2018. The upstream station consists of a free-flowing river section near Oyster River Road (ORR) upstream of the Mill Pond impoundment. The downstream station is represented by the site located at the Oyster River Dam. The upstream data (shown in red) reveals that the %DO saturation levels remains well above the 75% minimum threshold for the entire period while %DO saturation levels at the downstream station were often below the 75% threshold for extended periods during the summer months. The decline in %DO saturation is presumed to be attributable to the oxygen demand created by microbial activity and algal respiration within the impoundment during the summer months and illustrate how the impoundment adversely affects water quality in the Oyster River system.

3.5.1.2 Water Temperatures

With respect to water temperatures, **Table 3.5-2** shows that water temperatures measured in Mill Pond are higher than the reported upper limits considered to be optimal to blueback herring and alewives for approximately 56% and 39% of the days during the 2016 summer months (June through September). The percentage of days with temperatures above these thresholds were much lower in the other years but still represented approximately 7 to 45% of the days, excluding 2019, which only had data for 32% of the available period. The data suggests that in some years the warmer temperatures may extend over long enough periods to adversely affect the habitat potential for these anadromous fish species.

Table 3.5-2. Water Temperatures at Mill Pond[1]

	June 1 to September 30		
Year	**% of days with Water Temperature >22.8°C[2]**	**% of days with Water Temperature >24°C[2]**	**Completeness of Record (%)**
2013	38	23	100
2014	45	32	100
2015	24	14	100
2016	56	39	88
2017	7	0	100
2018	24	8	100
2019[3]	13	3	32

Notes:

1 Data provided by the UNH Water Analysis Systems Group.

2 22.8°C and 24.0°C are the upper limits for optimal spawning conditions for blueback herring and alewives, respectively.

3 The 2019 data only extends through July of 2019. Data provided by the UNH Water Analysis Systems Group.

Figure 3.5-3 presents the time series of the continuous water temperature readings recorded by WASG at the Oyster River Dam from June 2013 to July 2019. The graph shows the extent to which water temperatures generally fall between the optimal temperature range of 11°C and 24°C for two locally important anadromous fish species, blueback herring and alewives (Greene et al., 2009) during the critical period of April and September (shaded in light gray). The graph also shows the general duration and frequency with which water temperatures exceed the upper limit of the optimal temperature range (shown in black). These exceedances are most notable during the summer months of 2013, 2014 and 2017. The impact of the impoundment on increased temperatures in the river may help to explain the decreasing number of blueback herring occurring in the river. (See Section 3.8 below for further discussion.)

3.5.1.3 Nitrogen Dynamics

A principal focus of the UNH Water Systems Analysis Group (WSAG) monitoring effort was to develop a better understanding of the nitrogen dynamics within Mill Pond. The study developed mass-balance estimates of the nitrogen inputs and outputs from the pond using continuous and grab sampling data collected at three upstream sites including an upstream site in the Oyster River near Oyster River Road, (ORR), a site in Hamel Brook (HAM), and in College Brook (CLGB). The downstream site is located at the dam. This data was used to assess changes in chemistry between upstream and downstream locations of the pond and to determine whether the pond functions as potential sink or source of nitrogen as a result of the observed nutrient fluxes.

The lowest nitrate levels were usually observed within the impoundment or at the dam compared to the upstream stations. The highest nitrate concentrations were typically observed at the upstream station in College Brook and nitrate levels in Hamel Brook were somewhere in between. The lower concentrations in the impoundment are most likely due to biological uptake of nitrate by the abundant aquatic plant and algal species but also perhaps in part due to dentification processes under low dissolved oxygen conditions. If nitrate is assimilated though plant and algal uptake, it can often later return to the water column as dissolved organic nitrogen (DON) after plants and algae die-off and decompose. If the lower nitrate is due to denitrification processes, then the nitrogen would be permanently lost. Nitrogen can also be added into the system from nitrogen-fixing blue-green algae species that adsorb nitrogen from the atmosphere to fuel primary production. When this occurs, additional nitrogen can potentially be released downstream after plants and algae die-off. It is difficult to know for certain which any of these processes are likely to dominant or materially control the nitrogen balance and contributes to a potential net gain or reduction in impoundment and released downstream.

To assess the nitrogen balance within the Oyster River impoundment, the WSAG team measured the various nitrogen levels entering and exiting (at the dam) for two sampling periods during the summers of 2018 and 2019. Using estimated flow rates and recorded parameter levels, the WSAG team calculated the daily flux (net change based on inputs and outputs) within the pond for the study period. **Table 3.5-3** presents the estimated average daily flux (kg/day) of various nitrogen forms including nitrate-N (NO_3^-), dissolved organic nitrogen (DON) and total dissolved nitrogen (TDN), which is comprised of both nitrate and DON. Negative values indicate a net decrease or retention within the impoundment while the positive values indicate a net increase or release in the particular form on nitrogen when comparing upstream and downstream load estimates.

Table 3.5-3. Estimated Daily Flux of Various Nitrogen Forms at Mill Pond

Year	NO_3^-	DON	TDN
2018	-3.77 (4.19)	5.68 (8.69)	2.01 (5.04)
2019	-2.19 (3.32)	0.67 (3.07)	-1.10 (6.395)

Notes: Change in summer flux (kg/d) for nitrate (NO_3^-), dissolved organic nitrogen (DON) and total dissolved nitrogen (TDN) in Mill Pond, in 2018, n=4 sampling days averaged; for 2019, n=5. Standard deviation is reported in parentheses.

During both sampling periods, a net decrease in the amount of nitrate-N was observed suggesting that nitrate was being retained within the impoundment. In 2018, however, the nitrate retention was offset by a higher DON output resulting an estimated net release of TDN downstream. In 2019, only a minor amount of DON output was observed resulting in a net overall decrease in TDN for the sampling period. Although it is difficult to draw definitive conclusions, this data suggests that nitrate may initially be retained within the impoundment during summer months at the peak of plant and algal productivity but at times this nitrate-N retention may be offset or exceeded by releases of DON, which may occur as a result of a sudden die-off of certain algae species if they reach their end of life cycle or as a result of worsening water quality conditions, or were flushed out by an increase in flow.

It is interesting that higher DON releases were observed during the summer months or at the peak of the aquatic primary production period. It is possible that there was a sudden die-off resulting in a release of DON. It is also possible that the higher DON and TDN export was in part due to nitrogen fixation where nitrogen is extracted from the atmosphere by certain algal species that have nitrogen-fixing capabilities to fuel production. The added nitrogen incorporated into the algal biomass is the then transformed to dissolved organic nitrogen as the algal biomass occasionally dies-off.

3.5.2 Discussion of Potential Effects

For purposes of understanding water quality effects, both *Alternative 3 - Dam Stabilization with Dredging* and *Alternative 5 - Dam Removal* are considered. Aspects of these alternatives that could affect recreation are summarized below. Additional details about each alternative are provided in Section 2 of this report.

Under *Alternative 1 - No Action*, water quality conditions would remain the same with continued periods of low dissolved oxygen conditions, elevated water temperatures and extensive algae and aquatic plant growth. The current water quality impairments listed in the state's 303(d) list would remain unchanged.

Alternative 3 - Dam Stabilization which primarily involves structural enhancements, spillway stabilization and repair of the gated outlet structure, is expected to have a minimal effect on the future water quality in the impoundment. The potential dredging option associated with this Alternative could improve water quality by lowering the potential dissolved oxygen demand and potential nutrient inputs from the nutrient-enriched bottom sediment and organic material that is removed. The magnitude of the overall improvement is difficult to predict but since the bottom sediments represent only one of many factors that exert a demand on lower dissolved oxygen levels, it seems unlikely that the current dissolved oxygen impairment could be eliminated, at least until new sediments are eventually deposited in the dredge areas.

Under *Alternative 5 - Dam Removal* where the existing dam and fish ladder structures would be removed and the river would be returned to a more free-flowing condition, there is likely to be a more dramatic improvement in dissolved oxygen levels which would possibly eliminate the existing dissolved oxygen impairment. The reduced surface water size, increased travel time and reduced solar thermal inputs will help to lower water temperatures, which would also improve dissolved oxygen conditions. The improved dissolved oxygen levels and lower water temperatures will positively affect habitat conditions for diadromous fish.

A more free-flowing riverine environment would also reduce the amount of algae and aquatic plant biomass generated on an annual basis compared to the existing impoundment. As indicated by the WASG data discussed above, this algal and plant biomass growth can affect the nutrient dynamics and although the impoundment may temporarily retain nitrogen during the summer months, a potentially greater release of dissolved organic nitrogen could occur following plant die-off and the decomposition process. The decomposition of organic material also exerts a dissolved oxygen demand. Eliminating or reducing this biomass production could diminish the dissolved oxygen and nitrogen fluctuations produced under existing conditions.

In addition to the potential effects on dissolved oxygen, water temperatures and nitrogen fluxes, potential dam removal would also change salinity levels in the current impoundment. Increased salinity would result from the likely upstream migration of high tide levels after removing the dam, which will affect the distribution of vegetation species and aquatic organisms that prefer brackish conditions in tidally influenced areas. The potential effects of greater tidal influence or intrusion with the dam removed are discussed in Section 3.2 above.

3.6 Cultural Resources

Section 106 of the National Historic Preservation Act of 1966 (NHPA) requires federal agencies to take into account the effects of their undertakings on historic properties, and afford the Advisory Council on Historic Preservation a reasonable opportunity to comment. In the Section 106 process, the lead federal agency involved in the undertaking[22] identifies the historic properties, the effects on properties listed or eligible for inclusion on the National Register of Historic Places, and determines the appropriate mitigation for any adverse effects. These determinations are made in consultation with the New Hampshire Division of Historical Resources (NHDHR, also known as the State Historic Preservation Office) and other consulting parties.

3.6.1 Historic Structures (Above-Ground)

As further described below, above-ground historic resources identified within and adjacent to the project area include the Oyster River Dam, a National Register-listed Historic District, and a National Historic Landmark. The Durham Falls Bridge, which was replaced in 1991, is also located in the vicinity of the project area (see **Figure 3.6-1**).

The Oyster River Dam at Mill Pond (DUR0018)[23] is a historic property protected by state and federal law, including Section 106 of the National Historic Preservation Act and NH RSA 227-C relative to historic preservation. The dam was listed on the New Hampshire State Register of Historic Places in 2014 under State Register Criteria A and C for its associations with local history and for its engineering significance. The dam was erected in 1913 to replace a series of earlier timber dams dating back to the mid-seventeenth century. The Oyster River Dam is the oldest of seven Ambursen-type dams known to be extant in New Hampshire. The State Register listing boundary includes the dam and its immediate surroundings on the riverbank, as well as the Mill Pond that the dam impounds and the land on either side of the dam, based on the legally recorded lot lines shown on Durham tax maps.

The Oyster River Dam is located within the boundary of the Durham Historic District (DUR0030), which was listed in the National Register of Historic Places in 1980. The historic district contains 35 contributing resources that are representative of the Town of Durham

[22] The lead federal agency for this project has yet to be determined, but is likely to be the USACOE since a federal Section 404 Clean Water Act permit would be required for the project, regardless of alternative.

[23] This code and similar codes in this report refer to identifiers used by the NHDHR.

from the early seventeenth century to the 1830s. This period of significance is inclusive of the origins of the town through its height of prosperity as a shipbuilding and trading center. The Oyster River Dam is not included as a contributing property to the historic district.

The General John Sullivan House at 23 Newmarket Road (DUR0031) was listed as a National Historic Landmark in 1973 and is located southeast of the dam on the southeast side of NH 108. The property was the home of John Sullivan, a major general of the Continental Army during the Revolutionary War, from 1764 to 1795. The house was restored and renovated in 1966 but retains a high level of integrity as an eighteenth-century house. The property also includes a small cemetery where Sullivan is buried and a monument to Sullivan erected by the State in 1894.

Immediately south of the Oyster River Dam is the Durham Falls Bridge, built in 1907, which carries NH 108 over the Oyster River. The Durham Falls Bridge (DUR0035) was originally studied for eligibility in 1989, but was replaced in 1991.

3.6.2 Archaeological Resources

In the fall of 2019, project team member Independent Archaeological Consultants (IAC) completed a Phase IA Archaeological Sensitivity Assessment which conformed to the NHDHR guidance for dam removal studies (IAC, 2020).[24] The assessment study area included the dam site, the impoundment upstream approximately 1000 feet on the Oyster River, Hamel Brook to the NH 108 crossing, and the downstream channel banks to the high tide mark. The Phase IA survey area encompassed landforms within 820 feet of the Oyster River for a total of approximately 595 acres.

Within this survey area, archaeologists identified four Pre-Contact and or Post-Contact Euroamerican archaeologically sensitive areas (SAs). All four SAs are sensitive for Pre-Contact Native American cultural deposits based on well drained soils, level topography, proximity to the Oyster River, and the distribution of known Pre-Contact archaeological sites. Three of the four SAs are sensitive for both Pre-Contact and Post-Contact archaeological resources. Historical review, map review, and walkover survey confirmed the survey area encompasses the earliest Post-Contact settlement in Durham, including the 1640s homestead of Valentine Hill and his 1649 mill right. These and other seventeenth-century garrisons are present within or near the survey area. Potential resources within the survey area include seventeenth-century homestead sites, unmarked burials for the victims of the 1694 Oyster River Raid, eighteenth – and nineteenth century domestic dwelling sites and archaeological resources associated shipyards, wharves, landings, warehouses and stores.

3.6.3 Discussion of Potential Effects

Alternative 3 - Dam Stabilization proposes stabilization work that would be implemented in a way that would limit changes to the existing structure while providing structural

[24] In keeping with NHDHR policies, archaeological surveys are considered confidential, and generally are not made available to the public. For this reason, the IAC survey report is summarized here, rather than appended to this feasibility study.

enhancements, such as spillway stabilization and gated outlet structure repair. The main component of this alternative would be to fill the existing dam cells with concrete.

While the dam would remain in place, and would therefore retain Mill Pond, the modification to the structural design of the dam is expected to be deemed a Section 106 "adverse effect" to the State Register-listed resource. The dam is significant under Criterion C for its design and construction value, as an embodiment of the distinctive characteristics of an Ambursen dam-type and concrete slab and buttress method of construction. The characteristics that make it strongly representative of this type of dam include the evenly spaced downstream buttresses with hollow cells between, and the solid sloping reinforced concrete slab on the upstream side, with curved concrete spillway crest. Alternative 3 proposes to construct a "new" spillway within the confines of the existing spillway by pumping reinforced concrete within each of the spillway cells, which would alter the original design and construction, for which the resource derives its significance under Criterion C. Because *Alternative 3 – Stabilization* has limited hydraulic effects, it is not anticipated to have any potential impacts to upstream or downstream archaeological resources. However, if this alternative is selected, then the potential impacts of construction access is warranted.

Alternative 5 - Dam Removal would remove the entire existing dam and fish ladder, while preserving the gated outlet at the right abutment and the left abutment to help ensure bank stabilization and minimize historic impact. The Oyster River channel would be reconstructed and returned to its natural form.

The removal of the dam would have a substantial adverse effect to this State Register-listed resource. Not only is the dam significant for its engineering and design under Criterion C, as outlined above, it is also significant under Criterion A. The dam played an important role in the local history of the Town of Durham. Its construction in the early twentieth century was part of a pattern of philanthropic activities and community planning and development that helped create the University of New Hampshire Campus and Downtown Durham. In addition, removal of the dam and restoration of the river channel would create a landscape that has not existed since the seventeenth century.

Dam removal may cause potential impacts to archaeological resources due to changes in sediment transport (erosion and aggradation) near potential archaeological sites along Hamel Brook and the Oyster River. In addition, removal of the dam may expose previously submerged sites, making any potential sites below the current waterline vulnerable to degradation. A Phase IB intensive archaeological investigation of sensitive areas is recommended prior to potential dam removal where reactive meander bends may affect Pre-Contact or Post-Contact archaeological resources. Following dam removal, an inspection of presently submerged terrain features exposed by the river restoration is also recommended.

Neither alternative would be expected to result in impacts to the Durham National Register Historic District or the General John Sullivan National Historic Landmark.

Because both Alternatives 3 and 5 would result in adverse effects, discussions have begun with the Town of Durham and the Durham Historic District/Heritage Commission. Proposed mitigation under each alternative would focus on the significance of the State Register-listed dam that is being adversely affected. For Alternative 3, the dam would remain in place, but the significance derived from the dam's engineering would be adversely affected. Therefore, appropriate mitigation may result in interpretation of the design and construction of the dam. Under Alternative 5, as the dam would be removed, which eliminates both the dam's engineering significance and its significant associations with the community planning and development of Durham. Therefore, commensurate mitigation under Alternative 5 may entail a two-fold interpretation of the dam's engineering and history.

3.7 Recreation and Conservation Lands

The purpose of this section is to identify the recreational activities and conservation lands along the Oyster River impoundment, and to discuss how these resources may be affected by the modification or removal of the dam.

3.7.1 Existing Conditions

3.7.1.1 Recreational Properties

Despite shallow depths and an abundance of vegetative growth occurring over time within the pond, Mill Pond is still valued by residents for its aesthetic value and recreational opportunities. The stretch of the Oyster River impounded by the dam provides recreational opportunities in the form of fishing, kayaking, boating, or ice skating on the water, and picnicking or birdwatching from one of the Town of Durham's publicly developed lands along the banks of the pond and river.

There are multiple town-owned public lands along Mill Pond and the Oyster River that allow for a variety of recreational activities. These public lands include Old Town Landing, Jackson's Landing, and Oyster River Park.

Old Town Landing is a 3-acre public space downstream of the impoundment that consists of a small grassy area with benches that allows the public to enjoy the aesthetic views of the dam. This spot is also known for picnicking, birdwatching, and fishing. A public boat launch can also be accessed from this site.

Farther downstream is an area known as Jackson's Landing which is a 2-acre public space used for a fishing access point as well as a nonpower boat launch. Kayakers, paddleboarders, or canoers that depart from this location can access the downstream portion of the Oyster River beyond Oyster River Dam.

Located along a portion of the Oyster River above the Mill Pond impoundment, Oyster River Park is a 4.5-acre natural area with a trail system that allows for a nature experience along the banks of the river as well as walking/exercising opportunities. Multiple fishing access points are also present.

3.7.1.2 Conservation Land

Four conservation properties are located along the banks of the Oyster River and Mill Pond impoundment.

Mill Pond Center and the Durham Conservation Area are both privately owned and permanently protected conservation lands that were acquired through conservation easements by the Southeast Land Trust. Mill Pond Center is a 10-acre parcel located along the eastern bank of the impoundment, whereas the Durham Conservation Area is an 8-acre parcel located just off the southeastern edge of the impoundment. Appalachian-oak-pine and wet meadow/shrub wetland habitats can be seen throughout both locations.

The two other conservation parcels within the project area are the Ray MacDonald Natural Area and Milne Tract. While neither location is protected by a formal conservation easement, they are publicly owned lands used for both conservation and recreation.

Located along the western edge of the impoundment within the 78.9-acre forested area of McDonald Lot, the Ray MacDonald Natural Area is a 13-acre portion of the woodlot that borders the Oyster River. The land was left to the University of New Hampshire in 1977 by Ray F. and Elizabeth MacDonald to ensure that it was not subdivided and to prevent further pollution to the Oyster River. The area is home to a diverse plant community and often used for educational purposes by UNH.

The Milne Tract is a 1.5-acre protected parcel of land owned by the Town of Durham that sits immediately downstream of Oyster River Dam. The land was donated to the town by Drs. Lorus and Margery Milne, with a deed restriction stating that the land must be "used, maintained, and administered as a wildlife sanctuary for the preservation of wild plants and native animals, a source of serenity, and a place to observe undisturbed nature" (Milne Nature Sanctuary Property Summary, 2008). A $25,000 endowment was created at the time of donation to go towards maintenance of the property and the creation of a stone memorial monument with a small wildflower garden surrounding it. This stone memorial is still present today, and the sanctuary provides numerous benches that allow visitors to site and enjoy the aesthetic beauty of the area.

In addition to being classified as conservation lands, both Milne Tract and the Ray Macdonald Natural Area are also home to trail systems that provide additional recreational opportunities.

3.7.2 Discussion of Potential Effects

Over time, sediment transported from the Oyster River has accumulated in Mill Pond which has affected water depths in the pond. This has allowed for an increase in the amount of plants seen growing in the pond, in turn limiting the amount of open water and becoming a hindrance for certain recreational activities such as boating and ice skating. Under the existing conditions, the water depth of Mill Pond under normal conditions has decreased to an average of approximately 2.2 feet. If no action is taken, these conditions would remain unaltered, although recreational activities could decrease further if the pond continues to become shallower.

Alternative 3 -Dam Stabilization would limit changes to the existing dam while providing structural enhancements, such as spillway stabilization and gated outlet structure repair, designed for long term stability. As such, changes to the pond depths and water quality of the Mill Pond impoundment would be minimal. However, in conjunction with this Alternative, Pond Dredging (Option 1), may be implemented. If so, this dredging would remove a portion of the accumulated sediment that has collected over time. The dredging of the pond would occur in three pre-determined locations with the goal of creating a 6-foot target water depth in the pond. For this to be successful, however, ongoing maintenance and dredging would need to occur as sediment will continue to be transported into the pond.

If Option 1 is implemented, the amount of open water would increase, and the current density and abundance of vegetative would decrease. According to the HEC-RAS model, which was developed to assess a variety of changes to the Oyster River and Mill Pond hydraulics, the median average depth of the pond would increase to 3.7 feet, with the dredge areas being 6 ft deep. From a recreation perspective, the removal of vegetation and an increase in water depth would improve open water recreational opportunities such as boating and ice skating. While the water level in the pond is too shallow to realistically support motorized boats, non-motorized boats such as kayaks and canoes would be able to more easily navigate around the pond, especially with the removal of vegetation. Access to public boat launches and fishing spots within the pond would remain, and other recreational activities such as birdwatching and walking along the banks of the pond would remain unaffected.

Alternative 5 - Dam Removal would result in a hydrological change of the impoundment area and existing habitat conditions. According to the HEC-RAS model, the open water pond would be eliminated with a dam removal, with an average median surface water depth of 0.5 feet in the Mill Pond reach. The average width of the impoundment would decrease from 514 feet at current conditions to only 32 feet. This would result in a habitat change from open water to more aquatic bed and emergent marsh habitat, with some degree of tidal action in the currently impounded reach. While the habitat transition would likely benefit biodiversity, the recreational experience would be substantially different.

Regarding the impacts on recreational activities within the Mill Pond impoundment area, the water depth would not support motorized or non-motorized boating, except for shallow draft kayaks and canoes. While the abundance of recreational fishing locations would decrease in Mill Pond with the dam removal, there would be an improvement in the fish passage from the upstream portions into the tidal portions of the Oyster River. In this scenario, winter ice skating on Mill Pond would no longer be viable. However, birdwatching as a form of recreation would not be negatively affected, as the expected wetland habitats are home to numerous species of birds.

Regarding recreational opportunities within downstream portions of the Oyster River, there will not be any meaningful change. Public boat launches and boating activities in the downstream tidal portion of the Oyster River will be unaffected. Pedestrian access for fishing, birdwatching, and other purposes will continue to be provided within these portions of the river. Enhanced habitat connectivity is expected to result from the dam removal, creating cooler and faster flowing water conditions that may enhance opportunities for coldwater fishing. As these activities contribute to improved sport fish populations in the area, increases in angling may result. Fish species composition in the immediate vicinity of Oyster River Dam is expected to shift from, but not eliminate, warm water species such as smallmouth bass and sunfish to diadromous and riverine species such as river herring, shad, and chub.

3.8 Fisheries

3.8.1 Existing Conditions

The Oyster River provides a critical and diverse habitat for several ecologically important native freshwater and anadromous fish species. Eighteen species of fish are known to use the river, including a mixture of warm water, cold water, and anadromous species. Some of these species include largemouth bass (*Micropterus salmoides)*, yellow perch (*Perca flavescens*), brook trout (*Salvelinus fontinalis*), and black crappie (*Pomoxis nigromaculatus*). While the Oyster River has one of the most diverse fish species assemblages in the state, it most notably contains the only known population of American brook lamprey (*Lethenteron appendix*) in New Hampshire, listed by the state as endangered. Anadromous species such as blueback herring (a type of river herring), and catadromous species such as the American eel (*Anguilla rostrata*) are also found within the Oyster River.

Anadromous fish species are those that spawn in freshwater and then migrate to the sea to grow to maturity before returning to freshwater. These species rely on gaining access to upstream freshwater river habitat for spawning and nursery life cycle functions annually during the spring and early summer. Catadromous species (American eel) spawn in the ocean and then migrate to estuarine and freshwater rivers as they mature, relying on the rivers to provide nursery habitat. Eels can live in the fresh and brackish water system for upwards of 20 to 30+ years before returning to the ocean to spawn. The two groups of anadromous and catadromous species are referred to collectively as diadromous fish species. Most upstream migration of these species occurs during spring with the peak migration typically during the month of May (Bigelow and Schroeder, 1953). These species generally must be able to freely pass Oyster River Dam between the marine and freshwater ecosystem to complete their life cycles.

Historically, the river herring returns to the Oyster River have been one of the highest yearly returns among all coastal rivers monitored by NHFGD (Patterson, et al., 2019.) Presently, however, the numbers of returning river herring have generally been declining since 1990 and are now less than 5 percent of those seen at the peak from 1990-1992. (See **Table 3.8-1**.) Since 1976, the fish count for river herring has ranged between approximately 350 to 157,000 returns. In 2018, the fish return of river herring in the Oyster River was roughly 5,700, down from the peak of 157,000 in 1992. This decrease in number is largely attributed to a decrease in water quality and water levels along the river and throughout Mill Pond, as well as impediments to downstream migration. This restricts emigration of river herring, and subjects them to periods of poor water quality in the impoundment, such as low levels of dissolved oxygen in impoundment reaches of the Oyster River.

Table 3.8-1. River Herring Returns, Oyster River, 1976-2019

Year	Oyster River	Year	Oyster River
1976	11,777	2000	70,873
1977	359	2001	66,989
1978	419	2002	58,179
1979	496	2003	51,536
1980	2,921	2004	52,934
1981	5,099	2005	12,882
1982	6,563	2006	6,035
1983	8,866	2007	17,421
1984	5,179	2008	20,780
1985	4,116	2009	11,661
1986	93,024	2010	19,006
1987	57,745	2011	4,755
1988	73,866	2012	2,573
1989	38,925	2013	7,149
1990	154,588	2014	4,227
1991	151,975	2015	1,803
1992	157,024	2016	863
1993	73,788	2017	4,492
1994	91,974	2018	5,716
1995	82,895	2019	4,969
1996	82,362		
1997	57,920		
1998	85,116		
1999	88,063		

Source: Patterson, *et al.* (2019)

NH Fish and Game has been actively working to restore river herring in the Oyster River since the early 1970's with the goal of establishing self-sustaining populations. The methods include stocking gravid river herring and shad adults and eggs above barriers into prime spawning and rearing habitat and providing upstream fish passage at Oyster River Dam from the head-of-tide. The fish ladder at the Dam, which was established in the mid 1970's, allows for upstream passage of diadromous fish to reach spawning and nursery habitat. However, there are not specific passageways for American eels looking to return to the river from the tidal portions, limiting the habitat for this species. A small number of brook trout are also stocked in the Oyster River each spring and sea lamprey adults have been sporadically stocked.

In total, the Oyster River watershed is home to nine fish species of special conservation concern listed in New Hampshire's *Wildlife Action Plan* (New Hampshire Fish and Game Department, 2015). These include both freshwater and diadromous fish species such as American eel, alewife, blueback herring, sea lamprey, and American shad. A designation of "special concern" indicates that the species has the potential to become threatened if no conservation actions are taken.

3.8.2 Fish Passage Design Evaluation

The proposed channel design is intended to result in favorable conditions for upstream fish migration during the spring. VHB developed a design to remain within design guidelines for channel slope, maximum velocity, and pool geometry provided in a 2016 Federal Interagency Technical Memorandum on nature-like fishway passage design (Turek, *et al.* 2016). The most recent 2018 and 2019 New Hampshire Marine Fisheries Diadromous Fish Investigations indicates that river herring returns for the Oyster River consist of a roughly half Alewife and half Blueback Herring, with Blueback Herring historically having slightly higher numbers. Therefore, this analysis focuses on these two migratory fish species that would benefit from dam removal. NRCS Technical Supplement 14N, "Fish Passage and Screening Design" presents the cruising, sustained, and darting speed of many species of fish. **Table 3.8-2** below summarizes the characteristics of the species of interest in the Oyster River.

Table 3.8-2. Relative Swimming Speeds of Adult Fish

Species	Maximum Cruising Speed (ft/s)	Maximum Sustained Speed (ft/s)	Maximum Darting Speed (ft/s)	Migratory Season
Alewife	n/a	n/a	3	Spring
Blueback Herring	3	5	7	Spring

The dam is located at the head of tide; immediately downstream of the project limits, the existing channel slope of the Oyster River contracts and steepens as it flows over bedrock falls through the downstream Newmarket Road (NH 108) bridge. This reach through the bridge is characterized by vertical drops and a narrowed channel width, and during low tide it represents a potential barrier to fish passage. However, during high tide these falls are inundated and do not obstruct fish passage. Therefore, VHB only evaluated proposed channel design under high tide tailwater scenarios where migrating fish could be expected to access the channel above the bridge without difficulty.

VHB used the HEC-RAS hydraulic model to evaluate three flow scenarios and estimate water velocities through the project reach during the migration period. The scenarios evaluated were probabilistic flows during the April-June fish migration season representing the 5%, 50% (median), and 95% flows to capture a comprehensive range of potential conditions during fish migration. At this location, the high tide elevation ranges from 3.8 feet NAVD88 (Mean High Tide, or MHW) to 4.4 feet NAVD88 (Mean High Higher Tide, or MHHW); the HEC-RAS model assumes a tailwater elevation equal to the MHHW. For reference, the thalweg elevation at the upstream limit of the proposed reconstructed channel is 4.0 feet NAVD88.

The total length of the reconstructed channel is approximately 750 feet, corresponding to the section between HEC-RAS cross-sections 6701 and 7409. VHB assumed that this reach constitutes the greatest potential challenge to fish passage as the longest distance fish would pass at a sustained speed. It was used to evaluate fish passage success rates using the survivorship model provided to VHB by USFWS. Estimates of fish passage rates for the select target species is provided in **Table 3.8-3** below.

Table 3.8-3. Passage Rates for Select Fish Species – 750 ft reach

Flow Scenario	Flow (cfs)	Avg Velocity (fps)[1]	Max Velocity (fps)[1]	Proportion of Fish Passage at Average Velocity[2]	
				Alewife[3]	Blueback Herring[3]
Apr/June 5 %	4.9	0.2	1.0	0%	23%
Apr/June Median	30.7	0.7	1.6	0%	15%
Apr/June 95 %	139.7	1.9	2.7	0%	3%

Notes:

1 Avg velocity between HEC-RAS STA 6701 and 7409; Max velocity at HEC-RAS STA 7409 (upstream limit of reconstructed channel)

2 Water temperature assumed to be 55˚F (12.8 ˚C)

3 Alewife & Blueback Herring for length assumed to be 9.4 in (239 mm)

Although average velocities are relatively low, the survivorship model indicated that an uninterrupted 750-foot reach would be too long for acceptable survivorship rates for Alewife and Blueback Herring, with Alewife the limiting control on fish passage success at the site. This led VHB to use the survivorship model to estimate maximum distances Alewife could travel during the three flow scenarios to achieve acceptable passage rates. These distances are provided in **Table 3.8-4**.

Table 3.8-4. Maximum Passage Distance for Alewife

Flow	Average Velocity (fps)	Distance	Passage Rate	Distance	Passage Rate
Apr/June 5 %	0.2	85	70%	125	60%
April/June Median	0.7	75	70%	110	60%
Apr/June 95 %	1.9	58	70%	85	60%

The results from **Table 3.8-4** were used to determine the maximum spacing of boulder clusters and/or pools in the proposed channel, which would provide velocity shelters to allow successful passage of Alewife during the migration period. VHB determined the maximum distance between clusters to be 60 feet which would allow 70% passage of Alewife during the highest flows (Apr/June 95% flows). This would require at least 13 clusters of boulders evenly spaced along the full 750-foot length of reconstructed channel. The design should incorporate boulders arranged in clusters of 3 to 5, and spaced approximately 1 boulder diameter apart (3 to 4 feet). The boulder clusters would also be placed along the water surface fringe for the median and 5% flow to provide velocity shelters during various flow conditions.

The survivorship model provided by USFWS is conservative but does provide a useful tool in evaluating fish passage. Based on the use of this model, and recommended boulder cluster spacing, VHB estimates a 70% passage rate for Alewife through the cobble bed channel during 90% of flow conditions during the spring migration season.

3.8.3 Discussion of Potential Effects

Under *Alternative 3 – Dam Stabilization*, river herring and other anadromous fish would continue to pass upstream via the existing fish ladder as they presently do, given the inherent limitations of such ladders. The fish ladder is a standard design that is used throughout New England to successfully pass such fish upstream. However, water depths and hydraulics in and around such ladders typically do not provide optimal upstream fish passage. The modifications proposed under Alternative 3 would not alter the function or hydraulics of the existing fish ladder unless additional modifications were pursued as part of the overall project. Additionally, Alternative 3 would not directly improve water quality conditions in the impoundment – thought to be a component of the decrease in blueback herring return numbers – unless this alternative is combined with Option 1 – Pond Restoration Dredge. As discussed previously, however, Option 1 is very expensive, is unlikely to receive environmental permits, and would not be a permanent solution to the water quality issues.

Alternative 5 - Dam Removal would eliminate the barrier to upstream fish passage and address the declining water quality in Mill Pond and the upstream impoundment. These two effects would have a significant net benefit on fishery resources. This alternative involves restoring a more natural profile of the Oyster River at and immediately above the dam. This suggests that river herring will successfully ascend the restoration reach that would be exposed following dam removal, supporting a self-sustaining river herring run. This ability of anadromous fish to readily the project reach is consistent with the historic evidence that these species commonly ascended the river prior to dam construction.

3.9 Wildlife and Natural Communities

The area within and adjacent to the impoundment created by the Oyster River Dam at Mill Pond contains a number of habitat types, wetland systems, and conservation areas that allow for an abundance of wildlife. The types of habitats present and the potential effects on these communities is discussed in the following sections.

3.9.1 Habitat Types

VHB conducted research using the New Hampshire Wildlife Action Plan, NHGRANIT, and field inspections to review the existing wildlife and plant habitat conditions that occur within the Oyster River Dam impoundment area. Along with the open water conditions of the Oyster River, five different habitat land cover types are present throughout the impoundment. The landscape is primarily dominated by Appalachian oak-pine habitat, but temperate swamp, hemlock-hardwood-pine, wet meadow/shrub wetland, and grassland habitats are also present albeit in lesser abundance.

Appalachian Oak-Pine Habitat

The Appalachian oak-pine habitat within the project reach is found primarily in a large tract directly adjacent to both banks of the Oyster River and Mill Pond impoundment area. This habitat continues to stretch in a southwesterly direction beyond the project limits. Appalachian oak-pine habitat occurs mostly below 900 feet in elevation in Southern New Hampshire. In these forests, the climate is typically warmer and drier, elevations are lower, and the growing season is longer than more northern forest systems. This forest habitat is characterized by tree species with a distribution centered in the central Appalachian states further to the south, which are largely absent from other New Hampshire forests. These include several oak species such as white oak (*Quercus alba*), black oak (*Quercus velutina*), scarlet oak (*Quercus coccinea*), and chestnut oak (*Quercus montana*), as well as hickories (*Carya spp*.), sassafras (*Sassafras albidum*), pitch pine (*Pinus rigida*), and mountain laurel (*Kalmia latifolia*).

Temperate Swamp

Temperate swamp habitat is found dotted sporadically along the banks of the Mill Pond impoundment area, with a few slightly larger tracts found along the southeastern edge of the impoundment. The largest tract of temperate swamp is found within the section of the Oyster River located above the impoundment area.[25] This community starts after the confluence and continues along the Oyster River beyond the project limits.

Temperate swamp habitat consists of forested wetlands found primarily in central and southern New Hampshire, and corresponds to the temperate peat swamp, coastal conifer peat swamp, and temperate minerotrophic swamp systems. These swamps are typically found within isolated or stagnant basins with saturated, organic soils. The temperate swamp habitat is most frequently dominated by red maple (*Acer rubrum*), with an understory characterized by tall shrubs such as highbush blueberry (*Vaccinium corymbosum*) and winterberry (*Ilex verticillate*). Temperate swamps occupy roughly 2% of New Hampshire's land cover and provide critical functions such as flood control, pollutant filters, shoreline stabilization, sediment retention and erosion control, and food web productivity.

Hemlock-Hardwood-Pine

Hemlock-hardwood-pine habitat is found only in one small tract located on the southwestern side of the impoundment area, immediately adjacent to the edge of the bank. This small tract of habitat is surrounded on the other three sides by the Appalachian-oak-pine habitat. It is not uncommon to have such small representation of the hemlock-hardwood-pine habitat in this area of New Hampshire. This habitat is a transitional forest region that occurs between the northern hardwood-conifer forests to the north and at higher elevations and the Appalachian-oak-pine forests to the south and at lower elevations.

This transitional forest lacks most boreal species and central hardwood species that characterize the Appalachian-oak-pine habitat, but consists of many Alleghenian species such as white pine (*Pinus strobus*) and hemlock (*Tsuga canadensis*). Hemlock-hardwood-pine

[25] Additional discussion of wetlands systems is provided in Section 3.10.

forests are found throughout the state from the White Mountains on south at elevations below about 1,500 feet. This habitat commonly occupies areas with dry-mesic to mesic glacial till soils, as well as river terraces, which explains its occurrence along the Mill Pond impoundment area. The main matrix forest community that defines this habitat system is hemlock-beech-oak-pine forest, with red oak (*Quercus rubra*) typically abundant along with the white pine and hemlock trees. Variation in soils or landscape position within this system explains why such great variation can occur within the community composition of this habitat.

Hemlock-hardwood-pine habitat is the most widely distributed forest type in New Hampshire, covering approximately 34% of the state's land area. This habitat type supports over 140 vertebrate species in the state.

Wet Meadow/Shrub Wetland

Wet meadow/shrub wetland habitat is found in small patches throughout the impoundment area along a portion of the Oyster River located above the impoundment. Most of these small patches are located along the edge of river banks and then continue inland. However, there is one large tract of standalone wet meadow/shrub wetland habitat located away from the impoundment area on the eastern edge of the project area.

The wet meadow/shrub wetland habitat found within the project area corresponds to the drainage marsh-shrub swamp and sand plain basin marsh systems. Drainage marsh-shrub swamp systems have a broad flood regime gradient that is often affected by the presence or abandonment of beaver activity. The trophic regime of these systems is moderately to strongly minerotrophic, with soils consisting of poorly drained decomposed muck and minerals with a pH between 5 and 6.

The drainage marsh-shrub swamp system is often grouped into three broad habitat categories that include meadow marshes (wet meadows), emergent marshes, and scrub-shrub wetlands. Meadow marshes are often dominated by herbaceous vegetation, particularly sedges, that are usually less than 1 meter in height and saturated for long periods of the growing season, but seldom flooded. Emergent marshes are dominated by emergent herbaceous vegetation and have a water table that is generally at or above the surface throughout the year, but can fluctuate seasonally. Shrub swamps, on the other hand, consist of woody vegetation that is predominately saplings and shrubs.

Eighteen species of conservation concern in the state of New Hampshire rely on the wet meadow/shrub wetland habitat, while many other species use the habitat for foraging, nesting, breeding, and cover. Wetland habitats such as this provide a number of critical functions similar to the temperate swamp habitat, such as flood control, pollutant filters, shoreline stabilization, sediment retention and erosion control, and food web productivity. The wet meadow/shrub wetland habitat is widespread throughout New Hampshire, with a high volume in southern and eastern New Hampshire.

Grassland

Grassland habitat is found in three locations along the far reaches of the project area at the southern edge of the impoundment and the eastern edge of the Oyster River location above the impoundment. The grassland habitat tracts are found adjacent to the Appalachian-oak-pine, wet meadow/shrub wetland, and temperate swamp habitats, but are not immediately abutting the open water.

Grassland habitats include hayfields, pastures, fallow fields, cropland, and sedge-dominated meadows. Native plant species typical of northeastern grassland include goldenrod (*Solidago spp*.), aster (*Symphyotrichum spp*.), big bluestem (*Andropogon gerardii*), little bluestem (*Schizachyrium scoparium*), and meadowsweet (*Spirea alba*).

In New Hampshire, grasslands serve as primary breeding and nesting grounds for several bird species of conservation concern including Northern Harrier (*Circus cyaneus*), Upland Sandpiper (*Bartramia longicauda*), Grashopper Sparrow (*Ammodramus savannarum*), Horned Lark (*Eremophila alpestris*), Vesper Sparrow (*Pooectes gramineus*), and Eastern Meadowlark (*Sturnella magna*). The value of some grassland habitats is increasingly recognized for pollinators like the Monarch butterfly and bumble bees. These habitats provide important foraging habitat to a wide range of wildlife, particularly in the non-breeding season.

NH Ranked Habitats

The Wildlife Action Plan Ranked Habitat system was created to compare habitat condition data in a meaningful way across the entire landscape of New Hampshire. This system ranks habitats in three tiers: 1, the highest ranked habitat in the state, 2, the highest ranked habitat in the region, or 3, supporting landscape. The ability of wildlife to use habitats can be affected by numerous features, some of which include habitat size, proximity to other habitats, land development, flooding, and pollutants. Taking these features into account, a method was developed to assess the relative ecological condition of habitats using statewide GIS data that represents species diversity, landscape context, and human impacts. The data was normalized to a 100-point scale and averaged to create a general habitat condition score, which was then used for the ranking (Wildlife Action Plan, 2015).

The Highest Ranked Habitat in the State is comprised of the top 15% of all terrestrial and wetland habitats. Because New Hampshire has a wide range of ecological conditions, both natural and human-altered, this system divided the state into biological regions to better compare the habitat data. The Highest Ranked Habitat in the Region includes the top 30% of all terrestrial and wetland habitats. Because the conditions of top-ranked habitat patches may deteriorate over time if the surrounding area is degraded, the third tier ranking of Supporting Landscape was created by including the top 50% of all habitats in the biological region, as well as the top-ranked forest blocks identified by the Nature Conservancy.

Using this GIS data and the Ranked Habitats map, it was determined that all three ranked habitats in New Hampshire are present within portions of the Mill Pond impoundment area. Most of the landscape surrounding the Oyster River Dam and impoundment area is ranked as either (Tier 1) Highest Ranked Habitat in the State or (Tier 3) Supporting Landscape, with very little area concluded to be (Tier 2) Highest Ranked Habitat in the Region. The Tier 1 habitats are primarily located either within the Oyster River itself or immediately adjacent to the water's edge. The Tier 3 habitats, in contrast, are more terrestrial and for the most part immediately border the Tier 1 habitats. This data helps to show that the habitats surrounding the Oyster River Dam are ecologically significant and diverse.

3.9.2 Discussion of Potential Effects

Appalachian Oak-Pine Forest, Hemlock-Hardwood Pine Forest & Grassland

The Appalachian oak-pine forest, hemlock-hardwood pine forest, and Grasslands are upland, habitats; the Oyster River does not have a major, direct influence on the occurrence of these habitat types. Implementation of either *Alternative 3 – Dam Stabilization* or *Alternative 5 – Dam Removal* is unlikely to have significant direct impact to upland habitat and wildlife populations. The largest threat to wildlife habitat in the northeast is the excessive fragmentation of undisturbed blocks of land associated with increased urbanization, which is not a significant factor in the decision to remove or modify the dam.

Temperate Swamp and Wet Meadow/Shrub Wetland

Impacts to temperate swamp and wet meadow/shrub swamp habitats would result from the dam removal by lowering the surface water elevations within the Oyster River, therefore affecting the adjacent wetland habitats. Open water habitat for waterfowl would likely decrease substantially, but not enough to eliminate the use of the area by this group of species. Use of the river by opportunistic animals such as deer and raccoon, which are utilizing the upland forests and grasslands, is not expected to change significantly. Downstream of the NH 108 Bridge, the project is not likely to translate into wildlife habitat impacts.

Whatever impacts may occur would likely be offset by beneficial impacts. Beneficial impacts associated with wildlife habitat would result from the presence of increased numbers of forage fish, as represented by adult and juvenile river herring, in the Oyster River upstream of the dam. Changes to the fish populations and species assemblages within the river would benefit wetland-dependent species such as otter, osprey, and kingfisher by providing a larger and more diverse forage base. In summary, it is expected that the overall effects of this alternative on wildlife would be minor and would be offset by the benefits of restoring upstream migration to anadromous fish species.

3.10 Wetlands

Several freshwater wetlands are present within the Oyster River impoundment; some of these wetland systems depend to some degree on the backwater conditions created by the dam. An analysis of potential effects on these systems was developed using GIS analysis, as described below.

3.10.1.1 Existing Conditions

VHB conducted research using various databases such as the National Wetland Inventory and NHGRANIT to map the existing wetland habitats present along the Oyster River, and supplemented these sources with field observations. (See **Figure 3.10-1** and **Table 3.10-1**.) Several wetland systems are present within the general project area, primarily within Mill Pond and along the southern portion of the impoundment. The wetlands present are classified as “palustrine” or freshwater systems, with the three primary wetland types being freshwater emergent wetlands and freshwater forested wetlands, and scrub-shrub wetlands. These wetland types can be further classified based on characteristics such as soil saturation, dominant vegetation, hydrology, and other characteristics.

Table 3.10-1. Wetlands Adjacent to the Mill Pond Impoundment, by Cowardin Classification

Cowardin Classification	Corresponding Wetland Description
PABHh	Aquatic bed wetlands, permanently flooded, diked/impounded
PEM1Ch	Emergent wetlands, herbaceous hydrophytes, persistent, seasonally flooded/saturated, diked/impounded
PEM1Eh	Emergent wetlands, herbaceous hydrophytes, persistent, seasonally flooded/saturated, diked/impounded
PEM1E	Emergent wetlands, broad-leaved deciduous, herbaceous hydrophytes, persistent, seasonally flooded
PSS1E	Scrub-shrub, dominated by broad-leaved deciduous plants, seasonally flooded/saturated
PEM1Fh	Emergent wetlands, persistent, semi-permanently flooded, diked/impounded
PFO1/4E	Forested, dominated by needle-leaved evergreen and broad-leaved deciduous plants, seasonally flooded/saturated
PSS1Eh	Scrub-shrub, dominated by broad-leaved deciduous plants, seasonally flooded/saturated, diked/impounded
PFO1E	Forested, broad-leaved deciduous, seasonally flooded/saturated

Note: The intent of this table is to provide a legend to the Cowardin classification code in the left column, which are deciphered in the right column.

As can be seen in this table, multiple wetland systems within the impoundment area were either created by the dam impoundment or exist to some degree because of the impoundment. These wetlands are primarily located immediately adjacent to the banks of Mill Pond and are indicated with the “h” modifier.

Aquatic Bed Habitat (PABHh)

Aquatic bed habitats are areas that are permanently flooded or standing water areas that are dominated by plants that grow principally on or below the surface of the water for most of the growing season. Vegetation typically found within these habitats include pickerelweed, (*Pontederia cordata*), water lilies (*Nymphaea* spp.), Bladderwort (*Utricularia vulgaris*), coontail/hornwort (*Ceratophyllum demersum*), milfoil (*Myriophyllum heterophyllum*), and waterweed (*Elodea canadensis*) (Drociak, 2008). Aquatic bed habitats are usually bordered by emergent marshes or unconsolidated deepwater habitats.

Within the project area, there are three separate aquatic bed habitat units, all of which have been formed by the impoundment of the Oyster River. Two of these aquatic bed habitats are immediately adjacent to the Oyster River Dam within Mill Pond, while the third aquatic bed habitat is located at the top of the impoundment area.

Emergent Wetlands (PEM)

Emergent wetlands are freshwater wetlands (marshes and wet meadows) with a tree and shrub coverage of less than 30 percent of the area, but where the total cover of emergent vegetation in the wetland is 30 percent or greater. The vegetation in this habitat is present for most of the growing season, with a dominance of herbaceous and grass-like plants. Emergent wetlands encompass both freshwater marshes and wet meadows. Freshwater marshes are seasonally flooded wetlands commonly saturated at or near the surface when not flooded, whereas freshwater wet meadows are seldom-flooded wetlands that are saturated throughout the growing season.

Freshwater emergent marshes are usually dominated by broad-leaf and narrow leaf cattail (*Typha latifolia* and *T. angustifolia*), wool grass (*Scirpus cyperinus*), spike rush (*Eleocharis* spp.), shallow and pointed broom sedges (*Carex lurida* and *C. scoparia*), soft rush (*Juncus effusus*), three-square sedge (*Scirpus americanus*), reed-canary grass (*Phalaris arundinacea*), sphagnum moss. American elderberry (Sambucus canadensis), swamp milkweed (*Asclepias incarnata*), and Joe-pye-weed (*Eupatorium* sp.), while not as dominant, can also found in some emergent marsh areas.

Forested Wetlands (PFO)

Forested wetlands within the project area consist primarily of deciduous forested swamps, with all but two having a Needle-Leaved Evergreen component (i.e., PFO1/4). Wetlands within this split-subclass are dominated by both deciduous, broad-leaved trees, such as red maple, as well as young, needle-leave evergreen trees such as hemlock. Surface water is present for extended periods (generally for more than a month) during the growing season, but is absent by the end of the season in most years. When surface water is absent, the substrate typically remains saturated at or near the surface.

Dominant vegetation in the mixed deciduous/evergreen forested swamp (PFO1/4E) consists of red maple, white pine, eastern hemlock (*Tsuga canadensis*), American elm *(Ulmus americana*), white ash *(Fraxinus americana)*, and yellow birch (*Betula alleghaniensis*) in the tree canopy; glossy buckthorn *(Rhamnus frangula)*, northern arrow-wood (*Viburnum recognitum*), highbush blueberry *(Vaccinium corymbosum)*, and nannyberry (*Viburnum Lentago*) in the shrub layer; and cinnamon fern *(Osmunda cinnamomea)*, sensitive fern *(Osmunda sensibilis)*, skunk cabbage *(Symplocarpus foetidus)*, goldthread (*Coptis groenlandica*), poison ivy *(Toxicodendron radicans)*, and sphagnum moss (*Sphagnum* sp.) in the herbaceous layer.

Forested wetlands usually occur either in isolated depressions or within the floodplain of a river. As such, these wetlands in the project area are located along the southern banks of the impoundment and along the Oyster River floodplain above the impoundment and prior to the river confluence.

There are two small forested wetlands (PFO1E) adjacent to the impoundment. Dominant vegetation in these PFO1E wetlands typically consist of red maple *(Acer rubrum)* and white ash *(Fraxinus americana)* overstory; common winterberry *(Ilex verticillata)*, highbush blueberry, and glossy buckthorn shrub layer. Cinnamon fern, jewelweed *(Impatiens capensis),* sensitive fern, royal fern, poison ivy, skunk cabbage, and sphagnum moss provide herbaceous ground cover.

Shrub Wetlands (PSS)

Freshwater wetlands with less than 30 percent tree areal coverage and greater than 30 percent shrub aerial coverage are classified as PSS. Shrub wetlands also include wetlands where trees and shrubs, individually, cover less than 30 percent of an area, but in combination provide 30 percent or more areal coverage. These shrub wetlands generally occur as seasonally flooded, densely vegetated, fringing habitats bordering forested and emergent wetlands.

There are two shrub wetlands located within the project area: one located adjacent to Mill Pond and situated between two emergent wetlands, and the other located inland off the eastern side of the impoundment area. Scrub-shrub wetlands are dominated by woody vegetation less than 6 meters tall. This includes true shrub species, young saplings, and trees or shrubs that are small or stunted because of environmental conditions. Common species within these wetlands are highbush blueberry, glossy buckthorn, silky dogwood (*Cornus amomum*), speckled alder (*Alnus rugosa*), honeysuckle (*Lonicera spp.*), and multiflora rose (*Rosa multiflora*), with skunk cabbage, sensitive fern, cinnamon fern, and poison ivy in the herbaceous layer.

3.10.2 Discussion of Potential Effects

It is generally accepted that the ecology of riparian systems benefit from a natural flow regime. Alteration to the natural flow regime can occur by reducing or increasing flows, altering seasonality of flows, changing the frequency, duration, magnitude, timing, predictability and variability of flow events, altering surface and subsurface water levels and changing the rate of rise or fall of water levels. Alteration of the natural flow regimes of rivers is recognized as a factor that can impact biological diversity and ecological function in aquatic ecosystems, including floodplains and their associated wetlands.[26]

Alternative 3 – Dam Stabilization would maintain the current hydraulic characteristics of the existing dam. Under this alternative, there would be no permanent impacts to wetlands either upstream or downstream of the dam.

If *Option 1 – Pond Restoration Dredge* is implemented as part of the dam stabilization alternative, then approximately 2.4 acres of freshwater emergent and aquatic bed wetlands would be directly impacted, converting those areas from wetland to open water habitat (see **Table 3.10-2**). This impact would reduce the structural diversity of the Mill Pond system, and would decrease plant and animal diversity on a local scale. Beneficial effects on dissolved oxygen levels and water temperatures would be associated with deepening the pond, however. (See further discussion in Section 3.5.) Despite these benefits, the NHDES Wetlands Bureau has indicated that obtaining a permit for a freshwater dredge of this size would be

[26] See, for example, Poff, *et al.* (1997).

difficult or impossible (David Price, NHDES Wetlands Inspector, personal communication, July 31, 2020.)

Table 3.10-2. Wetland Impact, Option 1

Cowardin Classification	Approximate Impact (acres)
PABHh	0.9
PEM1Eh	1.5
TOTAL	**2.4**

Source: VHB analysis of field adjusted National Wetlands Inventory (NWI) mapping.

As discussed in Section 3.2, *Alternative 5 – Dam Removal* will substantially reduce surface water depth and width within Mill Pond and the greater impoundment area.

These changes would affect wetlands surrounding the impoundment that have a direct hydraulic connection to the Oyster River. The influence of the dam removal will be more pronounced in wetlands close the dam than those at the top of the impoundment, since the magnitude of hydraulic change decreases upstream. However, many of the wetland systems depicted in **Figure 3.10-1** depend to some degree on the backwater conditions created by the dam. Other wetland systems, such as the aquatic bed habitat found within Mill Pond, rely almost entirely on the artificially increased surface water elevations created by the dam.

While quantifying the precise amount of wetland affected is difficult at this level of study, a preliminary inventory of wetlands within the immediate project area was completed to develop information on the population of wetlands that could be affected by dam removal. In total, there were 15 individual wetland units adjacent to the impoundment that would be directly affected by the dam removal. These wetlands were all palustrine systems and include aquatic bed, emergent wetlands, scrub-shrub wetlands, and freshwater forested wetlands. **Table 3.10-3** provides an estimate of the amount of wetlands that would experience some hydrological change.

Table 3.10-3. Wetlands Adjacent to the Oyster River Dam Impoundment

Cowardin Classification	Affected Area (Acres)	Expected Habitat/Hydrological Change
PABHh	6.1	Shift to PEM1E or E2EM
PEM1Ch	0.2	Shift to PEM1B
PEM1Eh	2.5	Shift to PEM1B
PEM1E	0.5	Shift to PEM1B
PEM1Fh	0.3	Shift to PEM1E or PEM1C
PFO1/4E	0.7	Shift to PFO1/4B
PSS1Eh	0.3	Shift to PSS1B or PFO1E
PFO1E	0.2	Shift to PFO1E, potential upland
TOTAL	**10.8**	

Source: VHB analysis of field adjusted NWI mapping.

The “affected areas” shown in **Table 3.10-3** should not be interpreted as an amount of direct wetland impact or loss. Rather, reduction in surface water contours following dam removal would lead to a shift in the affected wetland’s hydrologic regime which would, in turn, result in the conversion of one wetland type to another. It can be predicted that removal of the dam would shift wetland cover types such that aquatic bed communities would develop characteristics of emergent marsh systems, scrub-shrub wetlands would acquire an overstory of red maple and perhaps silver maple and swamp white oak, and understory species would shift to those characteristics of forested wetlands.

Only at the very margins of the forested systems is there any potential loss of wetland acreage as marginal areas may be converted to upland. These changes would also likely occur over ecological time and would not likely be readily detectable for years to decades in the future.

Loss of wetlands at the margin would likely be at least offset by the development of new riparian aquatic bed, emergent, and scrub-shrub systems within the area currently inundated by the dam. With the drawdown of the impoundment, new surface area will be available to colonizing wetland plant species in areas currently submerged, which would eventually form new wetland habitat. Additionally, there is potential for new beaver activity to occur in wetlands adjacent to the river, which is also likely to offset some of these wetland shifts. Thus, while the dam removal would result in a loss of open water habitat, the overall effect of the removal on wetlands is likely to result in no net or a marginal loss.

In addition to the changes related to the loss of the impoundment, ecological changes related to changes in tidal conditions must also be considered. The dam currently represents a barrier to the upstream movement of tidal waters, often referred to as the “head of tide.” If the dam was removed, the influence of tidal waters would extend farther upstream creating additional tidal habitat. As discussed in Section 3.2, if the dam were removed, high tide would reach at least 550 feet further upstream into what is currently Mill Pond. Depending on the design of the active channel restoration, the influence of tidal waters at high tide would extend further upstream, as much as 2,250 feet upstream of the dam’s current location, well into the Middle Impoundment reach.

Based on the existing bathymetry data, it appears that the upstream migration of tidal inflow immediately following dam removal would be confined primarily within the main river channel. The river channel within the Mill Pond reach is confined within a submerged channel with top of bank limits that are generally at elevations of 6 to 8 feet (NAVD88). (See **Figure 3.10-2**.) Based on the estimated Mean Higher High Water (MHHW) elevation, portions of the dewatered pond that have bottom elevations of 4.4 feet or less would likely be inundated or influenced by tidal waters on a daily basis. Occasionally, the tidal waters may extend as high as 5.4 feet or more based on the highest observable tide line. In general, the new tidally-influenced area within the potentially dewatered pond is anticipated to be contained within the eastern half of the main river channel, based on the bathymetry data.

However, tidal action on adjacent wetland areas may occur if the adjacent dewatered pond bed subsides, and if sea level rise occurs to a degree that inundates areas not currently subject to tidal flow. Data published by Wake, *et al*. (2019) and the NH Coastal Flood Risk Science and Technical Advisory Panel (2019) indicates that there is a 67% probability that relative sea levels in coastal NH will rise between 1.0 foot and 2.9 feet by the year 2100, and a 5% chance that the rise will be as much as 3.8 feet.[27] Under these scenarios, much of the area occupied by Mill Pond would be subject to tidal flow, and would likely be converted to estuarine habitat types (brackish or salt marsh habitat). (**Figure 3.10-2**)

The area subject to tidal action on a daily basis would eventually acquire some of the characteristics of the portion of the Oyster River located immediately downstream of the dam, which is classified as a subtidal estuarine system with an unconsolidated bottom (E1UBL). Within this habitat type, brackish tidal water enters from the ocean, while the river carries nutrients, organic matter, and sediments to the downstream estuaries. These inputs combine to make estuaries extremely productive habitats with a great abundance of plants and animals. Outside of the immediate river channel, existing salt tolerant species observed downstream of the dam could provide a seed source for salt tolerant vegetation to become established in the new tidal influenced zone. The existing salt tolerant vegetation species include saltmeadow cordgrass (*Spartina patens*), prairie cordgrass (*Spartina pectinata*), blackgrass (*Alopecurus myosuroides*), and saltmarsh bulrush (*Scirpus robustus*).

3.11 Invasive Species

Field review for populations of existing invasive species communities along the Mill Pond impoundment has been continuously conducted by the Town of Durham Land Stewardship Committee in order to identify areas that have been or may be colonized by invasive species, and act quickly to remove them (Ellen Snyder, personal communication, February 14, 2020). Invasive species that have been found along Mill Pond include glossy buckthorn (*Frangula alnus*), multiflora rose (*Rosa multiflora*), bush honeysuckle (*Lonicera spp*.), Asiatic bittersweet (*Celastrus orbiculatus*), autumn olive (*Elaeagnus umbellata*), Japanese barberry (*Berberis thunbergii*), and Japanese knotweed (*Reynoutria japonica*). Areas throughout the Mill Pond impoundment that are currently inundated by water but will become dewatered if the dam removal option were chosen and are the locations that would most likely be impacted by new populations of invasive species.

Alternative 3 – Dam Stabilization is not expected to provide opportunity for the expansion of invasive species in the project area. This is because this alternative is designed to maintain the current pool elevation under normal flow conditions. Even if the Pond Restoration Dredging were included with this alternative, there would still be minimal opportunity for the further expansion of terrestrial invasive species.

However, *Alternative 5 – Dam Removal* would lower the surface water depth and surface water width of the impoundment. Decreased surface water elevation that would occur with the dam removal option would expose currently flooded lands. These areas would initially have no vegetation and would resemble mud flat habitats, but vegetation is expected to quickly grow on this bare ground. Typically, these mudflats will become fully vegetated within the first growing season. It should be noted, though, that invasive species are often "pioneer species"— ones that tend to quickly colonize disturbed or bare soils. Thus,

[27] These relative sea level rise projects are based on the RCP 4.5 global greenhouse gas concentration scenario, whereby carbon emissions begin to stabilize and then slowly decline after 2050, with a corresponding global temperatures rise of 2.4ºC (4.3ºF) (likely range 1.7 - 3.2ºC) by 2100, compared to 1850-1900. See Moss, *et al.* (2010) for further description.

depending on the underlying soils and seed bank, it could be expected that exposing previously inundated soils could result in colonization of these areas by invasive plants.

While the management of invasive plant species should be addressed further in the development of this alternative, it is important to understand that it is not reasonable to expect the complete control or eradication of invasive species. Rather, the goal should be limiting the spread of these plants to allow a diversity of native plant species to become well established and perpetuating.

Four common methods have been used to control and reduce the spread and presence of invasive species within wetland communities, such as the Mill Pond impoundment. The first three methods include mechanical, chemical and environmental control. The fourth method, biological control, is more complicated to implement as it usually involves the use of herbivorous insects to reduce specific invasive species.

Herbicides can be effective and have been used to control invasive species in New Hampshire marshes, but their use can raise health concerns, especially where wetlands intersect residential neighborhoods and developed areas. Two broad-spectrum herbicides, glyphosate and imazapyr, are currently considered safe to use in an aquatic environment, although recent data indicates potential adverse effects on amphibian populations, suggesting that this method be used very conservatively. However, within the Milne Tract conservation area located along the banks of Mill Pond, no herbicides are allowed to be used, which limits the potential use of this method.

Mechanical removal involves the cutting, plowing, or grading of the impacted habitat. It is generally most practical and effective in areas with small pockets of invasive species, such as Japanese knotweed. Mechanical removal is common; however, it does require a substantial investment of labor; its short-term effectiveness has not always met expectations; and it often requires maintenance. Mechanical treatments can be used most effectively used following an herbicide treatment to remove dead stems and promote native plant growth. This also aids in the identification of new invasive growth for subsequent herbicide spot treatments.

Environmental control involves decreasing the vitality of the invasive population by manipulating certain elements of the surrounding environment such as soil moisture (e.g., temporary flooding) and pH, or the amount of sunlight through the over-story. This has proven to be effective in controlling invasive populations, but it should be used in combination with other techniques to improve its effectiveness.

Biological control is achieved through the use of herbivorous insects and is regarded as one of the most efficient, sustainable, and cost-effective strategies to date as a means of reducing the species to a level where it is still present but not dominant within a wetland system. The insects remain in the wetland system indefinitely making long-term control possible.

The Town of Durham Land Stewardship Committee has been actively working to reduce invasive species populations around the Mill Pond impoundment over recent year. This work has included hand-cutting Japanese knotweed stands, using herbicides to treat knotweed and other present invasive species at various locations (other than Milne Tract), hosting volunteers to hand-cut/pull invasive plants out of the Milne Tract Nature Sanctuary, removing several dozen Norway Maples, and planting native shrubs throughout the impoundment area to try to limit the spread of invasives. In addition to this work, in 2020 the Town planned to engage summer interns to map all invasive species around Mill Pond using a GIS-platform, as well as create a town-wide Japanese knotweed map and control plan (Ellen Snyder, personal communication, February 14, 2020). The hope is that these maps will help lead to the development and implementation of an overall invasive species control plan around Mill Pond and upstream on Pettee Brook, College Brook, and the Oyster River. However, if the dam removal alternative is chosen to move forward, additional planning will need to occur regarding how best to control the possible spread of invasive species.

3.12 Rare Species and Natural Communities

There are numerous state-list protected species of plants, vertebrates, and natural community types located within and adjacent to the impoundment. To determine whether there are any substantial effects on these resources, the NH Natural Heritage Bureau (NHNHB) was consulted. The NHNHB manages threatened and endangered species cooperatively with the New Hampshire Fish and Game Department (NHFGD). The NHNHB maintains a database of information on the distribution and abundance of these rare species and plant communities from the published scientific literature, from files of area scientists, and from various field surveys. This database provides information on the present, past, or probable existence of such species for improved land use planning and environmental impact assessment. The results of this review are presented below.

3.12.1 Existing Conditions

Table 3.12-1 identifies the rare plants, rare vertebrates, and exemplary natural communities that the NHNHB has on record. According to the NHNHB database, there are six rare plant species, six rare vertebrate species, and one natural exemplary community located within the greater project area. However, note that site-specific searches for these species have not been conducted recently. As such, some of the species listed in this review may not be located within the impoundment area. Each of the species or communities listed is briefly described, and its general location above or below the Oyster River Dam is provided.

3.12.2 Discussion of Potential Effects

The primary effect of the removal or modification of the Oyster River Dam would be a reduction in surface water depth and width within the Mill Pond impoundment, resulting in a transformation of habitat from open water and aquatic bed habitat to predominantly emergent marsh. Additionally, given that dam removal would eliminate a tidal barrier, the upstream migration of the tide line would increase salinity conditions upstream of the former dam site, such that the wetlands adjacent to the restored river would become brackish. The likelihood of impacts from these changes are discussed below for each of the populations or communities located within the study area.

Table 3.12-1. Rare Species and Exemplary Natural Communities Located within Project Study Area[1]

Common Name	Scientific Name	State Listing	Federal Listing	Location
Vertebrate Species				
Atlantic Sturgeon	*Acipenser oxyrinchus*	T	T	DS
Shortnose Sturgeon	*Acipenser brevirostrum*	E	E	DS
Banded Sunfish	*Emneacanthus obesus*	SC	--	US
Spotted Turtle	*Clemmys guttata*	T	--	US
Swamp Darter	*Etheostoma fusiforme*	SC	--	US
Blanding's Turtle	*Emydoidea blandingii*	E	--	US
Plant Species				
Arctic bur-reed	*Sparganium natans*	T	--	US
Beck's water-marigold	*Bidens beckii*	T	--	US
Ivy-leaved duckweed	*Lemna triscula*	E	--	US
Great bur-reed	*Sparganium eurycarpum*	T	--	US
Lake quillwort	*Isoetes lacustris*	E	--	US
Marsh horsetail	*Equisetum palustre*	E	--	US
Exemplary Natural Communities				
Sparsely Vegetated Intertidal System		--	--	DS

Notes:
1 Data is from the New Hampshire Natural Heritage Bureau
2 State Listing indicates the legal status of the plant or animal species in NH. SC = Special Concern; T = Threatened; E = Endangered. Exemplary Natural Communities are not legally protected and therefore not assigned a listing status.
3 Location refers to whether the species population or community is located upstream

3.12.2.1 Potential Impacts to Downstream Populations

Section 3.2 of this study presents a detailed discussion of the hydraulic changes associated with *Alternative 3 – Dam Stabilization* and *Alternative 5 - Dam Removal*. As demonstrated in the hydraulic modeling results, there would be little or no change in surface water depth or flow velocity within the downstream tidal portions of the Oyster River beyond the dam. The tidal influence of the Oyster River will serve to maintain existing hydraulic characteristics of this reach under all flow conditions. Thus, there is not expected to be any permanent impacts to populations located downstream of the dam.

Because of the lack of change to downstream hydraulic conditions, there are no expected impacts to the sparsely vegetated intertidal natural community, or the following rare species noted within the NHNHB report:

› Shortnose Sturgeon (*Acipenser brevirsotrum*): Shortnose sturgeon live in rivers and coastal waters. They hatch in the freshwater of rivers and spend most of their time in the estuaries of these rivers. Unlike Atlantic sturgeon, shortnose sturgeon tend to spend relatively little time in the ocean. When they do enter marine waters, they generally stay close to shore. In the spring, adults move far upstream and away from saltwater, to spawn. After spawning, the adults move rapidly back downstream to the estuaries, where they feed, rest, and spend most of their time. Given these habitat preferences, the dam removal may benefit shortnose sturgeon.

- Atlantic Sturgeon (*Acipenser oxyrinchus*): Atlantic sturgeon live in rivers and coastal waters from Maine to Florida. Hatched in the freshwater of rivers, Atlantic sturgeon head out to sea as juveniles, and return to their birthplace to spawn, or lay eggs, when they reach adulthood. Given these habitat preferences, the dam removal may benefit Atlantic sturgeon.

3.12.2.2 Potential Impacts to Populations in Oyster River Above Impoundment

Much like the downstream tidal portion of the Oyster River, the area of the Oyster River located above the impoundment will not see any noticeable hydraulic impacts from a dam removal. Because the characteristics of the river, including surface water depth and width, will remain relatively the same, the habitat conditions would remain the same. Thus, there are no expected impacts on the following species noted within the NHNHB report:

- Marsh Horsetail (*Equisetum palustre*): Marsh horsetail is typically found in fens, alder tickets, wet sedge meadows, lakes, marshes, or wetland margins. This species usually occurs in wetlands, but occasionally is seen growing in non-wetland environments. Marsh Horsetail is distinguished from other species in the genus by having whorled branches in which the first internode of the branch is shorter than the adjacent sheath. A population of this species if found throughout the portion of the Oyster River located just above the impoundment. This species is state-endangered.
- Arctic Bur-reed (*Sparagnium natans*): The state-threatened Arctic bur-reed is found in shallow, still or slow-moving water, including pools in peatlands. A population of Arctic bur-reed is found throughout the portion of the Oyster River substantially above the impoundment, and would be unaffected.

3.12.2.3 Potential Impacts to Populations within the Mill Pond Impoundment

As discussed throughout this study, removal of the dam would change the depth, width and flow velocities within the Mill Pond impoundment. The surface water width and depth would decrease substantially, resulting in the conversion of Mill Pond into emergent wetland habitat as the Oyster River would once again follow its natural path. With the impoundment width and depth decreasing significantly, much of the habitat that is currently inundated would transition to a wet marsh habitat and emergent wetland system, and tidal conditions would increase salinity in the system. As such, the populations listed below that were found to occur within the impoundment area may be affected by dam removal.

- Beck's Water-Marigold (*Bidens beckii*): Beck's water-marigold is a species of flowering plant in the daisy family that occurs in the shallow water of lakes or slow-moving rivers; an "extremely abundant" population was reported in Mill Pond in 1995. In flower, it is instantly recognizable for its showy yellow blooms that sit above the water's surface. Its submerged leaves are highly divided and feathery, whereas its aerial leaves are simple and toothed. This species can be usually found amongst other emergent vegetation, and needs a wetland habitat to survive. Threats to all aquatic plant species include significant changes in water levels. As this species is located within Mill Pond, the surface water reduction occurring with dam removal would negatively impact this species. However, because this plant is located on the fringes of the pond and can survive in emergent wetland habitats, it may be able to persist following dam removal, albeit in reduced numbers.

- Lake Quillwort (*Isoetes lacustris*): Lake quillwort is a perennial, nonflowering aquatic plant species that lives in standing water. It is usually found on stony or sandy bottoms of clear ponds, growing at a depth of anywhere between 2 inches to 10 ft of water. This species was previously observed in Mill Pond, but has not been documented since 1978. As with other species of aquatic plants, a decrease in surface water would threaten this species survival within the project area. Because this species grows on the bottom of ponds, the surface water reduction occurring as a result of dam removal would impact the population if found within the project area.
- Great Bur-reed (*Sparganium natans*): Great bur-reed is a perennial emergent species, closely related to the ubiquitous buttonbush, and is limited to deep marsh habitat which is permanently saturated to flooded. The leaves are alternate, stiff and erect or limp and linear. The plant is listed as Threatened in NH, but is globally secure. A population of Great Bur-reed was documented within Mill Pond in 1995 in an area consisting of aquatic bed and emergent wetland habitats. This species would potentially be impacted by the dam removal, as the surface water levels would decrease.
- Ivy-Leaved Duckweed (*Lemna trisulca*): Ivy-leaved duckweed is an aquatic plant usually found within lakes or ponds. This species can be found among other emergent vegetation or matted together in floating mats on the tops of surface water. Ivy-leaved duckweed is a state-endangered species and was last found in Mill Pond in 1998. Because this species requires a pond-like environment with standing water as its habitat, it is not likely to persist following a dam removal and subsequent decrease in water depth and width.
- Banded Sunfish (*Enneacanthus obesus*): Banded sunfish is a small sunfish with a rounded caudal fin, vertical stripes, and an iridescent green blotch behind the eye. Banded sunfish prefer stands of submerged aquatic vegetation along the margins of lakes, ponds, and slow flowing rivers. They are often found upstream in beaver ponds and small wetlands. These smaller stream environments provide a refuge from predators. Banded sunfish is a species of special concern within New Hampshire, and is found in various locations throughout the impoundment area and near the confluence of the Oyster River. Although habitat for this species within the impoundment area may be affected if the dam were removed, it would likely persist within the upstream portions of the river following dam removal.
- Swamp Darter (*Etheostoma fusiforme*): Swamp darters are a very small fish with grayish to olive colored markings. Swamp darters are usually found in vegetated backwaters and pond shorelines, but they may also inhabit gravel or sandy sections of river and streams. However, swamp darters have also been seen in larger rivers. This species is listed as a species of special concern in New Hampshire, and is found both within the impoundment area of Mill Pond and father upstream along the Oyster River. Although habitat for this species within the impoundment area may be affected if the dam were

removed, it would likely persist within the upstream portions of the river following dam removal.

Two other species listed within the NHNHB report are Blandings Turtle (*Emydoidea blandingii*) and Spotted Turtle (*Clemmys guttata*). Although these species are found in the greater vicinity of the project location, they are far enough out of the range of impact from the project that they will not be affected.

4

Literature Cited

Bigelow, H.B. and W. C. Schroeder. 1953. Fishes of the Gulf of Maine. Fishery Bulletin 74 Fishery Bulletin of the Fish and Wildlife Service; Volume 53. Contribution No. 592, Woods Hole Oceanographic Institution, United States Government Printing Office – Washington.

Cowardin, L.M., V. Carter, F.C. Golet and E.T. LaRoe. 1979. Classification of wetlands and deepwater habitats of the United States. US Fish and Wildlife Biological Services Program. FWS/OBS-79/31, Washington, DC. 103 pp.

Dunne, T. and L.B. Leopold. 1978. Water in Environmental Planning. W.H. Freeman and Co. August 15, 1978.

Drociak, J. 2008. A Field Guide to Common Aquatic and Riparian Plants of New Hampshire. New Hampshire Department of Environmental Services. Second Edition. Published March 2008.

Franzi, D., C. Wittkop, and C. Koteff. 2005. Surficial geologic map of the Newmarket quadrangle, Rockingham and Strafford Counties, New Hampshire. NHGS. [Online] Accessed from: https://ngmdb.usgs.gov/Prodesc/proddesc_107090.htm.

Goldthwait, J.W., L. Goldthwait, and R.P. Goldthwait. 1951. The Geology of New Hampshire Part I – Surficial Geology. New Hampshire State Planning and Development Commission. Concord, New Hampshire.

Leopold, L.B., M.G. Wolman, and J.P. Miller. 1964. Fluvial Processes in Geomorphology. W.H. Freeman. December 1, 1964.

Meyer-Peter, E. and R. Muller. 1948. Formulas for Bed Load Transport. Proceedings of 2nd meeting of the International Association for Hydraulic Structures Research, Delft. June 7, 1948.

Miller, H., 2019. Research Experience and Apprenticeship Program Final Report. Department of Civil and Environmental Engineering, University of New Hampshire. Issued November 1, 2019.

Moore, R. 1990. Geohydrology and water quality of stratified drift aquifers in the Exeter, Lamprey, and Oyster River Basins, Southeastern New Hampshire. US Geological Survey. Water-Resources Investigations Report 88-4128. Issued 1990.

Moss, R.H., Edmonds, J.A., Hibbard, K.A., Manning, M.R., Rose, S., van Vuuren, D.P., Carter, T.R., & Wilbanks, T.J. 2010. The Next Generation of Scenarios for Climate Change Research and Assessment. Nature, 463: 747-756.

National Institute of Standards and Technology. 2012. IR 85-3273-27. Energy Prices Indices and Discount Factors for Life-Cycle Cost Analysis. Annual Supplement to NIST Handbook 135 and NBS Special Publication 709. U.S. Department of Energy. Issued 2012.

National Oceanic and Atmospheric Administration, National Marine Fisheries Service. 2011. Flood Frequency Estimates for New England River Restoration Projects: Considering Climate Change in Project Design. Technical Publication FS-2011-01.

NH Coastal Flood Risk Science and Technical Advisory Panel. 2019. New Hampshire Coastal Flood Risk Summary Part II: Guidance for Using Scientific Projections. Report published by the University of New Hampshire, Durham, NH.

New Hampshire Fish and Game Department. 2015. New Hampshire Wildlife Action Plan. [Online] Accessed from: https://www.wildlife.state.nh.us/wildlife/wap.html.

NHDES. 2005. Draft Evaluation of Sediment Quality Guidance Document, NHDES-WD-04-9. Issued April 2005.

NHDES. 2011. The Oyster River Report to the General Court, 2011. New Hampshire Rivers Management and Protection Program. January 2011.

NHDES. 2016A. Guidance for Assessing and Managing Sediment Behind Dams/Barriers, NHDES-WD-16-04. Issued November 2016.

NHDES. 2016B. Memorandum from Matt Wood to Gregg Comstock, PE entitled “Updated TEC and PEC sediment thresholds” dated January 8, 2016.

NHDES. 2018. New Hampshire’s 2018 Clean Water Act §303(d) List. Accessed on February 25, 2020.

NHDES. 2019. Oyster River Environmental Fact Sheet. NHDES-WD-R&L-27. Issued 2019.

NHDES. 2020. New Hampshire Water Well Inventory. [Online] Accessed from: https://granitview.unh.edu/. 2020.

NHGS. 2005b. New Hampshire Bedrock Geology Metadata. [Online] Accessed from: https://granitview.unh.edu/. 2020.

Patterson, C., K. Sullivan, M. Dionne, R. Heuss, R. Atwood, C. O'Donnell, and K. Villone. 2019. Mill Pond Diadromous Fish Investigations Progress Report, New Hampshire Fish and Game Department. April 1, 2020.

Poff, N., J. Allan, M. Bain, J. Karr, K. Prestegaard, B. Richter, R. Sparks and J. Stromberg. 1997. The natural flow regime, a paradigm for river conservation and restoration. BioScience 47 (11): 769-784.

Sanborn, Head & Associates, Inc. 1998. Technical Report prepared for NHDES entitled Background Metals Concentration Study New Hampshire Soils, File 1571. November 1998.

Shields, A. 1936. Application of Similarity Principles and Turbulence Research to Bed-Load Movement. California Institute of Technology, Pasadena, California.

Simons, D.B., and F. Senturk. 1992. Sediment transport technology: water and sediment dynamics. Water Resource Publications, Littleton, Colorado. August 20, 1992.

Toffaleti, F. B. 1968. A Procedure for Computation of the Total River Sand Discharge and Detailed Distribution, Bed to Surface. Committee on Channel Stabilization (Army). November 1968.

Town of Durham, New Hampshire. 2020. History of Mill Pond Dam. Town of Durham, New Hampshire. [Online] Accessed from: https://www.ci.durham.nh.us/sites/default/files/fileattachments/historic_district/heritage_commission/page/55265/history_of_dam_for_website.pdf. Accessed on September 8, 2020.

Turek, J., A. Haro, and B. Towler. 2016. Federal Interagency Nature-like Fishway Passage Design Guidelines for Atlantic Coast Diadromous Fishes. Interagency Technical Memorandum. 47 pp.

USACE. 1994. Channel Stability Assessment for Flood Control Projects: Engineering Manual. US Army Corps of Engineers, Washington D.C, EM1110-2-1418. Issued October 31, 1994.

VHB, 2009. Final Technical Report entitled, "Mill Pond Bathymetric Survey and Sediment Sampling Study, Durham, New Hampshire." Issued November 2009.

Wake, C., Knott, J., Lippmann, T., Stampone, M., Ballestero, T., Bjerklie, D., Burakowski, E., Glidden, S., Hosseini-Shakib, I., Jacobs, J. 2019. *New Hampshire Coastal Flood Risk Summary – Part I: Science.* Prepared for the New Hampshire Coastal Flood Risk Science and Technical Advisory Panel. Report published by the University of New Hampshire, Durham, NH.

Weston & Sampson. 2018. Technical Report entitled "Mill Pond Study." Town of Durham, New Hampshire. Issued March 2018.

Weston & Sampson. 2020. Technical Memo entitled "Durham Mill Pond Dam – Design Flow Analysis Methodology." Issued February 20, 2020.

Wheeler, K., J. Cofelice, and J. Tumelaire. 2020. Technical Report entitled, "Phase 1A Archaeological Sensitivity Assessment: Oyster River Dam at Mill Pond." Independent Archaeological Consulting, LLC. Report No. 1467. Issued January 16, 2020.

Wilcock, P. 2001. Toward a practical method for estimating sediment-transport rates in gravel-bed rivers. John Hopkins University. December 18, 2001.

Glossary

Abutments

The part of a structure (e.g. a dam or a bridge) that directly receives thrust or pressure and supports the remaining portions of the structure.

Aggradation

The accumulation of sediment in rivers and nearby landforms. Aggradation occurs when sediment supply exceeds the ability of a river to transport the sediment.

Ambursen Dam

A style of dam created by Nils Ambursen, in which the design consists of a buttress dam requiring minimal buttress thickness in which the upstream portion is a relatively thin flat slab typically made of reinforced concrete.

Anadromous

Fish that spend all or part of their adult life in salt water and migrate to freshwater streams and rivers to spawn.

Aquifer

An underground porous, water-bearing geological formation.

Bankfull

The incipient elevation on a stream bank where flooding begins; associated with the flow that just fills the channel to the top of its banks and at a point where the water begins to overflow onto a floodplain.

Bankfull Discharge

A flow condition in which stream flow completely fills the steam channel up to the top of the bank. In undisturbed watersheds, the discharge condition occurs on average every 1.5 to 2 years and controls the shape and form of natural channels.

Bathymetry

The measurement of water depth at various places in a body of water.

Catadromous

Catadromous fish migrate between the sea and fresh water. These species live in freshwater but migrate to the sea to spawn. See also diadromous and anadromous.

Cofferdam

A temporary structure designed to keep water and/or soil out of the excavation in which a structure is built. When construction must take place below the water level, a cofferdam is built to give workers a dry work environment.

Confluence

The place at which two streams flow together to form one larger stream.

Deltaic

Pertaining to or like a delta. Sedimentary type deposits in a delta.

Denil-style

A style of *fish ladder* with a series of sloped ramps with inset baffle structures that act like a set of rapids with a wide range of water speeds that allows many fish species to successfully ascend over obstructions.

Diadromous

Refers to both species which live in the sea but migrate to freshwater to spawn (i.e., anadromous) as well as those species which live in freshwater but migrate to the sea to spawn (i.e., catadromous).

Emergent

Rooted below a body of water or in an area that is periodically submerged but extending above.

Fish Ladder

A sluice-like structure on a dam that enables fish to pass above the dam by swimming up a series of relatively low submerged steps over the dam spillway. The existing fish ladder on the Oyster River Dam at Mill Pond is a denil-style ladder.

Floodplain

Land immediately adjoining a stream which is inundated when the discharge exceeds the conveyance of the normal channel. The “100-year Floodplain” is the portion of the floodplain which can be expected to flood once in every 100 years.

Fluvial

Processes associated with rivers and streams and the deposits and landforms created by them. Comprises the flow of water and sediment and erosion or deposition on the river bed.

Fluvial Geomorphology

The study of rivers and streams and the processes that form them.

Freeboard

In dam design, a margin of safety added to account for waves, debris, miscalculations, or lack of data; the vertical distance between a stated water level and the top of a dam.

Geomorphological

Of or relating to the form or surface features of the earth

Geospatial

Having to do with entities or events that can be described in a geographic fashion; mapped information is geospatial data.

GIS (Geographic Information System)

A computer-based mapping and information management system tied to geographic data.

Glacioestuarine

Typically consist of clays and silts; deltaic deposits generally include silts interbedded with scattered coarser material, including sand and gravel.

Headcut

A type of erosional feature seen in flowing waters where a deep incision of the streambed forms, lowering the streambed and usually causing the riverbanks to eroded and collapse. A headcut migrates upstream; its uppermost point is called a *nickpoint*.

HEC-RAS (Hydraulic Engineering Center – River Analysis System)

A computer program that models the hydraulics of water flow through natural rivers and other channels developed in 1995 by the USACOE in order to manage the rivers, harbors, and other public works under their jurisdiction.

Hydrology

The study of a watershed's behavior during and after a rainstorm. A hydrologic analysis determines the amount of rainfall that will stay within a watershed - absorbed by the soil, trapped in puddles, etc. - and the rate at which the remaining amount of rainfall will reach the stream.

Hydraulics

The study of floodwaters moving through the stream and the floodplain. A hydraulic study produces determinations of flood elevations, velocities and floodplain widths at each cross section for a range of flood flow frequencies. These elevations are the primary source of data used by engineers to map the floodplain.

Impounding

To collect and confine (water) in or as if in a reservoir

Impoundment

A body of water formed by impounding

Impoundment Limit

The upstream point on a river where a downstream dam exerts no influence on water depths or velocities; the water flows freely under all flow conditions as if the dam were not in place.

Lacustrine

Inland wetlands and deep-water habitats associated with freshwater lakes and reservoirs, characterized by the absence of trees, shrubs, or emergent vegetation.

LiDAR

Light Detection and Ranging. A method of detecting distant objects and determining their position, velocity, or other characteristics by analysis of pulsed laser light reflected from their surfaces. LiDAR operates on the same principles as radar and sonar.

Low Hazard Dam

Those dams where failure or misoperation results in no probable loss of human life or low economic and/or environmental losses. In NH, this term has a regulatory meaning which is defined in NH Administrative Rule Env-Wr 101.07. Low hazard dams are sometimes called "Class A" structures in NH laws and regulations.

Mainstem

The main channel of a river as opposed to the streams and smaller rivers (i.e., *tributaries*) that feed into it.

Nickpoint

The top of a *headcut*, usually characterized by an unnatural grade change which is the result of erosion.

Palustrine

Inland, nontidal wetlands characterized by the presence of trees, shrubs, and emergent vegetation (vegetation that is rooted below water but grows above the surface). Palustrine wetlands range from permanently saturated or flooded land to land that is wet only seasonally.

PEC/Probable Effects Concentration

The level of a concentration in the media (surface water, sediment, soil) to which a plant or animal is directly exposed that is likely to cause an adverse effect.

PEL/Probable Effects Level

A chemical concentration in some item (dose) prey that is ingested by an organism, which is likely to cause an adverse effect. The ingested item is usually food, but can be soil, sediment, or surface water that is incidentally (accidentally) ingested.

Physiography

Physical geography, geomorphology.

Reach

A portion of a river, defines by one or more features, landmarks, of characteristics.

Riffle

A short, relatively shallow and coarse-bedded length of stream, where the stream flows at higher velocity and higher turbulence that it normally does compared to a pool.

Riparian

The interface between land and a river or stream.

Riverine

Relating to, formed by, or resembling a river. Relating to a system of inland wetlands and deep-water habitats associated with nontidal flowing water, characterized by the absence of trees, shrubs, or emergent vegetation.

Run of the River

Used to describe dams that allow all of the natural river flow to pass over the dam in a relatively a consistent and steady flow, vs. other dams which may divert, store, or release water flow for various reasons.

Scour

Erosion of streambed or bank material caused by flowing water, usually localized.

Spalling

Breaking into chips or fragments.

Spillway

The crest of a dam or a passage for surplus water to run over or around a dam.

Surficial
Relating to, or occurring on or near a surface.

TEC/Threshold Effects Concentration

A concentration in media (surface water, sediment, soil) to which a plant or animal is exposed, above which some effect (or response) will be produced and below which it will not.

TEL/Threshold Effects Level

A chemical concentration in some item (dose) that is ingested by an organism, above which some effect (or response) will be produced and below which it will not. This item is usually food, but can also be soil, sediment, or surface water that is incidentally (accidentally) ingested as well.

Thalweg

The line defining the lowest points along the length of a river bed or the portion of a stream channel that contains the deepest flow.

Thermal Stratification

The thermal stratification of lakes refers to a change in the temperature at different depths in the lake, and is due to the change in water's density with temperature.

Tributary

A stream that flows into a larger stream or body of water at a *confluence*.

Watershed

A land area that drains into a lake, stream or river. Also called "basins," watersheds vary in size. Larger ones can be divided into sub-watersheds.

List of Figures

Figure 1.1-1

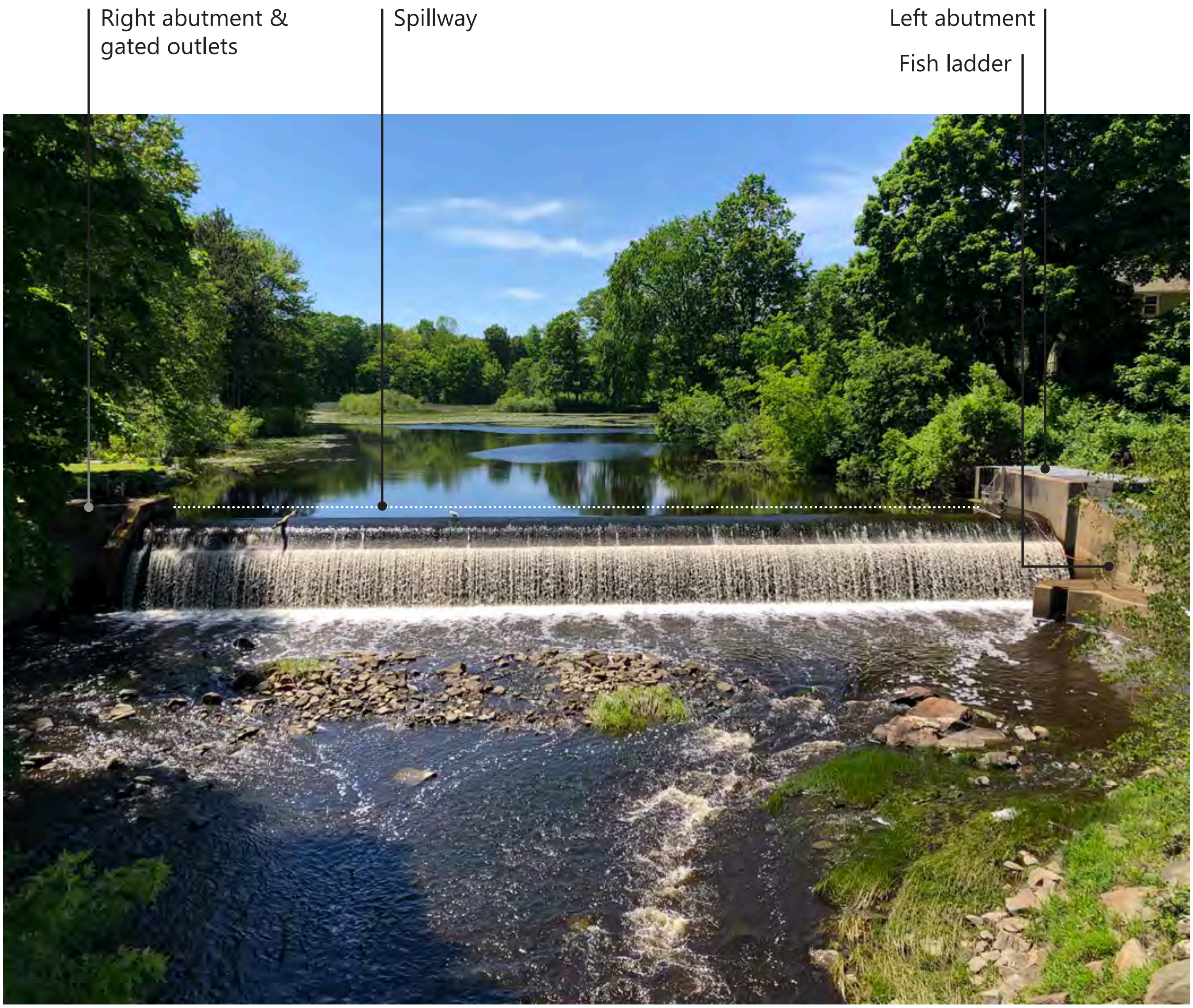
\\vhb\gis\proj\Bedford\52633.00 Mill Pond Dam Feasibility Project\Mill_Pond_Dam.aprx

Oyster River Feasibility Study | Durham, New Hampshire

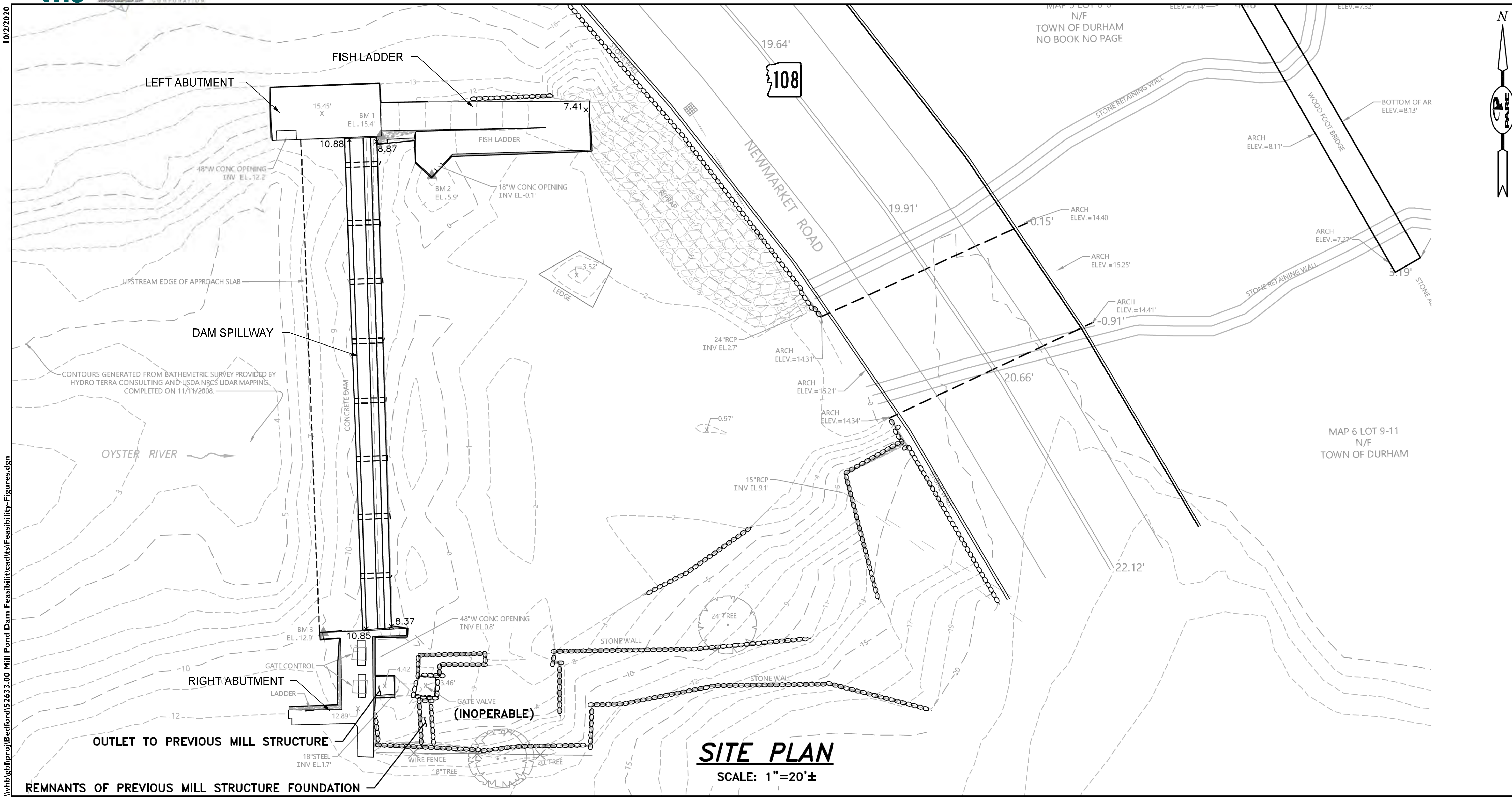
Site Location

Source : NHDES, VHB, ArcGIS Online

Figure 1.4-1



A view of the Oyster River Dam, looking upstream from the NH 108 Bridge.

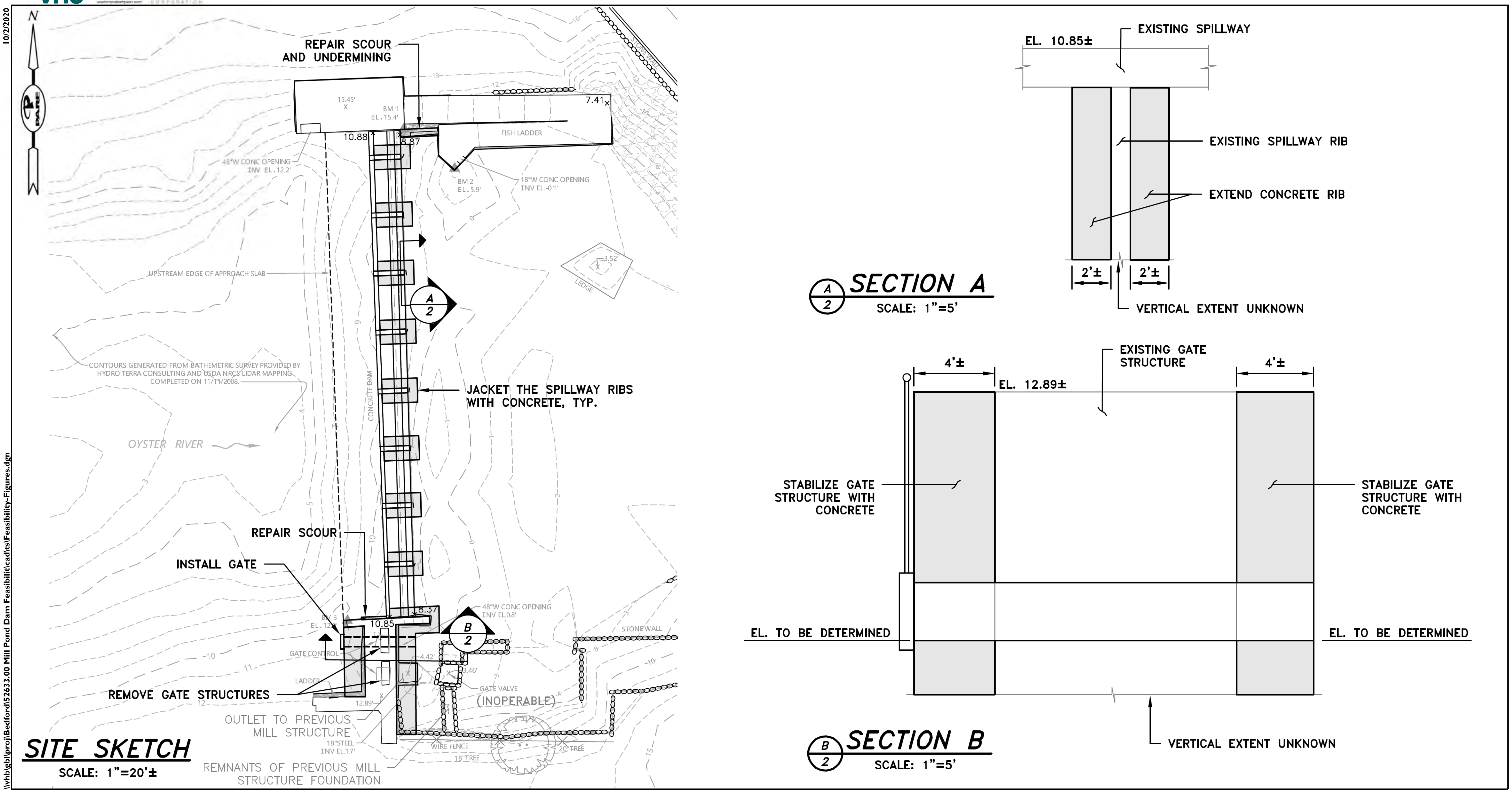


10/2/2020

\\vhb\gbl\proj\Bedford\52633.00 Mill Pond Dam Feasibility\cad\ts\Feasibility-Figures.dgn

Oyster River Dam
Existing Conditions

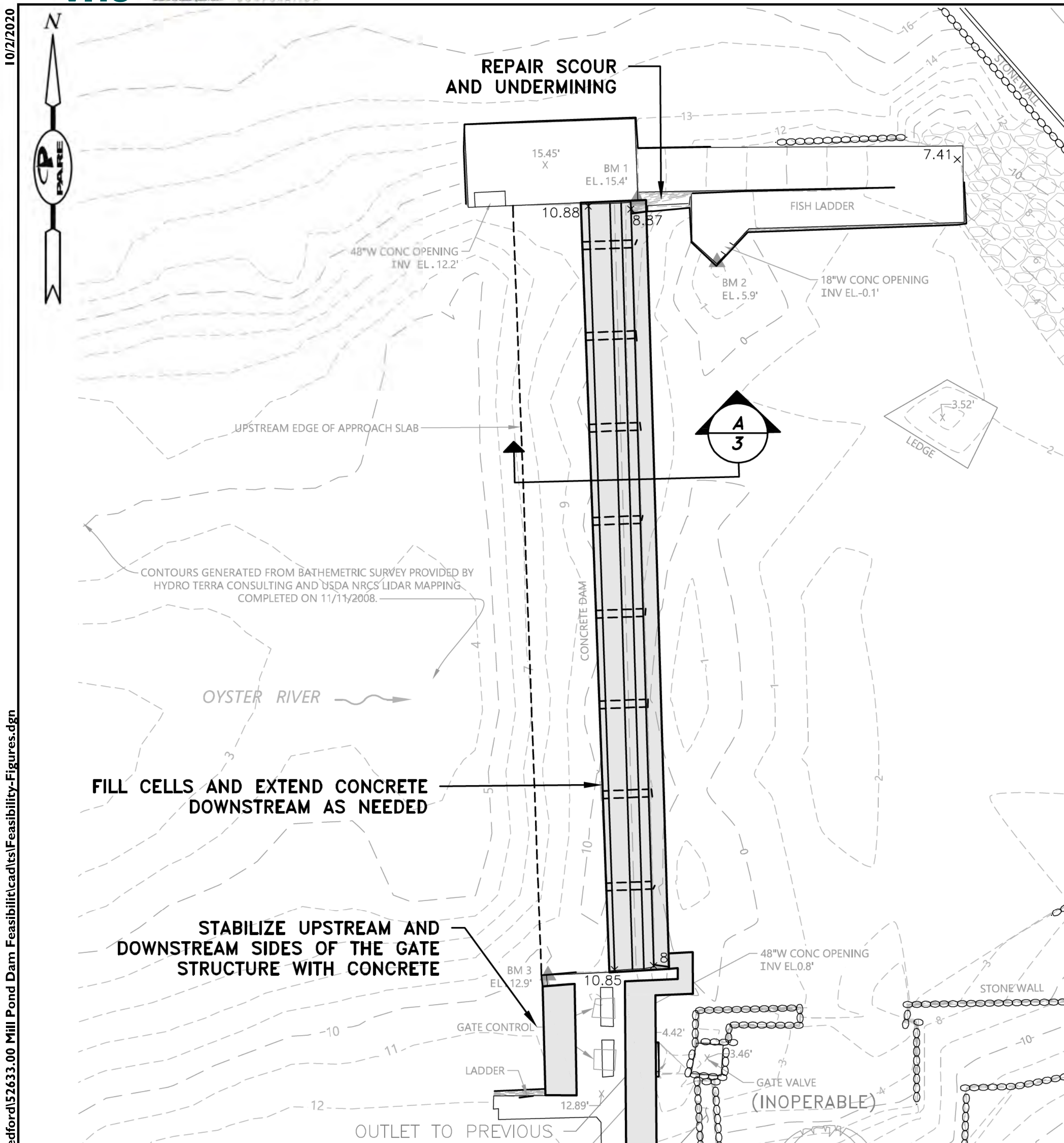
Figure 2.3-1



Oyster River Feasibility Study | Durham, New Hampshire

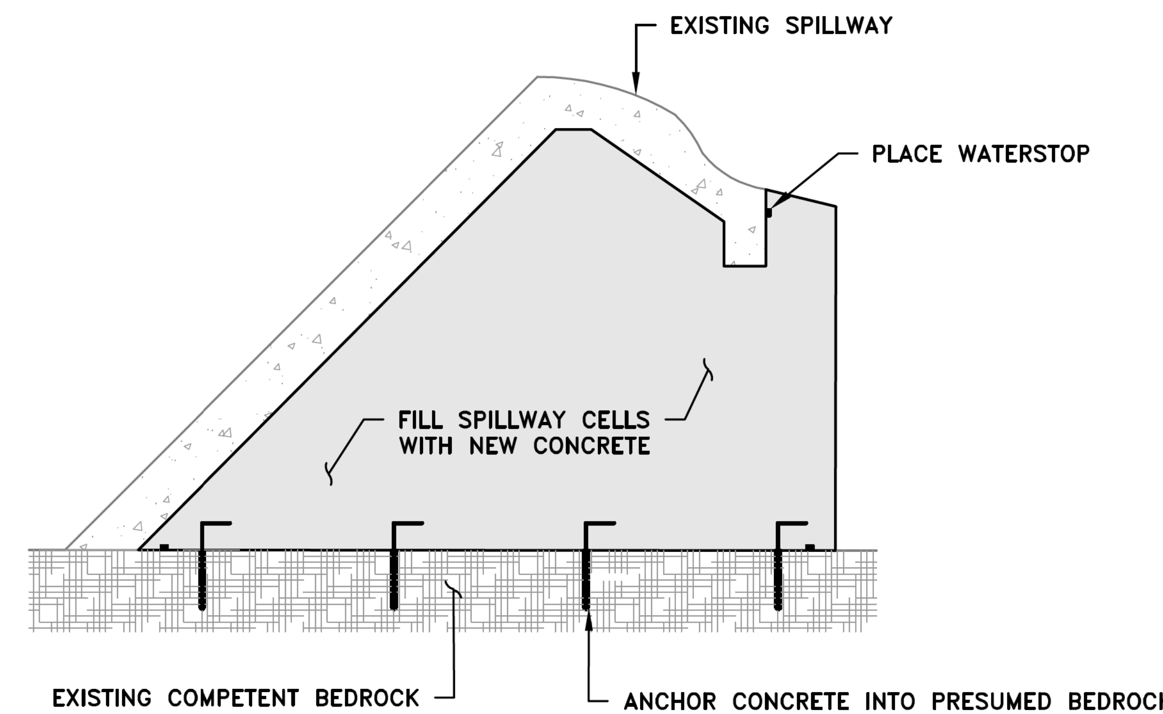
Alternative 2
Dam Repair

10/2/2020



SITE SKETCH

SCALE: 1"=20'±



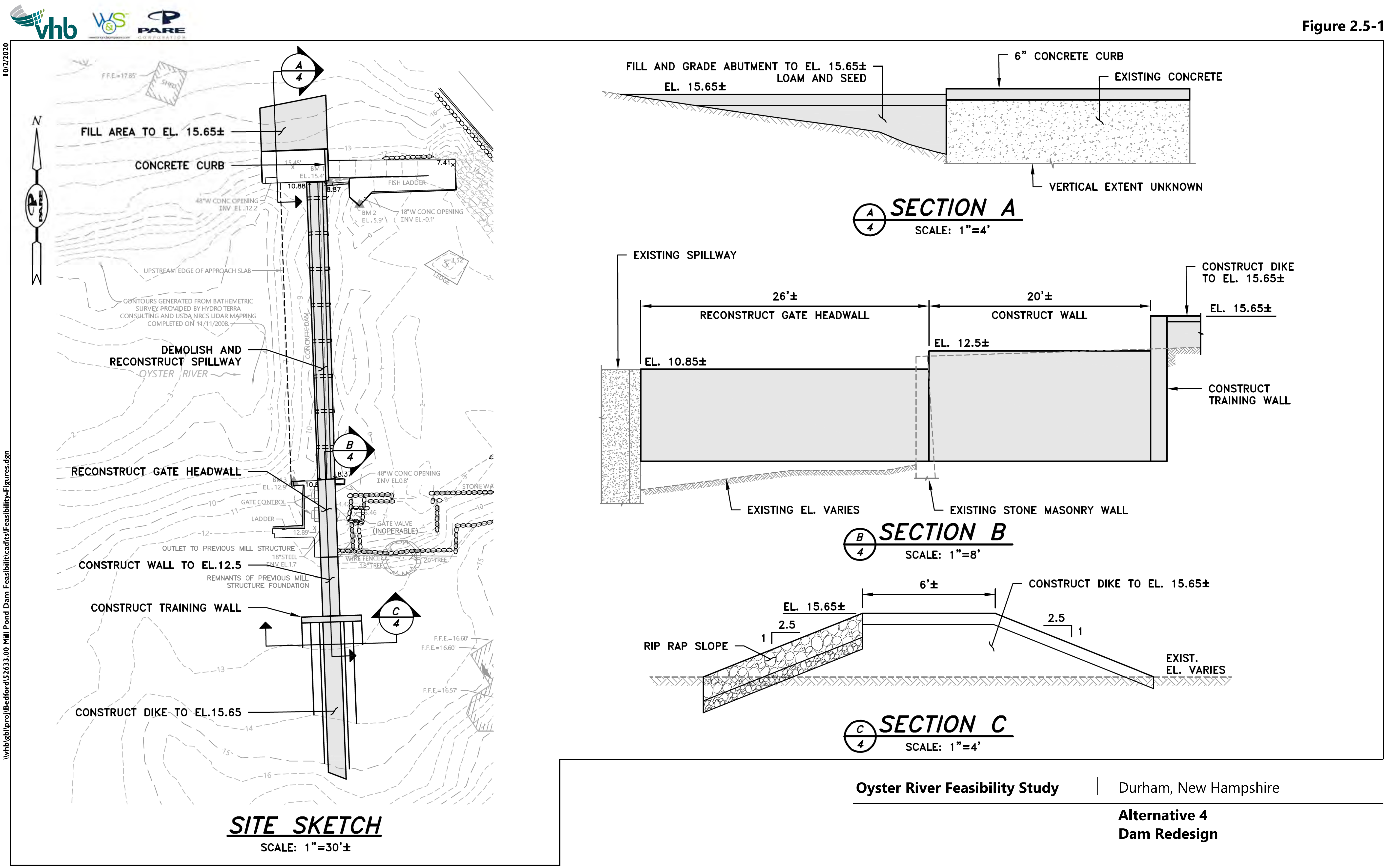
A/3 *SECTION A*

SCALE: 1"=2'

\\vhb\gbl\proj\Bedford\52633.00 Mill Pond Dam Feasibilit\cad\ts\Feasibility-Figures.dgn

Oyster River Feasibility Study | Durham, New Hampshire

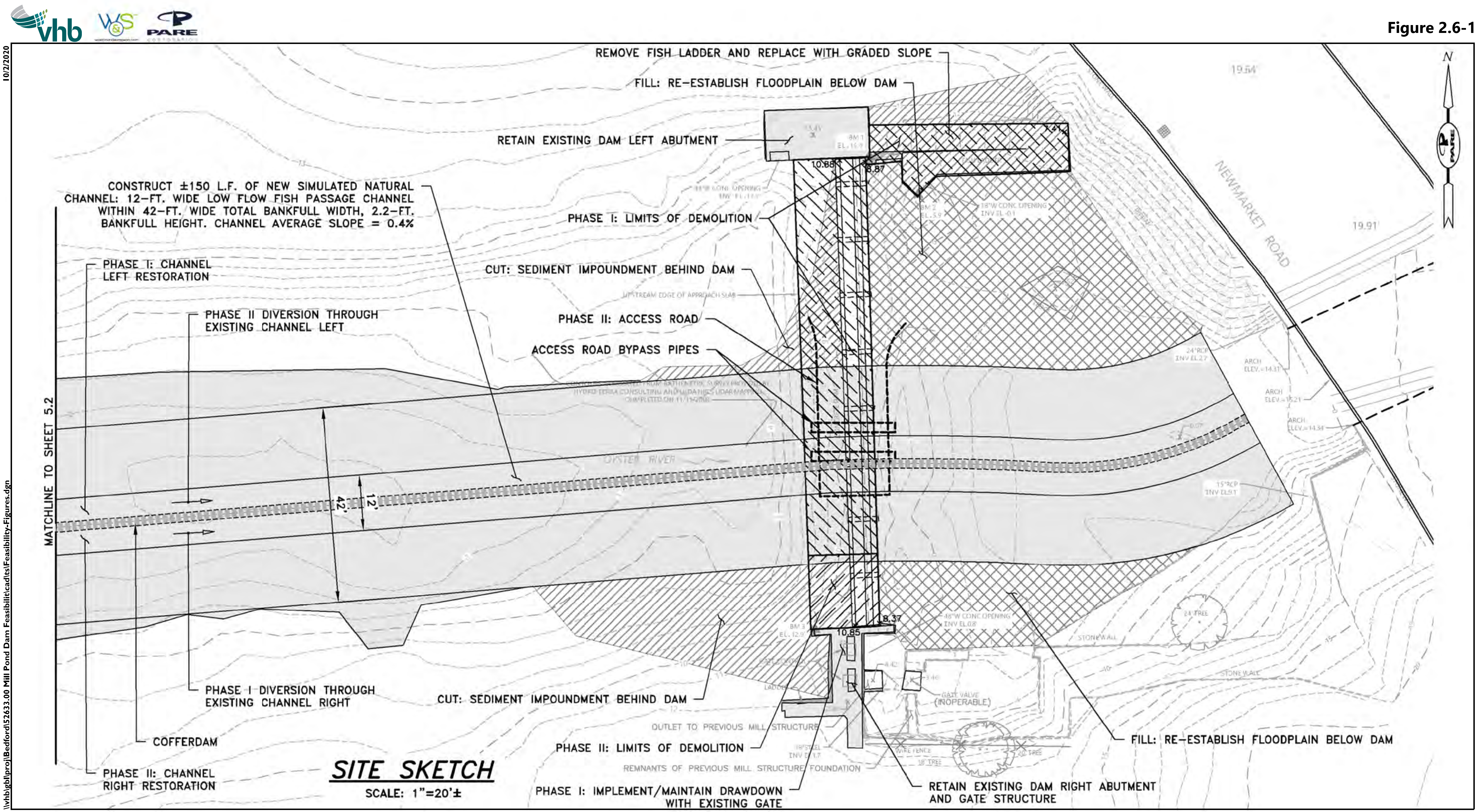
Alternative 3
Dam Stabilization



Oyster River Feasibility Study | Durham, New Hampshire

Alternative 4
Dam Redesign

Figure 2.6-1



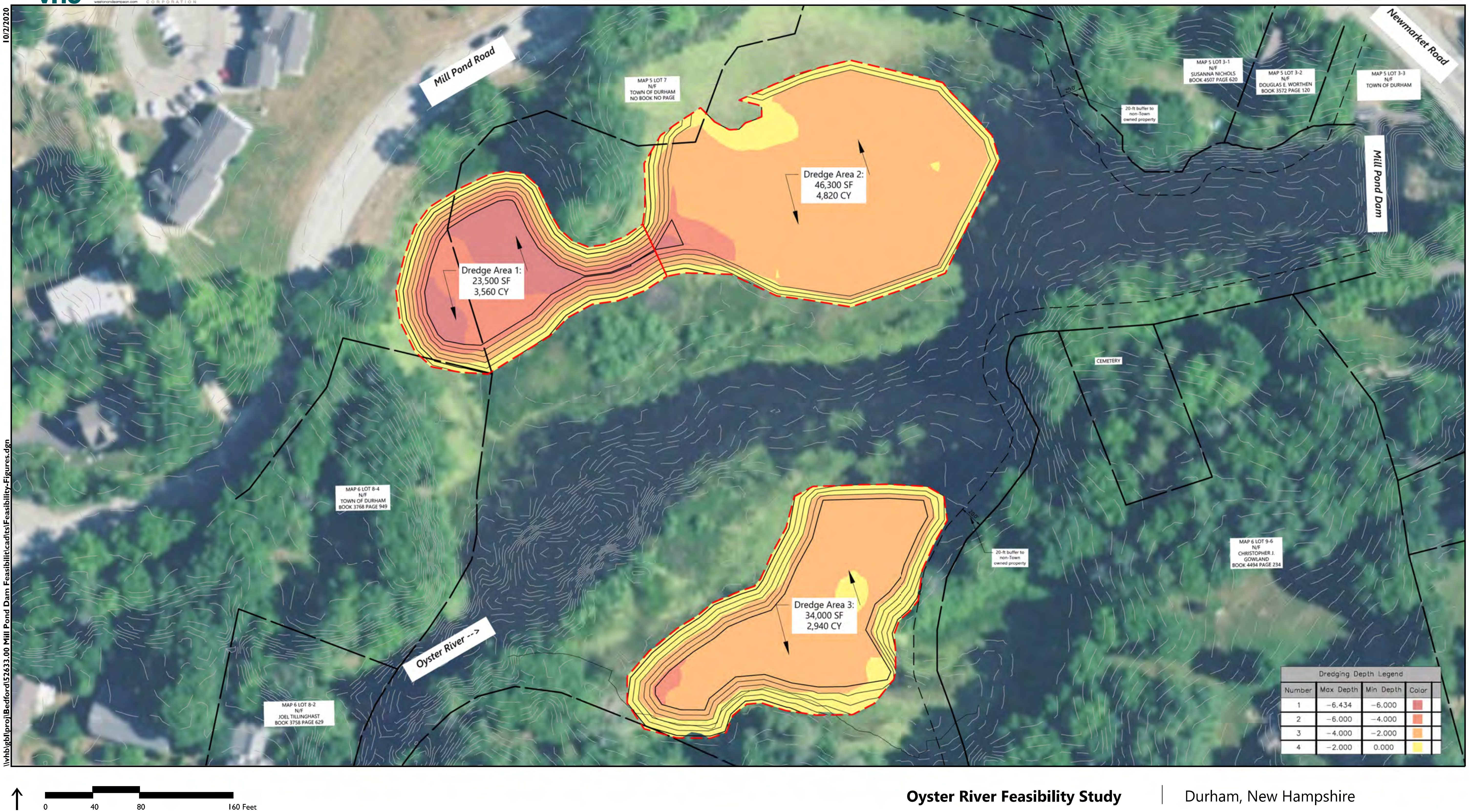
Oyster River Feasibility Study | Durham, New Hampshire

Alternative 5
Dam Removal

Figure 2.7-1

10/2/2020

\\vhb\gbl\proj\Bedford\52633.00 Mill Pond Dam Feasibilit\cad\ts\Feasibility-Figures.dgn



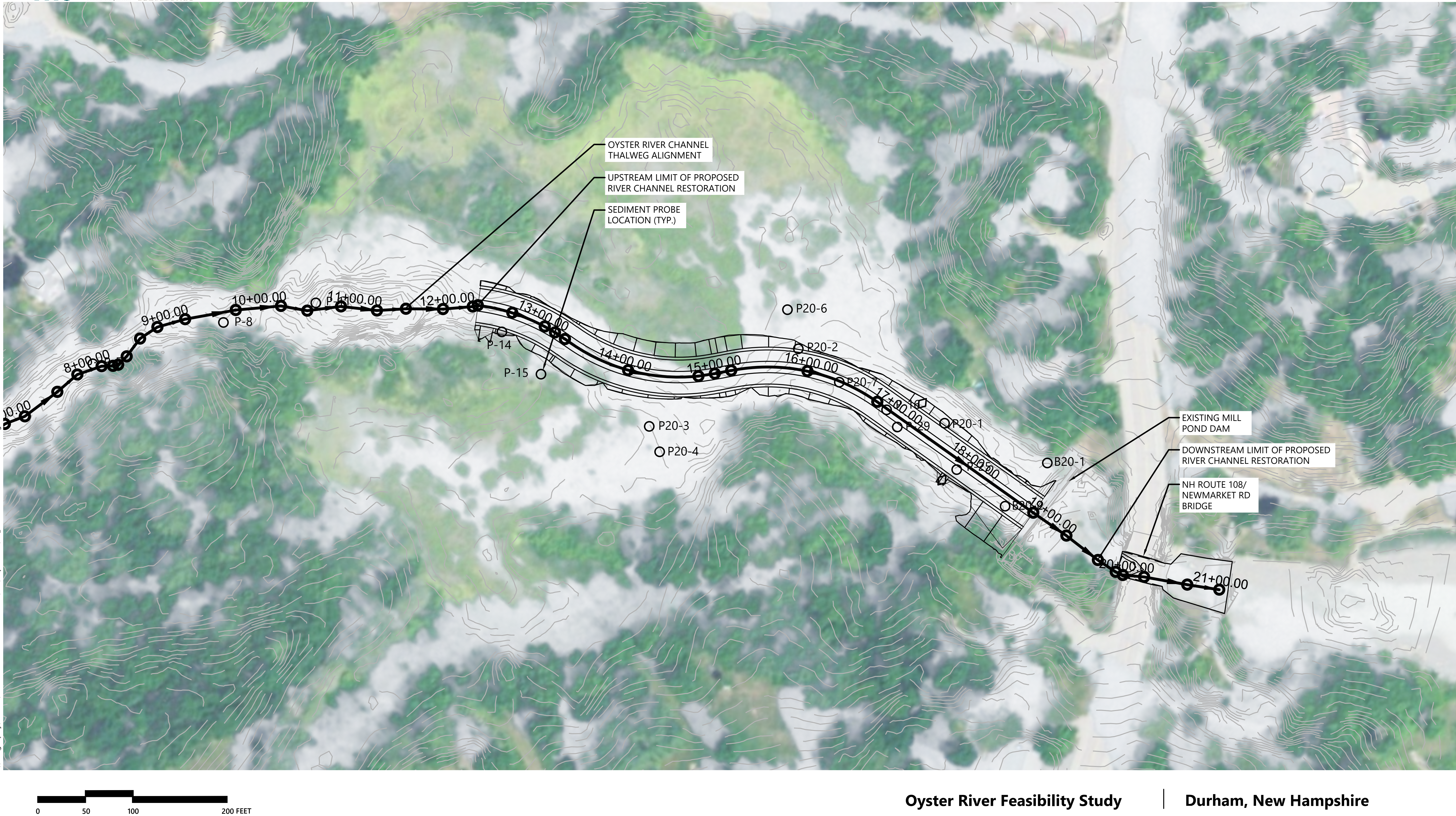
Dredging Depth Legend

Number	Max Depth	Min Depth	Color
1	−6.434	−6.000	
2	−6.000	−4.000	
3	−4.000	−2.000	
4	−2.000	0.000	

Oyster River Feasibility Study | Durham, New Hampshire

Option 1
Pond Restoration Concept Plan

Figure 2.8-1

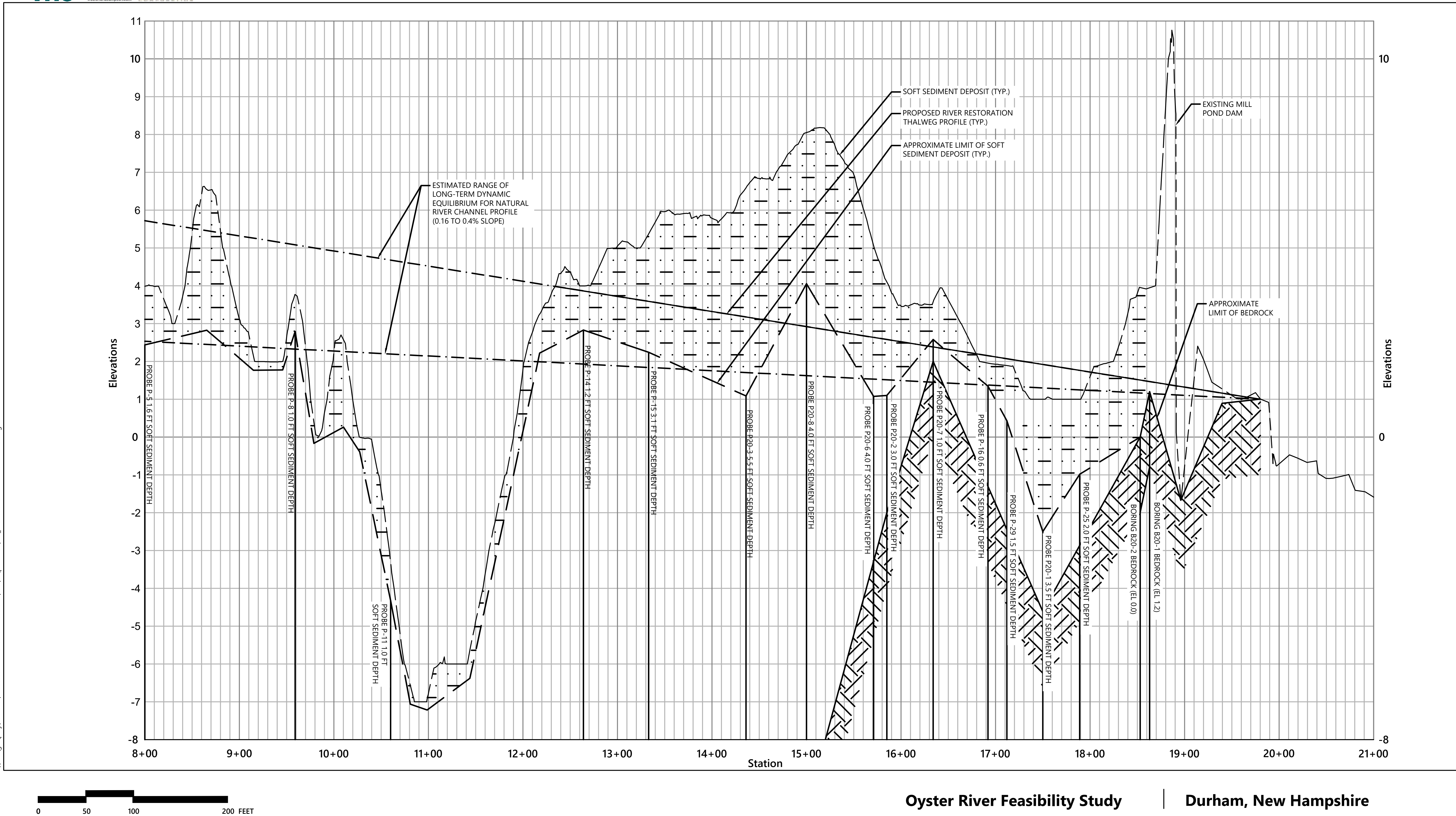


\\vhb\gbl\proj\Bedford\52633.00 Mill Pond Dam Feasibilit\cad\ev\planmisc\FIG_X-52633-CHANNEL-GRADING.dwg

Oyster River Feasibility Study | **Durham, New Hampshire**

Option 2
Channel Restoration - Plan View

Figure 2.8-2

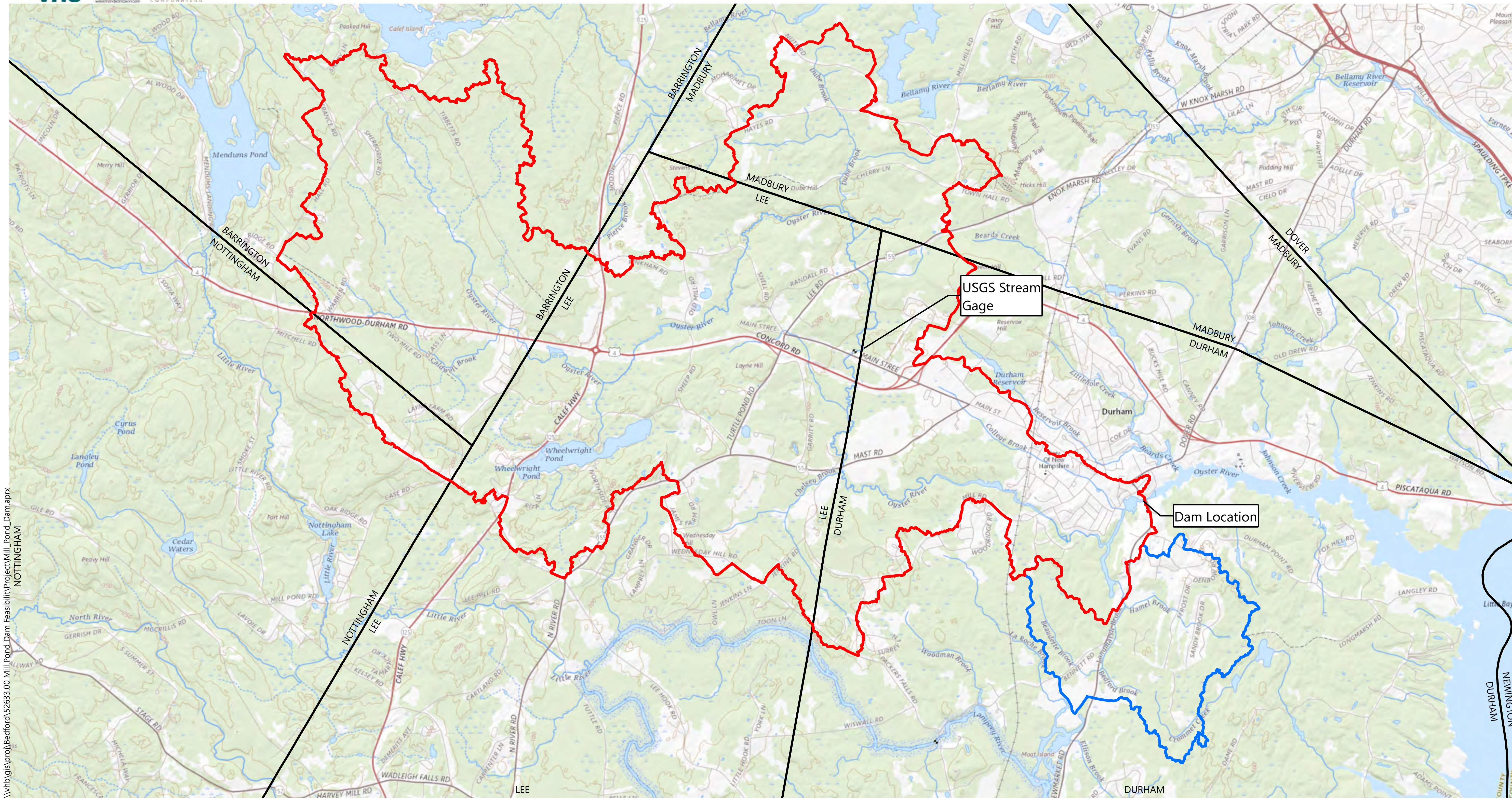


\\vhb\gbl\proj\Bedford\52633.00 Mill Pond Dam Feasibility\cad\ev\planmisc\FIG_X-52633-CHANNEL-GRADING.dwg

Oyster River Feasibility Study | **Durham, New Hampshire**

Option 2
Channel Restoration - Profile View

Figure 3.2-1



\\vhb\gis\proj\Bedford\52633.00 Mill_Pond_Dam Feasibility\Project\Mill_Pond_Dam.aprx

0 2000 4000 8000 Feet

Hamel Brook Watershed

Oyster River Watershed

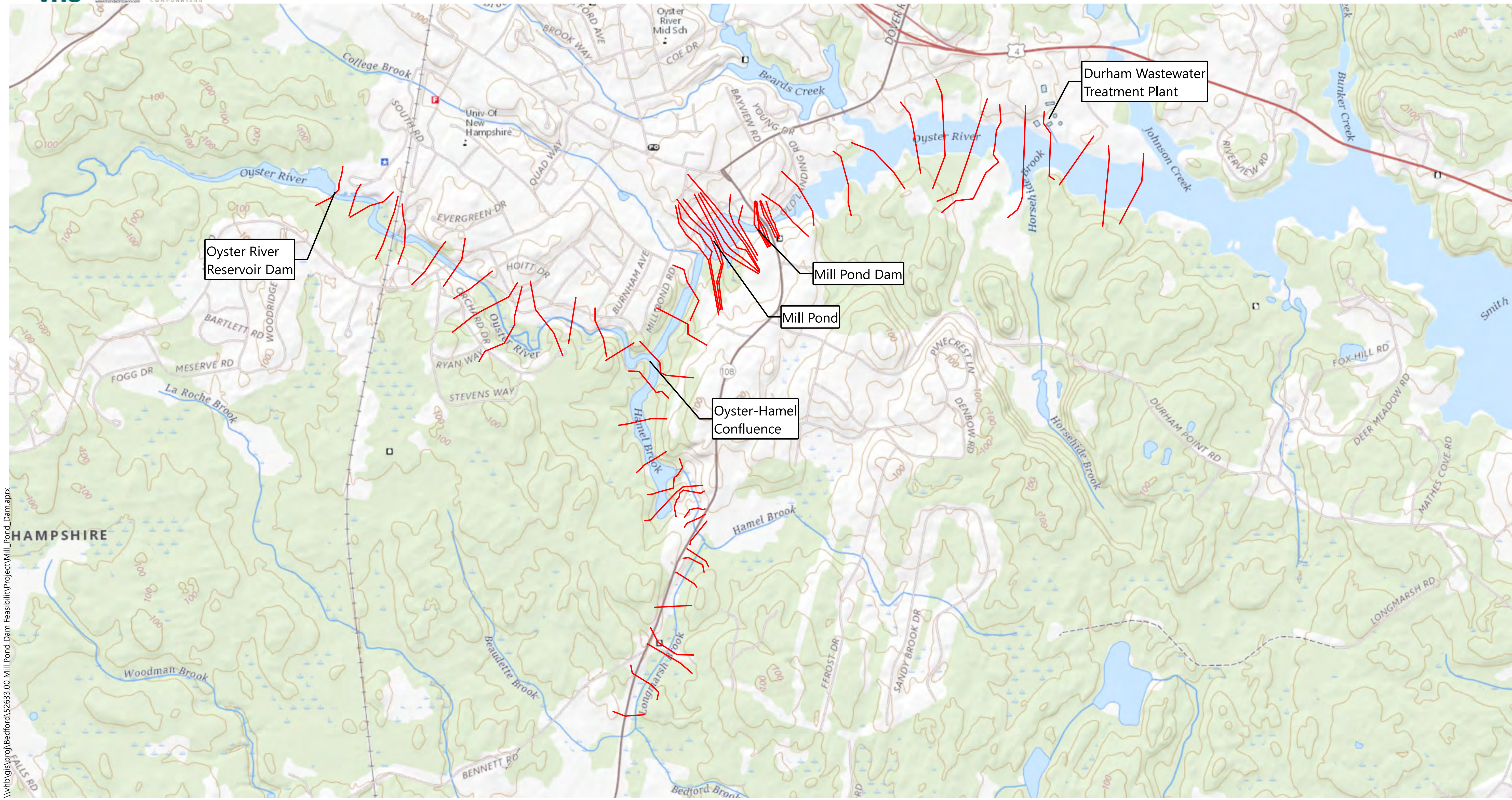
Town Boundary

Oyster River Feasibility Study | Durham, New Hampshire

Oyster River Watershed

Source : NHDES, VHB, ArcGIS Online

Figure 3.2-2



0 1000 2000 4000 Feet

Cross-Section

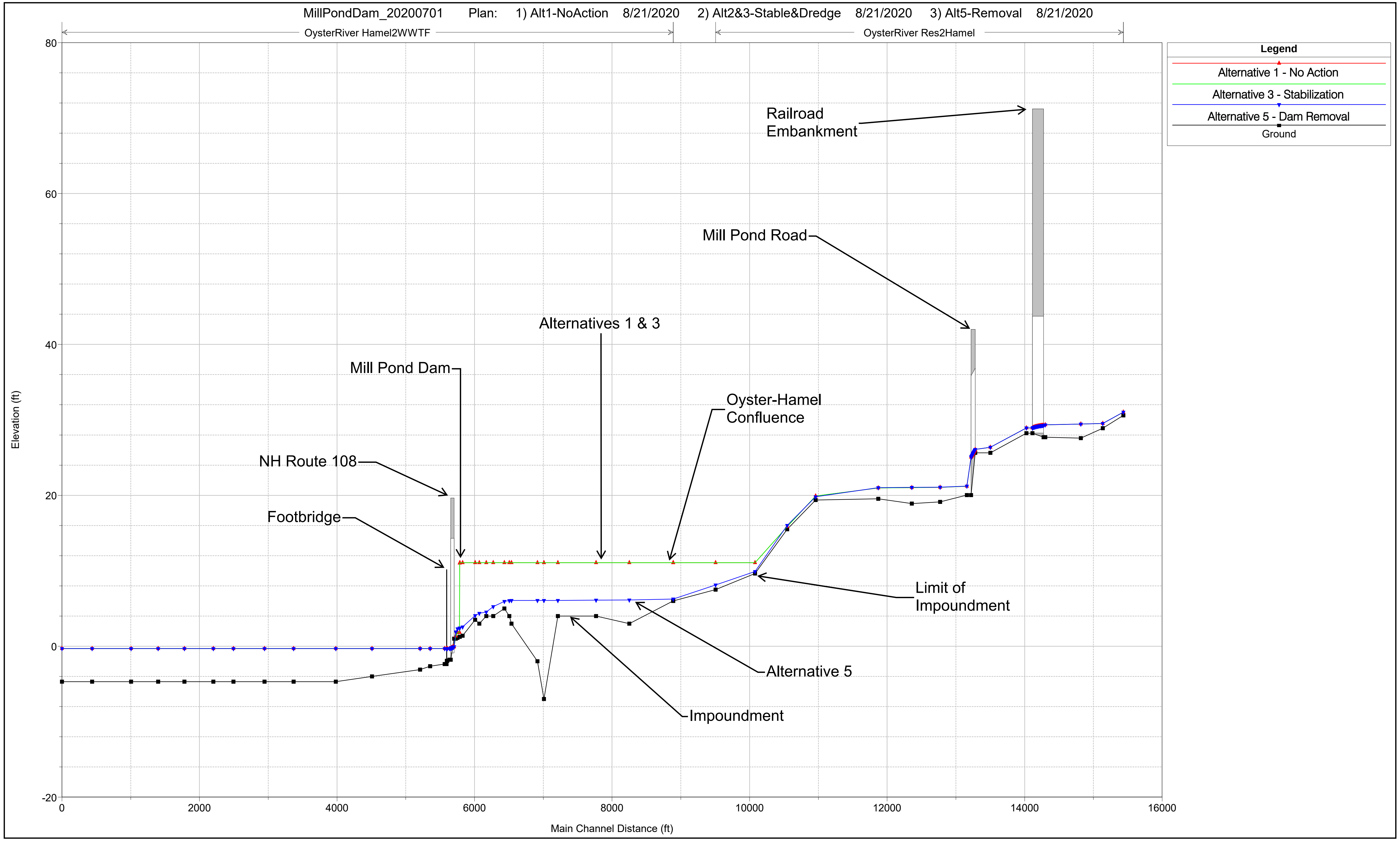
\\vhb\gis\proj\Bedford\52633.00 Mill Pond Dam Feasibility\Project\Mill_Pond_Dam.aprx

Oyster River Feasibility Study | Durham, New Hampshire

Model Cross-Sections

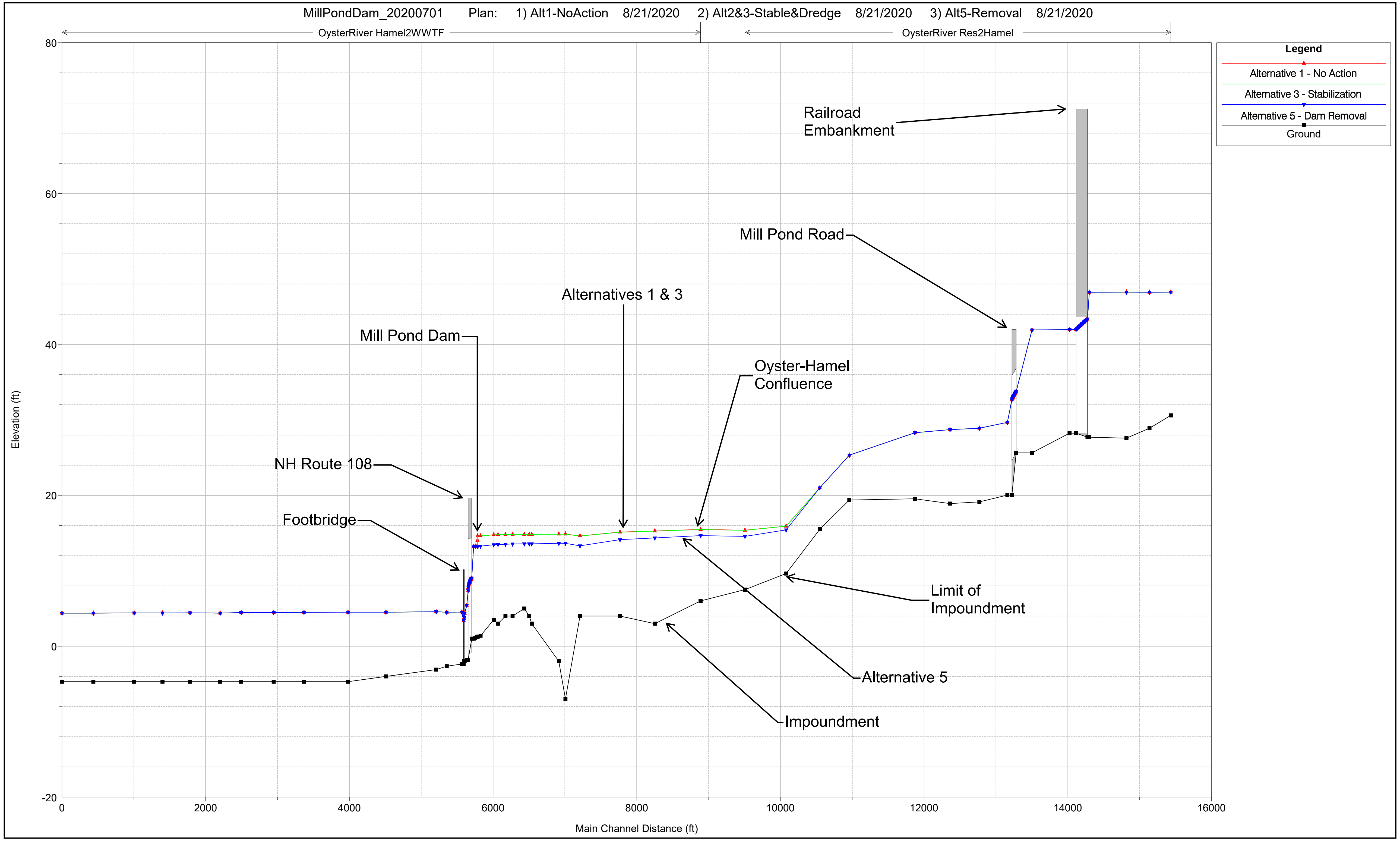
Source : NHDES, VHB, ArcGIS Online, Weston & Sampson

Figure 3.2-3



Oyster River Feasibility Study | Durham, New Hampshire

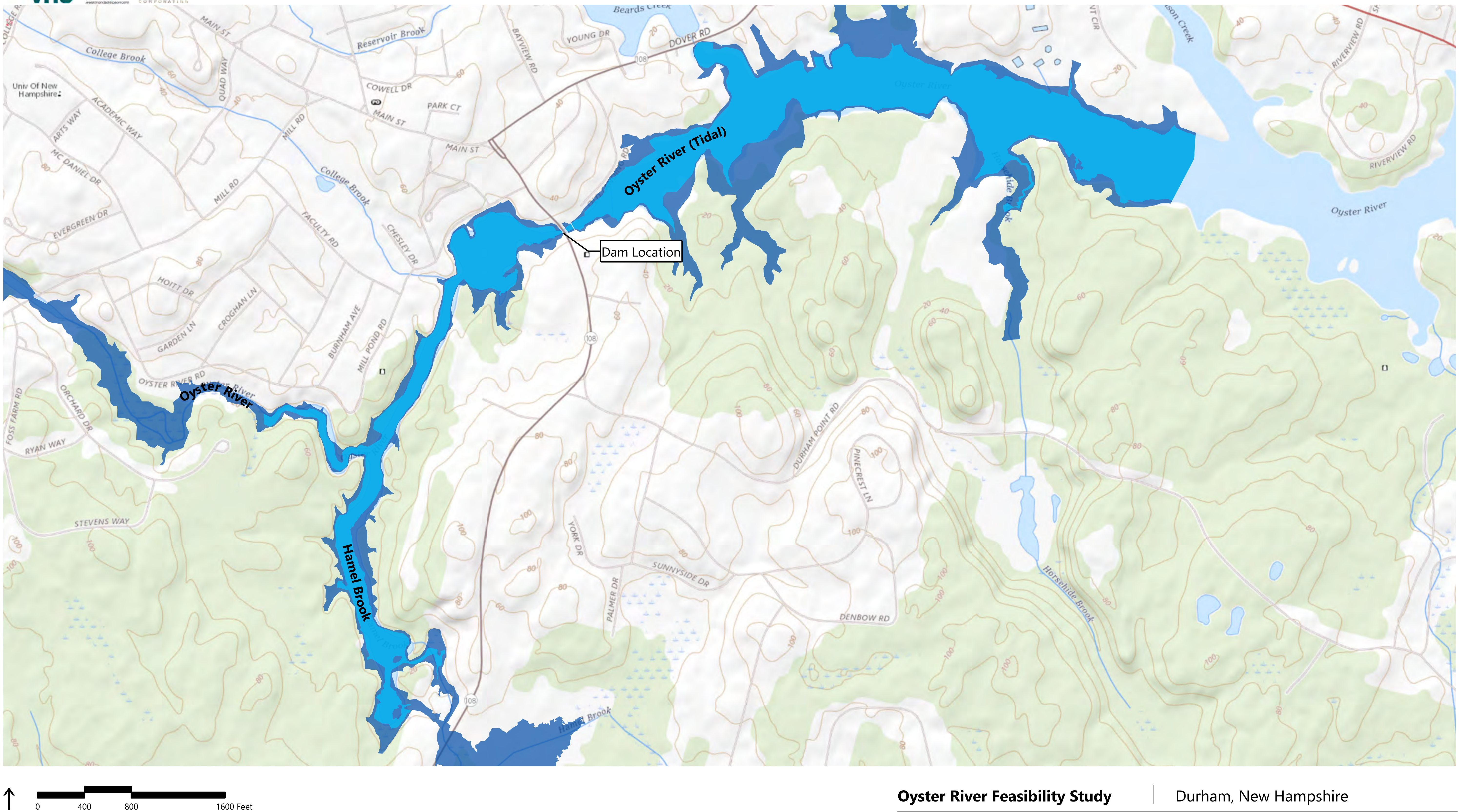
Median Annual Flow Profile



Oyster River Feasibility Study | Durham, New Hampshire

50-year Flood Profile

Figure 3.2-5

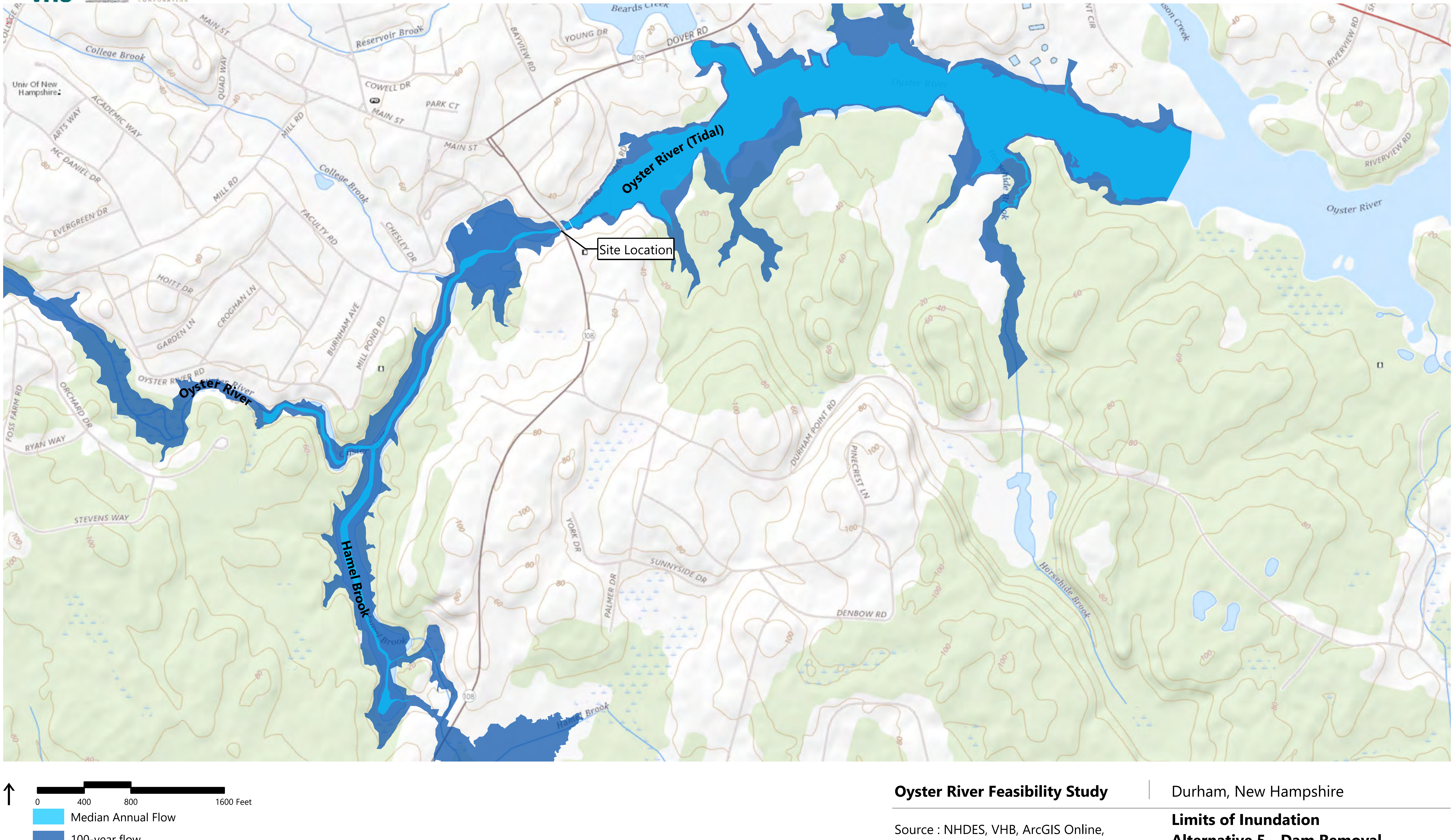


Oyster River Feasibility Study | Durham, New Hampshire

Limits of Inundation
Alternative 3 - Dam Stabilization

Source : NHDES, VHB, ArcGIS Online, Weston & Sampson

Figure 3.2-6

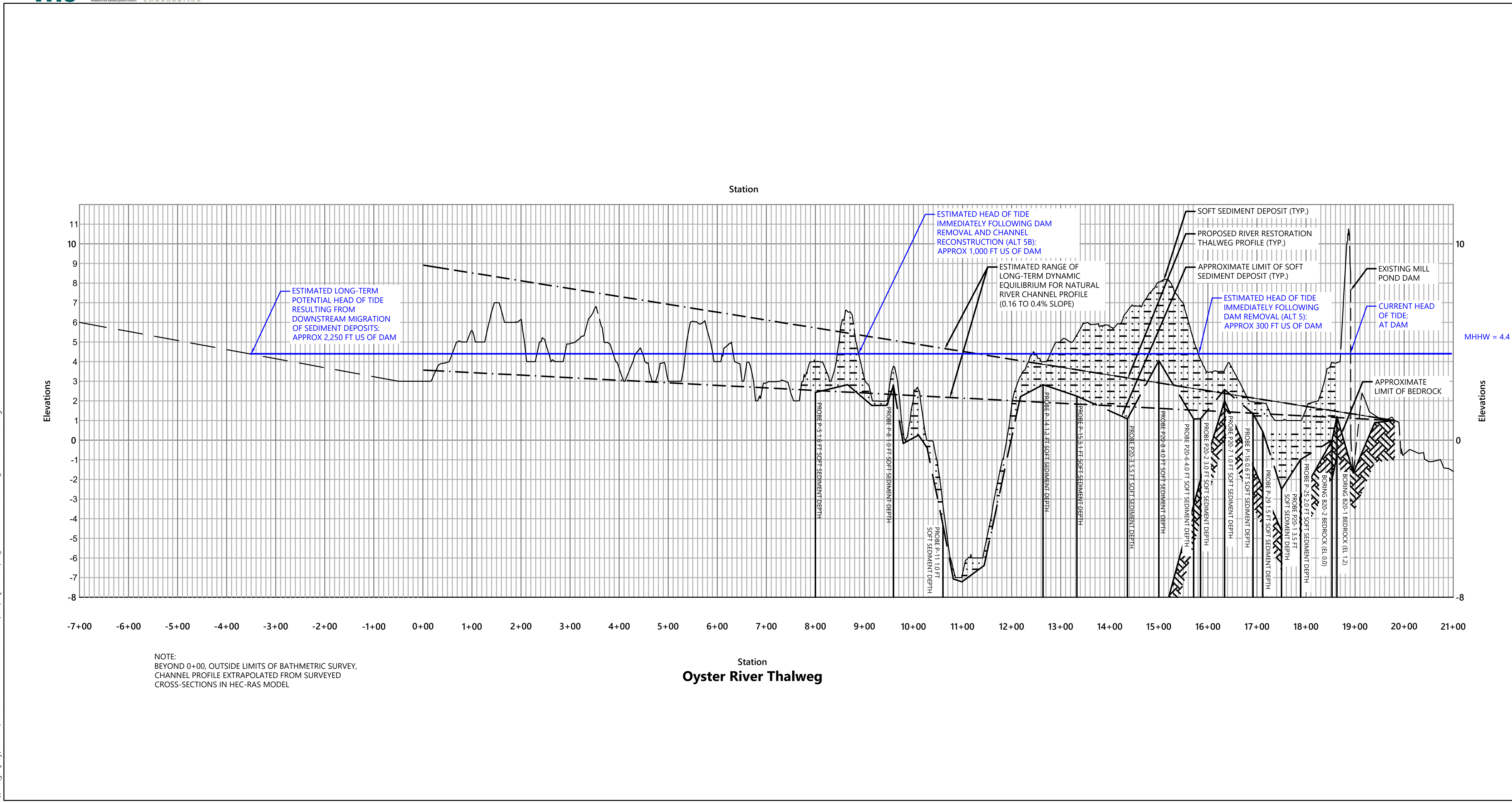


Oyster River Feasibility Study | Durham, New Hampshire

Source : NHDES, VHB, ArcGIS Online, Weston & Sampson

Limits of Inundation
Alternative 5 - Dam Removal

Figure 3.2-7



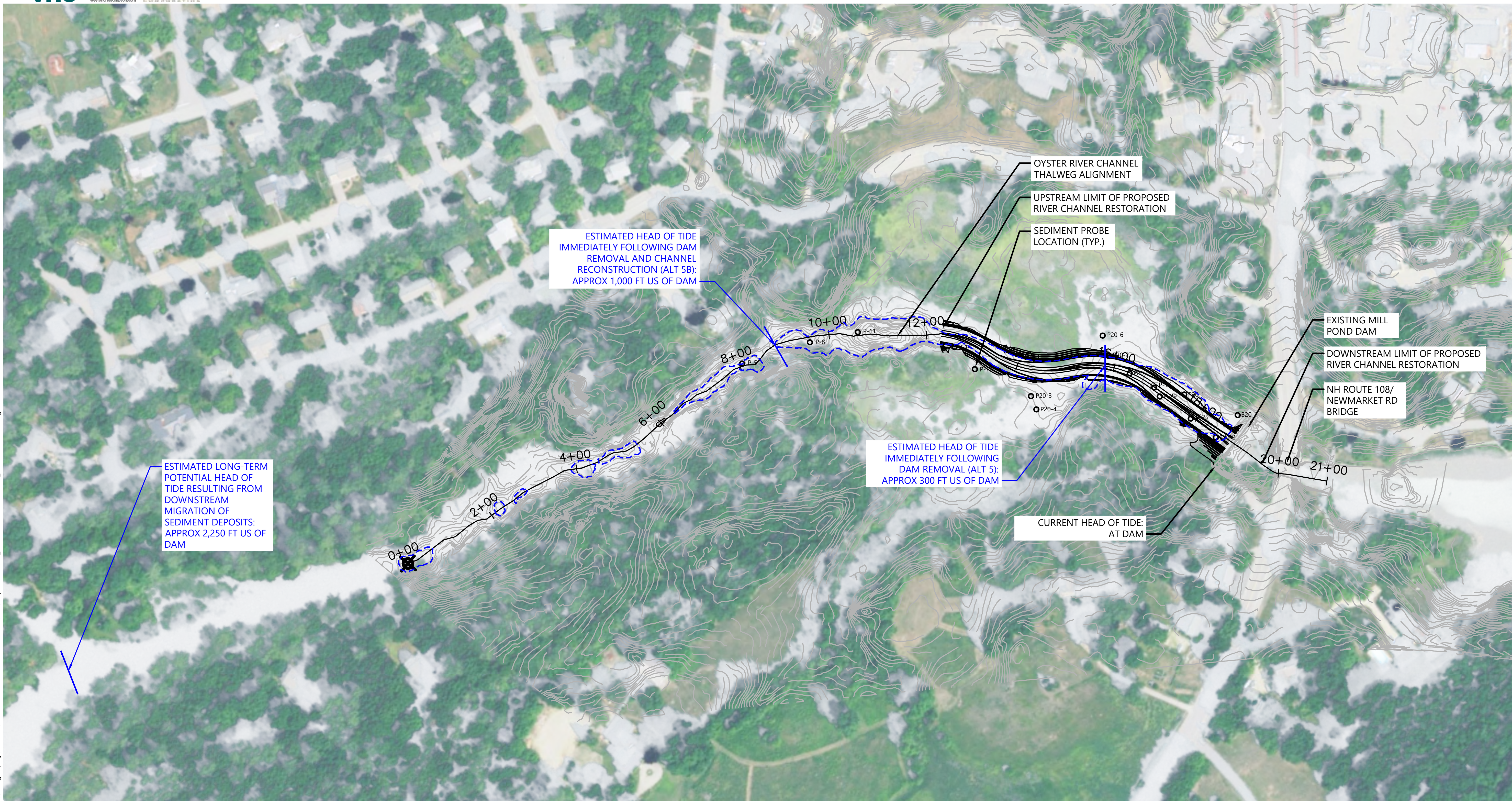
\\vhb\gbl\proj\Bedford\52633.00 Mill Pond Dam Feasibilit\cad\ev\planmisc\FIG_X-52633-HEAD-OF-TIDE_REV2020-11-09.dwg

0 100 200 400 FEET

Oyster River Feasibility Study | **Durham, New Hampshire**

Tidal Influence - Profile View

Figure 3.2-8



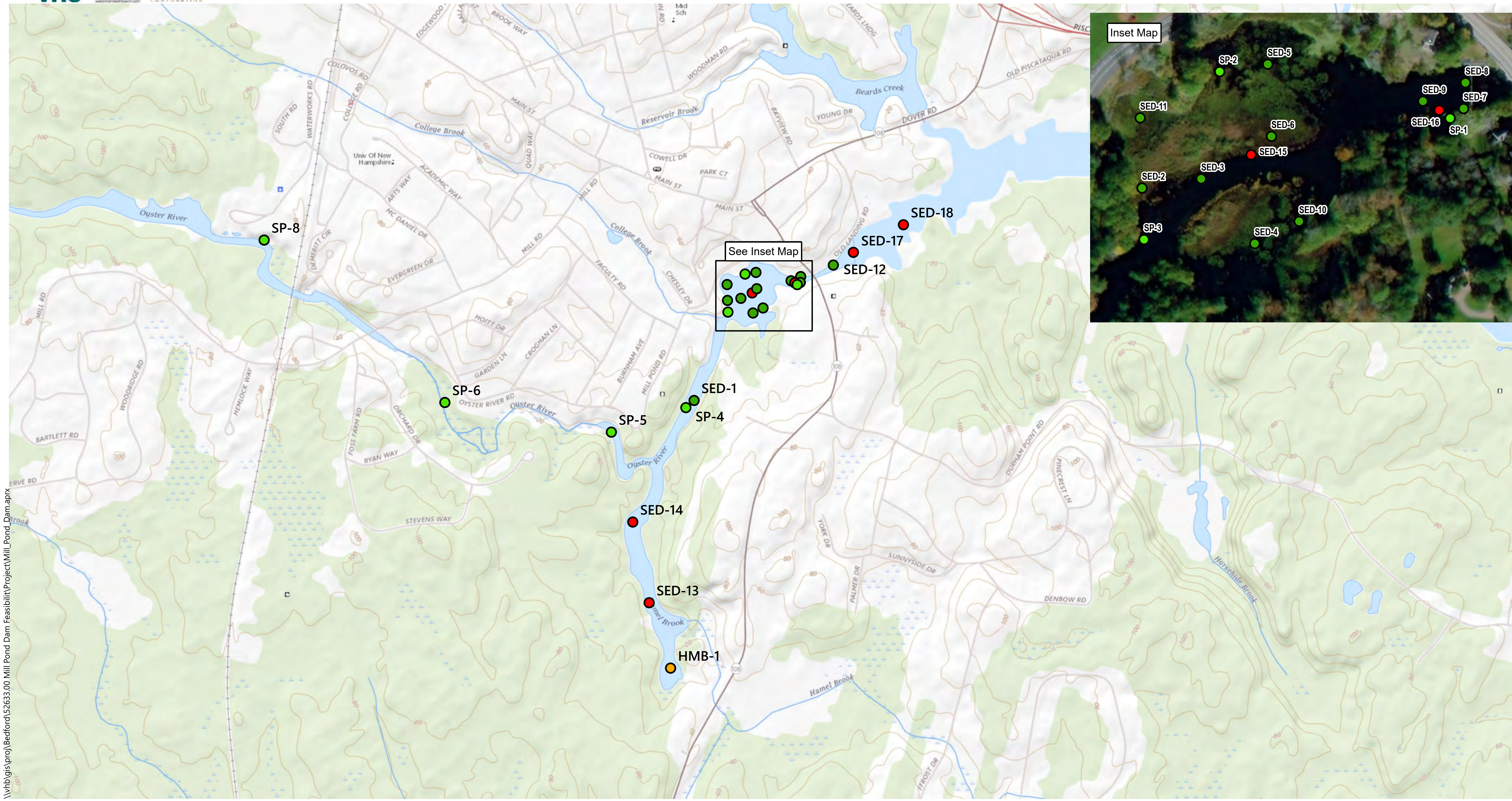
0 100 200 400 FEET

\\vhb\gbl\proj\Bedford\52633.00 Mill Pond Dam Feasibilit\cad\ev\planmisc\FIG_X-52633-HEAD-OF-TIDE_REV2020-11-09.dwg

Oyster River Feasibility Study | **Durham, New Hampshire**

Tidal Influence - Plan View

Figure 3.2-9



\\vhb\gis\proj\Bedford\52633.00 Mill Pond Dam Feasibility\Project\Mill_Pond_Dam.aprx

0 500 1000 2000 Feet

Sampling Locations

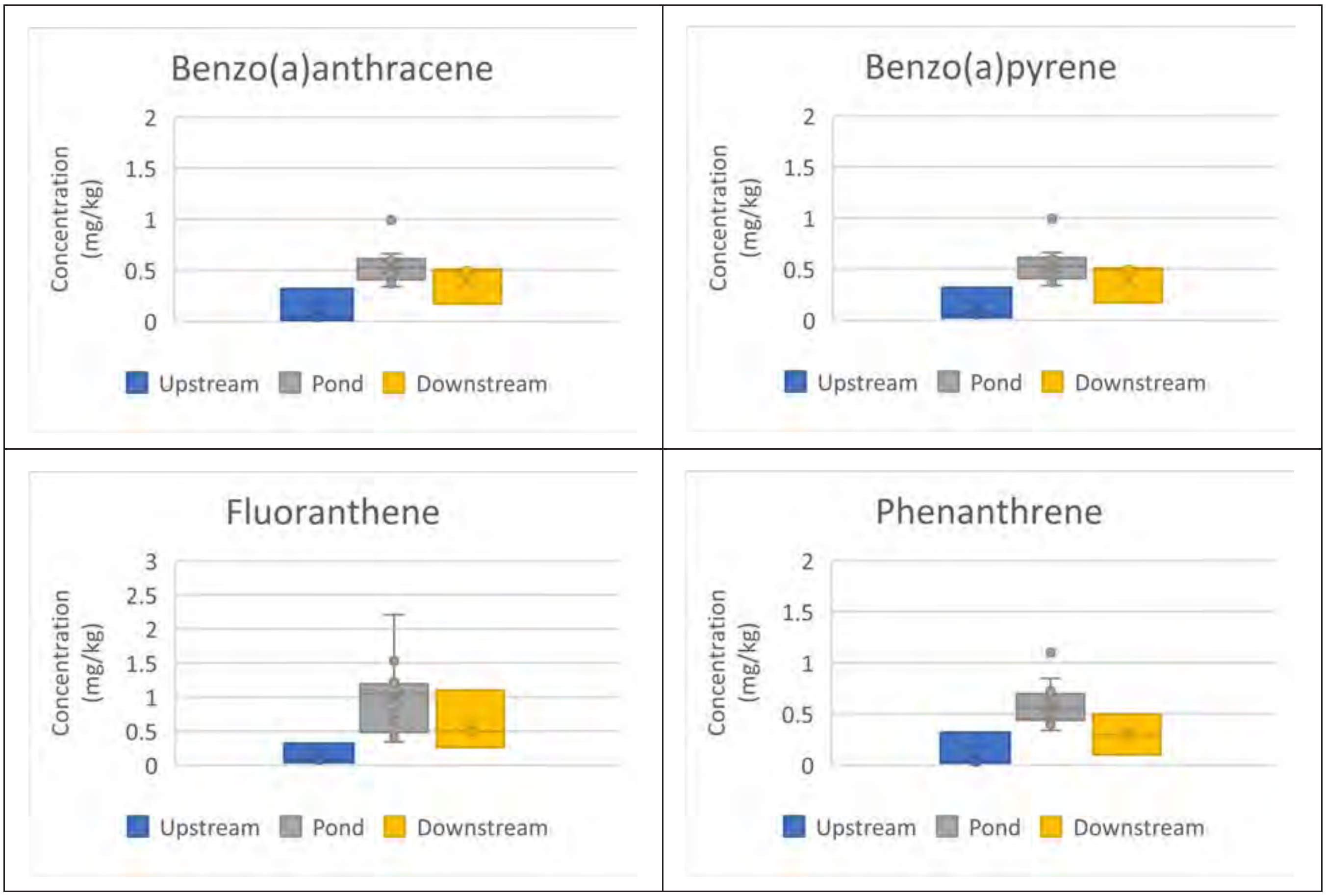
- 2009
- 2017
- 2019
- 2020

Oyster River Feasibility Study | Durham, New Hampshire

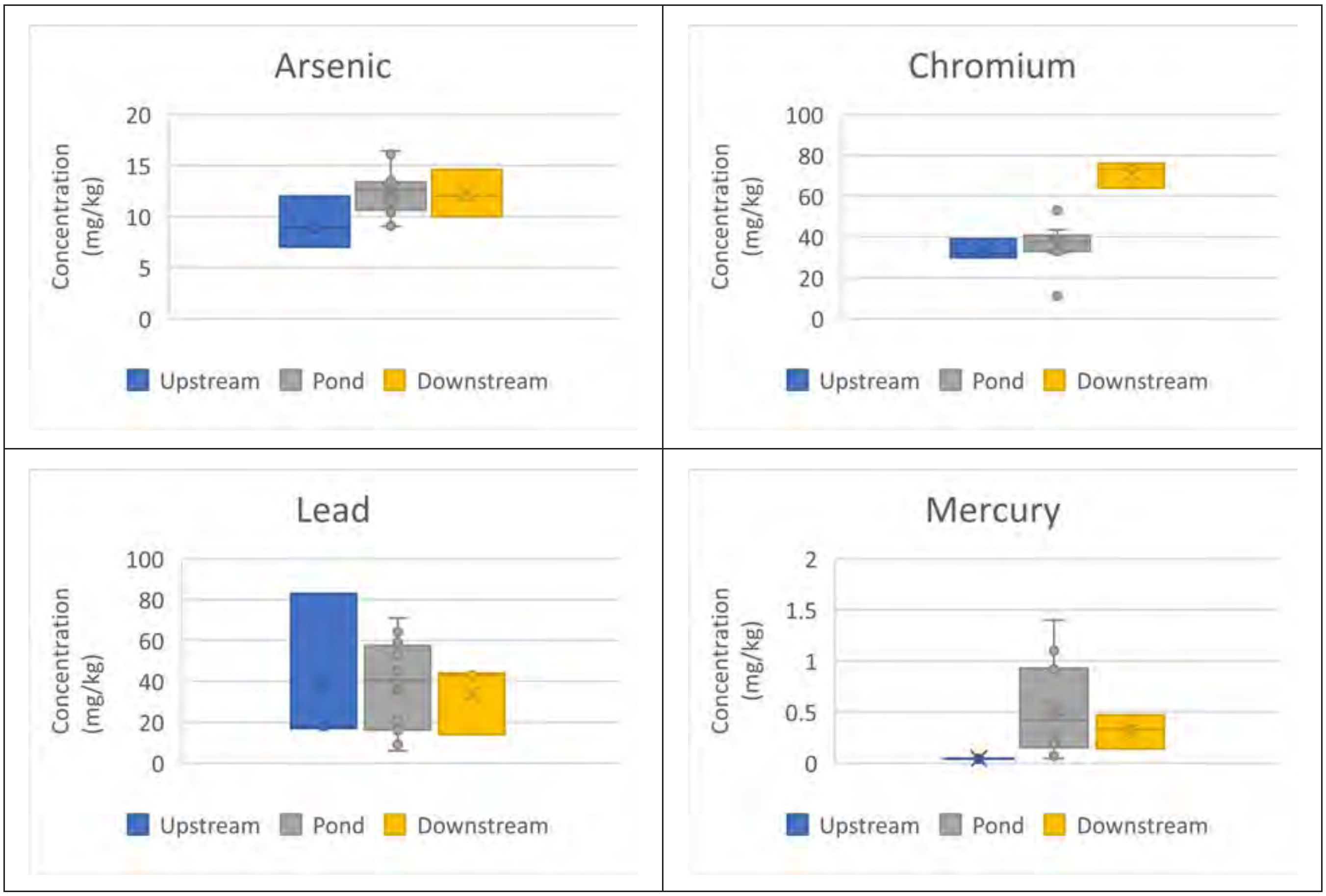
Sediment Sampling Locations

Source : NHDES, VHB, ArcGIS Online

Figure 3.3-1

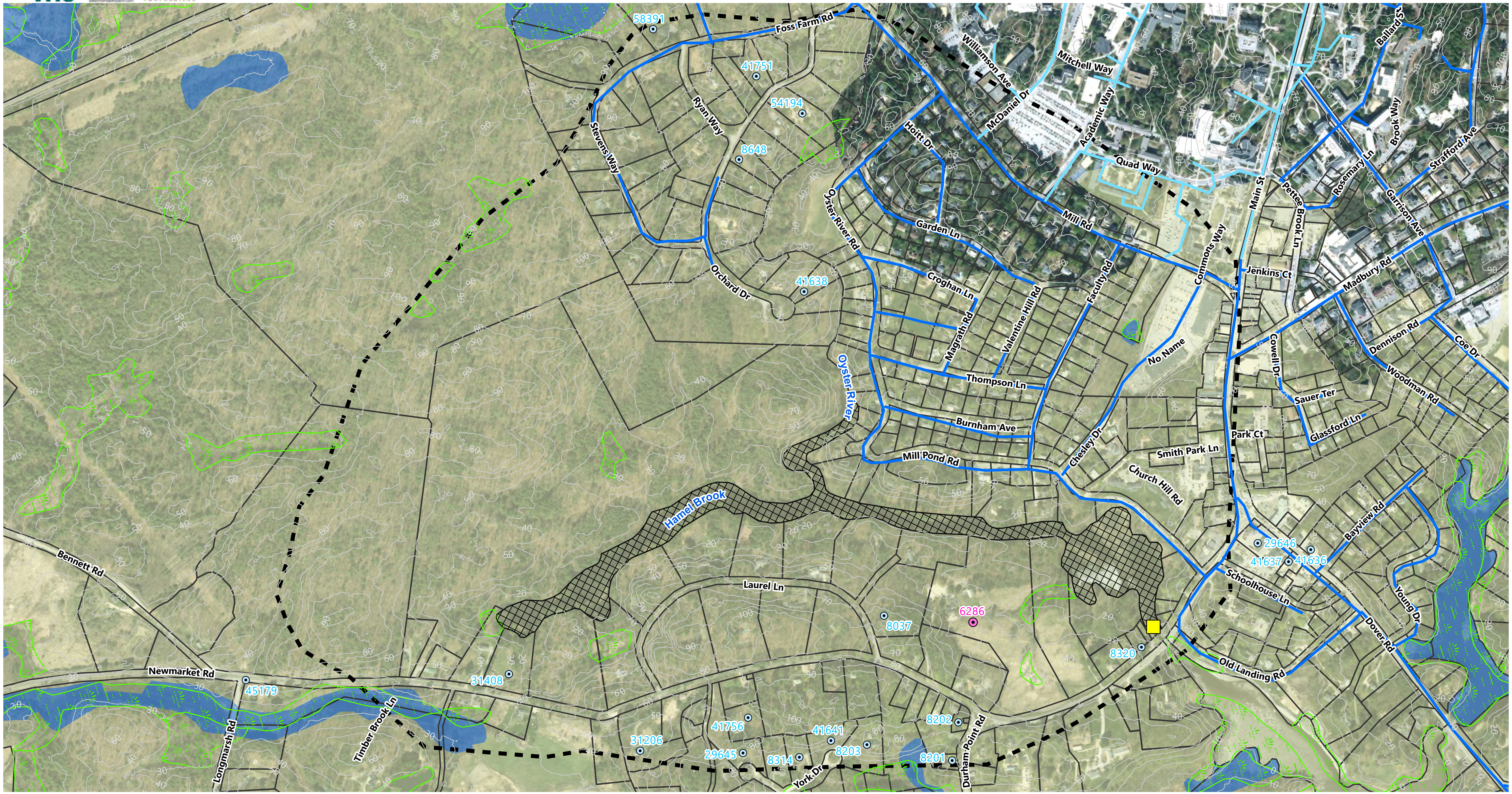


Distribution of Sample Concentrations for Select PAHs



Distribution of Sample Concentrations for Select Metals

Figure 3.4-1



0 325 650 1300 Feet

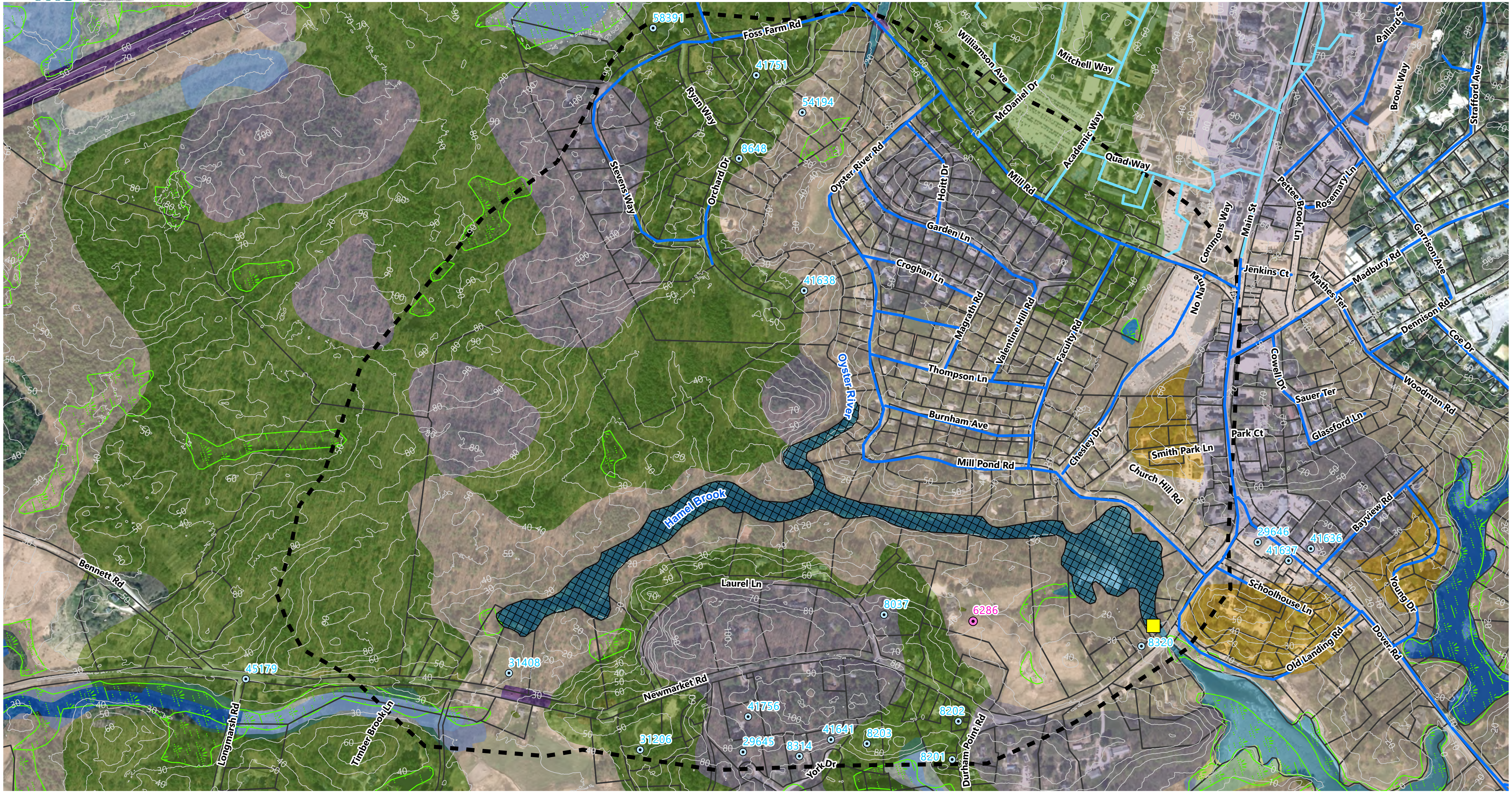
- Existing Dam Location
- Existing Impoundment
- Well Analysis Study Area
- Water Well Inventory
- Public Water Supply Wells
- 10' Countor
- Aquifer Transmissivity - 0 feet sq./day
- Wetlands (NHDES)
- Waterbody (NHD)
- Town of Durham Water Line
- UNH Water Line
- Parcel Boundary

Oyster River Feasibility Study | Durham, New Hampshire

Sources: NHDES, VHB, ArcGIS Online

Well Analysis - Aerial Map

Figure 3.4-2



0 325 650 1300 Feet

Oyster River Feasibility Study | Durham, New Hampshire

Sources: NHDES, VHB, ArcGIS Online

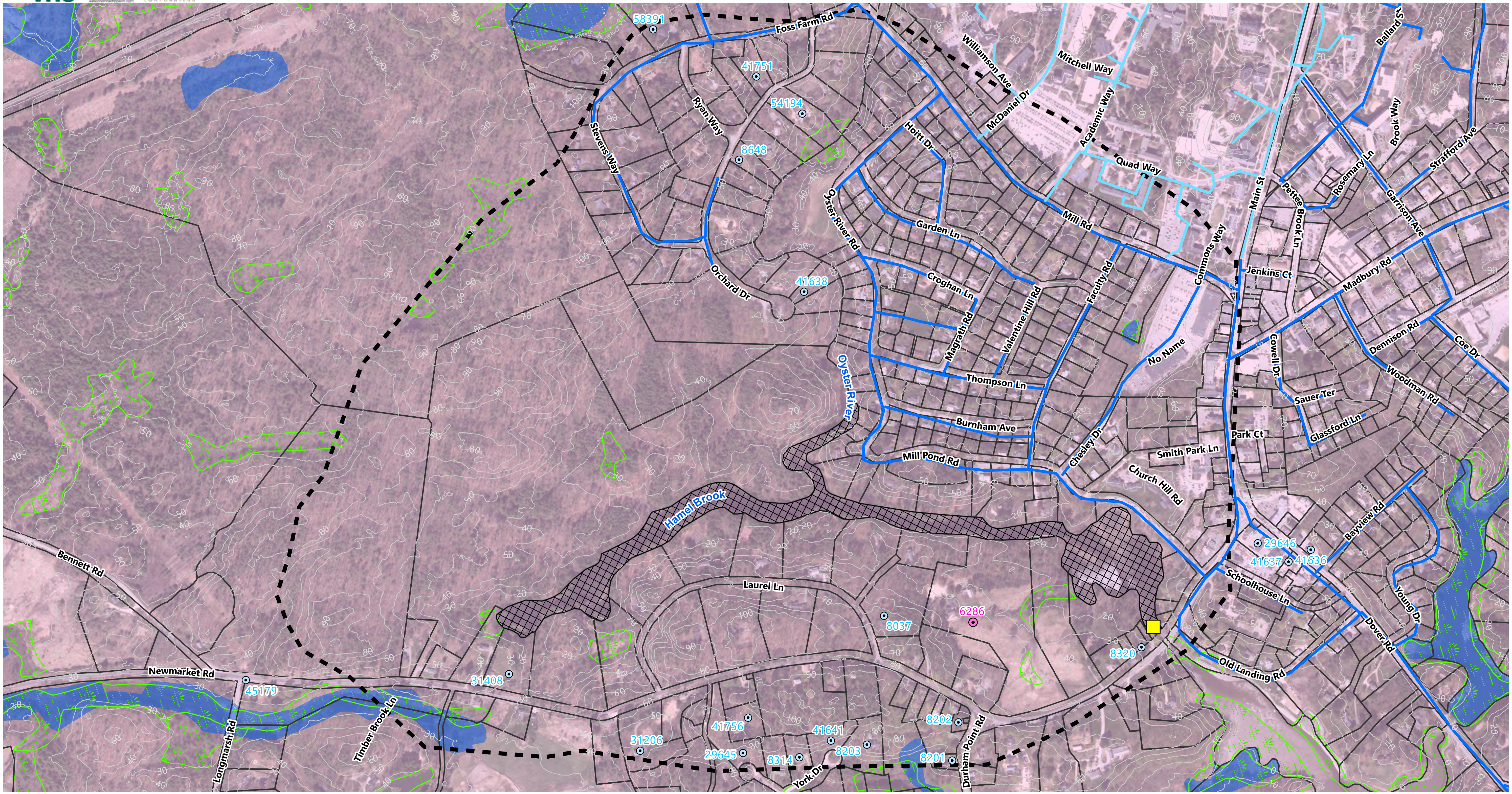
Well Analysis - Surficial Geology

Existing Dam Location
Existing Impoundment
Well Analysis Study Area
Well Water Inventory
Public Water Supply Well
10' Countor

Surficial Geology
Qpc
Qpct
Qsm
Qt
Qtt
Qw
af
bedrock
water

Wetlands (NHDES)
Waterbody (NHD)
Town of Durham Water Line
UNH Water Line
Parcel Boundary

Figure 3.4-3



0 325 650 1300 Feet

Existing Dam Location	Well Water Inventory
Existing Impoundment	Public Water Supply Well
Well Analysis Study Area	10' Countor
Wetlands (NHDES)	Town of Durham Water Line
Waterbody (NHD)	UNH Water Line
	Parcel Boundary

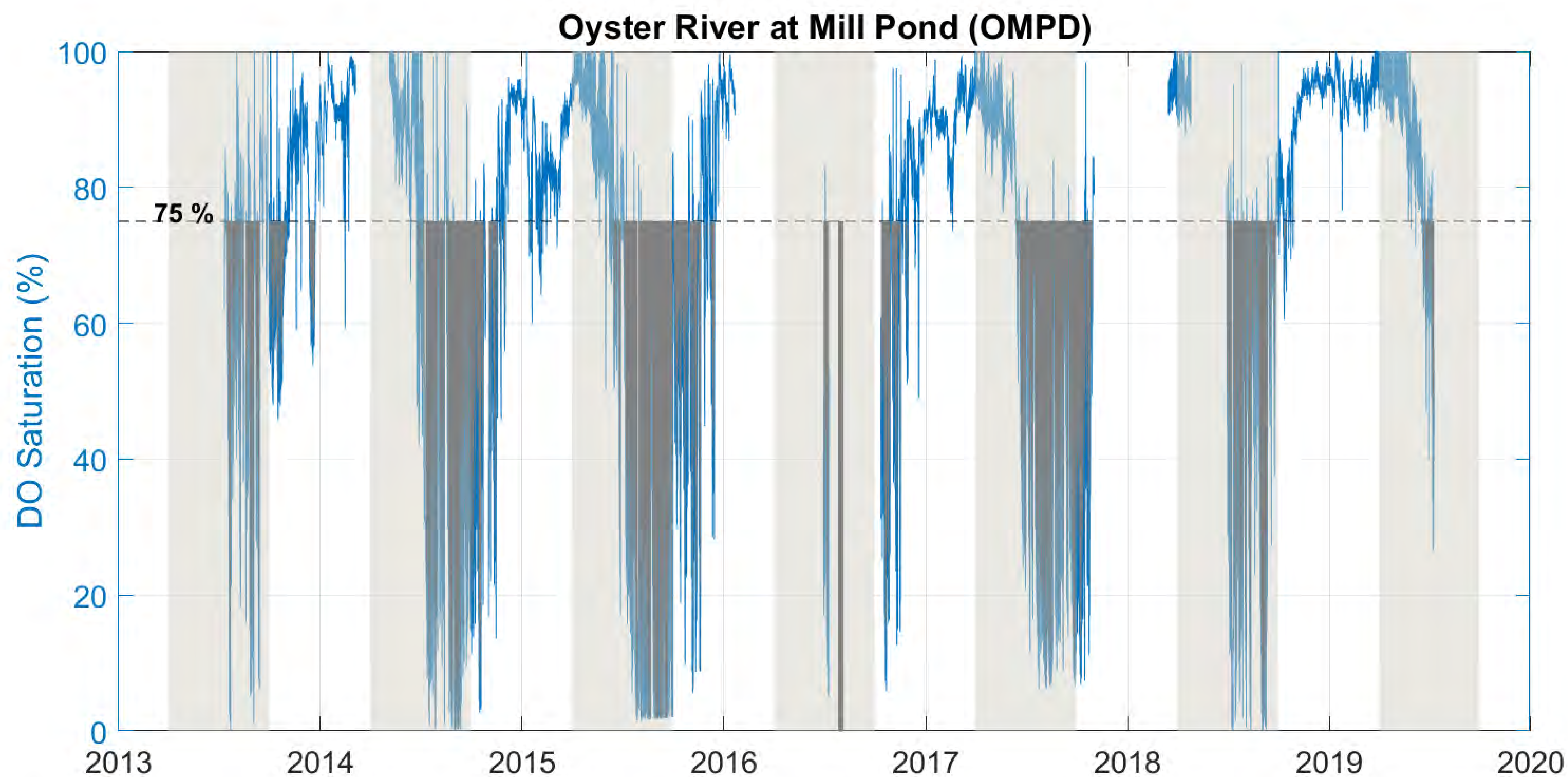
Bedrock Geology

De9

Oyster River Feasibility Study | Durham, New Hampshire

Well Analysis - Bedrock Geology

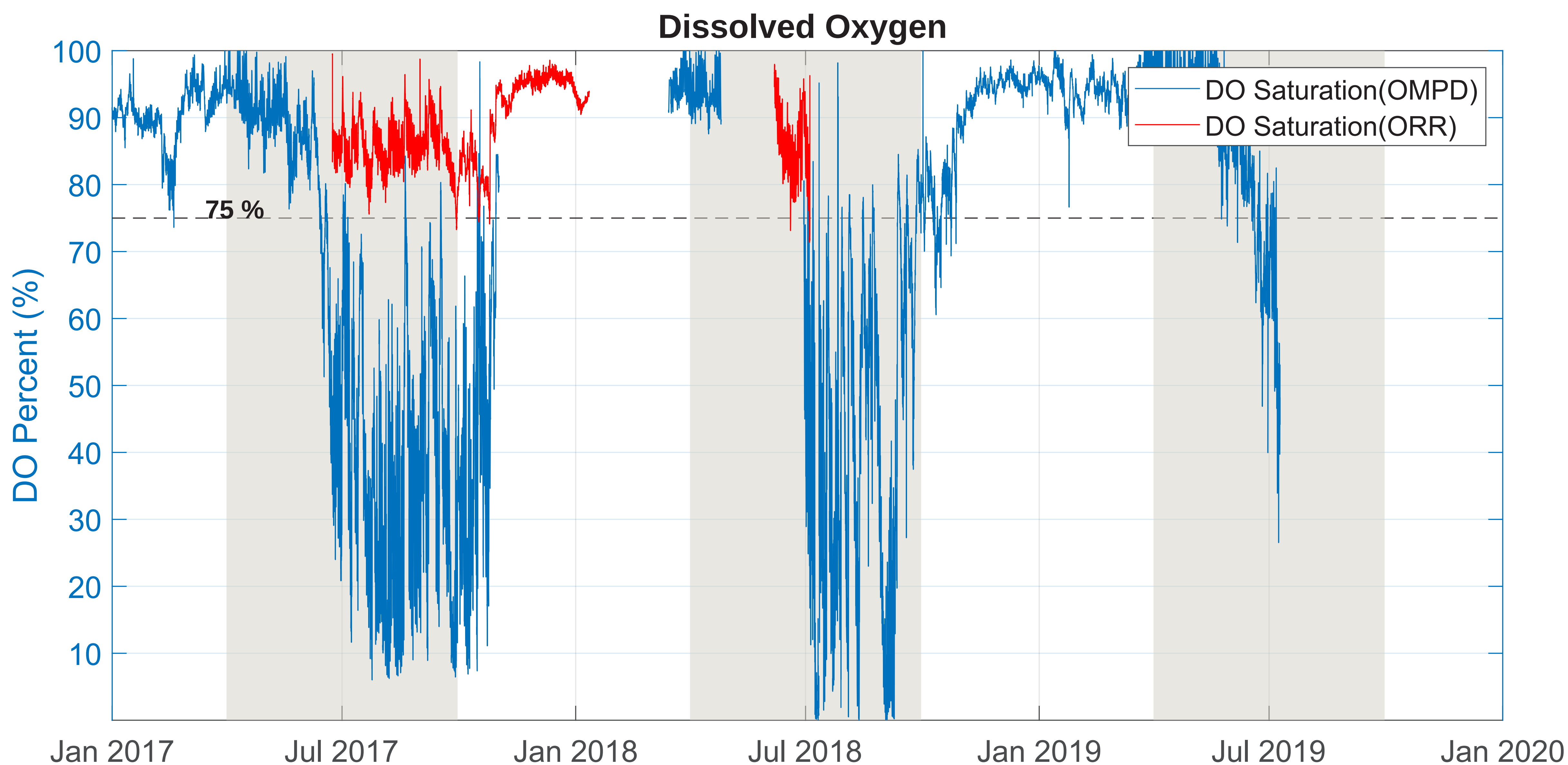
Sources: NHDES, VHB, ArcGIS Online



Notes: Continuous DO % saturation measurements in Mill Pond from 2013 to 2019. Darker shaded areas show time period when DO % saturation is below the water quality standard threshold of 75%. Lighter shaded vertical bands highlight the period between April 1–September 30. Data provided by the UNH Water Analysis Systems Group.

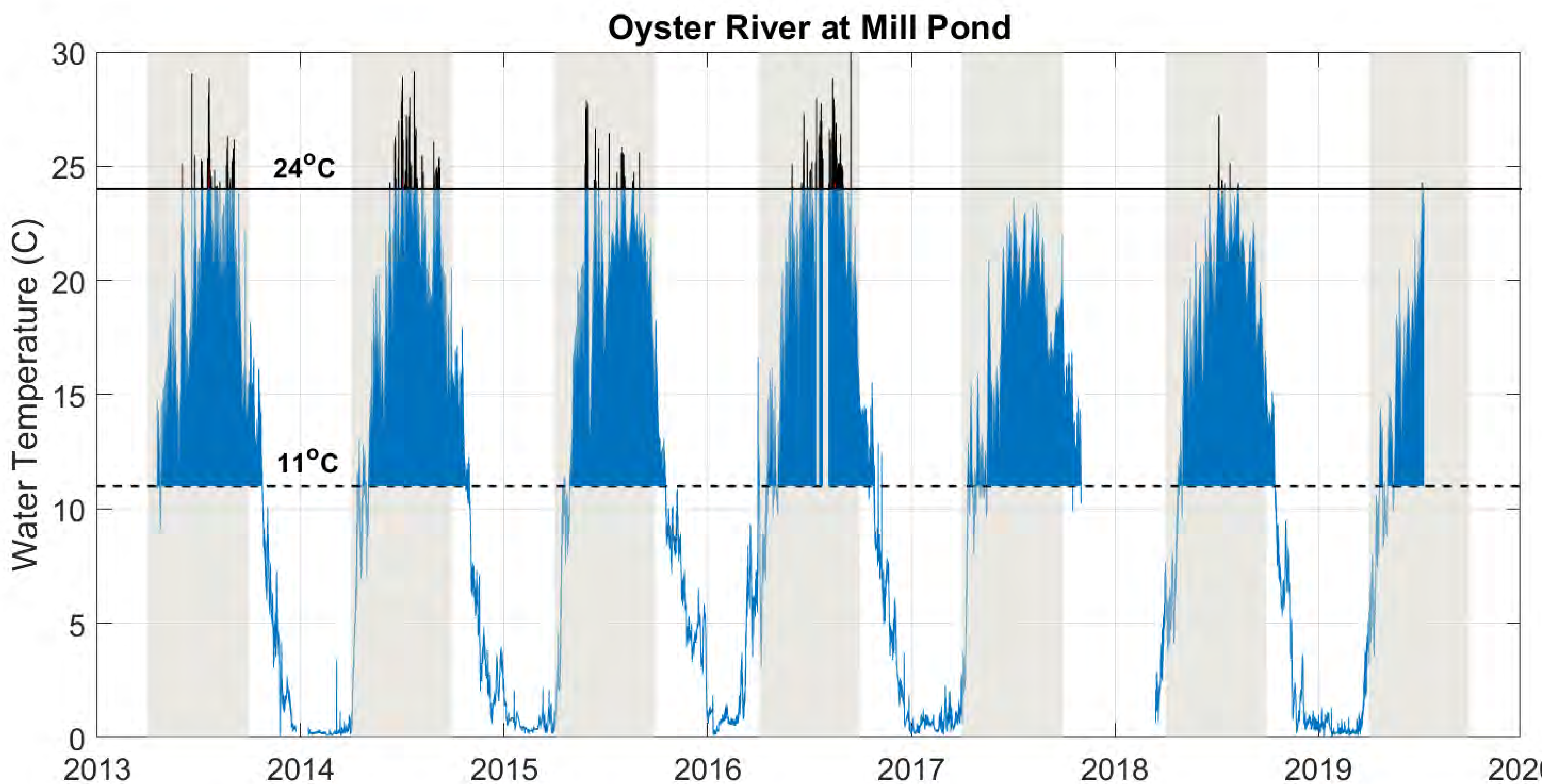
Dissolved Oxygen Percent Saturation Measurements

Figure 3.5-2



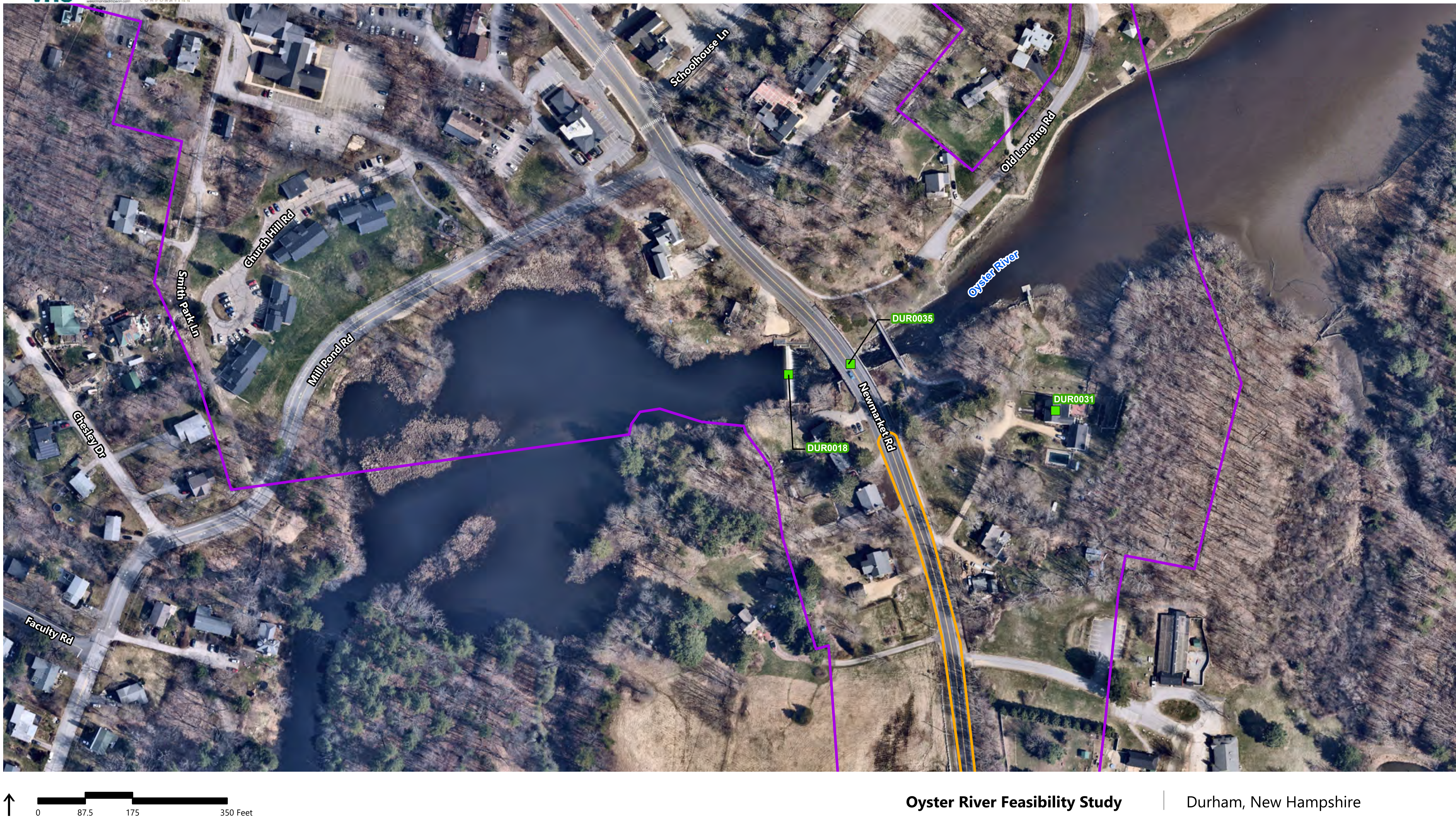
Notes: Comparison of Upstream and Downstream % DO Saturation Readings in the Oyster River at the Upstream Station (ORR) and at the Mill Pond Dam (OMPD) from July 2017 to July 2018.
Data provided by the UNH Water Analysis Systems Group.

Comparison of Upstream and Downstream Dissolved Oxygen Percent Saturation



Notes: Continuous water temperature readings in Mill Pond from June 2013 to July 2019. Light gray shaded areas denote the period from April 1 to September 30th. The horizontal bars of 11°C and 24°C to Greene et al., 2009. Data provided by the UNH Water Analysis Systems Group.

Figure 3.6-1



Previously Surveyed or Listed Properties (NHDHR, EMMIT)

Route 108 Project Area (ZMT-R108)

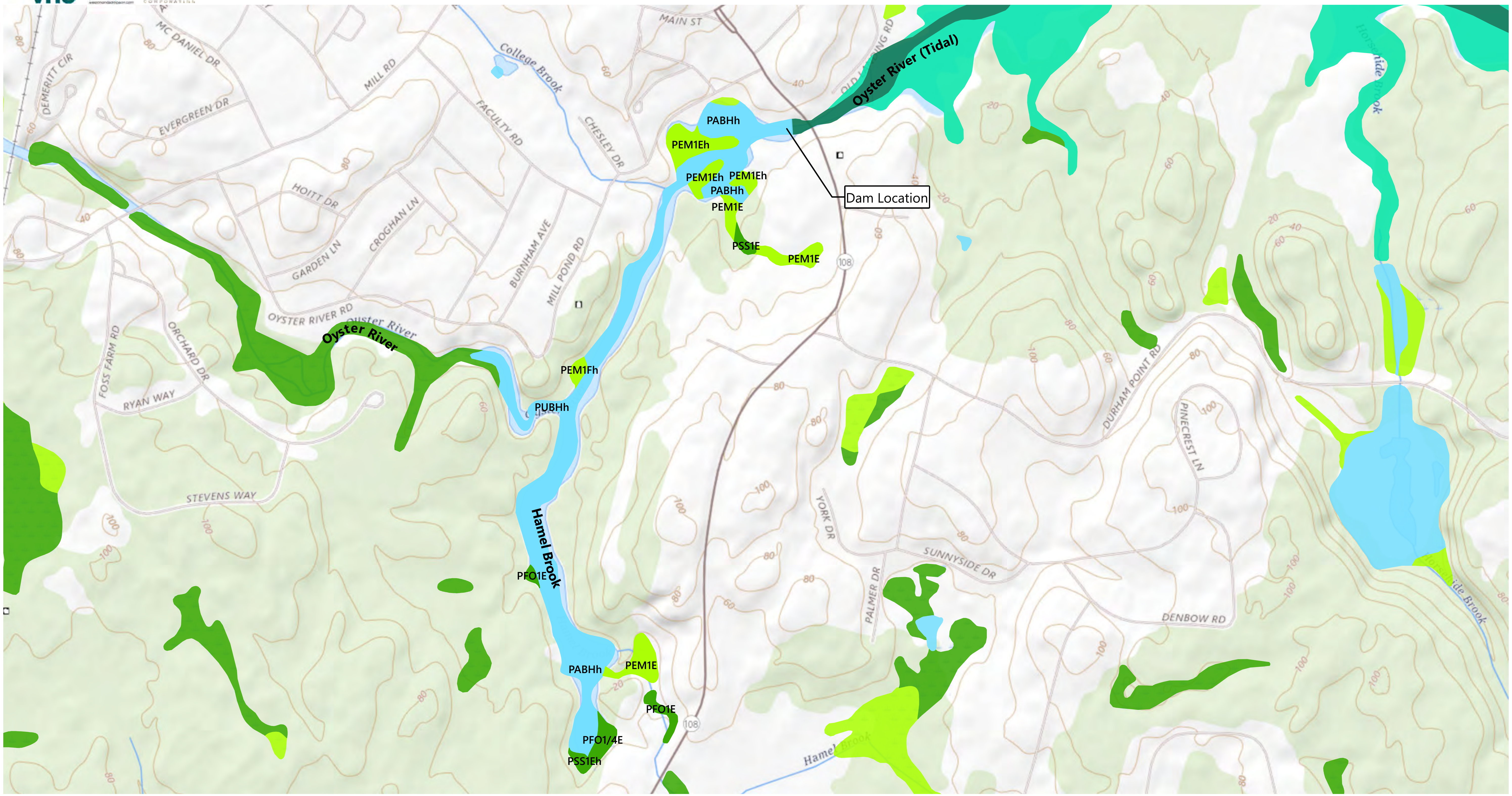
Durham Historic District (DUR0030)

Oyster River Feasibility Study | Durham, New Hampshire

Historic Structures

Source : NHDES, VHB, ArcGIS Online, Weston & Sampson

Figure 3.10-1



0 325 650 1300 Feet

NWI Wetland

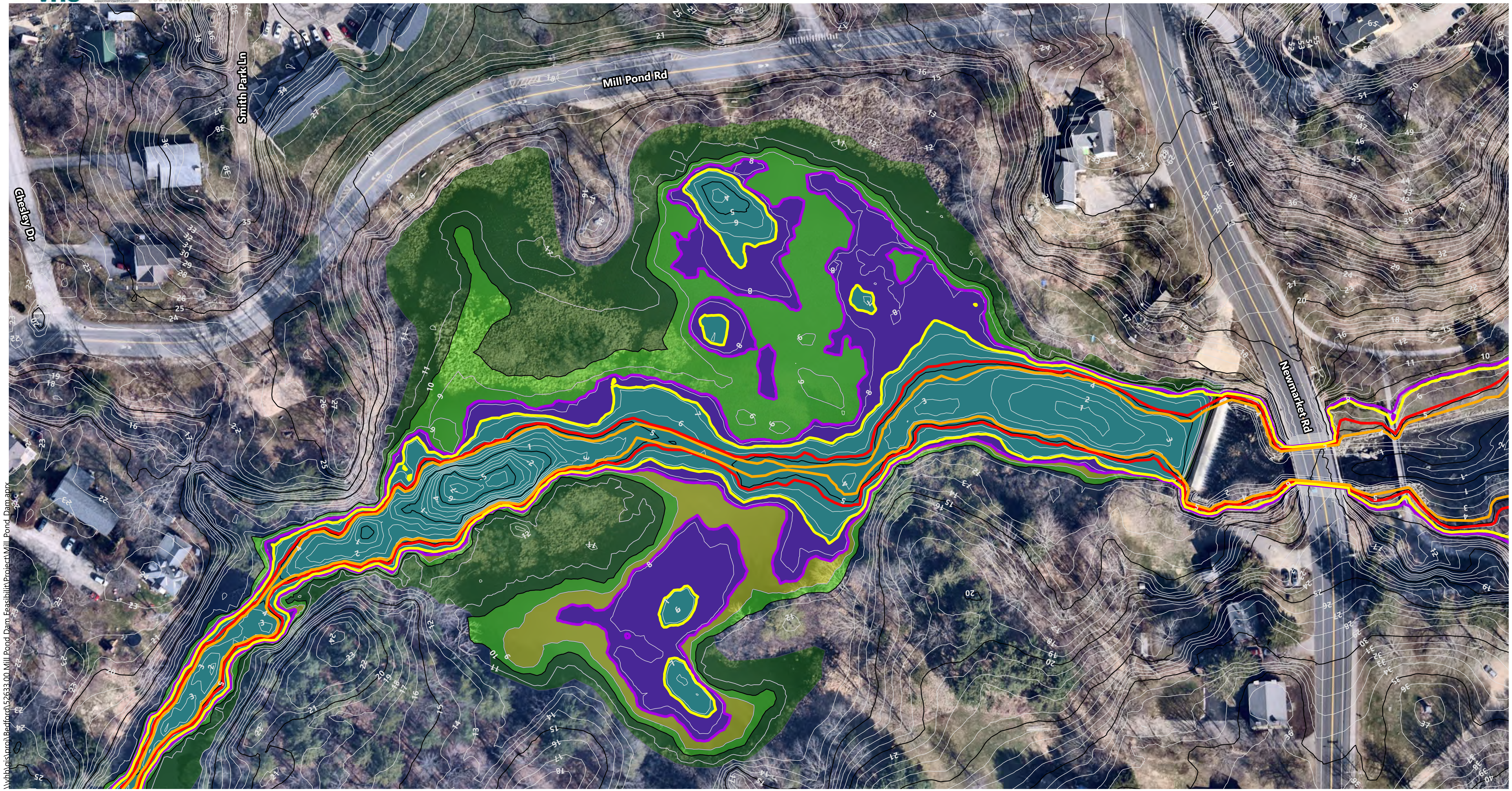
- Estuarine and Marine Deepwater
- Estuarine and Marine Wetland
- Freshwater Emergent Wetland
- Freshwater Forested/Shrub Wetland
- Freshwater Pond

Oyster River Feasibility Study | Durham, New Hampshire

Source : NHDES, VHB, ArcGIS Online

Wetlands Adjacent to the Oyster River Dam Impoundment

Figure 3.2-10



0 50 100 200 Feet

Anticipated Vegetation Transition Zones

- < 5' Open Water
- 5'-6' Emergent Wetland
- 6'-8' Freshwater Emergent Marsh/Shrub
- 9'-10' Marsh/Shrub/Forested Wetland
- >10' Shrub/Forested Wetland/Upland Transition

Anticipated High Water Lines

- Mean Higher High Water - 4.4' - Higher Low Marsh
- Head of Tide Limit - 5.4' - High Marsh
- Mean Higher High Water + 2.9' RSLR (Likely Range)
- Mean Higher High Water + 3.8' RSLR (5% Chance)

- Index Contour (5 ft)
- 1' Contour Intervals

Oyster River Feasibility Study | Durham, New Hampshire

Source : NHDES, VHB, ArcGIS Online

Alternative 5 - Dam Removal Predicted Tidal Influence and Wetland Habitats