FINAL TECHNICAL REPORT

# Exeter River Great Dam Removal Feasibility and Impact Analysis

SUBMITTED TO

**The Town of Exeter**

SUBMITTED BY


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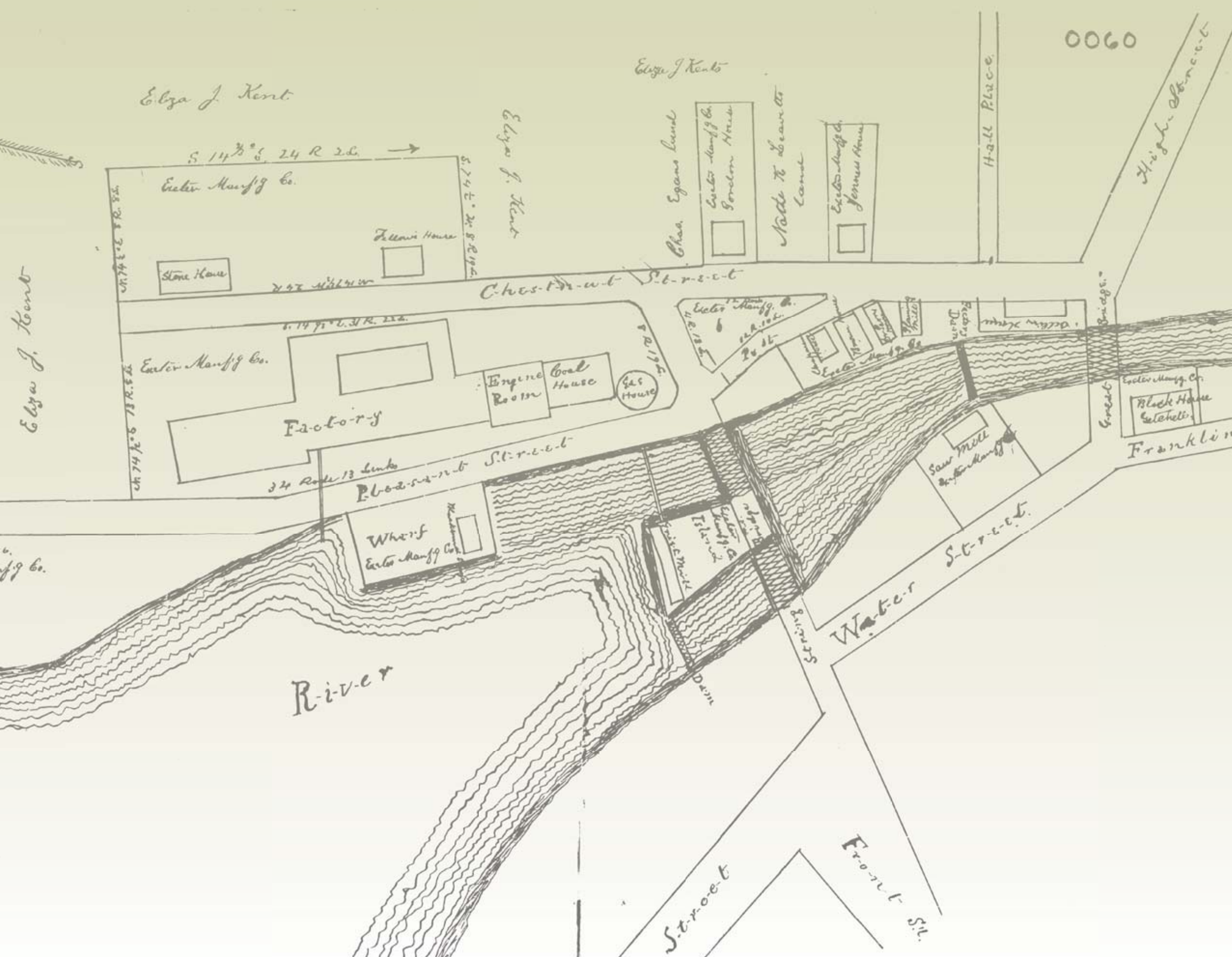
Bedford, New Hampshire

IN ASSOCIATION WITH

**Field Geology Services**
**Kleinschmidt Associates**
**Weston & Sampson**


OCTOBER 2013


0060
Eliza J. Kent
Exeter Manf'g Co.
Stone House
Chestnut Street
Factory
Engine Room
Coal House
Gas House
Pleasant Street
Wharf
River
Water Street
Saw Mill
Block House
Franklin
High Street
Hall Place
Front St.
Street
Dam

**Final Technical Report -** NHDES Dam #082.01

# *Exeter River Great Dam Removal Feasibility and Impact Study*

## Exeter, New Hampshire

Prepared for **Town of Exeter, NH**

Prepared by ***VHB*/Vanasse Hangen Brustlin, Inc.**
**Bedford, New Hampshire**

In association with Weston & Sampson
Kleinschmidt Associates
Field Geology Services
Tom Ballestero, PhD

**FINAL – October 2013**

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***Note: Gray shading throughout this Final Report indicates changes made since the Draft Report was issued in June 2013 in response to public comments.***

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# List of Acronyms

| | |
|---|---|
| APE | Area of Potential Effect |
| ASTM | American Society of Testing and Materials |
| BMP | Best Management Practices |
| BTAG | Benchmarks for Toxicological Assessment Guidance |
| CEM | Channel Evolution Model |
| CRREL | US Army Corps of Engineers, Cold Regions Research & Engineering Laboratory |
| CWRP | Corporate Wetlands Restoration Partnership |
| DHC | District Heating and Cooling |
| DO | Dissolved Oxygen |
| DOI | Department of Interior |
| ESA | Endangered Species Act |
| ERSC | Exeter River Study Committee |
| ESRLAC | Exeter Squamscott River Local Advisory Committee |
| EQIP | Environmental Quality Incentives Program |
| FEH | Fluvial Erosion Hazards |
| FEMA | Federal Emergency Management Agency |
| gpm | Gallons per Minute |
| HEC-HMS | US Army Corp of Engineers, Hydraulic Engineering Center-Hydraulic Modeling System |
| HEC-RAS | US Army Corp of Engineers, Hydraulic Engineering Center-River Analysis System |
| IPM | Integrated Pest Management |
| ITP | Incidental Take Permit |
| LAC | Local Advisory Committee |
| LCC | Life Cycle Cost |
| LCHIP | Land and Community Heritage Investment Program |
| LOD | Letter of Deficiency |
| LWD | Large Woody Debris |
| mgd | Million Gallons per Day |
| MPM | Meyer-Peter Mueller Method |
| MRL | Method Reporting Levels |
| NCAP | National Coastal Assessment Program |
| NGVD29 | National Geodetic Vertical Datum of 1929 |
| NHDAMF | New Hampshire Department of Agriculture, Market and Food |
| NHDES | New Hampshire Department of Environmental Services |
| 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 |
| NRCC | Northeast Regional Climate Center |
| NRCS | Natural Resource Conservation Service |
| NWI | National Wetlands Inventory |
| O&M | Operations and Maintenance |
| OMP | Operations & Maintenance Plan |
| NOAA | National Oceanic and Atmospheric Administration |
| PAH | Polynuclear Aromatic Hydrocarbons |
| PCB | Polychlorinated Biphenyls |
| PEA | Phillips Exeter Academy |

| | |
|---|---|
| PEC | Probable Effect Concentration |
| PEL | Probable Effect Levels |
| PEC-HQ | Probable Effect Concentration - Hazard Quotient |
| QAPP | Quality Assurance Project Plan |
| RGA | Rapid Geomorphic Assessment |
| RHA | Rapid Habitat Assessment |
| SCS | Soil Conservation Service, of the US Department of Agriculture |
| SGA | Stream Geomorphic Assessment |
| SQUIRT | NOAA Screening Quick Reference Tables (SQuiRT) |
| 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 |
| VRAP | Volunteer River Assessment program |
| WDR | Width to Depth Ratio |

# Glossary

### Abutments

The part of a structure (as an arch 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.

### Anadromous

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

### Anoxic

Areas of salt water, freshwater or groundwater that are depleted of dissolved oxygen.

### 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.

### Base Flow

Stream discharge derived from groundwater sources as differentiated from surface runoff.

### 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 the Great 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 Great Dam is a denil-style ladder.

### Fish Weir

A lower small dam, below the main spillway of the Great Dam, which is designed to direct migrating fish to the fish ladder entrance.

### 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 or another celestial body

### 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.

## Glaciolacustrine

Sediments deposited by glacial meltwater into a lake environment, from glacial erosion or deposition.

## Glaciomarine

Sediment deposited by glacial meltwater into an ocean environment.

## 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*.

## Headpond

A natural or artificial pond or lake used for the storage and regulation of water.

## Headworks

Structure at the head or diversion point of a waterway. Used to divert water from a river into a canal or from a larger canal into a smaller canal.

## 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 US Army Corps of Engineers 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.

### Lentic

Ecology of, relating to, or inhabiting still water.

### 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.

### Meander Belt

The zone along a valley floor that encloses a meandering river; the area between lines drawn tangential to the extreme limits of fully developed meanders.

### Main stream

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.

### Obermeyer Flashboard/Gate/System

A proprietary system designed and manufactured by Obermeyer Hydro, Inc. which consists of a hinged steel plate supported by a rubber bladder that acts as the crest of a dam.

### Ogee

A style of run-of-river spillway; a double curve, resembling the letter S, formed by the union of a concave and a convex line.

### Oxbow

U-shaped bend in a river or stream.

### 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.

### Penstock

A sluice, gate or intake structure that controls water flow or an enclosed pipe that delivers water.

### Physiography

Physical geography, geomorphology.

### Planform

The contour, outline or an object or mass as viewed from above.

### 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.

### Sinuosity Value

In *fluvial geomorphology*, a measure of the relative straightness or curvature of a channel. Values range from 1 to 4. A completely straight channel will have a sinuosity of 1. Channels with ratios approximately 1.5 are sinuous channels. Channels with higher ratios are called meandering channels.

### 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.

# Executive Summary

## ES-1 Background

The Great Dam is located in the Exeter River at the center of Exeter's business district, just upstream of where the river flows into the tidal Squamscott River. The dam impounds the river about 4.5 miles upstream, including a portion of the Little River.

The dam is a reinforced concrete run-of-river[1] dam consisting of a spillway, a fish ladder including a small lower dam or "weir" structure, a low level outlet and a penstock. The dam is approximately 136 feet long by approximately 16 feet high measured from its highest point to the streambed at its downstream face. The fish ladder was installed by the NH Fish and Game Department in the late 1960's to help restore upstream passage for certain fish that live in the ocean, but swim upstream to freshwater in order to spawn.

The New Hampshire Department of Environmental Services (NHDES) Dam Bureau has identified safety problems with the Great Dam. Most notably, the dam does not meet dam safety regulations which require low-hazard[2] dams to safely withstand a 50-year storm event without overtopping the abutments. The town was notified of these problems in a Letter of Deficiency (LOD) issued by NHDES on July 25, 2000.[3] The NHDES has given the Town deadlines to either modify or remove the dam to meet this legal requirement. The most recent deadline passed on December 31, 2011, but NHDES is aware that the town is in the process of making a decision on how best to address the dam safety issue.

Various alternatives have been considered to solve this safety problem, including the permanent modification of the dam and removing the dam entirely. Previous studies indicate that the Great Dam would require significant modifications to increase its discharge capacity to meet NHDES requirements. The current report is intended to determine the feasibility of removing the Great Dam from the Exeter River and to compare the impacts, benefits and costs of dam removal to other options such as modifying the dam to increase its discharge capacity.

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[1] "Run of the river" dams allow all of the natural river flow to pass over the dam in a relatively consistent and steady flow as opposed to other dams which may divert, store, or release water flow for various reasons.

[2] "Low hazard is used in the regulatory sense. See NH Administrative Rule Env-Wr 101.07 for the regulatory definition of a "low hazard" structure.

[3] The original LOD was amended on June 1, 2004 and March 2, 2009 to allow the Town more time to study potential solutions.

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 specific recommendation regarding whether the dam should be modified or removed. Rather, the intent of this study is to provide specific information to allow the Town to choose an alternative at a future date.

## ES-2 Alternatives Considered

A total of eight alternatives were considered during this study. Three of these alternatives were discarded due to issues related to regulatory, cost or constructability considerations. Five alternatives were brought forward for further analysis including:

- **Alternative A – No Action (Existing Conditions)**. Under this scenario, the existing dam and fish ladder would remain as is, with no modifications. However, this alternative was eliminated based on safety and regulatory concerns. Nevertheless, its inclusion in the study provides a baseline against which other alternatives can be evaluated.

- **Alternative B – Dam Removal**. This alternative involves the removal of the entire existing dam structure, including the fish ladder and lower dam, and reshaping of the river channel within the footprint of the existing dam and immediately upstream and downstream. This alternative substantially changes river elevations upstream from the existing dam site and river hydraulics, both upriver and at the former dam site.

- **Alternative F – Partial Removal.** Under this alternative, the dam spillway would be permanently lowered by 4 feet. Because this would permanently lower the water level upstream of the dam, the existing fish ladder would no longer work properly. Therefore, this alternative also involves construction of a new fish ladder on the eastern side of the reconfigured dam (opposite of the position of the existing ladder).[4]

- **Alternative G – Stabilize in Place.** During this study, it was determined that one potential solution would be to better anchor the existing dam to its underlying bedrock. Engineering calculations indicate that the dam could be made stable even if it is overtopped by a flood. This is a very different approach than trying to increase the hydraulic capacity of the dam. Thus, Alternative G would keep the dam more or less in its current configuration, with no changes to the spillway elevation, abutments or fish ladder. Based on the conceptual design developed as part of this study, ten "post-tension rock anchors" would be installed through

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[4] Gray shading throughout this Final Report indicates changes made since the Draft Report was issued in June 2013 in response to public comments.

the dam to anchor it.[5] While this information has yet to be fully reviewed by the NH Department of Environmental Services Dam Bureau, preliminary indications are that this alternative meets dam safety rules.

- **Alternative H – Dam Modification – Inflatable Flashboard/Gate System.** This alternative would lower the spillway by 4.5 feet then replace this portion of the spillway with a 4.5 ft tall adjustable flashboard system. The existing low-level gate would be replaced with a 14 ft long by 7 ft tall adjustable gate. The recommended adjustable flashboard and gate would be an "Obermeyer" system, which has been installed on numerous dams around the world and relies on an inflatable bladder to support the flashboard/gate structure. Because the removal of so much concrete from the dam would impact its stability, this alternative also would require installation of 13 rock anchors.[6] The Obermeyer flashboard and gate will have the same crest elevation as the existing dam (i.e., Elev. 22.5 ft) under normal flow conditions, so would therefore maintain the functionality of the fish ladder. However, the flashboard and gate could be lowered in the event of a flood. This alternative would also require the construction of a compressor building adjacent to the dam (presumably in Founders Park) to control the flashboard and gate.

The main difference among the alternatives relates to their potential effects on the size and depth of the dam impoundment. Alternatives B and F would lead to a significant reduction of the impoundment, although water levels upstream would be maintained to an extent due to naturally occurring bedrock outcrop at the site of the present dam. Alternative G would maintain the impoundment at its current level. Alternative H would allow the impoundment to be raised and lowered depending on flow conditions. Note that.

## ES-3 Impacts and Benefits

The safety problems associated with the Great Dam are a significant challenge, and the Town faces an important decision. This study attempts to provide enough information to allow the community to make an informed decision on how to move forward. Below, we summarize the key findings that have developed over the course of the study.

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5 All of the conceptual designs presented in this report are preliminary and have yet to be fully reviewed by technical staff at the NHDES. They are therefore subject to change during final design.

6 All of the conceptual designs presented in this report are preliminary and therefore subject to change during final design.

## ES-3.1 Changes in Flooding and Hydraulics

Dam Removal and Partial Removal would substantially lower water levels upstream of the dam under normal flow conditions.

The removal of Great Dam would lower water levels and river widths substantially near the Great Dam. The changes would be less significant further upstream until they diminish to zero at the limits of the existing impoundment near the Amtrak (Boston & Maine) Railroad Bridge. For example, if the dam were removed or partially removed, the following changes are predicted to occur under the median annual flows:

- **Between the Dam and the Little River Confluence:** Current average depths would decrease from about 5.2 ft to about 2.5 to 2.6 ft and maximum depths of roughly 10 feet would drop to about 5.4 ft. Average river width is predicted to decrease 59 feet from 134 ft to 75 ft for the Dam Removal Alternative to about 100 ft for the Partial Removal Alternative.

- **From the Little River Confluence to NH 108 Bridge:** During the median annual flow, the average depth in this reach is predicted to drop 2.1 ft from about 6.2 ft to about 3.8 ft if Great Dam were removed either fully or partially. River width is predicted to decrease 15 feet from 75 ft to 60 ft wide under typical flows.

- **NH 108 Bridge to Railroad** Bridge**:** In the upper reach of the Great Dam impoundment on the Exeter River, from NH 108 to the impoundment limit, the hydraulic control of the Great Dam steadily diminishes. At the Linden Street Bridge, for example, the river depth would drop about 1.9 ft from 4.2 ft to 2.3 ft. The width of the river would also decrease, from about 40 ft wide to about 28 ft.

- **Little River, Confluence to Impoundment Limit:** The impact of dam removal or dam modification on river hydraulics is not limited to the Exeter River; the Little River reach from its mouth to Linden Street is also predicted to decrease in depth and width.

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

The Great Dam is a "run of the river" dam. The existing dam allows all of the natural river flow to pass over the dam in a relatively consistent and steady flow; it does not divert, store, or release water flow. 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 Squamscott River will continue to exert a much greater influence on the downstream portion of the river than the dam.

**For flood flows, the Dam Removal, Partial Removal and Dam Modification Alternatives would all have similar effects, reducing the depth of flooding substantially. The area subject to flooding would decrease, but not by a substantial amount.**

While Dam Removal or Partial Removal would generally lower flood depths more than the Dam Modification Alternative, the differences between the two are not very significant. They would both be effective at reducing flood depths, generally by similar amounts. However, because the adjacent floodplain is relatively flat, most of the area that currently floods along the river would continue to flood, although with shallower water.

**The Dam Modification Alternative could maintain the river in more or less its current state under normal flow conditions, but allow for management of river levels during floods.**

The main feature of the Dam Modification Alternative would be a tall adjustable flashboard/gate system in place of the current static spillway. The system would be upright under normal conditions so that the normal river level is maintained. Under higher flows, the gate could be lowered to allow for higher flows to pass without as much upstream flooding. The current conceptual design could pass approximately 2,300 cfs through the lowered flashboard and side gate without the water surface elevation increasing over its normal level (22.5 ft NGVD), which is about the 5 to 10 year flood range. It may be possible to design a system that would maintain more or less constant water levels up to these flood flows.

**The Stabilize in Place Alternative would meet dam safety rules, but would not mitigate future flooding damage, nor would it directly increase dissolved oxygen levels in the river or provide enhanced fish passage.**

Because Alternative G – Stabilize in Place would not change the dam elevations, future flooding conditions would not change. Additionally, water quality in the river would not improve (i.e., improved dissolved oxygen levels, decreased thermal stratification, etc.), as is expected for partial or full dam removal. This alternative also would not provide enhanced fish passage and the associated benefit to habitat in the river.

**The modification or removal of the dam is not expected to create hazards due to ice jams.**

Ice dynamics can be important for rivers in New Hampshire. However, based on the lack of documented ice jams on the Exeter River and the lack of field evidence of ice jamming in the impoundment, the modification or removal of the Great Dam should have no effect of river ice dynamics.

## ES-3.2 Sediment Transport and Potential Erosion

**Removal of the Exeter Dam is unlikely to initiate a significant upstream migrating headcut, but could create some erosion of streambanks, as is normal for a free-flowing river.**

Assessment of the Exeter River by a river scientist found that removal of the dam would not create a severe erosion feature known as a "headcut," because of the presence of ledge across the channel at the dam. A headcut is 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 erode and collapse. However, increased flow velocities are likely to increase channel migration along the meandering channel in the unconfined portion of the impoundment where a wide floodplain is present between the area where the Little River flows into the Exeter and the NH 108 Bridge. With little infrastructure in this marshy area, the increase in channel dynamics that might accompany dam removal or modification would have a positive impact on restoring normal river processes and improving aquatic habitat.

**Dam Removal, Partial Removal and Dam Modification would restore sediment transport to the river to normal or near normal conditions, leading to a substantial but temporary increase in the amount of sediment transported into the Squamscott River.**

River velocities would increase significantly near the dam, but that portion of the river bed is formed by bedrock which should be stable. Velocities and shear stress near Gilman Park and in other portions of the river will increase moderately. An engineering model of the river was constructed that suggests that sediment carried from the Exeter/Little River would increase from about 2,000 – 3,000 cubic yards over a five year period to about 10,000 cubic yards over the same period. This could affect ecological or recreational resources downstream, although these impacts would be temporary and are not expected to be very significant.

**Testing of the sediment in the Exeter and Little River indicates the presence of some environmental contamination, but not at levels that would cause serious ecological or health risks.**

Samples were taken from a total of six stations up- and downstream of the dam and tested for a wide variety of chemicals. While some chemicals were detected, the levels found do not raise serious issues that would eliminate any of the alternatives from consideration.

## ES-3.3 Infrastructure

**Bridges, walls and foundations upstream of the Great Bridge and downstream of the dam should not be affected by any of the Alternatives.**

Changes in water surface elevations, water depths and water velocities can change scour potential and hydraulic loading conditions and therefore affect the foundations of buildings or other structures. These potential effects on existing infrastructure are reduced upstream of the Great Bridge and considered relatively minor. Additionally, there would be no risk to structures downstream of the dam.

**Regardless of the alternative chosen, additional investigation is needed to ensure that structures in the immediate vicinity of the dam are properly founded and not damaged.**

Some of the structures just above the dam may be adequately anchored to resist the increased loading and scour, while others may not. Further investigation is recommended for the Great Bridge abutments, northeast and southeast wing-walls, and the building foundations for the Loaf and Ladle and 11 Water Street Restaurant. This analysis is recommended for all alternatives. Additional monitoring of exposed foundations may also be necessary after implementation of either alternative.

**Surface water intakes would be adversely affected by the Dam Removal, but these impacts could likely be mitigated. Costs associated with this mitigation, however, could be substantial.**

As documented in the Water Supply Alternatives Study (Weston & Sampson, 2010a), after some modifications to the existing river intake, the Town should still be able to utilize the river as a water supply source. However, Phillips Exeter Academy utilizes the river for their steam heating system and irrigation, and their intake appears to be too high to capture river water under normal flow conditions if the dam were to be removed. Similarly, the intake associated with the Exeter Mills Apartments would be impacted by the elimination of the impoundment, as would the fire hydrant at the Exeter Library. Because no good plans of the Exeter Mills or hydrants were found during this study, the precise impact cannot be determined. However, it is likely that all three of the impacted systems could be retrofit. Further engineering analysis would be required during final design of the selected alternative. However, the cost of retrofitting these intakes could be very substantial – possibly as costly as the Dam Removal or Partial Removal Alternatives themselves. Further information on costs is provided below. If Dam Removal is the selected alternative, then the timeline of the dam removal will need to be closely coordinated with retrofits of these intakes. The intakes should be addressed prior to the permanent lowering of the impoundment.

**Public and private wells are not likely to be impacted.**

The Gilman Park Well and the Stadium Well are located on either side of the Exeter River, approximately 500 feet upstream (south) of the confluence of the Exeter River and the Little River. These two wells represent a potential yield of 1.2 million gallon per day. The impact of lowered groundwater levels on the safe yield of these production wells was estimated using the pumping test and river drawdown data. Combined, the two wells are still projected to produce approximately 1.08 million gallons-per-day of safe yield under post-dam removal conditions. However, as discussed in previous studies sponsored by the Town, there are substantial costs to reactivating these wells. Additionally, the only known private water supply wells in the vicinity of the Exeter River are drilled in bedrock. Since these withdrawals are from the deep bedrock aquifer and the river is hydraulically isolated from the bedrock, no impact to private wells is expected as a result of the project.

## ES-3.4 Cultural Resources

**The Great Dam is a contributing element of Exeter's historic character. Its removal or modification would represent an impact to a historic structure important to downtown Exeter.**

The Great Dam has served an important role in the town's industrial history for almost 100 years. Its location just upstream of the Great Falls has been the site of a dam since the 1640s, which provided the source of water power for numerous mills that lined the banks. The dam lies within the Exeter Waterfront Commercial Historic District, which was originally listed in the National Register of Historic Places in 1980, with a boundary increase that added the former Exeter Manufacturing Company property in 1986. The dam has been determined eligible as a contributing resource to this district.

**Dam Modification would also create an adverse effect on Exeter's historic nature.**

Under Alternative H – Dam Modification, very significant modifications would need to be made to the dam in order to meet safety regulations, including removal of a large portion of the dam and the installation of a highly-engineered modern adjustable crest gate. The modified dam would not resemble the current dam. The impact of dam modification on the aesthetics of the dam would be significant, and would detract substantially from its historic nature.

**The area around the Great Dam is considered sensitive for archaeological resources which could be impacted by either removal or modification of the dam.**

Based on historical and environmental review and information gathered from the NHDHR archaeological site files, the area around the Great Dam should be considered archaeologically sensitive for Pre-Contact and Euro-American archaeological sites. Because of the level of construction expected during either alternative, steps should be taken to further investigate these resources and minimize impact if confirmed. Additionally, if the dam is removed, monitoring of archaeologically sensitive areas along upstream river banks is recommended.

## ES-3.5 Recreation

**The Stabilize in Place and Dam Modification Alternatives would not change the recreational experience on the river.**

Because these two alternatives would maintain the current pool under typical flow conditions, there would be no change to the river and recreation opportunities and facilities that exist now would continue unaltered.

**Dam Removal or Partial Removal would alter the recreational experience on the river, but opportunities would still be plentiful.**

Both Dam Removal and Partial Removal would lower river elevations upstream from the existing dam site under low and normal flows which would alter recreational opportunities. The reduced river width would affect, but not eliminate, access at existing formal and informal launch sites. The river would continue to be navigable to non-motorized watercraft, but portage around shallows or bars may be necessary under low flow conditions. Cooler and faster flowing water may enhance opportunities for coldwater fishing for trout species and provide more insect forage for all game species. Generally speaking, the Partial Removal Alternative would have less impact on these resources relative to the Dam Removal Alternative.

## ES-3.6 Natural Resources

**Removing the dam would likely result in decreased thermal stratification and improved dissolved oxygen conditions in the river, which would create a substantial net benefit on water quality. This same benefit would not occur if the dam were to be stabilized-in-place or modified.**

A decrease in residence time and surface area with a smaller impoundment would reduce the thermal gain that occurs in the reaches above the dam, which should improve dissolved oxygen conditions. Full dam removal, as proposed under Alternative B, would result in the greatest reduction in residence time and, would therefore have the greatest potential to improve dissolved oxygen levels relative to the other alternatives. In addition to the estimated reduction in residence time, the shallower water depths that would result from dam removal would allow for greater mixing and less temperature stratification at lower flows. Faster flow velocities could also lessen the accumulation of oxygen-consuming organic material and debris within the channel, and thus, reduce a source of oxygen demand. The Dam Modification Alternative would result in minimal change in the residence time for the typical flow conditions and would therefore not be expected to improve water quality.

**The removal of the Great Dam would have a significant benefit to important fish populations.**

The dam is a significant barrier to the upstream passage of fish, such as river herring, as well as other aquatic organisms. Removal of the dam would allow the fish to pass upstream to spawn, which would have a substantial benefit to the Exeter and Squamscott Rivers. Although the fish ladder currently allows some level of upstream passage, it is far less efficient than a free-flowing river.

**Dam removal or modification is not expected to result in significant adverse impacts to 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. Indirect effects could occur based on changing flood regimes or hydrology of wetland adjacent to the impoundment which could create shifts in plant communities. Whatever indirect impacts may occur would likely be offset by beneficial changes associated the presence of increased numbers of forage fish, including adult and juvenile river herring.

**The full or partial removal of the Great Dam could affect wetlands and floodplain forests which rely to some degree on flooding, including a rare swamp white oak forest community upstream.**

Elimination of the impoundment could affect the existing wetlands within and adjacent to the impoundment by lowering surface and ground water elevations such that wetlands with a direct hydraulic connection to the river would be affected. Indirect effects to wetlands could also occur by falling local groundwater levels that are predicted to occur with removal or modification of the dam. Additionally, flood events would be shallower and would inundate less of the floodplain forests along the impoundment including a floodplain forest dominated by swamp white oak (*Quercus bicolor*). It is impossible to quantify precisely the effects that these changes might have on wetlands and forest community dynamics. However, it seems unlikely that these changes would cause a sudden shift in community composition. Rather, gradual changes may occur which could allow plant species typically occurring in drier sites to colonize the forest. Ultimately, the areal extent of the swamp white oak forest community could decrease.

## ES-3.7 Technical and Cost Considerations

**Removal, Partial Removal, Stabilize in Place and Dam Modification are all feasible from a technical perspective.**

The study confirmed that all of the alternatives carried forward would be feasible from an engineering perspective and found no technical reason to eliminate any of these alternatives except the "No Action." Any of the five alternatives could be designed and constructed. Additional engineering would need to be completed prior to implementation of the selected alternative, and any alternative would require permitting through state and federal resource agencies.

Partially removing the dam would have the highest initial investment costs to the Town, while stabilizing in-place would have the lowest.

The initial investment required for each alternative would include the design, permitting and construction of the alternative plus the cost of mitigating various infrastructure and environmental effects. These costs, shown in Table ES-1, would total an estimated $1,244,758 for *Alternative B – Dam Removal*. *Alternative F - Partial Removal*, perhaps counter intuitively, would cost substantially more, about $2,251,238, due to the fact that it would require demolition of the existing fish ladder and installation of a new one. Of the two alternatives that could maintain current water levels upstream of the dam, the *Alternative G - Stabilize in Place* would be the less expensive option, at about $983,000, while *Alternative H - Dam Modification* would cost just over $1,811,200.

Table ES-1. Initial Construction and Mitigation Costs

| Alternative | Design, Permitting and Construction | Infrastructure and Environmental Mitigation | Total |
|---|---|---|---|
| Alt A - No Action | - | $550,000 | $550,000 |
| Alt B – Dam Removal | $732,150 | $512,608 | $1,244,758 |
| Alt F – Partial Removal | $1,338,630 | $912,608 | $2,251,238 |
| Alt G – Stabilize in Place | $418,000 | $565,000 | $983,000 |
| Alt H – Dam Modification | $1,016,000 | $795,200 | $1,811,200 |

Table ES-2. Total Costs including O&M and Replacement (30 Year Analysis)

| Alternative | Initial Cost | O&M and Replacement Costs | Total |
|---|---|---|---|
| Alt A - No Action | $550,000 | - | $550,000 |
| Alt B – Dam Removal | $1,244,758 | $0 | $1,244,758 |
| Alt F – Partial Removal | $2,251,238 | $385,170 | $2,636,408 |
| Alt G – Stabilize in Place | $983,000 | $181,894 | $1,164,894 |
| Alt H – Dam Modification | $1,811,200 | $616,724 | $2,427,924 |

These totals include the amount not only for construction, but also for mitigating potential impacts such as the cost to retrofit publicly-owned water intakes at the Exeter River Pumping Station and the fire hydrants at the Exeter Library and Founders Park, further archaeological and historic studies, future fish passage monitoring studies, and future water quality studies (due to the fact that the Exeter

River is an "impaired" surface water under state water quality standards). These totals do not include the funds needed to retrofit intakes owned by Exeter Mills and Phillips Exeter Academy, which are discussed below.

However, construction costs and direct mitigation costs are only one component of the total cost of an alternative. Therefore, the cost estimates also considered operation and maintenance as well as 30-year capital replacement costs for each alternative and are reported in Table ES-2.

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.

In addition to the direct costs to the Town of Exeter, two privately-owned water intakes would be impacted by the Dam Removal or Partial Removal Alternatives.

Phillips Exeter Academy and the Exeter Mills currently withdraw water from the river for various purposes. If the dam were either fully or partially removed, these intakes would require modification. A 2010 study by Weston and Sampson estimated the costs for these modifications as shown in Table ES-3.

Table ES-3. Cost of Retrofitting Private Water Intake Structures

| | Low Estimate (2013 dollars) | High Estimate (2013 dollars) |
|---|---|---|
| Exeter Mills Penstock | $271,000 | $542,000 |
| PEA River Intake | $108,400 | $271,000 |
| | $379,400 | $813,000 |

Note:
Weston and Sampson reported costs in 2009 dollars, which have been adjusted to 2013 dollars by applying an 8.4% inflation factor.

Grant funding may be available to offset the cost of implementing the selected alternative.[7]

Because of the importance of restoring coastal fisheries, a number of public and private grant funding opportunities exist for dam removal which could help to substantially offset the cost to the community if Alternative B – Dam Removal is selected. A sample of potential funding sources:

- National Oceanic and Atmospheric Administration - Community-based Restoration Program
- NH Fish and Game - Fish Habitat Program

[7] Grant funding opportunities are described in greater detail in a technical memorandum dated September 30, 2013 from Peter Walker, VHB to Paul Vlasich, Town of Exeter.

- NHDES - Watershed Assistance Grants, Clean Water Act Section 319
- US Fish and Wildlife Service - Fisheries and Habitat Restoration Grants
- Natural Resource Conservation Service - Environmental Quality Incentives Program
- Trout Unlimited - Embrace a Stream Grant Program
- NH Charitable Foundation - Community Grants Program
- NH Corporate Wetlands Restoration Partnership – Restoration Grant
- NH State Conservation Committee - Conservation "Moose Plate" Grant

An informal review of recent projects in New Hampshire indicates that grant funding typically covers a significant portion of the cost of removing a dam – between 50 to 100% of design, permitting and construction costs.

Additionally, grant funding opportunities exist for other alternatives, particularly those which would preserve the historic character of the dam or mitigate flooding issues. For example:

- NH Land and Community Heritage Investment Program – Community Grant Program
- National Trust for Historic Preservation – National Preservation Loan Fund
- Society for Industrial Archeology – Industrial Heritage Preservation Grants Program

It is notable that these grant streams tend to have relatively small average awards, and there are no known examples of grant funds being awarded for dam repair or reconstruction in New Hampshire. Thus, while the grant programs listed above could possibly be applied to Alternatives F, G and H, it seems less likely funds would be available to offset a significant portion of the costs for these alternatives relative to the dam removal alternative.

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# 1 Background

## 1.1 Introduction

The Great Dam, also known as the Exeter River Dam, is located in the Exeter River at the center of Exeter's business district. The dam is just downstream of the High Street Bridge (i.e., the Great Bridge) and upstream of the String Bridge. The dam impounds the river a few miles upstream, beyond Gilman Park to the NH 108/Court Street Bridge.[8] (See **Figures 1.1-1** and **1.1-2** and **Appendix A**.)

The current dam structure was built in 1914 according to the NH Department of Environmental Services' (NHDES) Dam Bureau database. However, historic records indicate there has been a dam at this general location since about 1640. The Great Dam was purchased by the Town of Exeter in 1981 for the purposes of recreation and water supply, and has been maintained by the Town ever since.

The NHDES Dam Bureau has identified safety deficiencies with the Great Dam.[9] Most notably, the dam does not meet dam safety regulations which require it to be able to pass a 50-year storm event with at least one foot of freeboard[10] between the water surface and the top of the dam abutments. Based on hydraulic calculations completed by NHDES and others, 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. Dam failure creates the potential for loss of human life, economic impacts of damage and social and environmental impacts.

8 Section 3.3 of this report contains a detailed discussion of the hydraulic effects of the dam under various flow conditions.

9 NHDES has issued a "Letter of Deficiency" in 2000, as well as follow up letters since that time, to requests that the town take action to address these safety concerns. These letters are contained in **Appendix C** and more explanation can be found in Section 1.3.2.

10 "Freeboard" is simply the height of the dam above a given level of water in the river.

To address these concerns, and to meet dam safety regulations, the Town of Exeter is considering various alternatives including the permanent modification of the dam by lowering its spillway or potentially 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 **N**.

## 1.2 Purpose and Scope of this Study

The Town of Exeter has studied options for addressing the Great Dam safety issue for several years.[11] This current study seeks to develop new information on the option of removing the dam entirely as a means of eliminating the safety concern, but also considers the option of modifying the dam to maintain the impoundment while allowing the required design storm to pass over the dam. Thus, the objectives and issues explored within this study are as follows:

- Determine the feasibility of removing the Great Dam from the Exeter River, including the engineering issues involved and the cost to remove the dam.

- Determine the impacts and benefits of removing the Great Dam 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;
  - 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;
  - 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;
  - Water Resources, such as the availability of water for public and private drinking water and the quality of the water in the river; and
  - Public and Private Infrastructure, including the possible effects on bridges, foundations and other structures located in or near the river.

[11] See Section 1.5 for a summary of previous relevant studies.

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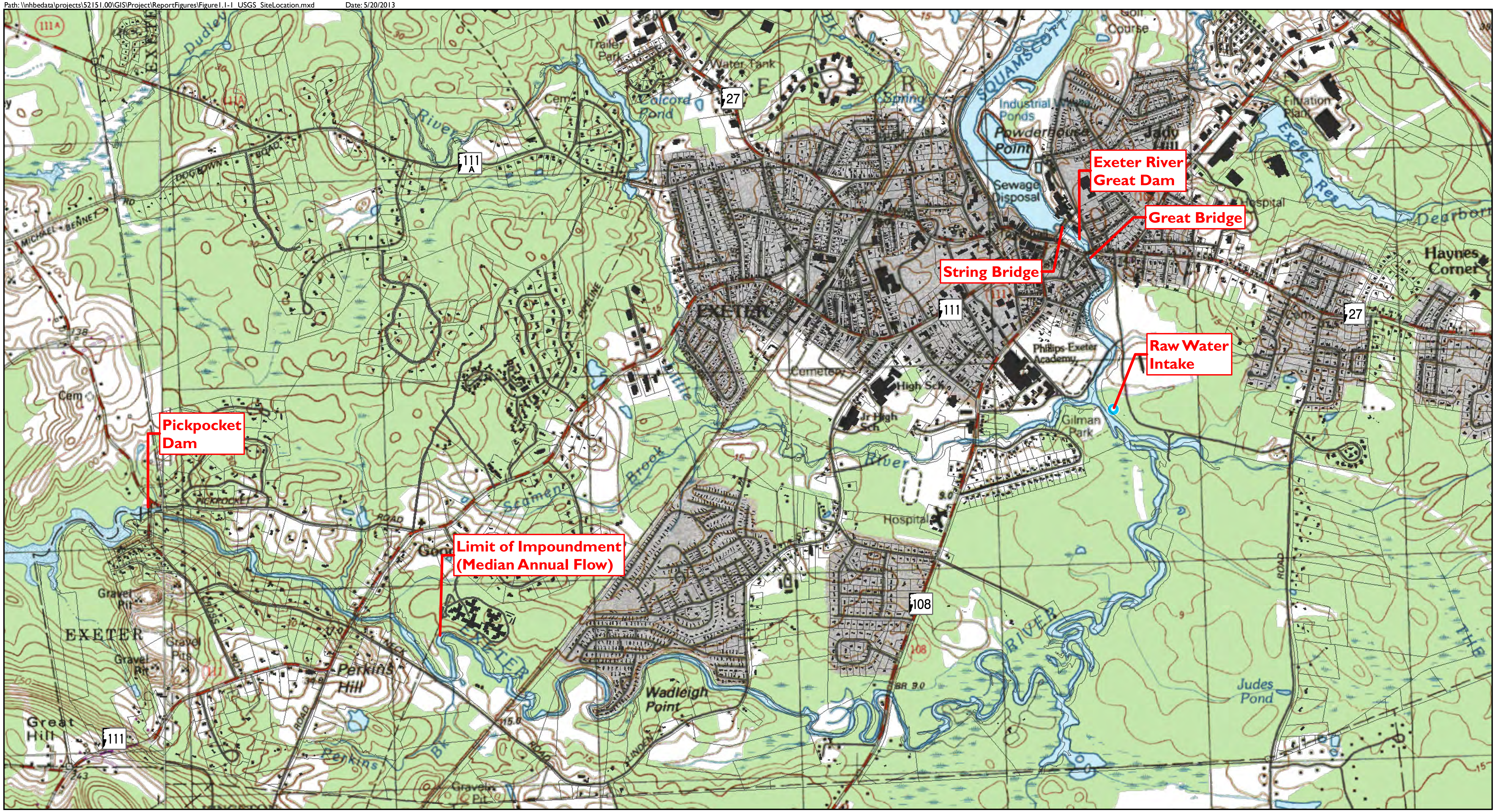


0 1,500 3,000 Feet

Source: USGS 7.5 Minute Quadrangles: Exeter, Kingston

Vanasse Hangen Brustlin, Inc.

**Figure 1.1-1**
**Site Location Map**
**Exeter Great Dam Removal**
**Feasibility & Impact Analysis**

**Exeter, NH**

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**Legend**

- Assessor's Tax Parcels
- Exeter Base Plan
- Building
- Parking Lot/Drive
- Concrete Wall/Dam
- Green Space
- Recreation
- Trail
- Sidewalk/Walkway

**Note:**
1. Base mapping data provided by the Town of Exeter.
2. 1' Bathymetric Mapping completed by Wright-Pierce.
3. 2010 imagery taken from the archives of NHGRANIT.

0 100 200 Feet

VHB *Vanasse Hangen Brustlin, Inc.*

**Figure 1.1-2**
**Great Dam Site Map**

**Exeter Great Dam Removal Feasibility & Impact Analysis**

**Exeter, NH**

TOWN OF EXETER FOUNDED 1638 NEW HAMPSHIRE

- Compare the impacts, benefits and costs of dam removal to other options such as modifying the dam.
- Provide this analysis in a clear to understand format so that the Town of Exeter 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 specific recommendation regarding whether the dam should be modified or removed. Rather, the intent of this study is to provide specific information to allow the Town to choose an alternative at a future date.

This study was coordinated with funding and assistance from local, state and federal agencies. It 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 Description of the Great Dam

### 1.3.1 Structural Description

The Great Dam is a reinforced concrete dam with an ogee style spillway, a fish ladder, a low-level outlet, and a penstock with its associated headworks. ***The Great Dam is a "run-of-the-river" dam, meaning that it allows all of the natural river flow to pass over the dam spillway in a relatively consistent and steady flow.*** (Other dams are built in a way that diverts, stores, or releases water flow for various reasons.) It is located approximately 150 feet downstream of the High Street Bridge and 340 feet upstream of the String Bridge in downtown Exeter.

***The dam is a Class A (low hazard)[12] concrete gravity dam approximately 136 feet long by approximately 16 feet high measured from the top of its tallest abutment to the streambed at its downstream face.*** The spillway crest is at an elevation of 22.5 ft (NGVD29), which is about 8 to 12 feet above the streambed on the downstream face but only a few feet above the streambed on the upstream side of the dam due to accumulated sediment on the upstream side. The downstream spillway face is a parabolic surface and the upstream face is a flat vertical surface. Wright-Pierce (2007) reports that existing design or construction drawings of the original dam are not

[12] See NH Administrative Rule Env-Wr 101.07 for the regulatory definition of a "Class A" or "low hazard" structure.

known to exist. A recent detailed survey of the dam and adjacent area is contained within **Appendix A**.

The dam was last inspected in September 2006 by engineers from Wright-Pierce. Their inspection found that overall the dam and associated concrete structures appeared to be in good condition. No deficiencies that required immediate repair were observed. However, Wright-Pierce (2007) did make recommendations on minor repairs to ensure the continued long-term use of the dam, including cleaning mud and vegetation from the concrete portions of the dam and repairing portions of the concrete that exhibited spalling or cracks.

***The dam includes a concrete penstock structure and sluice gate structure containing a low-level gate at its north end.*** The low-level gate is used to discharge water from the impoundment area to downstream of the dam. This gate can be manually opened and closed depending on flow conditions and the need to access the dam for inspection and maintenance. The operation of the low-level gate is governed by an Operation & Maintenance Plan (OMP) prepared by the Town, last revised on June 7, 2006. A copy of the Plan is included in **Appendix B** of this report. The gate is opened as needed to reduce upstream flooding insofar as reasonable and diligent monitoring, gate operations and gate capacity will allow, but to maintain water levels according to the following seasonal operational goals:

- **April 1 through June 30:** The water level will be maintained at approximately 6 inches above the concrete spillway crest to facilitate upstream and downstream fish migration as recommended by the NH Fish and Game Department.
- **July 1 through October 31:** The water level will be maintained at approximately 2 inches above the concrete spillway crest to allow for drinking water supply, recreation and downstream fish passage.
- **November 1 through March 31:** The water level will be maintained at approximately the level of the concrete spillway crest. Drinking water, recreation and fish passage considerations are less important during this period.

The ogee-style spillway, with its crest at Elev. 22.5, spans the river in a northeast-southwest direction, extending approximately 68.5 ft from the edge of the fish ladder before bending approximately 30 degrees and continuing for an additional 12.4 ft to the low-level outlet headworks. The low-level outlet headworks, which forms the beginning of the right or northeast abutment, houses a 3-ft wide by 4-ft high hand-operated slide gate with a sill at Elev. 15.8. The top surface of the low-level outlet headworks is approximately Elev. 27.1, and is approximately 17.5 ft wide where it abuts the headworks of the former mill penstock. The penstock headworks, approximately 18.3 ft. long, rises to Elev. 30.6 before returning to natural grades at Elev. 27.1.

The Exeter River Great Dam consists not only of the main spillway and headworks, but also a fish ladder and a lower dam structure. The concrete and steel denil-style fish ladder is located on the southwest side of the river with its upstream end located on the southwest end of the dam. The fish ladder was installed by the NH Fish and Game Department around 1968 in an effort to restore upstream passage for diadromous[13] fish. The fish ladder is approximately 110 ft long by 6 ft wide, with a 10 ft by 17 ft fish trap/counter at its top. The top surface of the fish trap is flush with the southwest abutment at approximately Elev. 25.7. The ladder structure is set at a pitch of approximately 7.6 percent from top to bottom. A 135-foot long concrete weir structure is located at the lower end of the ladder to guide migrating fish into the ladder. The top of the weir is approximately Elev. 14.6, or approximately 5.5 ft above the streambed on its downstream face.

The fish ladder, which is owned, controlled and maintained by the New Hampshire Fish and Game Department (NHFGD), requires certain flows to operate.[14] The Town currently has an Operation and Maintenance Plan for the Great Dam which was put into place in 2006. It provides a guide as to how the Town should operate the gate at the dam for maintenance and potential flood control purposes. The primary goals and parameters of the plan are based on seasonal flow needs for the fish ladder to operate for sufficient fish passage. As discussed above, the plan calls for the Town to maintain the water level approximately 6 inches above the elevation of the concrete spillway from April 1 to June 30 for efficient upstream fish migration. It also calls for a minimum of 2 inches to be maintained from July 1 to October 30 to allow for downstream fish passage.

### 1.3.2 Dam Safety Issues

As mentioned previously, the Great Dam in its current configuration does not comply with NHDES regulations on dam safety. The town was notified of these problems in a Letter of Deficiency (LOD) issued by NHDES on July 25, 2000. The original LOD was amended on June 1, 2004 and March 2, 2009 to allow the Town more time to study potential solutions. (See **Appendix C**.) Specifically, the 2000 NHDES LOD identified the following issues:

1. The dam cannot pass the 50-year design storm event with one foot of freeboard and no operations;
2. There was no operation and maintenance plan on file with the DES; and
3. There was minor brush within 15 feet of the concrete abutments.

13 Diadromous fish migrate between the sea and fresh water. The term diadromous refers both to 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).

14 The deed for the dam includes a paragraph that states, *"This site is subject to an Agreement concerning a fish ladder and weirs by and between Milliken Industrials, Inc. and the State of New Hampshire, dated September 9, 1968, recorded in Rockingham Records, Book 1960, Page 290."*

Items 2 and 3 have since been addressed. However, while the dam does not appear to be in immediate danger of failing, it does not meet NH Administrative Rule *Env-Wr 303.11* which requires Class A dams (i.e., "low hazard" dams) be able to pass the 50-year storm event with at least one foot of freeboard between the water surface and the top of the dam abutments without manual operations. Hydraulic modeling of the dam performed by NHDES and others has indicated that even with the low-level gate completely open, the existing dam abutments are overtopped during the 50-year flood. This modeling indicates that Great Dam requires significant modifications to increase its discharge capacity to meet NHDES requirements. NHDES has given the Town deadlines to either modify or remove the dam to meet this safety requirement.

In 2005, the Town retained Wright-Pierce, an engineering consulting firm, to conduct engineering studies and develop potential solutions to this dam safety deficiency. Their work focused on modifications to the dam, resulting in a technical report published in March 2007. (See additional information on the Wright-Pierce studies in Section 1.5 below and a further discussion of the possible alternative solutions in Chapter 2.)

### 1.3.3 History and Uses of the Dam

The Great Dam has served an important role in the town's industrial history for almost 400 years.[15] Its location just upstream of the Great Falls has been the site of a dam since the 1640s, which provided the source of water power for numerous mills that lined the banks of the Exeter River until 1828. In that year, the Exeter Manufacturing Company and Exeter Mill and Water Power Company purchased the existing dam and water rights and agreed to build a new dam. This dam served the Exeter Manufacturing Company, presumably until its replacement in 1914 with the existing concrete gravity dam. No plans of the current 1914 concrete gravity dam have been found and the reason for the dam's replacement in 1914 is unknown. Modifications were made to the 1914 dam in 1938 and 1968. The nature of the repairs in 1938 is unknown. In the latter year, a concrete fish passage and concrete weir were added by NHFGD to facilitate fish passage in the river. In October 1981, the dam and its associated water rights were sold to the Town of Exeter by the Miliken Manufacturing Company, which had taken over the operation of the Exeter Manufacturing Company complex in 1966.

Currently the Dam is used to create a water source for the Exeter Water Treatment Plant and provides irrigation and cooling water for Phillips Exeter Academy and the Exeter Mills Apartments.

▼

15 Section 3.9 contains a more detailed discussion of the dam's history and the potential effects of its modification or removal.

## 1.4 The Exeter River and its Watershed

The Exeter River rises from a group of spring-fed ponds in Chester, New Hampshire and flows approximately 33 miles to downtown Exeter where it changes its name to the Squamscott River, and becomes a tidal river and a primary tributary to Great Bay. Its watershed above the Great Dam covers approximately 68,672 acres (107.3 sq mi) in Rockingham County, including substantial portions of the towns of Brentwood, Chester, Danville, East Kingston, Exeter, Fremont, Kensington, Kingston, Raymond and Sandown. The watershed also includes small portions of five additional towns (Candia, Derry, Epping, Hampstead and Hampton Falls). There are eight dams on the mainstem of the Exeter River, including the Great Dam. (See **Figure 1.4-1**.)

The watershed features a number of tributary streams above the Great Dam including Wilson Brook, Towle Brook, Phillips/Lily Pond outlet, Wason Brook, Fordway Brook, Little River (Brentwood/Kingston), Great Brook and the Little River (Exeter). Phillips Pond (Sandown) is the largest pond in the watershed at 85 acres.

The watershed has rolling topography typical of the coastal plain. Large areas of wetlands occupy the lower lying portions of the landscape. Higher elevations and more hilly topography are found in the western part of the watershed around Sandown, Chester and Raymond. The maximum elevation of 649 feet is reached in Raymond on the northwest boundary of the watershed.

The upper reaches of the watershed (including Chester, Raymond, Sandown and Danville), are characterized by scattered farms and single family residences. In the lower reaches of the river between Fremont and Exeter, urban development becomes more prominent, including industrial and commercial land use in addition to residential development.

According to the Exeter Squamscott River Local Advisory Committee, land use in the watershed is primarily rural and forested. (See **Table 1.4-1**.)

### Table 1.4-1. Land Use in the Exeter River Watershed

| Land Use/Cover Type | Percent Cover |
|---|---|
| Forested Land | 67% |
| Developed Land | 16% |
| Farmland | 6% |
| Water and Barren Land | 6% |
| Wetlands | 3% |

Source: Exeter Squamscott River Local Advisory Committee. (Undated) "Exeter Squamscott River Facts" Retrieved January 23, 2013 from http://www.exeterriver.org/

Population growth in Rockingham County has been very high over the last several decades. In 1960, the US Census population was 98,065. By 2010, Rockingham County population had tripled to 295,223 residents.

The river's importance is made evident by the fact that the Exeter 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 the portion of the river from its headwaters in Chester to the river's confluence with Great Brook in 1995. More recently, a nomination for the Lower Exeter and Squamscott River, including the site of the Great Dam was approved by the Legislature in 2011.

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 Exeter River was formulated and adopted by the river's Local Advisory Committee (LAC) in 1997, while the development of a management plan for the Lower Exeter and Squamscott is in progress. These designations carry 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. Other regulations include protection of in stream flows and water quality.

## 1.5 Previous Studies of the Dam and the Exeter River

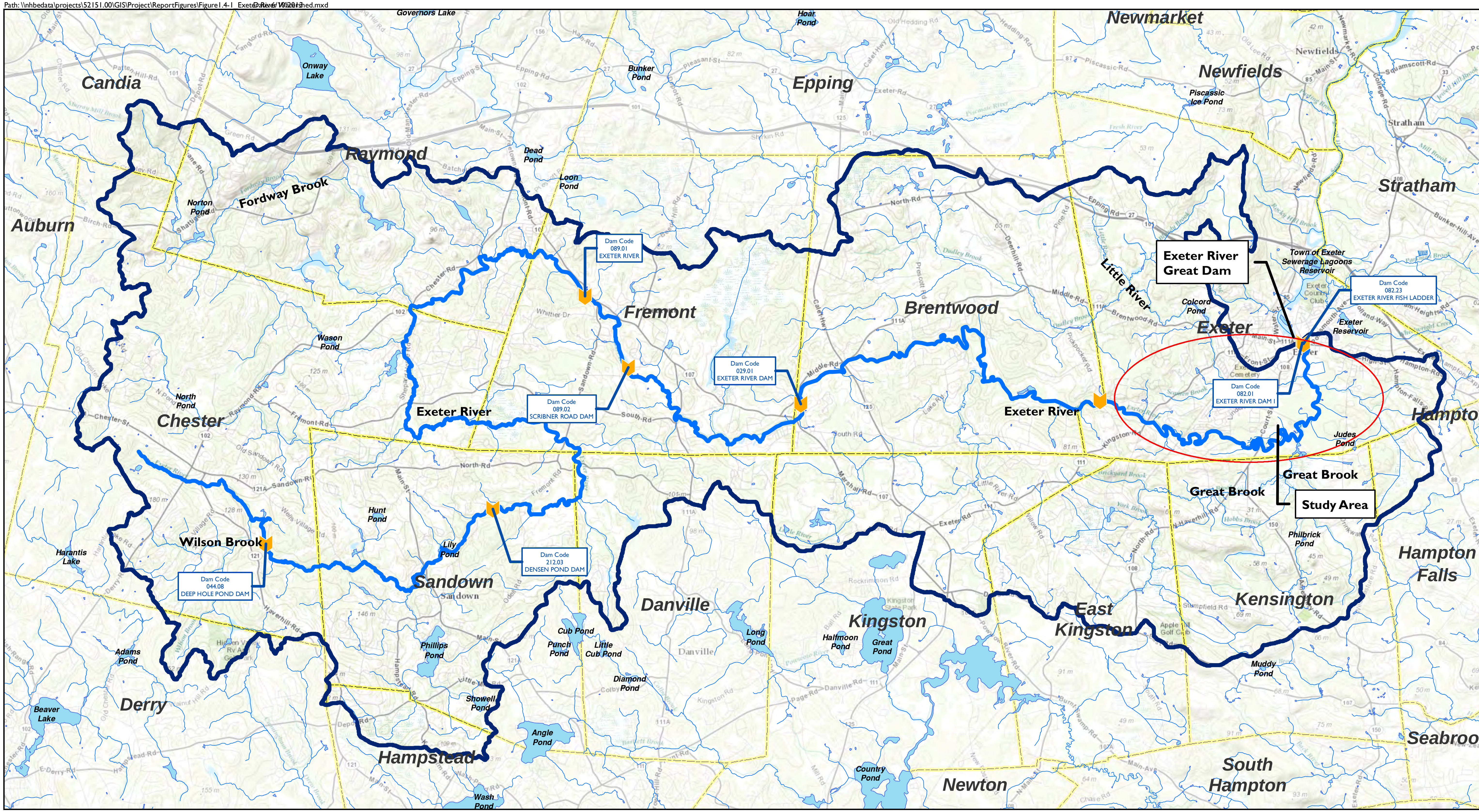
A number of studies have been conducted on the Great Dam and the Exeter River in general which are relevant to this study. A series of studies were conducted beginning in 2006 and continuing through 2010 that further evaluated issues surrounding the dam and its modification and provided alternatives to address them. The option of dam removal was not explored in great detail and thus the consequences of this alternative were not evaluated under these studies. Other recent studies conducted on the river were not focused on the Great Dam, but provide information that is relevant to the issues considered in this Feasibility Study. These reports are briefly summarized in this section, and are referenced elsewhere in this Feasibility Study as needed.

### Exeter River Study Phase I Final Report, Wright-Pierce, March 2007

The March 2007 report by Wright-Pierce provided a final summary of their work to develop alternatives for addressing the dam safety issues identified in the NHDES LOD. This report confirmed through more detailed hydraulic modeling that the Great Dam does not comply with NHDES rules that requires Class A dams be able to pass the 50-year storm event with at least one foot of freeboard. Their modeling indicated that the left and right abutments are overtopped by 3.0 feet and 1.6 feet, respectively, during a 50-year return interval hydrologic event.

Their results also suggested that the dam increases flood levels by about 1.2 feet at the NH 108/Court Street Bridge. Their modeling also highlighted the fact that the Great Bridge (i.e., High Street Bridge) also acts as a restriction to river flows –

Path: \\nhbedata\projects\52151.00\GIS\Project\ReportFigures\Figure1.4-1 Exeter River Watershed.mxd




Legend

Dam (NHDES)

Exeter River Watershed Boundary

River/Stream

0 7,000 14,000 Feet

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**Figure 1.4-1**
**Exeter River Watershed**

Exeter Great Dam Removal
Feasibility & Impact Analysis

Exeter, NH

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potentially as much as the dam itself during a high flow – increasing upstream flood levels by about 1.2 feet due to its restricted opening.

The Wright-Pierce study also examined the potential for management of upstream flood flows by opening the existing low-level outlet. They found that, because of its small size relative to the volume of water during flood flows, the outlet can only drop upstream flooding by a matter of a few inches. Even installing a larger low-level outlet at the Great Dam would have minimal effect in reducing upstream flooding. Taken together, Wright-Pierce concluded that the impact of pre-emptive drawdowns of the Great Dam impoundment to reduce upstream flooding is minimal.

Three dam modification concepts were developed in an attempt to satisfy NHDES discharge capacity requirements. Included among these dam modification conceptual alternatives is "Dam Modification Concept 2," further discussed in Chapter 2 of this Feasibility Study. Dam Modification Concept 2 proposed to lower the main spillway crest by 3 ft and replace it with an adjustable crest gate in order to provide additional hydraulic capacity under high flows. This alternative also proposed to increase the size of the existing low-level outlet on the northeast side of the dam. The Wright-Pierce study estimated the cost of three dam modification concepts to range between 1 million and 1.4 million dollars. (These costs were reported in 2006 dollars and have since escalated with inflation.)

Water quality monitoring (temperature and dissolved oxygen) was also performed as part of the Wright-Pierce study. The temperature data indicated that the Great Dam impoundment does experience thermal gain, meaning water temperatures increase as water moves downstream through the impoundment. The temperature data also indicate the impoundment experiences thermal stratification, a phenomena more typical of a lake or pond than a river. The warmer water is one of the causes of depleted dissolved oxygen levels which were found within the Great Dam impoundment. Low dissolved oxygen can cause impacts to fish and other aquatic species. Oxygen depletion in these areas can also be caused by biological oxygen demand (BOD) of the organic matter and accumulated sediments at the bottom of the impoundment. Taken together, these results indicate that the dam contributes to poor water quality conditions observed in the Exeter River.

### Riverbank Scour Analysis and Discharge Gate Design Impacts to Water Quality, Wright-Pierce, April 2008

Wright-Pierce's April 2008 report presented the results of a riverbank scour analysis and an analysis of the discharge gate on water quality. Wright-Pierce also examined whether dam removal could affect scour downstream at the String Bridge and Kimball Island. They found that velocities were already high enough in that portion of the river under existing conditions to warrant additional rip-rap or other bank protection measures, and that these velocities would not increase under any dam modification scenario. Specifically, they calculated existing velocities of 8 to 12 feet per second from the String Bridge to the confluence of the Squamscott River during the 100-year flood. Stone armoring of river banks is typically warranted when flow velocities exceed 10 feet per second. The report also recommended armoring of the river bank at the confluence of the Exeter and Squamscott Rivers, near the Exeter Mill Apartments and maintenance of the existing rock retaining wall/ledge armoring on the northeast bank downstream of String Bridge. The report also presents an analysis of the expected water quality benefits of reconfiguring the low-level outlet gate. The analysis concluded that locating the discharge gate discharge point at the base of the dam would have a minimal impact to improve water quality.

### Exeter River Geomorphic Assessment and Watershed-based Plan, Bear Creek Environmental, March 20, 2009

This study was performed by a consultant team of Bear Creek Environmental and Fitzgerald Environmental under contract to the NHDES Watershed Assistance Section and the Town of Exeter. The study focuses on providing a broad assessment of the Exeter River and its tributaries, including the study area considered in this Feasibility Study. The study sought to assess "fluvial geomorphic" and habitat conditions and develop a watershed-based restoration and protection plan for Exeter River.[16] This study also sought to predict stable and unstable river reaches, and provide recommendations for avoiding property damage over the long term.

The project team assessed forty-eight river and tributary miles to characterize the current physical condition of the river and identify stressors on the river, including four river reaches in the mainstem of the Exeter River from the Linden Street bridge downstream to the Great Dam. Data were gathered on each of these reaches, including relatively detailed information on the streambed, stream banks, floodplain and adjacent land uses. These data were, in turn, used to identify reaches which were actively eroding or aggrading versus reaches which were stable. However, because of the presence of the Great Dam, three of the four reaches were not fully assessed, since the impounded condition makes data collection impractical and because the impoundment dominates normal fluvial processes. The study did, however, identify six sites downstream of the Linden Street bridge which were considered "Opportunities for Restoration and Protection," including the Great Dam. An excerpt from this study, including a map of the potential restoration sites, is included in **Appendix D**.

### Exeter Great Dam Water Supply Alternatives Study, Weston & Sampson, January 2010

Weston & Sampson (2010a) assessed the consequences to the impoundment if the Great Dam were to be removed and provided options with respect to the mitigation

16 Fluvial Geomorphology is the study of rivers and streams and the processes that form them.

of the water supply if impacted by the dam removal. This study included the following major components:

- Investigate surface water intake alternatives at the Exeter River Pump Station.
- Investigate impact on other affected major withdrawals from Exeter River (Exeter Mills Condominium Complex, fire department hydrants, and Phillips Exeter Academy)
- Assess the viability of increasing the withdrawal potential of Skinner Springs (an existing groundwater source)
- Evaluate water system demand trends and efficiency potential.
- Develop integrated water system supply management operational plan.
- Develop cost estimates to mitigate lost drinking water supply and other issues.

As part of the study, an in-depth review of the Exeter River, including its watershed, impoundments and history, illustrates the potential changes to the river from an engineering (e.g., supply source/dam removal) perspective which would result if the Great Dam were to be removed. Safe yield assessments for the existing Skinner Springs, Lary Lane Well and Exeter Reservoir sources and proposed reactivated sources (Gilman and Stadium Wells) provide the framework for a revised management plan that would integrate each source into a year-round supply system, thereby reducing reliance on individual sources and ultimately mitigating potential lost withdrawal from the river as a result of dam removal. The results of the study provided validation that:

- Some loss of drinking water supply from the Exeter River is imminent (seasonal) due to the dam removal and/or water quality and quantity regulations.
- Lost supply can be mitigated with demand management efforts in conjunction with reactivation and development of additional groundwater supplies.
- An integrated water system supply and management operational plan can supply the Town with current and future water demands.

Potential capital upgrades for the water system were proposed, which would follow a phased approach, to allow for study and analysis of the success of each step prior to proceeding with additional work in the next phases. In addition, capital cost estimates were developed regarding anticipated upgrades to replace or retrofit other water intakes. The corresponding cost estimates are summarized as follows:

Table 1.5-1. Cost of Retrofitting Water Intake Structures[1,2]

| | Low (2009 $) | High (2009 $) |
|---|---|---|
| Exeter River Pump Station | $750,000 | $1,000,000 |
| Municipal Hydrants at Founders Park/Library | $125,000 | $250,000 |
| Exeter Mills Penstock | $250,000 | $500,000 |
| PEA River Intake | $100,000 | $250,000 |

Note:
1. Costs reported in this table are from Weston and Sampson, Water Supply Alternatives Study, January 2010. Costs for the various intake modifications were reported as a range in 2009 dollars.
2. See Section 2.11 and Appendix H for a more detailed discussion of the costs of the various alternatives presented in this report. Note also that costs estimates for the Exeter River Pump Station and the Library Municipal Hydrant have been revised since publication of the 2010 study by Weston and Sampson.

The report summarized the hypothetical scenario for the overall integrated management of the Town of Exeter's water supply sources with the integration of more groundwater and management of surface water sources to optimize their withdrawals. It found that a more diverse water supply would provide the Town of Exeter with more options for source water than is currently available. With the integration of more groundwater sources, the Town would also have a source of supply that has more consistent water quality and is easier and less expensive to treat than surface water sources.

More information on potential effects on public and private water supplies that would result from the removal or modification of the Great Dam is presented in Section 3.7 of this Feasibility Report.

### Exeter River Drawdown Study, Weston & Sampson, March 2, 2010

In November 2009, the Town of Exeter conducted a month-long "drawdown" of the impoundment behind the Great Dam to assess the impacts of a potential dam removal on public water supplies and other water withdrawals from the river (Weston & Sampson, 2010b). This effort was performed as an additional task of the Water Supply Alternatives Study undertaken by the Town through funding from the New Hampshire Coastal Program and performed by Weston & Sampson. The drawdown phase sought to gain insight regarding the following questions:

- Is there a natural impoundment without the Great Dam?
- What effect would lower water levels have on the Town's ability to withdraw water at the Exeter River Pumping Station?
- What effect would a lower impoundment have on nearby groundwater levels and the proposed reactivation of the Town's Stadium and Gilman wells?

By simulating a potential dam removal with the drawdown, the study sought to assess the Town's ability to continue to withdraw water with a lower impoundment as well as any impacts to other surface water withdrawals referenced in the Water

Supply Alternatives Study (Weston & Sampson 2010a). In addition, if the water level in the River were to drop from its current impounded level with the Great Dam in place, nearby groundwater levels might also be expected to drop to some degree. The drawdown allowed observation and estimation of the magnitude of those changes and their corresponding impact to the water availability at the Gilman and Stadium Wells.

The commencement of the drawdown roughly coincided with an approximately two-week period of little to no precipitation within the Exeter River watershed and correspondingly low river discharge. Discharge from the dam's gate, roughly 180 cfs, coupled with low inflow (between 30 and 50 cfs during that two-week period) resulted in a measurable drop in water level within the impoundment. A water level of approximately Elev. 18.25 ft was sustained at Great Dam from November 7 to November 14, representing a drop of 4.5 ft from the Dam's average pond level of Elev. 22.75 ft.

Typically, the Great Dam impoundment creates a flat hydraulic grade line or ponded water level from the dam to the river intake. During the drawdown, however, this relationship changed. When the water level at Great Dam was sustained at approximately Elev. 18.25 ft, the water level at the town's water supply intake in the Exeter River near Gilman Park was approximately one foot higher, creating a hydraulic grade line sloping from upstream to downstream.

Data derived from the drawdown was then analyzed to estimate the magnitude of impact to local water resources by the potential removal of Great Dam. The study concluded:

- **Natural Impoundment:** The drawdown revealed bedrock at on the streambed near the dam. This bedrock was determined to form a natural impoundment. Combined with the higher-than-expected bedrock ledge, the increased hydraulic slope that would result from a dam removal yielded promising results regarding the Town's ability to withdraw water at the river intake pump station with a lower impounded water level.

- **Gilman and Stadium Wells:** Removing the Great Dam would reduce the safe yield of these production wells by about 80 gallons per minute (gpm) or 0.12 million gallons per day (mgd), a drop of approximately 11 percent. Combined, the two wells are still projected to produce approximately 1.06 million gallons-per-day of safe yield under post-dam removal conditions.

- **Exeter River Withdrawals:** The Weston and Sampson drawdown study concluded that, while modifications to the Town-owned Exeter River Pump Station would be required if Great Dam were removed, the need for these modifications would not be as substantial as previously thought. They found that it is very likely that average water withdrawals, between 1.0 and 1.3 million gallons per day, may still be possible for some of the year, even without any modifications.[17]

### Exeter River Hydroelectric Study Review, Weston & Sampson, March 31, 2011.

Weston & Sampson (2011) reviewed two historical documents related to proposed hydroelectric generation projects on the Exeter River:

- "Exeter Hydropower and District Heating & Cooling (DHC) Study – July 1981" [Study]
- "The Federal Energy Regulatory Commission – Application for License for a Minor Hydroelectric Power Project – Pickpocket Dam/Exeter 1 Dam Hydroelectric Project" [Application].

The information presented in the report summarized updated engineering, environmental, permitting and cost considerations associated with the use of the Pickpocket and Great Dams for hydroelectric power generation. Based on the information provided in the assessment, Weston & Sampson updated the construction cost estimates, financing and potential revenues as presented in the 1981 Study and Application. The pros and cons of the potential hydroelectric redevelopment as proposed in the 1981 Study and Application were also reviewed. The report summarizes that the facilities put forward in the 1981 Study and Applications were sized too large for an efficient and cost-effective operation.

[17] Note that the drawdown study did not consider the possible effects of climate change, which is expected to result more common occurrences in extreme high flows and extreme low flows. This could affect the likelihood that the intake would function if not modified as described in Weston and Sampson's *Water Supply Alternatives Study*, January 2010.

# 2 Alternatives Considered

## 2.1 Introduction

One key element of this Feasibility Study is to define a reasonable range of alternatives for consideration by the community. Based on coordination with the Town of Exeter, the state and federal environmental agencies, the Exeter Study Committee Working Group, and the general public, several conceptual alternatives were developed for this study. The study provides a discussion of the costs associated with each of these alternatives, and later chapters provide an assessment of the impacts and benefits of each.

### 2.1.1 Background

As discussed in Chapter 1, a study completed in 2007 developed and evaluated several conceptual alternatives to achieve spillway capacity as required by the NHDES dam safety regulations. (Wright-Pierce 2007) This earlier study resulted in selection of a preferred alternative for modifying the dam, known as "Dam Modification Concept 2."[18] This alternative was initially included in this Feasibility Study so that a comparison could be made between the option of removing the dam and simply modifying it.

However, during the development of the present study, it was determined that flows in the Exeter River are higher than previously calculated, in part due to newly available rainfall data that show that the frequency of large storms in the Northeast has increased since the 1970s. These new data lead to the conclusion that the

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[18] More information on the alternatives developed and evaluated by Wright-Pierce is provided in their study report entitled *Exeter River Study, Phase I Final Report for the Town of Exeter, NH, March 2007.* Other alternatives considered during this phase of the work included alternative approaches such as: extending the spillway into Founders Park adjacent to the existing right abutment; constructing an emergency spillway in Founders Park; and construction of a new dam using a labyrinth weir structure on the existing spillway footprint.

appropriate “design flow” for the Great Dam is about 5,858 cfs rather than the 4,400 cfs estimate used by earlier studies. (A detailed discussion of this issue is contained in Section 3.3 and **Appendices E-1** and **E-2** of this report.) This increase of about 33 percent led to the conclusion that the 2007 Wright-Pierce “Dam Modification Concept 2” dam modification alternative would not, in fact, meet NHDES dam safety rules due to new regulatory requirements.

Following this determination, the present study developed several new dam modification alternatives. The development of these modification alternatives included a large number of possible approaches to solving the dam safety issues.[19] These included:

- Extension of the existing spillway or creation of an additional spillway in Founders Park;
- Construction of a labyrinth spillway;
- Partial removal of the Great Dam by lowering the spillway crest;
- Modification of the Great Dam by lowering the spillway crest with installation of an NHDES-approved mechanical flashboard system; and
- Stabilization of the dam.

A number of these conceptual alternatives could be dismissed relatively easily due to practical considerations or engineering constraints. For example:

- Extending or creating an additional spillway in Founders Park. Hydraulic calculations determined that the dam spillway would need to be extended over 300 ft to pass the required design flow. This is more than twice the length of the existing dam (which is about 136 ft long), and was therefore immediately deemed impractical.

- Construction of a Labyrinth Spillway - In the case of Great Dam, it was found that a labyrinth spillway would not provide the additional spill capacity needed to pass the 50 year flood flow. Hydraulic calculations were completed that showed that a five-cycle labyrinth design resulted in an increase of only 400 cfs from the existing dam – not enough increase to meet dam safety rules or warrant further consideration.

Following evaluation of these initial concepts, a number of alternatives were explored further including full removal, partial removal, several dam modification concepts and stabilization of the dam using rock anchors. The complete list of alternatives discussed in this Chapter is as follows:

- Alternative A – No Action/Existing Condition

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[19] See, among other studies and documents, **Appendix G** which contains a technical report entitled *Great Dam Modification Alternatives Analysis*, Kleinschmidt Associates, May 2013.

- Alternative B – Dam Removal
- Alternative C – Dam Modification Concept 2 (2007)
- Alternative D – Revised Dam Modification Concept 2 (0 ft Freeboard)
- Alternative E – Revised Dam Modification Concept 2 (1 ft Freeboard)
- Alternative F – Partial Removal
- Alternative G – Stabilize in Place
- Alternative H – Dam Modification - Inflatable Flashboard/Gate System

### 2.1.2 Public Process

The Exeter River Study Committee (ERSC) is a 12-person committee charged with providing advice to the Board of Selectmen in all matters relating to the management of the Exeter River, its tributaries, and watershed. In 2000, following the Letter of Deficiency notification that the Great Dam does not meet NHDES Dam Safety Bureau regulations, the Town and its many partners have been working to develop alternatives to address this deficiency. Meetings of the ERSC are held in the Town Offices and meeting times are publicly posted so that members of the public can attend if desired.

In 2010, the ERSC established a Working Group to incorporate public concerns, establish a task list and act as the liaison between the ERSC and the consultants conducting the Dam Removal Feasibility and Impact Study. The Working Group consists of the following members: Co-chairs Mimi Becker (Exeter Resident) and Deb Loiselle (NHDES), Rod Bourdon (Exeter Resident), Phyllis Duffy (Exeter Department of Public Works), Eric Hutchins (NOAA), John Merkle (Exeter Heritage Commission), Kristen Murphy (Exeter Planning Department), Peter Richardson (Exeter Resident and Exeter Squamscott River Local Advisory Group), Sally Soule (NHDES), Paul Vlasich (Exeter Department of Public Works), Roger Wakeman (Phillips Exeter Academy), and Richard Huber (Exeter Resident).

The Working Group serves as a forum for providing input to the consultant team, and has helped to provide an additional conduit for the distribution of study information to the community and each member's constituency. The Working Group is not a decision-making body, but helped to review and comment on study materials, and advised the consultant team in guiding the development of the project.

During the course of this study, several public informational meetings have been held, including the following:

- **April 29, 2010:** The Town of Exeter held a public meeting to obtain input on developing the scope of the Great Dam Removal Feasibility and Impact Analysis. The public's feedback was used to shape the request for proposals that the Town used to contract with the consultant conducting the study.

- **September 14, 2011:** The Town of Exeter hosted this meeting with its partners, including NHDES. The main objective of the meeting was to familiarize the public with the scope of the Great Dam Removal Feasibility and Impact Study and to solicit relevant information and opinions from the public. The meeting included time for citizens to interact with specialists at six information stations staffed by members of the consultant team as well as town and state officials. In addition to an open question and answer period, a number of citizens took the opportunity to submit comments on forms provided at the meeting.

- **May 23, 2012:** This meeting was intended to keep the public informed of the progress of the study and to address related questions and concerns. This second of three meetings related to the consultant's study focused on the results of a geological and physical survey of the river as well as a description of the historical resources in the area. Preliminary findings were presented on how the dam removal would reduce upstream flooding while not affecting downstream flooding.

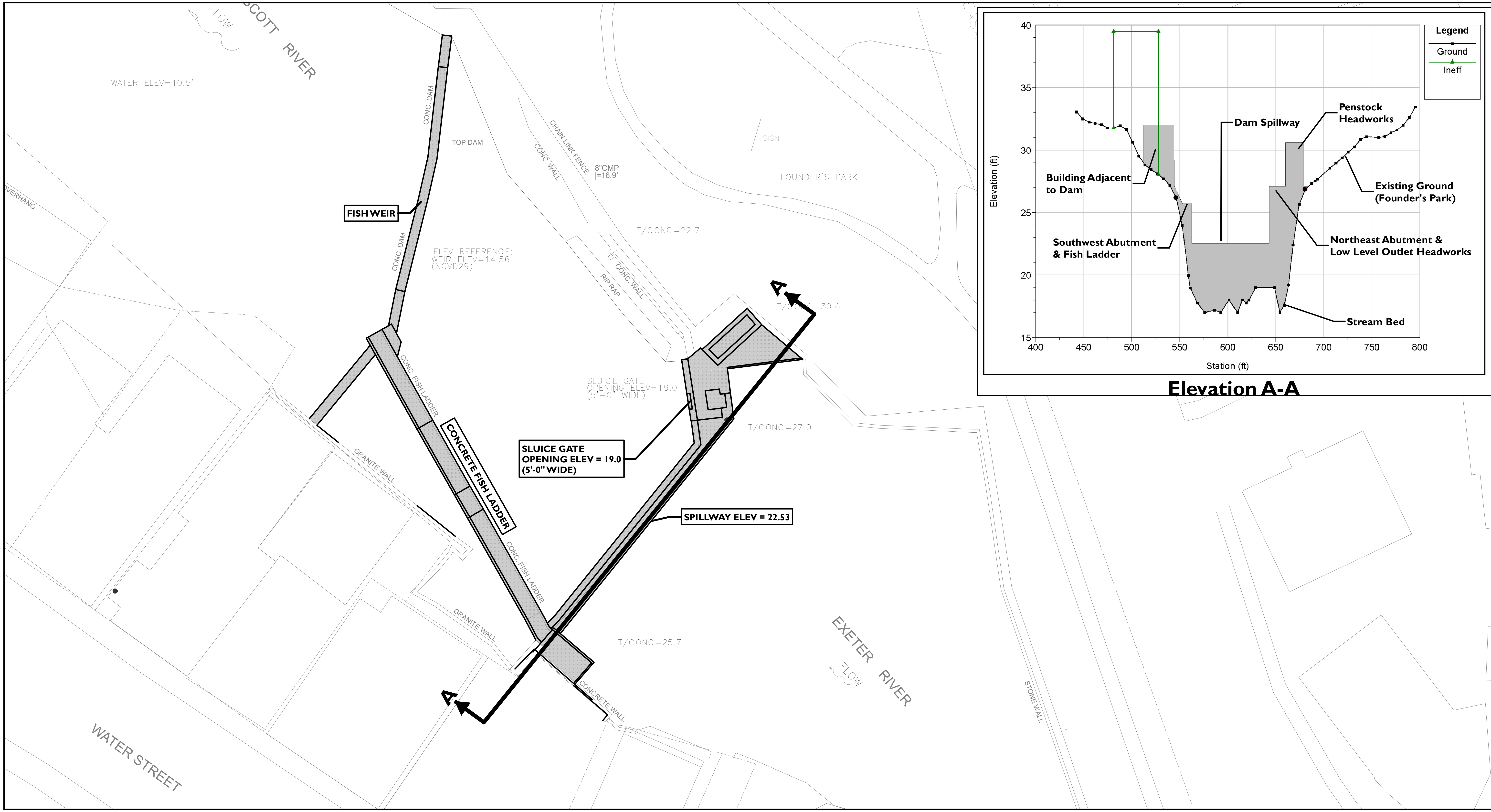
- **June 26, 2013**: Additionally, a fourth public meeting was held on June 26 to present the findings of this study to the community. This meeting summarized the various alternatives analyzed during the study, presented the main effects of each of the alternatives and presented cost estimates for each. The meeting also provided the public the opportunity to comment on the study report, which was subsequently revised based on the feedback received during the meeting and in written comments submitted by the public after the meeting. The result is this final report.

Notes and other information from the public meetings are contained in **Appendix F**.

## 2.2 Alternative A - No Action/Existing Condition

Under this scenario, the existing dam would remain as is, with no modifications. As explained in Chapter 1, it is readily apparent that this is not feasible due to safety issues, based on NHDES's inspection and subsequent LOD, a review of dam inspection reports and on a general knowledge of the Exeter River. Nevertheless, its inclusion in the study provides a baseline against which other alternatives can be evaluated. While there are no obvious immediate direct economic costs associated with this alternative, doing nothing would expose the town to significant liability, including possible legal action from the state and increased liability if the dam were to fail (i.e., a claimant could argue negligence).

A survey plan in **Appendix A** and **Figure 2.2-1** show the existing condition.




**All Elevations Referenced to the National Geodetic Vertical Datum of 1929 (NGVD 29)**

Vanasse Hangen Brustlin, Inc.

**Figure 2.2-1**
**Alternative A - Existing Condition**

**Exeter Great Dam Removal**
**Feasibility & Impact Analysis**

**Exeter, NH**

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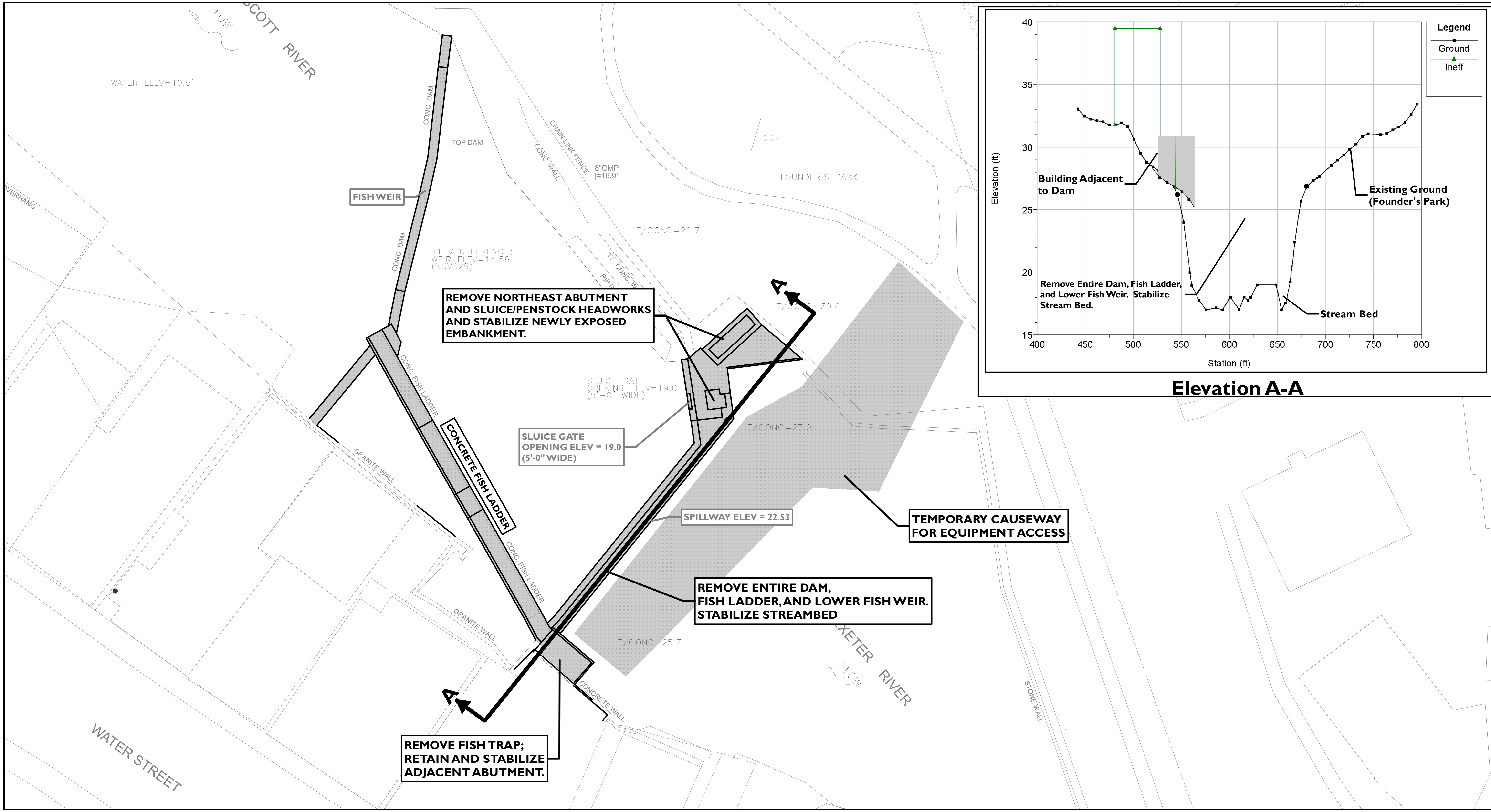
Date: 10/30/2013




**All Elevations Referenced to the National Geodetic Vertical Datum of 1929 (NGVD 29)**

0 30 60 Feet

*Vanasse Hangen Brustlin, Inc.*

**Figure 2.3-1**
**Alternative B - Dam Removal**
**Exeter Great Dam Removal**
**Feasibility & Impact Analysis**

**Exeter, NH**

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Date: 10/30/2013

## 2.3 Alternative B - Dam Removal

This alternative involves the removal of the entire existing dam structure, including the fish weir and lower dam, and reshaping of the river channel within the footprint of the existing dam and immediately upstream and downstream. **Figure 2.3-1** depicts the main features of this alternative.

The full removal alternative would create the most substantial change in the impoundment elevation and river hydraulics. These changes, in turn, would have a variety of effects including reduction of flooding conditions for upstream landowners, potential effects on upstream infrastructure through changes in erosion and deposition within the channel, as well as potential effects on wetlands and floodplain communities along the impoundment. These impacts are discussed in more detail in Chapter 3 while the direct economic costs associated with the construction work are presented in Section 2.7 below.

Removal of the dam is expected to take approximately three to eight weeks, and would typically be scheduled during the low flow months of August and September, under environmental controls designed to limit any temporary environmental effects.

It is anticipated that a cofferdam may be required to segment the work area from the flowing river, although low flow conditions may make this unnecessary. Equipment would most likely be staged on the northeast bank of the river at Founders Park, but access from the southwest side of the dam is also possible, contingent upon landowner permission for temporary use of the vacant lot at 23 Water Street. A portion of the bank would need to be graded to allow equipment access, including the possible installation of a temporary causeway. Removal of the concrete structures would require use of standard construction equipment such as a “hoe ram,” i.e., a large excavator-mounted jack hammer. All of the concrete and other construction material would be removed from the river, working from west to east, and hauled for disposal at a landfill. The causeway would also be removed entirely.

The channel substrate is largely bedrock and boulder material with smaller amounts of unconsolidated sediments. This substrate should be quite stable following dam removal. However, removal of the dam may result in some areas of unstable riverbed in the immediate vicinity. Therefore, minor 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, 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.

## 2.4 Alternative C – Dam Modification Concept 2 (2007)

Alternative C was developed in 2006 and 2007 by Wright-Pierce, working with the Exeter River Study Committee and was named "Dam Modification Concept 2" in their 2007 technical report. Their recommended design criteria used to develop this alternative included:

- Dam crest elevation to remain unchanged;
- No increase in the east abutment elevation (west abutment elevation to match east abutment);
- Achieve NHDES discharge capacity requirements;
- Maintain or improve performance of the existing fish passage facility; and
- Discharge gates are to be automated (to satisfy NHDES discharge requirements manually operated gates cannot be used in capacity calculations).

*Alternative C – Dam Modification Concept 2* consists of the following elements (shown in **Figure 2.4-1**):

- Removal of 3 ft along the entire spillway crest and installation of 3-ft high automated flashboards (crest gate) so as to maintain the existing dam spillway elevation;
- Increasing the height of the left (southwest) abutment by 1.3 ft so it is the same elevation as the right (northeast) abutment; and
- Increasing the low-level outlet dimensions to 6 ft high by 8 ft wide[20] with the invert set at an Elev. 15 ft with the installation of an automated sluice gate.

Because the left (southwest) abutment can likely be raised without changing the critical elevations of the fish ladder (i.e., its inlet and outlet elevations), there would be no direct impacts to this structure. However, increasing the size of the gated outlet could have an indirect impact on flows at the base of the ladder when the gate is open, which could impact the ability of upstream migrating fish to find the ladder entrance (Cheri Patterson, NH Fish and Game Department, personal communication).

***Alternative C – Dam Modification Concept 2 was eliminated from further consideration for the following reasons:***

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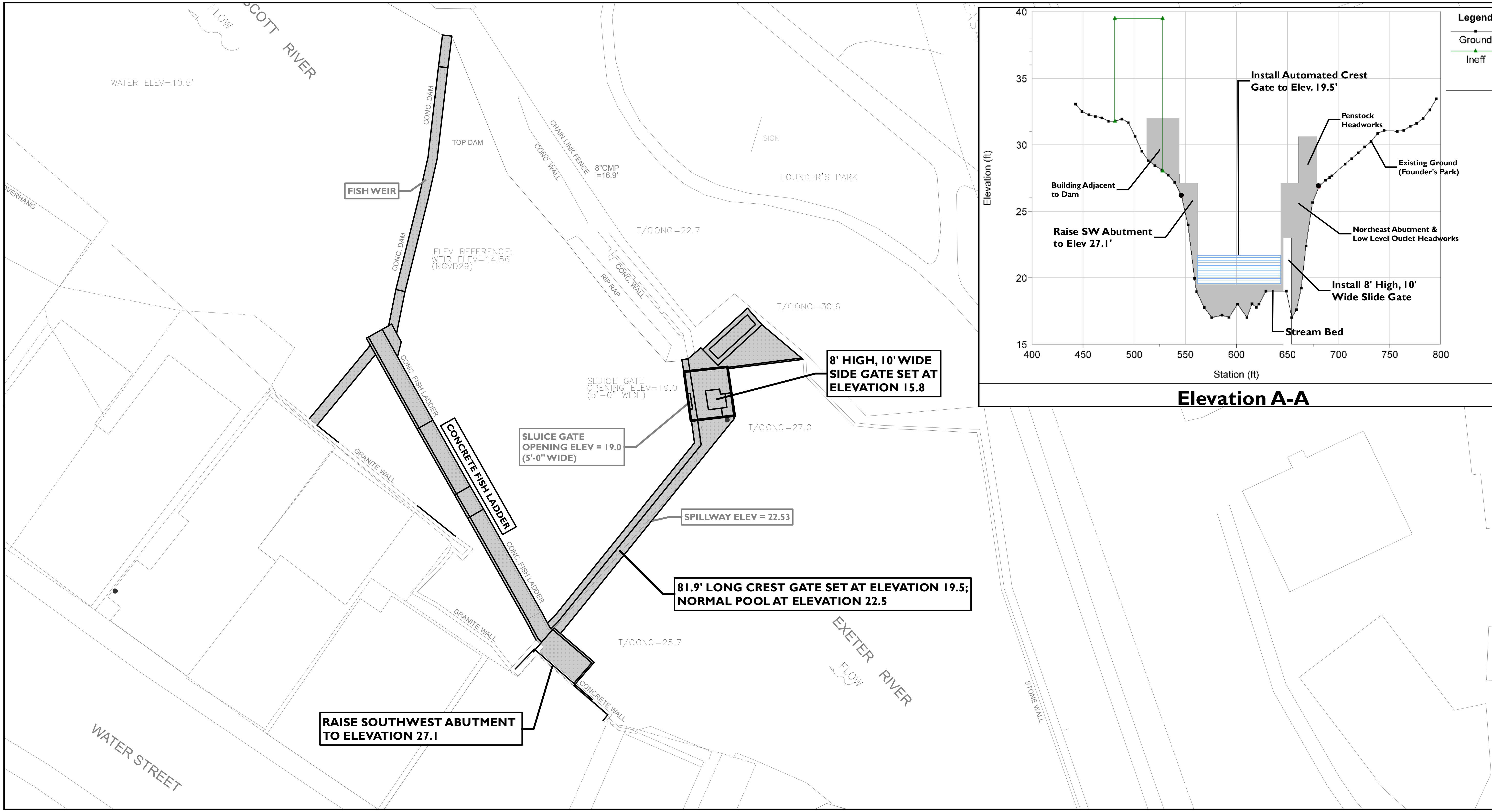
[20] Wright-Pierce noted that the size of the low-level outlet would need to be re-evaluated as part of a final design based on hydraulic characteristics of a selected low-level outlet gate structure, and the potential for reduced spillway capacity associated with automated flashboards.




All Elevations Referenced to the National Geodetic Vertical Datum of 1929 (NGVD 29)

0 30 60 Feet

*Vanasse Hangen Brustlin, Inc.*

**Figure 2.4-1**
**Alternative C - Concept 2 (2007)**
**Exeter Great Dam Removal Feasibility & Impact Analysis**

**Exeter, NH**

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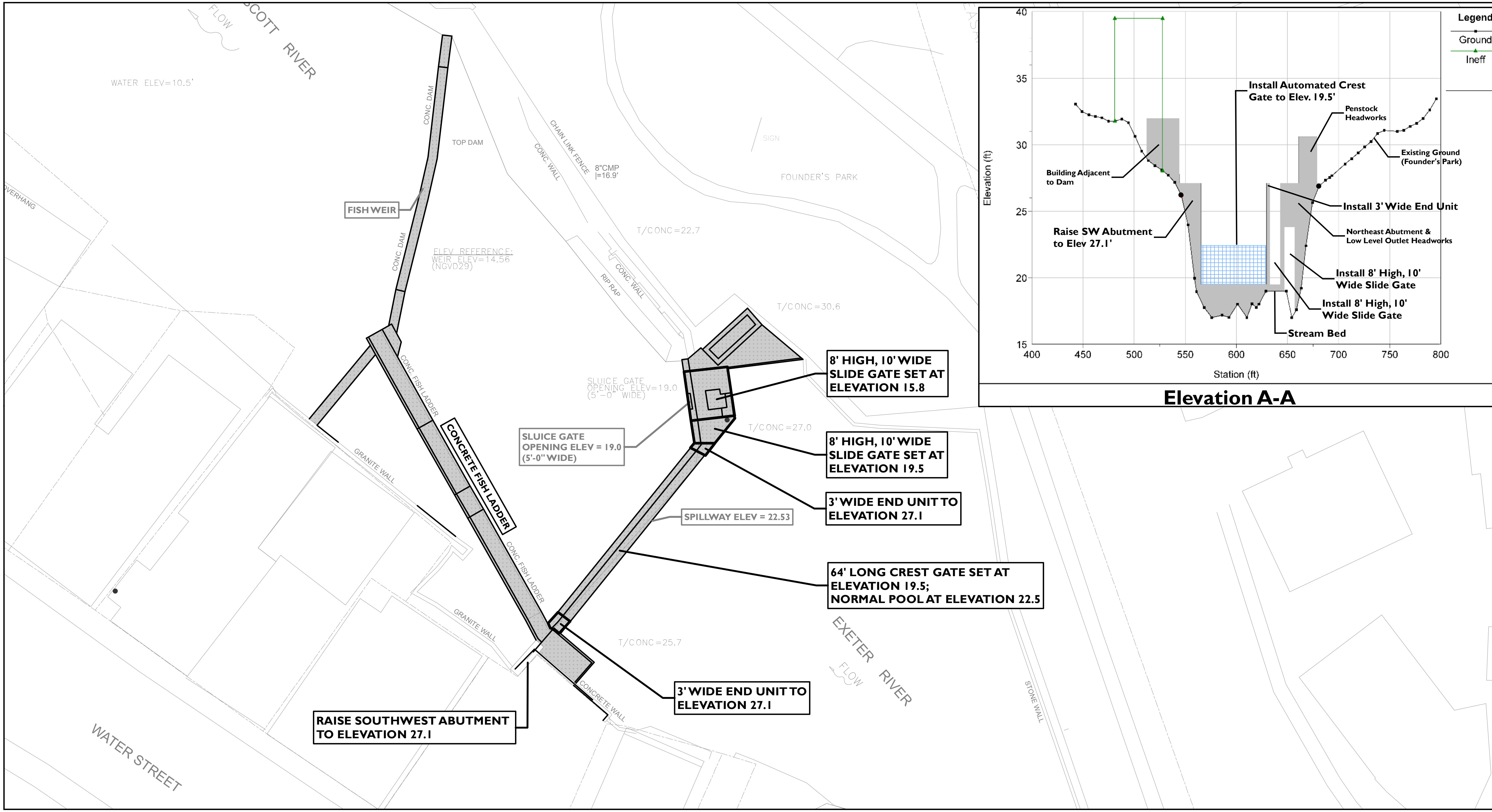


All Elevations Referenced to the National Geodetic Vertical Datum of 1929 (NGVD 29)

Vanasse Hangen Brustlin, Inc.

**Figure 2.5-1**
**Alternative D - Modified Concept 2 (0 ft Freeboard)**
**Exeter Great Dam Removal Feasibility & Impact Analysis**

**Exeter, NH**

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Date: 10/30/2013

- Wright-Pierce (2007) conducted hydraulic modeling of Dam Modification Concept 2 that demonstrated this alternative could pass the 50-year storm with more than one foot of freeboard. However, the 50-year design storm used for their analysis was 4,416 cfs. Revised hydrological analysis, described in Section 3.2, indicates that the 50-year design flow acceptable to NHDES is actually 5,858 cfs. New hydraulic modeling conducted during this Feasibility Study indicates that Dam Modification Concept 2 *does not* pass the revised 50-year flow with the required freeboard, a basic requirement of the NHDES dam safety rules.

- Based on the recent coordination with the NHDES Dam Bureau, automated gates *cannot* be included in discharge calculations as they are subject to mechanical failure and therefore considered "manual operations" which *cannot* be included in discharge capacity. NHDES has indicated that a waiver request complying with NH Administrative Rule *Env-Wr 202, Waivers*, could be submitted for the Department's review (Steven Doyon, personal communication, September 26, 2012). However, in order to obtain such a waiver, among other conditions, the following criteria must be met:

  - A ***hardship*** must exist and the town must provide an explanation of how compliance with the rule (in this case the requirement that the dam be able to pass the 50-year flood without manual operations) would create that hardship; and
  - The town must provide a full explanation of how the automated gates are consistent with the intent of RSA 482:11-a and RSA 482:12 and would ***adequately protect human life, public safety, and the environment***.

Given the very high standards required by the waiver regulations, and the fact that such waiver has never been granted by NHDES, it was determined that *Alternative C – Dam Modification Concept 2*, is not a viable alternative and was eliminated from further consideration. In fact, all alternatives which call for automated gates (e.g., Alternatives D and E, discussed below), were eliminated on this basis.

## 2.5 Alternative D – Revised Dam Modification Concept 2 (0 ft Freeboard)

Because the 2007 preferred alternative (i.e., Alternative C – Dam Modification Concept 2), is no longer considered hydraulically sufficient given the increased 50-year design flow, new dam modification alternatives were developed. Approved design criteria follow:

- Alternatives must pass the new 50-year design flood with the required freeboard;

- Alternatives must maintain the traditional current pool during non-flood conditions;
- Alternatives must maintain water levels no lower than 2 ft. below current pool during all conditions;
- Alternatives should minimize impact to the form and function of Great Dam;
- Alternatives must be constructible at a conceptual level; and
- Alternatives should be cost-effective.

Because the key components of Dam Modification Concept 2 remain promising options for modifying the Great Dam, variations and combinations of the crest gate and enlarged low-level outlet options were further evaluated for their ability to safely pass the new 50-year design flow with the required freeboard and to maintain the traditional current pool. Alternative D was developed in accordance with the design criteria outlined above.

*Alternative D – Revised Dam Modification Concept 2 (0 ft Freeboard)* consists of the following elements (shown in **Figure 2.5-1**):

- Increase the height of the southwest abutment 1.4 ft. to match the height of the northeast abutment;
- Remove 4 vertical ft. from 64-ft. section of the long spillway arm down to Elev. 18.5;
- Remove bedrock in the impoundment within approximately 30 ft. of the dam down to Elev. 18.5 as required;
- Install 64-ft. long crest gate to provide an "effective" spillway crest of Elev. 19.5 when fully opened;
- Install an 8-ft. tall by 10-ft. wide slide gate within the shorter spillway arm at Elev. 19.5; and
- Replace existing low-level outlet with an 8-ft. tall by 10-ft. wide slide gate at Elev. 15.8.

Because the left (southwest) abutment can likely be raised without changing the critical elevations of the fish ladder (i.e., its inlet and outlet elevations), there would be no direct impacts to this structure. However, increasing the size of the low-level outlet and adding a slide gate could have an indirect impact on flows at the base of the ladder when the gate is open, which could impact the ability of upstream migrating fish to find the ladder entrance (Cheri Patterson, NH Fish and Game Department, personal communication).

***Alternative D – Revised Dam Modification Concept 2 (0 ft Freeboard) was eliminated from further consideration for the following reasons:***

- Hydraulic model simulations of Alternative D indicate that with the crest gate fully down and both slide gates fully open, this alternative would pass the approved 50-year design flood (5,858 cfs) with a peak stage of Elev. 27.09, maintaining approximately 0.01 ft. of freeboard. However, note that this does not meet the requirement in the dam safety rules that the dam pass the design flood with at least one foot of freeboard without manual operations. This alternative requires manual operations including lowering of the crest gate and opening the slide gates, which are not allowed by DES's administrative rules.

- In addition, Alternative D incorporates an automated gate system. This would require NHDES to issue a waiver, which, as discussed in Section 2.4, would be very difficult to obtain.

## 2.6 Alternative E - Revised Dam Modification Concept 2 – (1 ft Freeboard)

Alternative E is virtually identical to Alternative D, with the same crest gate and slide gate configuration, except that it proposes to lower the concrete spillway crest by an additional foot (i.e., a total of 5 ft) and replace it with an automated crest gate that would be an additional foot taller. This provides an additional foot of adjustment to the crest gate and correspondingly more hydraulic opening.

*Alternative E –Dam Modification* consists of the following key components:

- Increase the height of the southwest abutment 1.4 ft. to match the height of the northeast abutment;
- Remove 5 vertical ft. from 64-ft. section of the long spillway arm down to Elev. 17.5;
- Remove bedrock in the impoundment within approximately 30 ft. of the dam down to Elev. 17.5 as required;
- Install 64-ft. long crest gate to provide an "effective" spillway crest of Elev. 18.5 when fully opened;
- Install an 8-ft. tall by 10-ft. wide slide gate within the shorter spillway arm at Elev. 18.5; and
- Replace existing low-level outlet with an 8-ft. tall by 10-ft. wide slide gate at Elev. 15.8.

**Figure 2.6-1** shows these features.

Because the left (southwest) abutment can likely be raised without changing the critical elevations of the fish ladder (i.e., its inlet and outlet elevations), there would be no direct impacts to this structure. However, increasing the size of the low-level outlet and adding a slide gate could have an indirect impact on flows at the base of the ladder when the gate is open, which could have an indirect impact on the ability of upstream migrating fish to find the ladder entrance (Cheri Patterson, NH Fish and Game Department, personal communication). This would be an issue for any alternative which proposes increasing the size or configuration of the low-level outlet.

Hydraulic model simulations of Alternative E indicate that with the crest gate fully down and both slide gates fully open, this alternative would pass the approved 50-year design flood (5,858 cfs) with a peak stage of Elev. 26.08, maintaining approximately 1.02 ft. of freeboard. However this alternative still relies on manual operations including lowering of the crest gate and opening the slide gates, which are not allowed by DES's administrative rules.

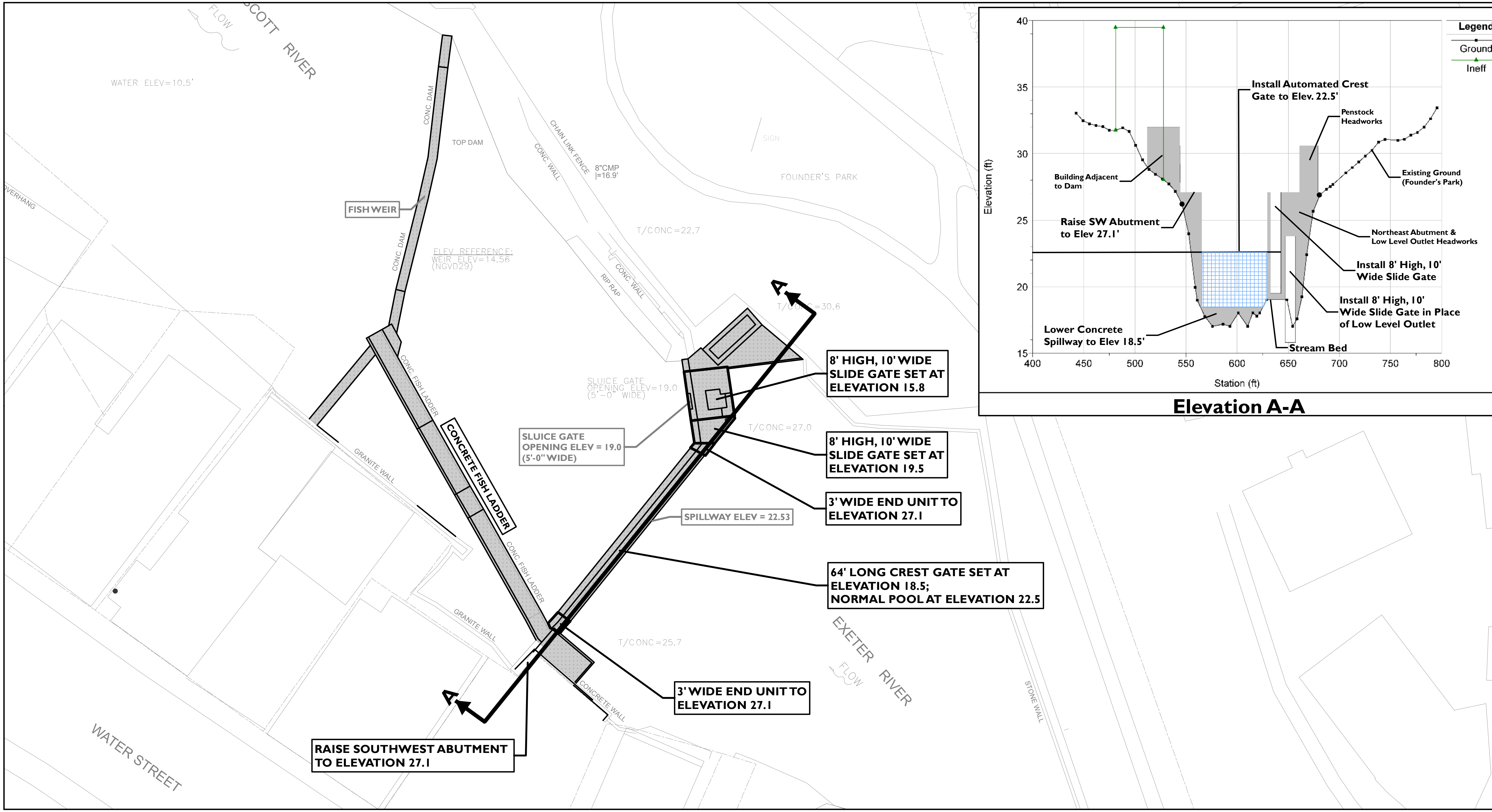
Additional detail on the features of this alternative is provided below.

### Crest Gate

The main feature of this alternative is a 64-ft. long crest gate, located along the 68.5-ft. long main arm of the existing spillway. While Alternative C - Dam Modification Concept 2 (2007) was developed with crest gates extending the full length of both the long and short arms of the existing spillway, further evaluation revealed constructability issues associated with this configuration. Therefore, Alternative E (and Alternative D described above) limits the crest gate installation to the long arm of the existing spillway only, as its ability to open fully would be impaired by the presence of a crest gate on the shorter arm. In addition, it is expected that 2-3 ft. of the length of the existing long arm of the spillway would be lost to a concrete stanchion or end unit adjacent to the fish ladder, required to frame the crest gate. An additional 2-3 ft. of spillway length would be lost to the construction of a similar stanchion or end unit at the spillway bend to frame the other end of the crest gate and one of the slide gates.

The crest gate would require a foundation base slab anchored to the bedrock to support the bottom hinge and side stanchions to seal the ends of the gate. The gate would be supported and actuated by hydraulic pistons anchored in reinforced concrete slots formed in the bedrock below the downstream side of the gate. The piston activation would be controlled automatically by trends in the electronically-monitored water level at Great Dam. As the water level at Great Dam rises in the early hours of a large flood event, the pistons would be retracted to automatically lower the crest of the gate a short distance. If water levels continued to rise, the gates would be lowered further. If instead, water levels began to drop, the gates would be raised again. In this manner, the crest gate could be operated to maintain the traditional current pool elevation during normal flow periods, but could be lowered several feet to pass a significant portion of large flood events.

Installation of a crest gate would require substantial alteration of the existing spillway; several vertical feet of the long spillway arm would be removed. The depth of that removal would be approximately equal to the required operating height of the crest gates plus an additional foot to account for the vertical profile of the crest gate and its mechanical controls when fully opened. Crest gate installation would also




**All Elevations Referenced to the National Geodetic Vertical Datum of 1929 (NGVD 29)**

0 30 60 Feet

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Date: 10/30/2013

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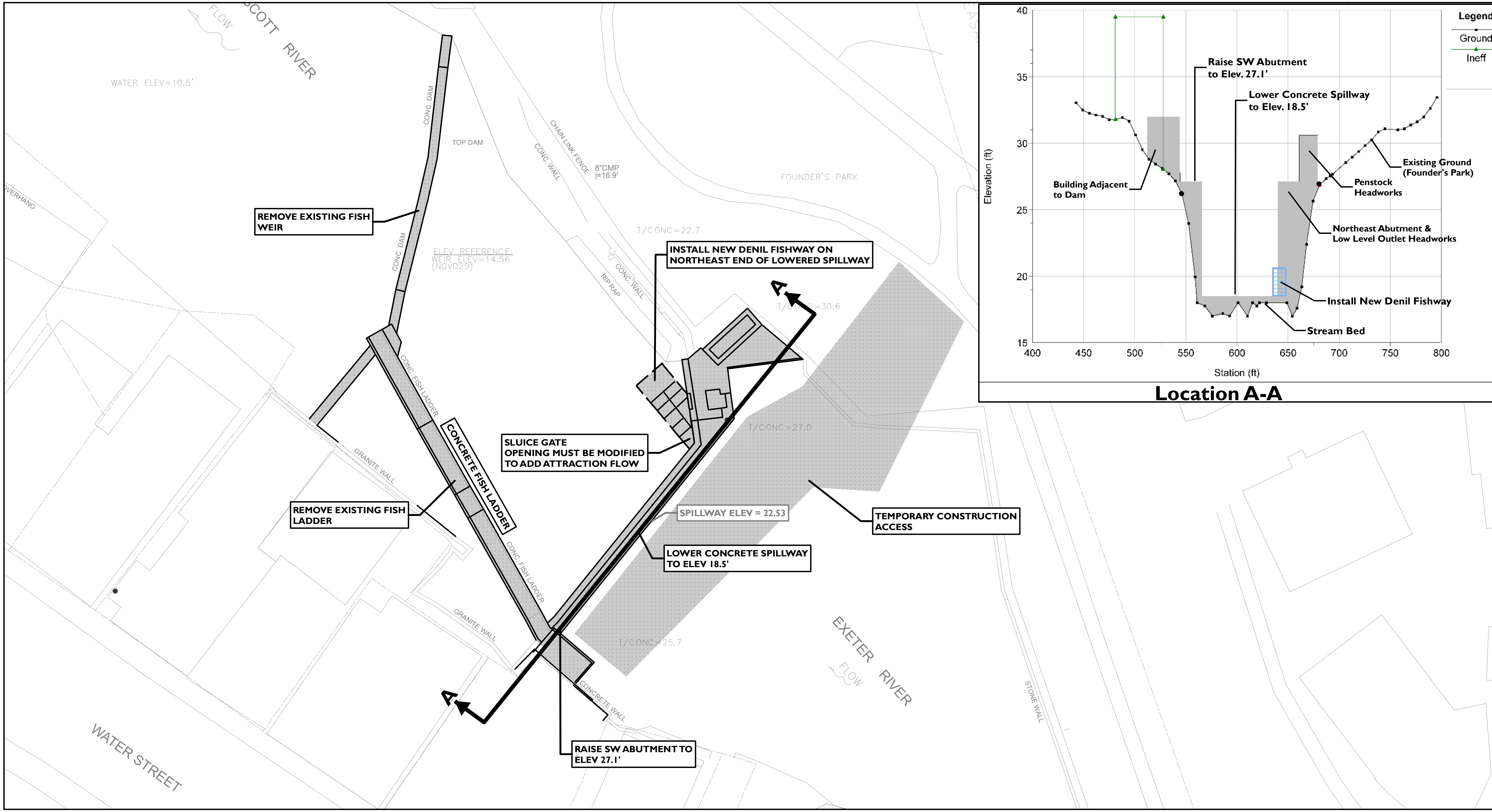
**Figure 2.6-1**
**Alternative E - Modified Concept 2 (1 ft Freeboard)**

**Exeter Great Dam Removal**
**Feasibility & Impact Analysis**

**Exeter, NH**




1. All Elevations Referenced to the National Geodetic Vertical Datum of 1929 (NGVD 29)
2. Conceptual design only based on preliminary calculations and maybe changed during final design if this alternative is chosen.

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Date: 10/30/2013

VHB Vanasse Hangen Brustlin, Inc.

**Figure 2.7-1**
**Alternative F - Partial Removal**

**Exeter Great Dam Removal**
**Feasibility & Impact Analysis**

**Exeter, NH**

require substantial excavation into the bedrock to form a stable foundation slab for the gate and to accommodate the hydraulic actuating pistons. The impoundment bottom upstream of Great Dam is primarily bedrock and the bedrock surface has been surveyed as high as Elev. 19.0 in this area. The Dam is likely constructed directly on bedrock. The depth of bedrock removal below the gate would likely be as deep as the required operating height of the crest gates plus one or two feet to accommodate the pistons. Accordingly, if the gate operates through a 4 ft. height range, bedrock excavation would probably extend to 6 ft. below the bottom of the gate hinge for the piston slots. In addition, as indicated above, removal of some bedrock upstream of the dam may be required to ensure that flow approaches the crest gate unhindered. The crest gate controls will also have to be housed in a building or protective enclosure near the gate. The location and size of the enclosure will need to be assessed during final design if this alternative is selected.

### Slide Gates

In addition to a 64-ft. long crest gate, Alternative E (and Alternative D) includes the installation of two 8 ft. high by 10 ft. wide slide gates. One slide gate would be located between the bend in the existing spillway and the existing low-level outlet headworks. The sill elevation of that slide gate would be located at the "effective" spillway crest: Elev. 18.5 for Alternative E (Elev. 19.5 for Alternative D). The purpose of this slide gate is to supplement the capacity of the 64-ft. long crest gate in an area of the existing spillway that cannot be equipped with its own crest gate. The second slide gate would be installed as a replacement to the existing 4 ft. high by 5 ft. wide low-level outlet. The sill of the replacement gate would match that of the existing outlet at Elev. 15.8. The purpose of the second slide gate would be to supplement the discharge capacity of Great Dam during the design flood event, but also to provide a means of drawing the impoundment down for maintenance on the other outlet structures or the dam itself. In addition, the second slide gate or the crest gate could be used to satisfy any downstream flow needs. Like the crest gate, both slide gates would be hydraulically actuated and automatically raised and lowered in response to electronically-monitored water levels at the dam.

***Alternative E – Revised Dam Modification Concept 2 (1 ft Freeboard) was eliminated from further consideration for the following reasons:***

- Hydraulic model simulations of Alternative E indicate that with the crest gate fully down and both slide gates fully open, this alternative would pass the approved 50-year design flood (5,858 cfs) with a peak stage of Elev. 26.08, maintaining approximately 1.02 ft. of freeboard.

- However, Alternative E relies on an automated gate system to pass the 50-year storm. As discussed elsewhere, NHDES does not allow such gates to be included in dam discharge calculations because they are subject to mechanical failure and therefore considered "manual operations." Thus, construction of this alternative would require NHDES to issue a waiver to their dam safety rules, which, as discussed in Section 2.4, would be very difficult to obtain.

## 2.7 Alternative F – Partial Dam Removal

The main design criteria used in developing dam modification alternatives included the requirement that dam crest elevation remain unchanged (or adjustable) in order to maintain the impoundment under normal flow conditions. However, because development of a viable alternative meeting this criterion became difficult, and in response to public comments indicating that a partial removal alternative should be considered, it was decided that review of a partial removal alternative should be included in this analysis.

*Alternative F –Partial Removal* consists of the following key components (shown in **Figure 2.7-1**):

- Remove 4 vertical ft. from 75-ft. section of the long spillway arm down to Elev. 18.5;
- Remove bedrock in the impoundment within approximately 30 ft. of the dam down to Elev. 18.5 as required;
- Removal of the existing fish ladder and lower fish weir;
- Construction of a new fish ladder on the northeast side of the reconfigured dam.

A significant issue with the Partial Removal Alternative is that it would lower the headpond by 4 ft. and therefore prevent the existing fish ladder from functioning correctly. Therefore, this alternative would require that a new fish ladder be constructed to match the new impoundment level. While the new fish ladder would need to be designed in consultation with the NH Fish and Game Department and other interested resource agencies, a preliminary conceptual design consists of a Denil fish ladder approximately 3.5 ft. wide at a 1:8 slope. The entrance would be located near the existing low-level outlet gate, with a sloped section from the entrance to a 180 degree (non-sloped) turnaround, with another sloped section from the turnaround to the exit at the headpond. The exit invert would be set at approximately Elev. 18 ft. with an entrance invert set at approximately Elev. 12 ft. With a 6 ft. head differential, the fish ladder would need to be about 48 ft. long with room for the turnaround. The low-level outlet gate would need to be moved or modified so that it can provide an "attraction flow."[21]

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[21] Attraction flows provide a cue to upstream migrating fish and attract the fish towards the ladder entrance.

## 2.8 Alternative G – Stabilize in Place (Rock Anchors)

While the focus of the dam modification alternatives described above is on increasing spillway capacity to pass the 50-year flow, NHDES Dam Safety Rules allow for another potential solution. Specifically, these rules allow for a dam to be overtopped by the design storm, as long as:

- A completed stability analysis shows that the dam is safe against sliding, overturning, or erosion by overtopping at the 50-year flood; or
- If not stable in its current condition, the dam owner may stabilize the dam such that it is safe during the 50-year flood.

Therefore, a conceptual design to stabilize the dam in place was developed, which is a fundamentally different engineering solution compared to an alternative that increases the dam's discharge capacity by modifying its geometry (i.e, Alternatives C, D, E, F and H). Details of the development of this alternative can be found in **Appendix G**.

Alternative G involves installing post-tension anchors into bedrock. (See Photograph G-1-4 in **Appendix G-1**.) These "rock anchors" will pin the dam down, creating a condition in which 100% of the dam base is in compression with its underlying substrate and thereby stabilizing the Great Dam during a 50-year flood. The process of installing rock anchors involves drilling through the dam from the crest through the heel to a specified depth below the dam. Then tendon strands are inserted into the drill hole and set into place with epoxy/grout. The strands are then pulled into tension and held into place at the force needed to stabilize the dam. The drill hole is then covered to complete the installation.

Thus, *Alternative G –Stabilize in Place,* consists of the following key components, shown in **Figure 2.8-1**:

- Retain the dam in its existing configuration, with no changes to the spillway elevation, abutments, discharge gates or fish ladder;
- Installing eight (8) "post-tension rock anchors," spaced 10 ft. apart, along the spillway crest, with two (2) additional anchors placed in the northeast abutment.[22]

The rock anchors would be embedded in the dam such that there will be no change in flow characteristics over the spillway and dam during flood events. Because Alternative G – Stabilize in Place does not change the geometry of the dam spillway

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[22] The number, type and configuration of rock anchors needed to stabilize the dam has been determined only on a preliminary basis and has not been fully reviewed by state safety officials. Therefore, the specific features of this alternative are subject to change.

or abutments, it does not change the hydraulics of the Exeter River compared to the Alternative A – No Build/Existing Condition.

## Dam Stability Analysis

The stability of the Great Dam in its existing condition was determined using the methods outlined in Chapter Three of *Engineering Guidelines for Evaluation of Hydropower Projects* by the Federal Energy Regulatory Commission (FERC 2013). The NHDES Dam Bureau refers to these methods in the dam regulations for the State. Using available information, it was determined that the Great Dam in its existing condition *does not* meet the factor of safety criteria for both sliding and overturning during the 50-year flood. (See **Appendix G-2** for these calculations.) These calculations demonstrate that the dam, if left in its current configuration, is at risk for failure by either sliding or overturning.

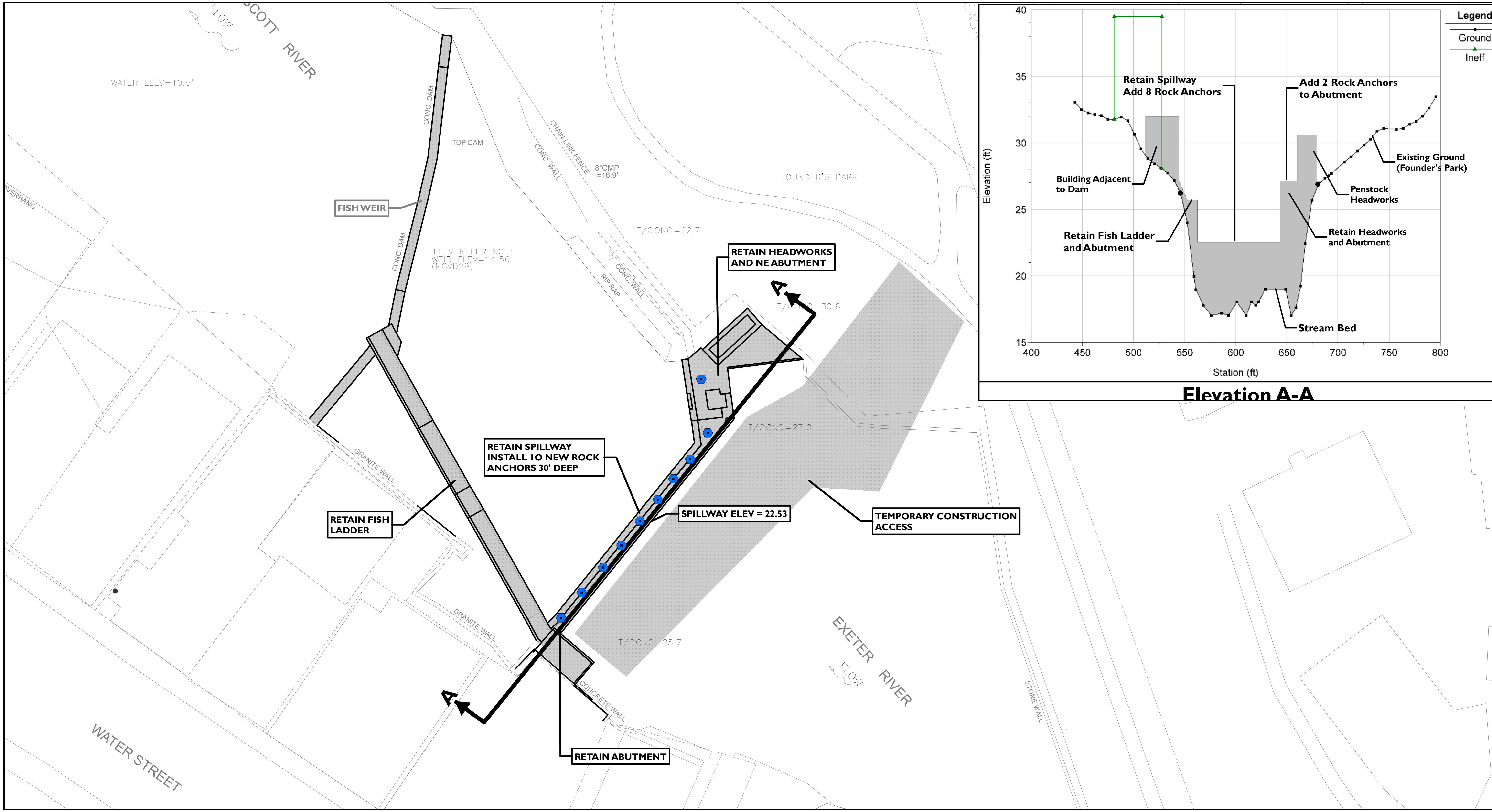
Because the dam does not meet the required factors of safety, the dam must be modified to either pass the 50-year flood or be stabilized in place. Stabilizing in place involves adding mass to the dam or pinning it to underlying bedrock. Fortunately, available data indicates that bedrock is close to the surface underneath the dam.[23]

The rock anchor conceptual design is based on the additional force needed to resist overturning and sliding of the dam. The required stabilizing force is 12,000 pounds per linear foot of dam based on the deficiency calculated in the existing condition stability analysis. Each post-tension anchor strand can supply 35,000 pounds, so if the rock anchors are spaced 10 feet on center, then four (4) strands are required for each rock anchor. General rules of thumb for post-tension anchors are a minimum embedment depth of 15 feet and maximum rock anchor spacing of double the dam height.

A subsequent set of stability calculations which assumed ten (10) rock anchors in place found that stabilizing in place would result in acceptable factors of safety for sliding and overturning.

The design life of post-tension rock anchors is 75 to 100 years (FHWA 1999). However, failures have been documented with poorly installed systems, unsuitable geologic conditions, and unsatisfactory corrosion protection. Fully bonded rock anchor strands (ASTM A416) are recommended to protect against corrosion. Further, it is assumed that the dam is founded on bedrock and this geology is suitable to embed rock anchors. The nearest geotechnical boring data (collected by the NHDOT during the reconstruction of Great Bridge/High Street Bridge) indicates that bedrock is present at a depth of 14 ft. which supports this assumption. However, before the

[23] The location of bedrock in relation to the dam should be confirmed with additional geotechnical investigations if this alternative is chosen.




**Note:**

1. See Kleinschmidt Associates (2013) for more detail.
2. Conceptual design only based on preliminary calculations and maybe changed during final design if this alternative is chosen.
3. All Elevations Referenced to the National Geodetic Vertical Datum of 1929 (NGVD 29)

0 30 60 Feet

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**Figure 2.8-1**
**Alternative G - Stabilize in Place**

**Exeter Great Dam Removal**
**Feasibility & Impact Analysis**

**Exeter, NH**

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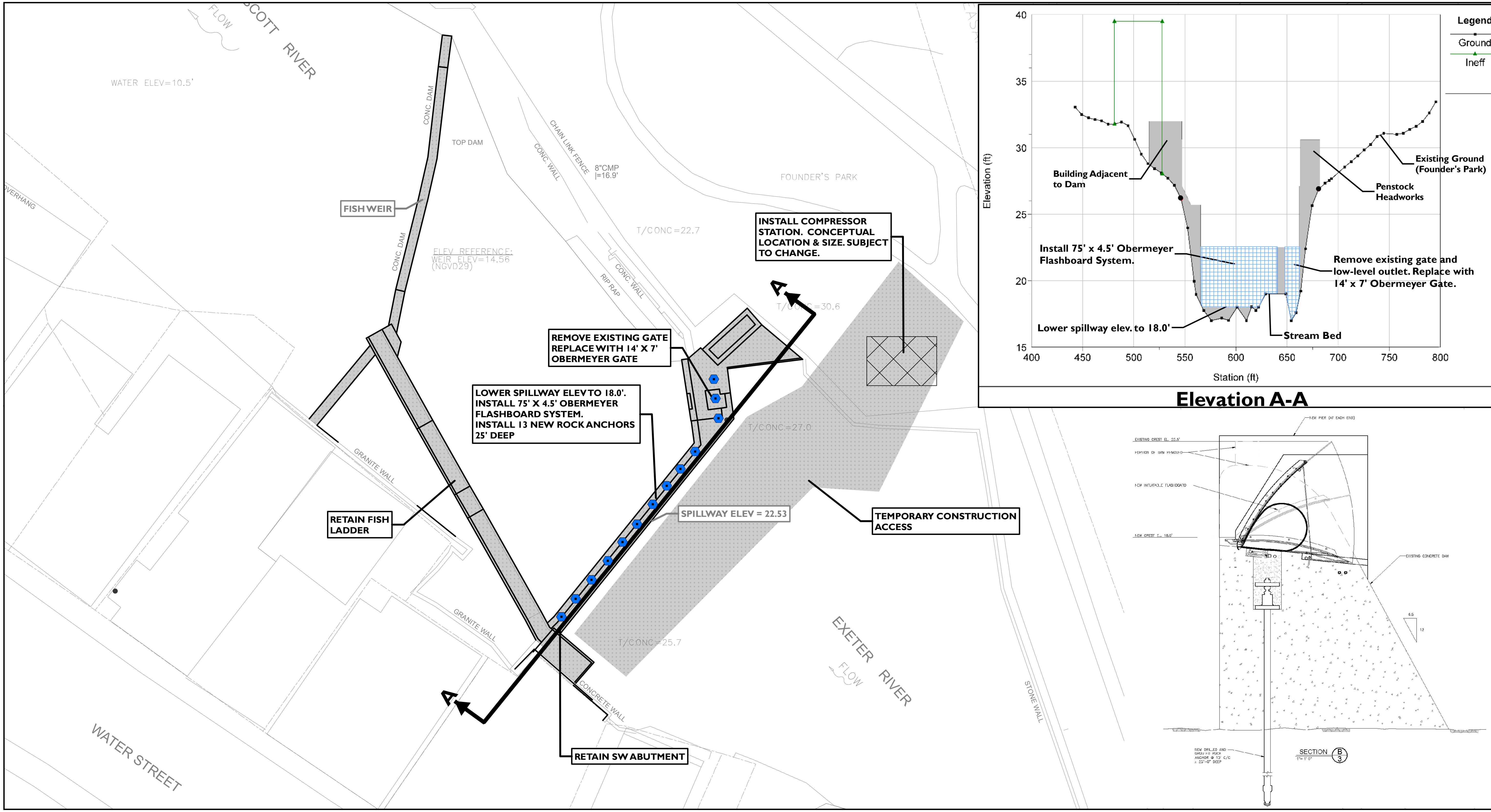


**Note:**

1. See Kleinschmidt Associates (2013) for more detail.
2. Conceptual design only based on preliminary calculations and maybe changed during final design if this alternative is chosen.
3. All Elevations Referenced to the National Geodetic Vertical Datum of 1929 (NGVD 29)

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Date: 10/30/2013

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**Figure 2.9-1**
**Alternative H - Dam Modification**

**Exeter Great Dam Removal Feasibility & Impact Analysis**

**Exeter, NH**

TOWN OF EXETER FOUNDED 1638 NEW HAMPSHIRE

rock anchors can be installed, a significant amount of site investigation and material testing is required to bring the conceptual plan to final design.

The Stabilize in Place Alternative provides a relatively inexpensive way to maintain the status quo while satisfying regulatory requirements. However, at this level of design there are uncertainties regarding this option:

- For example, the NHDES Dam Bureau will not completely eliminate erosion by overtopping as a failure mode without further investigation (Steve Doyon, personal communication). If erosion by overtopping is deemed a potential failure mode, then abutment modifications could be designed to mitigate this risk. These modifications would result in National Flood Insurance Program ramifications because they would modify the "regulatory floodway," which could be difficult to permit.
- Additional investigations (e.g., geotechnical borings) may produce results that could complicate the final design of the rock anchors and make the project more expensive. While not expected, it remains a possibility.

In spite of these uncertainties, it is reasonable to conclude that Alternative G – Stabilize in Place is feasible, at least from an engineering perspective. However, Alternative G also has some significant environmental limitations. These issues are discussed further in Chapter 3:

- Alternative G does nothing to mitigate upstream flooding. The discharge capacity of the Great Dam is 20% of what it needs to be to pass the 50-year flood. The flood risk could be managed better by increasing the size of the low-level outlet, but not nearly enough to pass the 50-year flood or even the 10-year event.

- Alternative G, while allowing the current fish ladder to operate, would not remove the barrier to upstream fish migration that is associated with the dam.
- Perhaps most significantly, as is documented in Section 3.8 of this report, the Great Dam has an adverse impact on water quality in the Exeter River. The Stabilize in Place Alternative would do nothing to mitigate this impact. Note that the impounded reach of the Exeter River is considered "impaired" according to the state's water quality standards. Because it is impaired, the Town of Exeter will eventually be required to take actions to improve water quality in the river. The scope of these actions is unknown at this time, but additional environmental studies would be conducted and pollutants of concern would need to be managed at the town's expense. By eliminating the dam, water quality could be improved to the point where these costs could be substantially reduced.

## 2.9 Alternative H – Dam Modification - Inflatable Flashboard/Gate System

Alternative H involves significantly lowering the Great Dam spillway and installing an Obermeyer flashboard and gate system. An Obermeyer system consists of a hinged steel plate supported by a rubber bladder that acts as the crest of a dam. (See **Appendix G** for more information.)

Specifically, *Alternative H –Dam Modification – Inflatable Flashboard/Gate System* consists of the following key components (shown in **Figure 2.9-1**):

- Remove 4.5 vertical ft. from a 75-ft. section of the spillway down to Elev. 18;
- Install a 75 ft. long by 4.5 ft tall Obermeyer flashboard system to provide an "effective" spillway crest of Elev. 22.5 when the flashboards are fully up and Elev. 18 when fully down;
- Demolish the existing low-level gate and associated structure and replace it with a 14 ft long by 7 ft tall Obermeyer gate;
- Remove bedrock in the impoundment within approximately 30 ft. of the dam down to Elev. 18 as required; and
- Install 13 rock anchors approximately 25 ft deep to stabilize the dam.

The Obermeyer flashboard and gate will have the same crest elevation as the existing dam (i.e., Elev. 22.5 ft) and will therefore maintain the functionality of the fish ladder. Based on visual inspection of the dam, the fish ladder would withstand the spillway removal without the need for major repairs.

Because this alternative removes such a substantial amount of mass from Great Dam, the modified dam would not meet dam stability requirements even though the water surface elevation would drop during the 50-year storm. Therefore, Alternative H will require installation of rock anchors before the flashboard and gate system is installed.

There are three main benefits of the Obermeyer system over other adjustable crest gate systems:

- The steel plates protect the rubber bladders from ice and debris load,
- The stiffness of the plate allows the system to raise and lower the water surface elevation by partial deflation where a rubber dam without a steel plate can only be completely inflated or deflated, and

- The Obermeyer can be designed to be failsafe (i.e., pull the plug and the force of the water will cause the bladders to deflate and the flood can pass without operation).[24]

This allows the town maximum flexibility controlling the water levels and may improve the fish passage effectiveness by better controlling the flow over the dam. Also, the size of the side gate will allow the Town to rapidly drain the impoundment for maintenance activities. The system would be upright under normal conditions so that the normal river level is maintained. Under higher flows, however, the gate could be lowered to allow for higher flows to pass without as much upstream flooding. The current conceptual design could pass approximately 2,300 cfs through the lowered flashboard and side gate without the water surface elevation increasing over its normal level (22.5 ft NGVD), which is about the 5 to 10 year flood range. It may be possible to design a system that would maintain more or less constant water levels up to these flood flows, which is a substantial improvement over the existing dam conditions.

Typically, these systems are installed for an operating hydro power facility that has a powerhouse to store the compressors. This is not the case for the Great Dam, and therefore Alternative H would require either building a new small building to house the compressors (ideally above the 100 year flood elevation) or have a local building (e.g., the public library) house the compressors. The compressors usage is a function of the amount of leakage in the system and the need for water level management. If the goal is to keep the crest of the dam at 22.5 feet (NGVD29) as much as possible and the system is maintained properly, the compressors do not need to be operated constantly. This minimizes depreciation and energy usage.

Alternative H involves the addition of mechanical and electrical components to the Great Dam. These components will increase the need for operation, maintenance, and repair. In addition to the operation and maintenance activities the Exeter Public Works Department already performs on the existing dam, the following is a list of new maintenance activities associated with this Alternative H:

- Air compressor oil check (weekly) and change (dependent on usage)
- Air compressor belt check (weekly) and change (dependent on usage)
- Obermeyer abutment seal check (yearly and after floods)
- Obermeyer air bladder check (yearly and after floods)
- Obermeyer restraining straps (yearly and after floods)
- Inspect coalescing filter (yearly with periodic replacement)
- Inspect air dryer (yearly with periodic replacement)
- Torque main anchor bolts (every 12 to 18 months)
- Operate failsafe purge valves (every October)

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[24] This is a critical design feature that could allow the NHDES to issue a waiver for its use, even though an Obermeyer system is a "manual operation."

In addition to these tasks, the systems requires energy to run the compressors, air dryers, provide lighting in the compressor house, and potentially heat the compressor house. In the case of the loss of electric supply, the system could run on a portable generator. However, this is not required because well maintained bladders will hold their air and the failsafe purge valves will not require electricity to function. In the unlikely case of catastrophic failure of the system, the impoundment would drain to the invert of the gate. If this occurs during high flows, the system would not be able to be fixed for weeks or even months. This could have large ramifications for the effectiveness of the fish ladder.

Similar to Alternative G, most but not all of the ecological and water quality impacts of the dam would remain. These issues are discussed further in Chapter 3.

## 2.10 Alternatives Brought Forward for Further Analysis

As described above, a large number of alternatives were considered during this and previous studies. **Table 2.10-1** provides a summary of the key features of these alternatives.

Based primarily on the hydraulic sufficiency of each alternative, combined with considerations of cost, practicality and compliance with regulatory requirements, the following alternatives were carried forward for further detailed evaluation in Chapter 3:

- Alternative A – No Action/Existing Condition
- Alternative B – Dam Removal
- Alternative F – Partial Removal
- Alternative G – Stabilize in Place
- Alternative H – Dam Modification (Inflatable Flashboard/Gate System)

Alternative C was eliminated from further consideration because revised hydrological and hydraulic modeling indicates that it does not provide adequate capacity to pass the 50-year design storm and would require a waiver from the NHDES to allow for the inclusion of automated gates in calculation of this discharge capacity. Alternative D was eliminated for similar reasons - it does not provide one foot of freeboard and would therefore require a waiver to be issued by NHDES. Alternatives D and E were eliminated primarily because they would require a waiver from the NHDES to allow for the inclusion of automated gates in calculation of this discharge capacity.

The impacts and benefits of each of these alternatives is discussed further in Chapter 3, including consideration of hydraulic effects (i.e., flooding), natural resources, social resources, cultural resources, water quality and supply, as well as other issues.

Table 2.10-1. Summary of Alternatives Considered

| Alternative | Main Features | Pass 50-yr Flow with 1 ft Freeboard? | Maintain current water level? | Reduce Flooding? | Improve Fish Passage? | Require a NHDES Dam Waiver? |
|---|---|---|---|---|---|---|
| Alternative A - No Action | Maintain status quo | No | Yes | No | No | Yes. Not permittable. |
| Alternative B - Dam Removal | Remove dam entirely | NA | No | Yes | Yes. Restores fish passage | No |
| Alternative C - Dam Modification (2007) | Reduce spillway height by 3 ft, replace with automated crest gate. Increase size of low-level outlet. | No | Yes | Yes | No | Yes. Not permittable. |
| Alternative D - Revised Dam Modification Concept 2 (0 ft Freeboard) | Reduce spillway height by 4 ft, replace with automated crest gate and slide gate. Increase size of low-level outlet. | No | Yes | Yes | No | Yes. Not permittable. |
| Alternative E - Revised Dam Modification Concept 2 – (1 ft Freeboard) | Reduce spillway height by 5 ft, replace with automated crest gate and slide gate. Increase size of low-level outlet. | Yes | Yes | Yes | No | Yes. Not permittable. |
| Alternative F – Partial Removal | Permanently lower spillway elevation by 4 ft. Construct new fish ladder on northeast. | Yes | No | Yes | Yes. Would require entirely new fish ladder. | No |
| Alternative G – Stabilize in Place | Leave dam essentially as is, but install 10 rock anchors to increase dam stability. | No | Yes | No | No | No |
| Alternative H – Dam Modification – Inflatable Flashboard/Gate System | Reduce spillway height by 4.5 ft, replace with Obermeyer flashboard/ gate system. Install 13 rock anchors to stabilize reconfigured dam. | Yes | Yes | Yes | No | Yes |

## 2.11 Cost Estimates

The cost of a particular alternative consists primarily of the expenses related to design, permitting and construction. However, several alternatives would have associated costs related to environmental mitigation and infrastructure retrofits (e.g., adjusting water intakes). Additionally, it is important to consider that all alternatives, except the Dam Removal Alternative, would have future costs related to operation and maintenance. This section describes the costs associated with each of the five potential alternatives for each of these three categories.

### 2.11.1 Design, Permitting and Construction

To allow for comparison of the direct economic costs of the alternatives, preliminary Opinions of Probable Cost were prepared in 2013 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 is expected to 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.

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, 32nd Annual Edition, 2013*; and
- Data from the NH Department of Transportation including their *Weighted Average Unit Prices for 2012 Qtrs 1-4* accessed via the internet.
- Recent vendor quotes for similar items, especially a 2012 bid for an inflatable flashboard system.

Several important assumptions were made in developing the estimates, including the following:

- If Dam Modification is the selected alternative, then a detailed geotechnical and structural analysis of Great Dam, including test borings with rock coring and destructive and non-destructive testing of concrete, is recommended to evaluate the dam's post-modified stability and to determine structural modification requirements. This evaluation may indicate the need for additional rehabilitation or strengthening of the dam. Because the need for this work cannot be determined at this time, it is presently unknown if rehabilitation or strengthening of the dam would be required. We have, however, included the cost of installing rock anchors, which is expected to be sufficient.

- Work on the Dam Removal or Partial Removal Alternatives could be substantially completed over a period of approximately eight weeks.
- 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 all of the alternatives. This includes permitting through NHDES, the US Army Corps of Engineers, as well as the cost of preparing a FEMA Letter of Map Revision on behalf of the Town of Exeter.
- Construction monitoring is also included. This is the expected costs to the Town to oversee and manage the contractor during construction.
- Capital costs for Fish Passage are addressed as follows:
  - *Alternative B – Dam Removal* does not include costs for fish passage because removal of the dam would eliminate the need for a fish ladder.
  - The cost estimate for *Alternative F – Partial Removal* includes $500,000 for construction of a new denil fish ladder. See Section 2.7 for a discussion of the conceptual design of this ladder.
  - *Alternative G – Stabilize in Place* would allow the existing fish ladder to continue to operate as is, so no capital costs are included for modifications or replacement.
  - *Alternative H – Dam Modification* would also retain the existing fish ladder as is, so no capital costs are included for modifications or replacement. However, note that modification of the dam by the addition of the Obermeyer system would likely affect the operation and performance of the fish ladder. See Section 3.11 for more discussion.

The cost estimates provided in **Table 2.11-1** are an initial investment associated with the design, permitting and construction of each alternative. Details of the construction cost estimates are provided in **Appendix H**.

Table 2.11-1. Preliminary Construction Opinions of Probable Costs, Build Alternatives (2013 dollars)

| Alternative | Construction, including Contingency[5] | Engineering/ Permitting/ Monitoring[6] | Total |
|---|---|---|---|
| Alt B – Dam Removal[1] | $613,500 | $118,650 | $732,150 |
| Alt F – Partial Removal[1,2] | $1,133,340 | $205,290 | $1,338,630 |
| Alt G – Stabilize in Place[3] | $341,000 | $77,000 | $418,000 |
| Alt H – Dam Modification[3,4] | $875,000 | $141,000 | $1,016,000 |

Notes:

1. Cost estimates for *Alternative B - Dam Removal* and *Alternative F – Partial Removal* were prepared by VHB.
2. Cost estimate for *Alternative F* includes demolition of the existing fish ladder and construction of a new one in its place.
3. Cost estimates for *Alternative G – Stabilize in Place* and *Alternative H – Dam Modification* were prepared by Kleinschmidt Associates.

4. Cost is for *Alternative H - Inflatable Flashboard/Gate System*.
5. Contingency is assumed to be 20 percent of construction costs.
6. Includes geotechnical/engineering studies, materials testing, final design and permitting as well as construction phase engineering and environmental inspections.

### 2.11.2 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 a structure must consider costs associated with the 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* (1995) with the *2012 Supplement* was used to determine the life cycle costs for the proposed alternatives. At this level of study, a simple method was utilized that accounts for initial investment, capital replacement, energy, and operation, maintenance, and repair.

Total life cycle costs for the Partial Removal, Stabilize in Place and Dam Modification Alternatives (i.e., Alternatives F, G and H) are detailed in Appendices G and H and summarized in **Table 2.11-2**. Life cycle costs for the No Build (Alternative A) and are not provided because there would be no future occurring cost associated with these alternatives. Life cycle costs for Dam Removal (Alternative B) are limited to the cost to remove the dam, i.e., the construction costs discussed above. (But see Section 2.11.3 below regarding other related costs.)

Because the design life of properly constructed partial removal and properly installed rock anchors is at least 75 years, a capital replacement cost of 40% of the initial investment value was used in this analysis for Alternative G. However, the design life of an Obermeyer system is considerably shorter - an expected 30 years – so a capital replacement cost of 90% of the initial investment value was used for Alternative H. This assumes that some of the parts (i.e., piping system) would maintain value. The energy usage was estimated by looking up average household energy usage rates in New Hampshire.

The operation, maintenance, and repair annual cost was derived from conversations with the Exeter Public Works Department (PWD) which estimated an average of 140 labor hours with $500 in material costs. The labor hours consisted of regular and flood event operation and maintenance which include some overtime pay rates. Additional hours and materials were included in the annual O&M cost for Alternative H to account for the added mechanical complexity of this system. (See Section 2.9 for a list of these items.)

The costs provided in **Table 2.11-2** can be thought of as the total cost of the alternative over a 30 year time period, including construction of the improvements, the cost of replacing, repairing and maintaining those improvements, as well as the cost of energy for the alternative (i.e., Alternative H would require electricity to run the Obermeyer system).

Table 2.11-2. Total Estimated Costs to Operate, Maintain and Replace, by Alternative

| Alternative | Cost |
|---|---|
| Alt A - No Action | - |
| Alt B – Dam Removal | $0 |
| Alt F – Partial Removal | $385,170 |
| Alt G – Stabilize in Place | $181,894 |
| Alt H – Dam Modification | $616,724 |

Note: See Appendices G and H for more detail.

## 2.11.3 Other Related Costs

In addition to the construction and life cycle costs, all of the alternatives have the potential to create impacts to environmental and cultural resources as well as adjacent infrastructure.

### Public Water Intake Retrofits

Because they would permanently lower the impoundment, Alternative B - Dam Removal and Alternative F - Partial Removal would likely require retrofits to several water intakes. Weston & Sampson (2010b) provided a discussion of these impacts, including developing cost estimates for retrofits. Further investigations conducted as part of this Feasibility and Impact Analysis clarified and modified these costs somewhat. Additional discussion is provided in Section 3.7 of this study.

The water intakes include two installations owned by the Town of Exeter:

- **Town of Exeter River Water Intake**. This intake withdraws water from the Exeter River near Gilman Park and pumps it to the Exeter Reservoir. The intake would need to be lowered if the river is lowered. Weston & Sampson (2010b) estimated that the potential cost associated with retrofitting this intake would be approximately $750,000 to $1,000,000 (2009 dollars). However, this figure included pump station upgrades that are not directly tied to the potential dam removal, some of which have already occurred. Therefore, a new cost estimate was developed which put the cost of upgrading the pump station at approximately $338,208 (2013 dollars)

- **Dry Hydrant at Founders Park**. This hydrant provides water for firefighting. Weston & Sampson (2010b) estimated that the potential cost associated with replacing this hydrant with a new hydrant located upstream to be approximately $125,000 to $250,000. However, additional analysis has reduced this estimate to approximately $27,100 to $54,200 (2013 dollars).

Because *Alternative G -Stabilize in Place* and *Alternative H - Dam Modification* would maintain the normal pool elevation in the impoundment, these alternatives would not require these expenditures. However, it would cost the Town an estimated $365,308 to $392,408 to retrofit or replace these two publicly-owned intakes if either *Alternative B – Dam Removal* or *Alternative F – Partial Removal* is selected.

## Environmental and Cultural Resource Mitigation

All of the alternatives would have impacts to environmental and/or cultural resources to one degree or another. A detailed discussion of these impacts is presented in Chapter 3. For purposes of this cost estimate, it is appropriate to incorporate some of these costs. For example, there could be additional costs associated with further historical or archaeological studies, sediment management, or mitigation of water quality impacts. For example:

- **Historic Documentation of the Dam.** Dam Removal, Partial Removal and Dam Modification would all have substantial effects on the historic nature of the dam which would require mitigation. (See Section 3.9.) The exact nature of this mitigation would be developed in consultation with the NH Division of Historical Resources, lead federal agencies, consulting parties, and the town, but can be expected to cost approximately $30,000.

- **Archaeological Monitoring at Dam.** Because of the level of earth disturbance associated with construction, all of the alternatives have the potential to affect archaeological resources near the dam. It is very likely that a Phase IB Archaeological Study would be required prior to environmental permitting. The cost of such a study should be approximately $15,000.

- **Archaeological Monitoring Upstream.** Additionally, because the Dam Removal and Partial Removal Alternatives could cause upstream bank slumping in areas that are considered archaeologically sensitive, it is likely that a multi-year monitoring study would need to be conducted if either of these alternatives is chosen. For purposes of this study, a cost of approximately $25,000 is expected.

- **Fish Passage.** In order to receive environmental permits for the Partial Removal, Stabilize in Place and Dam Modification Alternatives, it will likely be necessary to conduct monitoring studies to ensure that fish are able to effectively pass the reconstructed dam - both upstream and downstream. The scope of such studies cannot be precisely defined at this time, and would need to be developed in consultation with the NH Fish and Game Department, the US Fish and Wildlife Service and the National Marine Fisheries Service. However, based on similar projects, the cost of a monitoring study for the Great Dam would likely be $50,000 per year. Such monitoring studies are typically conducted for three years.

- **Water Quality Studies.** As documented in Section 3.8, the Dam Removal would improve water quality in the Exeter River, with Partial Removal also having some benefit. The No Action, Stabilize in Place and Dam Modification Alternatives would not substantially improve the documented water quality impairments in the river. Thus, additional future water quality studies are likely to be a condition of any environmental permit issued for these alternatives. If Alternative B – Dam Removal is not the selected alternative, due to the existing impairments, it is likely that the 401 water quality certificate would need to include some conditions to require ongoing monitoring, additional study and/or identification of ways to improve water quality to ensure compliance with these standards. Also, additional study and/or corrective actions may be needed to address the impacts on fish habitat caused by the lack of low flow mobility. Furthermore, under the proposed EPA National Pollutant Discharge Elimination System (NPDES) General Stormwater Permit for Small Municipal Separate Storm Sewer Systems (MS4), the town would likely be required to create a Water Quality Response Plan (WQRP) for dissolved oxygen and chlorophyll-a in the impoundment. In Exeter, it is expected that the 401 Water Quality Certificate for the dam project would need to be aligned with anticipated MS4 requirements, and ultimately the WQRP, to address any residual water quality impairments attributable to the dam project. And, to the extent that impairments could be resolved by the dam project, the requirements for compliance with the either the 401 Certification and/or the NPDES MS4 programs could be simplified and become less expensive. Such studies typically range from $250,000 to $1,000,000. For purposes of this cost estimate, a figure of $250,000 to $550,000 is used, depending on the extent that the alternative provides water quality benefits. It should also be noted, that to the extent that the studies demonstrate that water quality can be improved by the installation of Best Management Practices, and the Town has responsibility to install the BMPs (under the MS4 permit authority), the costs associated with BMPs are unknown but could be quite high. This unknown cost is likely avoided under Alternative B - Dam Removal. (See Section 3.8.)

- **Sediment Management.** Alternative B – Dam Removal, Alternative F – Partial Removal and Alternative H – Dam Modification would create conditions where sediment is transported downstream at a higher rate than under existing conditions. (See Section 3.2.4 and Section 3.5 for a detailed discussion of sediment transport dynamics.) Because the possible effects are not easily predictable, a sediment management plan should be developed and implemented if one of these three alternatives is chosen. The sediment management plan could include items such as vegetating exposed stream banks, installation of a sediment curtain at the PEA boat basin and monitoring of downstream areas to identify any potential ecological or infrastructure impacts. A total of $50,200 was included to cover the potential cost of these measures.

Table 2.11-3. Other Infrastructure, Cultural Resource and Environmental Mitigation Costs[1]

| Alternative | Water Intake Retrofits[2] | Historic Documentation | Site Phase IB | Archaeological Monitoring | Fish Passage Field Study | Water Quality | Sediment Management | Total |
|---|---|---|---|---|---|---|---|---|
| Alt A - No Action | $0 | $0 | $0 | $0 | $0 | $550,000 | $0 | $550,000 |
| Alt B – Dam Removal | $392,408 | $30,000 | $15,000 | $25,000 | $0 | $0 | $50,200 | $512,608 |
| Alt F – Partial Removal | $392,408 | $30,000 | $15,000 | $25,000 | $150,000 | $250,000 | $50,200 | $912,608 |
| Alt G – Stabilize in Place | $0 | $0 | $15,000 | $0 | $0 | $550,000 | $0 | $565,000 |
| Alt H – Dam Modification | $0 | $30,000 | $15,000 | $0 | $150,000 | $550,000 | $50,200 | $795,200 |

Notes:
1. See Appendix H for detail.
2. Includes only the Exeter River Pump Station and the Dry Hydrant at Founders Park. Costs for private intakes are addressed below.

## 2.11.4 Total Estimated Costs by Alternative

Considering all of the costs of each alternative, direct as well as indirect and future costs, leads to the conclusion that *Alternative G – Stabilize in Place*, at about $1.2 million, would be the least expensive alternative over the 30-year analysis period. *Alternative H – Dam Modification* would cost approximately $2.4 million, including a relatively large construction investment as well as continued O&M costs. *Alternative B - Dam Removal* would also be relatively expensive, at about $1.2 million, due in part to the cost of retrofitting existing intake structures on the river. The most expensive of the alternatives carried forward for further consideration is *Alternative F – Partial Removal,* which is expected to cost about $2.6 million. The cost of the Partial Removal Alternative is increased by the fact that a new fish ladder would need to be constructed, as well as the substantial volume of demolition and disposal involved in removing the spillway, fish ladder and lower fish weir. While we have included a cost for *Alternative A – No Action* for consistency, it is clear that this alternative is not feasible due to safety and regulatory considerations. (See **Tables 2.11-3** and **2.11-4**.)

Table 2.11-4. Initial Construction and Mitigation Costs

| Alternative | Design, Permitting and Construction | Infrastructure and Environmental Mitigation | Total |
|---|---|---|---|
| Alt A - No Action | - | $550,000 | $550,000 |
| Alt B – Dam Removal | $732,150 | $512,608 | $1,244,758 |
| Alt F – Partial Removal | $1,338,630 | $912,608 | $2,251,238 |
| Alt G – Stabilize in Place | $418,000 | $565,000 | $983,000 |
| Alt H – Dam Modification | $1,016,000 | $795,200 | $1,811,200 |

Table 2.11-5. Total Costs including O&M and Replacement (30 Year Analysis)

| Alternative | Initial Cost | O&M and Replacement Costs | Total |
|---|---|---|---|
| Alt A - No Action | $550,000 | - | $550,000 |
| Alt B – Dam Removal | $1,244,758 | $0 | $1,244,758 |
| Alt F – Partial Removal | $2,251,238 | $385,170 | $2,636,408 |
| Alt G – Stabilize in Place | $983,000 | $181,894 | $1,164,894 |
| Alt H – Dam Modification | $1,811,200 | $616,724 | $2,427,924 |

Note:

1. No direct or O&M costs were calculated for the No Build Alternative because this alternative is not feasible due to safety concerns. However, lack of compliance with the NHDES Letters of Deficiency leaves the Town liable for potential future enforcement actions including fines, and would complicate compliance with state Water Quality Standards for the Exeter River.

## 2.11.5 Other Potential Related Costs and Benefits

In addition to the direct and indirect costs to the Town of Exeter related to this project, there are other indirect costs which should be considered in making a decision about which alternative to pursue.

### Private Water Intake Retrofits

In addition to the publicly-owned surface water intakes discussed above, two privately-owned water intakes would also be impacted by *Alternative B - Dam Removal* and *Alternative F - Partial Removal*:

- **The Exeter Mills Water Intake**. This intake, located near the dam, provides the mill apartments with water for cooling and fire protection. Potential cost associated with retrofitting this intake was estimated by Weston & Sampson (2010b) to be approximately $250,000 to $500,000.

- **Phillips Exeter Academy Intake**. The academy uses river water for irrigation of its athletic fields and has an intake near Gilman Park. Lowering this intake would cost approximately $100,000 to $250,000 according to by Weston & Sampson (2010b).

Because *Alternative G -Stabilize in Place* and *Alternative H - Dam Modification* would maintain the normal pool elevation in the impoundment, these alternatives would not require these expenditures.

#### Emergency Management Costs

Flooding costs private citizens as well as the public for repairs to their property and lost time. The Town has to pay for emergency management planning and emergency response. As discussed in Section 3.2, a decrease in flooding would result from the implementation of either *Alternative B – Dam Removal, Alternative F – Partial Removal* or even *Alternative H – Dam Modification*. While there is currently no accurate way to quantify the potential savings to the property owners or the Town, it is appropriate to consider this potential benefit in making a decision on which alternative to choose.

#### Flood Insurance Premiums

Portions of the Town of Exeter are currently within the mapped 100-year floodplain associated with the Exeter River and the Little River. Properties within these zones require flood zone certifications (i.e., flood insurance) for real estate transfer and mortgage purposes. Alternatives B, F and H would all help to limit the extent of the flood zone relative to Alternative G – Stabilize in Place. This raises the possibility that any future updated Flood Insurance Rate Maps would depict reduced flood zone. This could result in cost savings to present and future home buyers and sellers.

### 2.11.6 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.

## Potential Funding Available for Alternative B - 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 the Exeter project and most have provided funding for previous projects in NH.

**NOAA Habitat Conservation Grants, Northeast Region**
Through the Community-based Restoration Program, 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. Although the Town submitted a pre-proposal in June 2013 and was not selected for funding, it could be that the Town would be successful in the future if the decision is made to remove the dam.

**NH Fish and Game - Fish Habitat Program**
The Department of Fish and Game's Fish Habitat Program has funded several previous dam removal projects. A review of 2012 annual reports from the program indicates that the program expended approximately $59,000 on four restoration projects with expenditures ranging from a few hundred dollars to over $36,000. 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. 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. The Watershed Assistance Section requests proposals for the Watershed Assistance Grants program annually (usually in June, but this is subject to change). 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.

**USFWS Fisheries and Habitat Restoration Grants**
The 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 Great 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 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 (EQIP)**
The federal Farm Bill 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 currently does not allow for grants to municipalities. However, it is reported that this may change in subsequent years. EQIP is a voluntary program that provides financial and technical assistance to landowners for projects that improve water quality among other priorities. Unfortunately, the Farm Bill was last authorized in 2008 and expired this fiscal year, and the 2008 Farm Bill limited the NRCS grant programs to private landowners. (Previous versions allowed grants to be issued to municipalities such as Exeter.) The EQIP program provides for a maximum grant of $350K and has no match requirement. It is unclear when Congress will act to pass a new Farm Bill, but it seems likely to happen in the next year or two.

**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 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. Typical Embrace-A-Stream grants range from $25,000 to 50,000 with a maximum amount of $70,000.

**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. Maximum grants are either $20,000 or $25,000, depending on the nature of the project. Public (state or municipal) agencies are eligible to apply, but an organization may receive only one grant per year through the Community Grants Program.

**NH Corporate Wetlands Restoration Partnership**
The NH Corporate Wetlands Restoration Partnership (CWRP) is the state chapter of the national CWRP program, a private-public initiative aimed at preserving, restoring, enhancing and protecting aquatic habitats throughout the United States. Bringing together corporations, federal and state agencies, non-profit organizations and academia, the CWRP allows members to contribute financial support to restoration activities. Grants in NH are generally relatively small, from $5,000 to $15,000, but do not require match. Grant applications are accepted on a rolling basis.

**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 October 1 of each year in which funds are available, with awards announced in December. Municipalities are eligible applicants. For 2013, the program awarded almost $300,000 to 15 projects throughout NH, with awards ranging from $4,900 to $40,000.

## Sources of Funding for Dam Repair/Reconstruction

**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. Although LCHIP was defunded in recent years, an estimated $4 million will be available for grants in fiscal years 2014 and 2015. Rehabilitation of an historic dam would be eligible to apply for LCHIP funding, so long at the historic character of the dam is preserved. However, LCHIP environmental grants are limited to land

acquisition for preservation purposes. Therefore, it seems that only *Alternative G – Stabilize in Place* would potentially qualify.

**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 $350,000 and loan terms range from one to seven years. The average loan amount is $200,000. The Loan Fund has approximately $10 million in available revolving funds, and applications are accepted on a rolling basis, year round. Each application is considered individually for funding by our loan committee.

**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.

# 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 A, B, F, G and H), including discussion of existing environmental conditions, method of analysis, and major conclusions:

- **Alternative A – No Action.** As discussed elsewhere, this alternative is not feasible due to safety and regulatory concerns. Doing nothing would result in liabilities to the town, including legal action from the state and additional liability if the dam were to fail. It is discussed here to provide a basis for comparison with the two other alternatives.
- **Alternative B – Dam Removal.** Under this scenario, the dam, fish ladder, and fish weir would be removed from the river and the banks and bed of the stream stabilized.
- **Alternative F – Partial Removal.** The spillway crest would be permanently lowered by 4 ft. A new fish ladder would be constructed on northeast.
- **Alternative G – Stabilize in Place**. The dam would be left largely intact, but would be anchored to the underlying bedrock by way of "rock anchors" which would ensure that the dam would not slide or overturn during the 50-year flood.
- **Alternative H – Dam Modification.** The spillway crest would be lowered by 4.5 vertical ft and a 4.5 ft tall Obermeyer flashboard system would be installed to provide an effective spillway crest of Elev. 22.5 when the flashboards are fully up (i.e., the same height as the existing dam) and Elev. 18 when fully down. Additionally, the existing low-level gate and associated structure would be demolished and replaced with a 14 ft long by 7 ft tall Obermeyer gate. Because so much mass would be

removed from the dam, it will also be necessary to install a number of rock anchors.

More information on 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:

1. Either the alternative would maintain or partially maintain the impoundment, as is the case for Alternatives A, G and H; or

2. The Alternative would lead to reduce the depth of water upstream of the dam site, as is the case for Alternatives B and F.

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 Exeter River and the Little River, both upstream and downstream of the Great 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 US Army Corps of Engineers’ HEC-RAS program, Version 4.1.0, 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:

- **Hydrological Input**. The hydrological input to the model describes the volume of water that flows through the river at various times. Flow changes with time and is a function of local climate/weather conditions. Flow is generally expressed as 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," e.g., "100-year flow," meaning the flow levels that would be expected to occur once in 100 years (or have a 1 percent chance of occurring in any given year).

- **Hydraulic Model (HEC-RAS).** 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 Exeter River under different flow events if the dam is removed or modified?
- Could water velocities under dam out conditions scour existing infrastructure such as the Great 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 USGS stream gage at Haigh Road on the Exeter

River and the nearby Parker River and adjusted those flows for climate change;[25] 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.

Generally speaking, both approaches are capable of producing good estimates of river flows and flood frequencies. Statistical analysis 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 USGS Gage Data Statistical Analysis

#### Flood Flows

Design flows were estimated by applying the Log Pearson Type III distribution[26] to a record of peak stream flow (greatest discharge rate in a given water year, October 1st to September 30th) for the Exeter River that was synthesized from the peak stream flow records of the nearby Parker River. While the USGS operates a stream flow gage (USGS 01073587) in the Exeter River, its limited record of only 13 years (1997-2009) is not sufficient to properly estimate design flows, requiring the synthesis of a long-term record based on the stream flow record of a nearby basin. USGS gages in several nearby basins, shown in **Figure 3.2-1**, were considered. Ultimately the Parker River gage (USGS 01101000) was found to be more closely correlated to peak stream flow in the Exeter River than other rivers in the region including the Lamprey and Oyster Rivers which were also evaluated. Based upon that close correlation, a linear relationship was developed to translate Parker River peak stream flow to Exeter River peak stream flow. This 64-year synthesized record of peak stream flow in the Exeter River was fit to the Log Pearson Type III distribution to yield the 2-, 5-, 10-, 25-, 50-, 100-, 200-, and 500-year design flows.[27]

25 **Appendix E** contains a technical memorandum that explains the statistical method in detail, including the reasons why the Parker River gage was selected to develop design flows using this approach.

26 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 analysis.

27 More detail on the hydrologic methods and results can be found in Weston & Sampson's technical memorandum entitled, *Exeter River Design Flows*, dated January 4, 2012. See **Appendix E**.

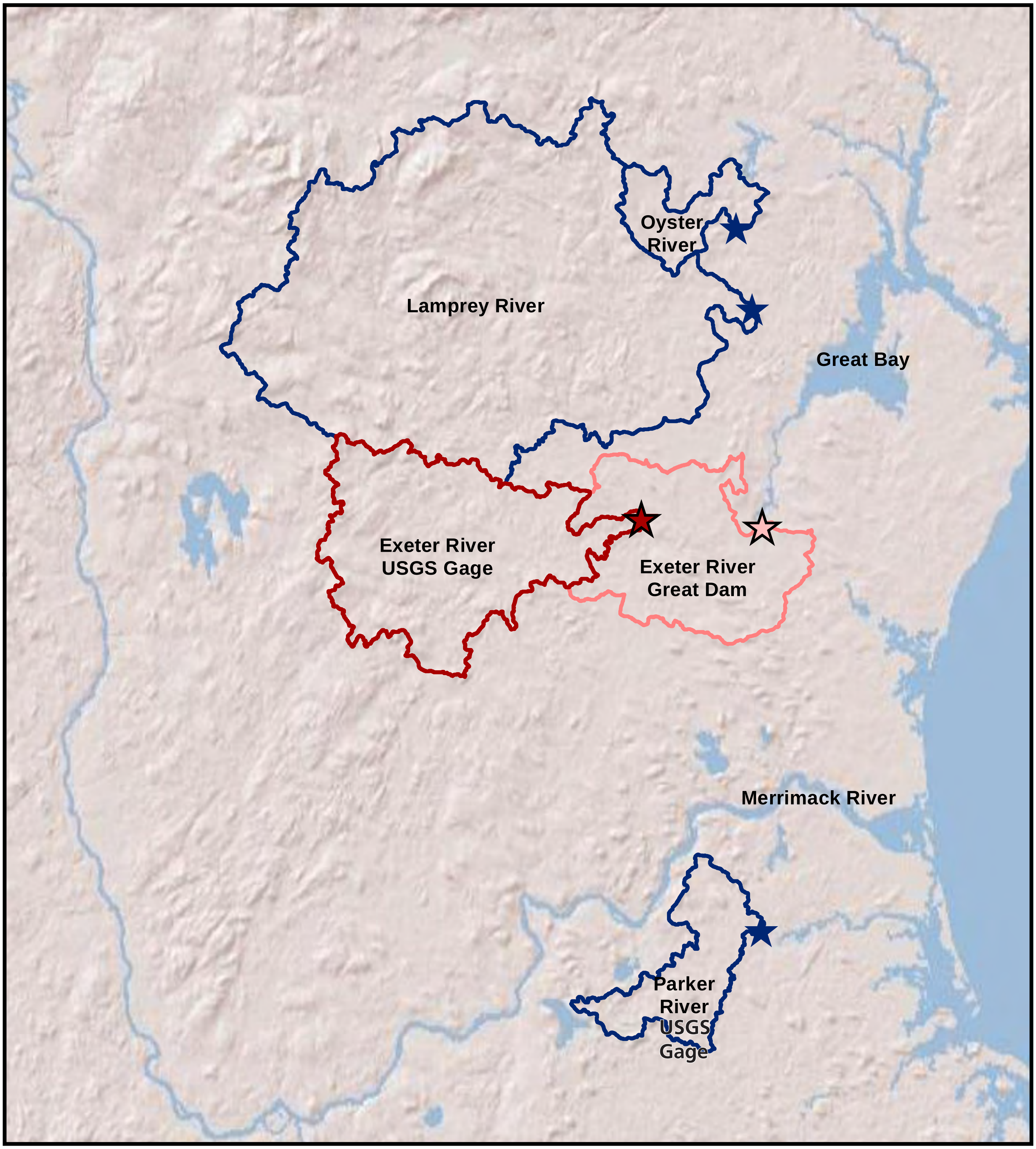


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Figure 3.2-1
USGS Gages in Nearby Basins

Exeter Great Dam Removal Feasibility and Impact Study
Exeter, NH

Source: Weston & Sampson, January 4, 2012 Technical Memorandum

Design flows were further analyzed to reflect the latest methods and data on changes in precipitation, as guided by the NOAA publication FS-2011-01, *"Flood Frequency Estimates for New England River Restoration Projects: Considering Climate Change in Project Design."* According to NOAA FS-2011-01, over the past decade, numerous academic and governmental studies have documented an increase in the frequency and magnitude of significant flood events throughout the United States, including New England. As these events grow in magnitude and frequency, so too must the design flows that guide the design and construction of American infrastructure. NOAA cites several studies that find this increase in flooding occurred, not as a slow progression over many years or decades, but rather as a step change that occurred in approximately 1970 (NOAA Fisheries Service, 2011). For this reason, NOAA recommends that river restoration projects recognize the potential impacts of this step change in New England climate by comparing design flows estimated from stream flow records pre- and post-1970. Design flows estimated from the modified synthetic record for Great Dam, split into two time periods in this way, are shown in **Table 3.2-1**. Recognizing the impact of climate change on the magnitude and frequency of floods in New England, the hydraulic analysis (Section 3.2) used the design flows estimated from the synthetic stream flow record at Great Dam for the period 1971-2009 to evaluate the potential impacts of removing Great Dam (i.e., the highlighted row in **Table 3.2-1**).

Table 3.2-1. Great Dam Design Flows Incorporating Climate Change[1]

| | Design Flow (cubic feet per second) | | | | | | |
|---|---|---|---|---|---|---|---|
| Data Set | 2-year | 5-year | 10-year | 25-year | 50-year[2] | 100-year | 200-year |
| Modified Synthetic record (1946-2009) | 1,427 | 2,225 | 2,891 | 3,914 | 4,823 | 5,873 | 7,086 |
| Modified Synthetic record (1946-1970) | 1,375 | 1,940 | 2,356 | 2,928 | 3,391 | 3,885 | 4,416 |
| Modified Synthetic record (1971-2009) | 1,481 | 2,427 | 3,245 | 4,539 | 5,718 | 7,109 | 8,745 |

Notes:
1. Data from Weston and Sampson, 2012. See Appendix E.
2. See Section 3.2.1.2 for a discussion of the development of the 50-year flow used in the subsequent hydraulic modeling for this project.

### Median/Low Flows

In addition to the flows generated through the analysis described above, median flows (i.e., median annual, median May, and median September) and low flows were calculated from the USGS stream flow record of daily mean discharge recorded by the Haigh Rd. gage on the Exeter River from October 1996 through September 2009. Median annual flow was developed to analyze dam removal or dam modification impacts under "current conditions." The median May discharge was developed to facilitate 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. **Table 3.2-2** shows these derived flows:

Table 3.2-2. Median and Low Flows from USGS Haigh Road Stream Gage[1]

| Location | Flow (cfs) | | |
| --- | --- | --- | --- |
| | Median Annual | Median May | Median Sept |
| Great Dam[2] | 71 | 104 | 5.9 |
| Little River[3] | 11 | 16 | 0.9 |
| Upper Exeter River[4]River | 60 | 88 | 5 |

Notes:
1. Data from Weston & Sampson technical memorandum dated January 4, 2012.
2. Mainstem of the Exeter River at the Great Dam.
3. Little River at its confluence with the Exeter River near Gilman Park.
4. The "Upper Exeter River" is defined in the project hydraulic model as the river above its confluence with the Little River.

Median September flow was developed to represent a low flow condition.[28] Traditionally, analyses of low flows make use of the 7Q10, the lowest 7-day average flow rate that is expected to occur every 10 years on average. Estimation of a 7Q10 flow requires the analysis of the lowest 7-day average flow rate from multiple years. However, in the case of the Haigh Rd. gage, only 14 years of daily discharge records are available, making any estimate of the 7Q10 statistically weak. For that reason, the project team employed the median September flow in its place, as the 420 data points (30 daily rates for each year on record) were sufficient to produce a statistically strong measure of "low flow conditions."

### 3.2.1.2 Rainfall Runoff Model

Because the modification or removal of the Great 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 Code of Administrative Rules 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 1.3.2, NHDES Dam Safety rules require a low-hazard dam such as the Great 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.[29]

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

- The size of the drainage area;

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[28] September was chosen as it had the lowest median monthly flow rate of any month (just lower than the median August flow). Most rivers in New England will be driest during one of those two months.

[29] While the 50-year flow used in all subsequent hydraulic modeling was derived from the rainfall-runoff model, the flows derived from the statistical methods described in Section 3.2.1.1 were used to calculate flows for all other recurrence intervals.

- 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 Army Corps of Engineers Hydrologic Engineering Center's software package HEC-HMS v.3.4, which generally employs the TR-20 methodology developed by the Soil Conservation Service (SCS) of the US Department of Agriculture.[30] These methodologies were developed to estimate the response of a watershed to specified rainfall depths and distributions based on a few defining watershed characteristics as listed above.

Table 3.2-3. Design Rainfall Depths for the 50-year Storm, Exeter River Watershed

| Storm Duration | Rainfall Depth (in) |
|---|---|
| 5 min | 0.54 |
| 15 min | 1.12 |
| 60 min | 2.16 |
| 120 min | 2.85 |
| 3 hr | 3.34 |
| 6 hr | 4.39 |
| 12 hr | 5.75 |
| 24 hr | 7.20 |
| 48 hr | 8.32 |
| 4 day | 9.41 |

Source: Northeast Regional Climate Center

Watershed parameters were estimated from publicly available geospatial datasets and from field observations gathered during other recent projects for the Town of Exeter. The calibrated rainfall-runoff model was subsequently used to estimate the 50-year design flows for Great Dam. The design rainfall depths, assumed to fall homogenously over the entire Exeter River watershed, were obtained for the approximate center of the Exeter River watershed from the online tool developed by the Northeast Regional Climate Center (NRCC) and the National Resources Conservation Service.[31] Design rainfall depths are provided in **Table 3.2-3**. The rainfall data from this online database has become the standard reference for

30 Detailed methodology and results for the rainfall-runoff model are contained in Weston & Sampson's technical report entitled *Rainfall-Runoff Design Flow Report*, June 2012. See **Appendix E**.

31 The data tool is maintained by Cornell University and is available online at *http://precip.eas.cornell.edu/*.

hydrologists performing studies in the northeast. These data supersede older publications such as NRCC's *"Research Publication RR 93-5, Atlas of Precipitation Extremes for Northeastern United States and Southeastern Canada,"* 1995.

The rainfall depths for the 50-year, 24-hour frequency storm was incorporated into the HEC-HMS rainfall-runoff model with the peak rainfall intensity occurring at exactly halfway through the storm duration. The HEC-HMS model platform completed runoff calculations based on the physical attributes of the watershed, yielding a 50-year design flow estimate of 5,858 cfs. Note that this flow agrees well with the 50-year design storm developed using the statistical analysis of gage data (which was estimated to be 5,718 cfs) discussed in Section 3.2.1.1. However, because NHDES rules require the use of a watershed model for dam safety analyses, it was decided to use the NHDES-approved flow of 5,858 cfs as input to the HEC-RAS river channel hydraulic model will be used to estimate freeboard and other necessary hydraulic characteristics of the Great Dam and its impoundment. (Refer to Section 3.2.1 for more explanation of the alternative methods.)

### 3.2.2 Development of a HEC-RAS Model

The final HEC-RAS model for this project included more than 90 cross-sections[32] that extended from approximately 1,000 feet downstream of the dam (i.e, below the head of tide in the Squamscott River) to approximately 7.6 miles upstream of the dam (at the Pickpocket Dam).[33] A large portion of the Little River was also included in the model, extending about 2.4 miles upstream from its confluence with the Exeter near Gilman Park. The locations of selected model cross-sections are shown on **Figure 3.2-2**. The model included five dams (including the Great Dam) and 12 bridges crossing the Exeter River, including the Great Bridge, the footbridge at the Phillips Exeter Academy athletic fields, the NH108/Court Street Bridges on both the mainstem of the Exeter River and the Little River, and the Linden Street Bridge.

The HEC-RAS model geometry was developed from multiple sources. The base geometry of the floodplain and valley walls is derived from LiDAR data[34] (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, provided through personal communication with Rob Flynn of the

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32 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 from throughout the length of the river under study, a three-dimensional representation of the shape of the river is built which is used by the model to perform calculations,

33 While NHDES does not regulate the hydraulic modeling efforts in support of dam removal feasibility studies, the numerical model of the Great Dam and Exeter River channel and floodplain was 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.

34 LiDAR is a relatively new method of surveying topography which uses pulsed laser light from an aircraft-mounted instrument to measure ground elevations. LiDAR operates on the same principles as radar and sonar.

USGS. The LiDAR data was selected as it offers considerably better accuracy than the satellite-derived Digital Elevation Models currently offered by the USGS; the LiDAR (dataset used for this project has a maximum error of +/-0.49 feet and an average error of +0.02 feet across the dataset's 25 quality control points spread over an area of approximately 965 sq mi. The base geometry of HEC-RAS cross-sections in the vicinity of the low-lying athletic fields of Phillips Exeter Academy was further adjusted based on a 2011 survey of the floodplain on both sides of the Exeter River, conducted in support of a separate project for the Academy.

The bathymetry of the Exeter River and Little River channels was incorporated into the HEC-RAS model geometry from five sources:

- A 2006 bathymetric survey, conducted for the Town of Exeter, which included more than 3,400 survey points by Wright-Pierce Engineers (Exeter River Study – Phase I Final Report, 2007);
- A 2011 bathymetric survey, conducted for the Town of Exeter, of five cross-sections to "spot check" the earlier survey, conducted by the project team;
- A 2011 bathymetric survey of 13 cross-sections conducted independently by the USGS (USGS, Rob Flynn);
- A 2009 bathymetric survey of six cross-sections conducted by Stantec, Inc. in support of permitting for the Linden Commons Subdivision (Hydraulic Study Report – Little River No. 1); and where necessary,
- The current effective FEMA Flood Insurance Study hydraulic model geometry (ID 33015CV001A).

Bathymetric survey points are especially dense in the first two miles of the Exeter River system, including the Great Dam project area. This area of dense bathymetric data extends from the tidal reaches of the Exeter/Squamscott River immediately downstream of the String Bridge upstream to the NH 108 Bridge as well as in the Little River from its mouth to its own NH 108 Bridge.

Geometry representative of the five dams and 12 bridges included in the HEC-RAS model was developed, where possible, from field survey data taken in 2011. Where no 2011 survey data was available, these structures were modeled from the 2006 survey data or from FEMA hydraulic model 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. These ineffective flow areas are particularly relevant in the first mile of the Great Dam impoundment and associated floodplain where significant parts of the floodplain

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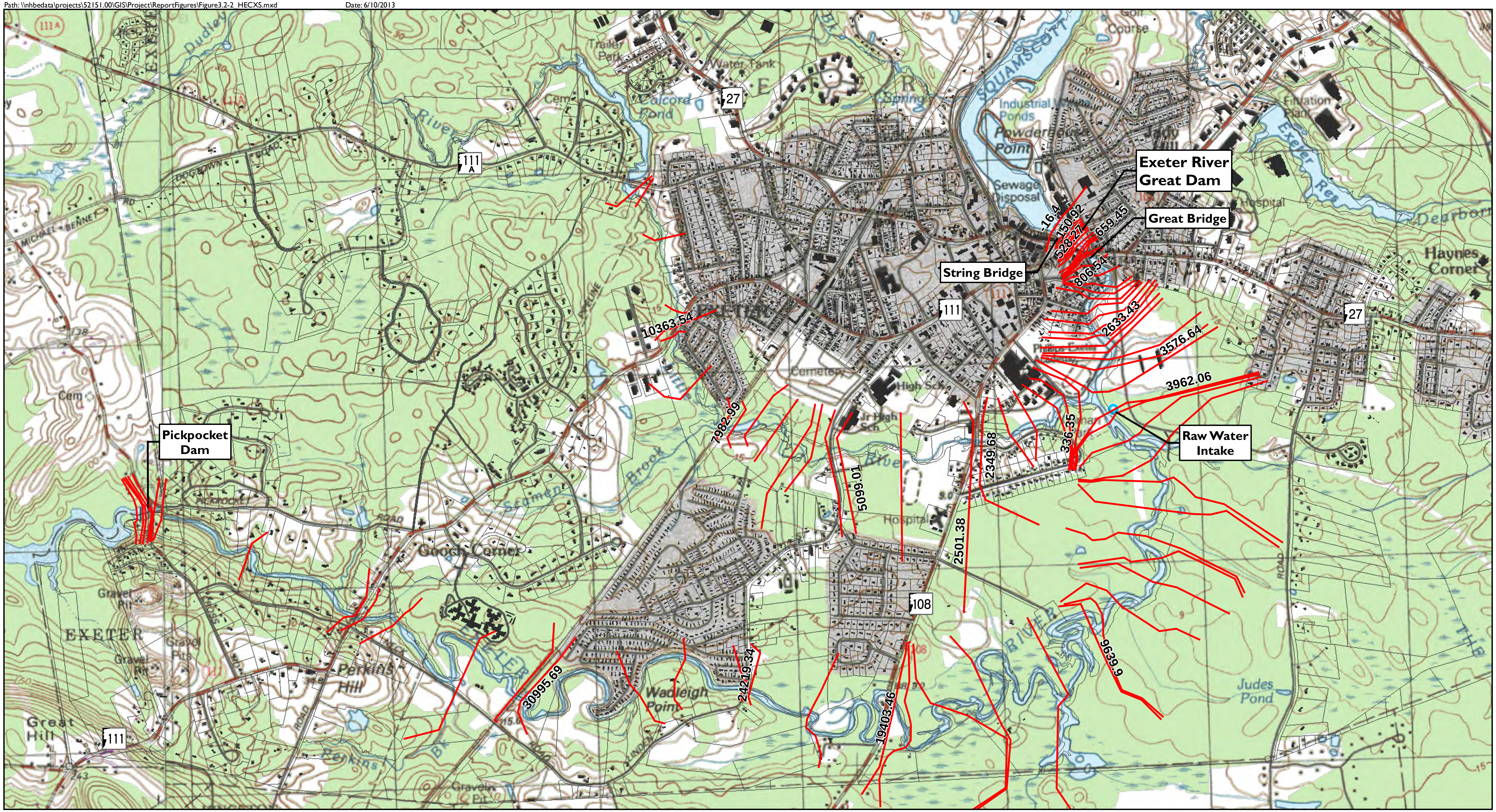


**Legend**

HEC-RAS Model X-Section (Only selected cross-sections are labeled for clarity)

0 1,500 3,000 Feet

Source: USGS 7.5 Minute Quadrangles: Exeter, Kingston

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**Figure 3.2-2**
**HEC-RAS Model Cross-sections**
**Exeter Great Dam Removal**
**Feasibility & Impact Analysis**

**Exeter, NH**

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would be expected to flood during large events, but would not be expected to convey flow downstream.

As with all numerical models, the HEC-RAS model developed for this project requires boundary conditions.[35] Boundary conditions are set within the model for each reach and can be established at internal locations within the river system to develop the flow data. For subcritical flow, boundary conditions are only required at the upstream end. The boundary conditions for this hydraulic model were defined for the most downstream cross-section on the Exeter/Squamscott River and the most upstream cross-sections on both the Exeter and Little Rivers. The most downstream cross-section is located approximately 500 feet into the tidally-influenced Squamscott (Exeter) River and was conservatively assigned an elevation equal to the highest high tide on record for when the model was used to calculate flood conditions upstream and as the lowest tide on record for scour and sediment transport simulations. The boundary conditions of the most upstream cross-sections in both the Exeter and Little Rivers are located immediately upstream of Pickpocket Dam and Colcord Pond Dam, respectively. The boundary conditions at these cross-sections were defined as the estimated rating curve for the primary spillway of each dam.

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.

Following initial model development and the successful CHECK-RAS analysis, the model was subjected to a steady state calibration simulation. HEC-RAS is capable of modeling both steady-state (where discharge rate may vary by cross-section location but not over time) and transient flow conditions (may vary over location and time). As this project is interested in the water surface elevations, velocities, and other hydraulic parameters of the Exeter River system during the seven design flows and not in the timing of any one event, the HEC-RAS model was calibrated for steady-state conditions only. The steady-state calibration process consisted of comparing model results against information provided through the FEMA Flood Insurance program. The effective FEMA Flood Insurance Study for Rockingham County (ID

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[35] "Boundary conditions" are the physical conditions at the boundaries of a system represented in a model. In this case, the boundary conditions represent water surface elevations at the upstream and downstream extent of the model. As discussed, these parameters are specified as input to the model..

33015CV001A) provides discharge rates and water surface profiles in the Exeter River for 10-, 50-, 100- and 500-year flood events. Those discharge rates were entered into the HEC-RAS model and the resulting peak water surface elevations were compared against their counterparts from the FEMA Flood Insurance profiles. These comparisons were made for all four discharge rates and at more than a dozen locations throughout the Exeter-Little River system. Model input variables were adjusted as necessary to maximize the agreement between model output and published discharge-flood elevation data pairs.

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

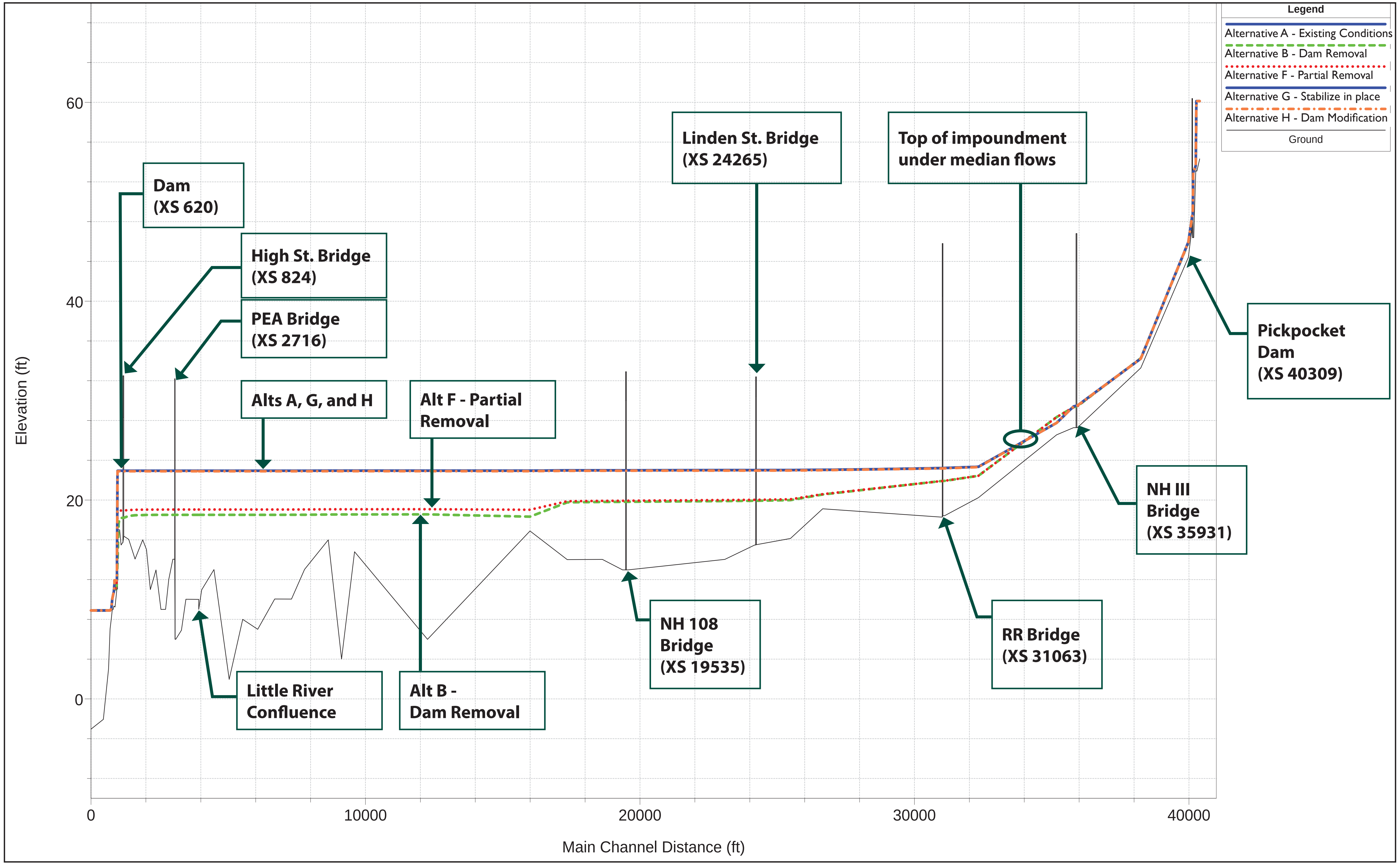
### 3.2.3 Predicted Hydraulic Changes in the Great Dam Impoundment

Several hydraulic parameters were calculated by the HEC-RAS model at each cross section for the alternatives and various flows. 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. Velocity, for example, is important for understanding streambank erosion and sediment transport for different dam conditions and flows. The analysis can also tell us about how conditions for fish passage would change. And, changes in total reach 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 3.2-4** and **3.2-5** summarize the predicted changes in the impoundment volume and area under dam repair and dam removal scenarios, while **Table 3.2-6** summarizes the predicted change in average river depth. Additionally, **Figures 3.2-3** through **3.2-9** show the extent of flooding under the median annual flow and the 50-year flow for each of the alternatives. The major conclusions that can be drawn from this analysis are discussed below.

- **For normal flows, there would be no perceivable change in the impoundment under *Alternative G – Stabilize in Place* and *Alternative H – Dam Modification*.** The Stabilize in Place Alternative would not make any real change to the hydraulic characteristics of the dam. And, because the Dam Modification Alternative is intended to maintain the current pond elevation under normal flows, the impoundment would not change relative to the Existing Condition (Alternative A). Thus, there




Notes:

1. This graph shows the water levels in the river for the annual median flow of 71 cfs under each of the five alternatives. Dam Removal and Partial Removal would have relatively similar effects on water levels, so the lines representing these water levels converge especially upstream of the NH 108 Bridge. Similarly, the Stabilize in Place Alternative would have the same effect as the Dam Modification. Alternative – essentially the water level would not change compared to the existing condition.
2. Additional graphs for other river flows are contained in the appendices.
3. "XS" = River Cross-section in feet from the HEC-RAS model.

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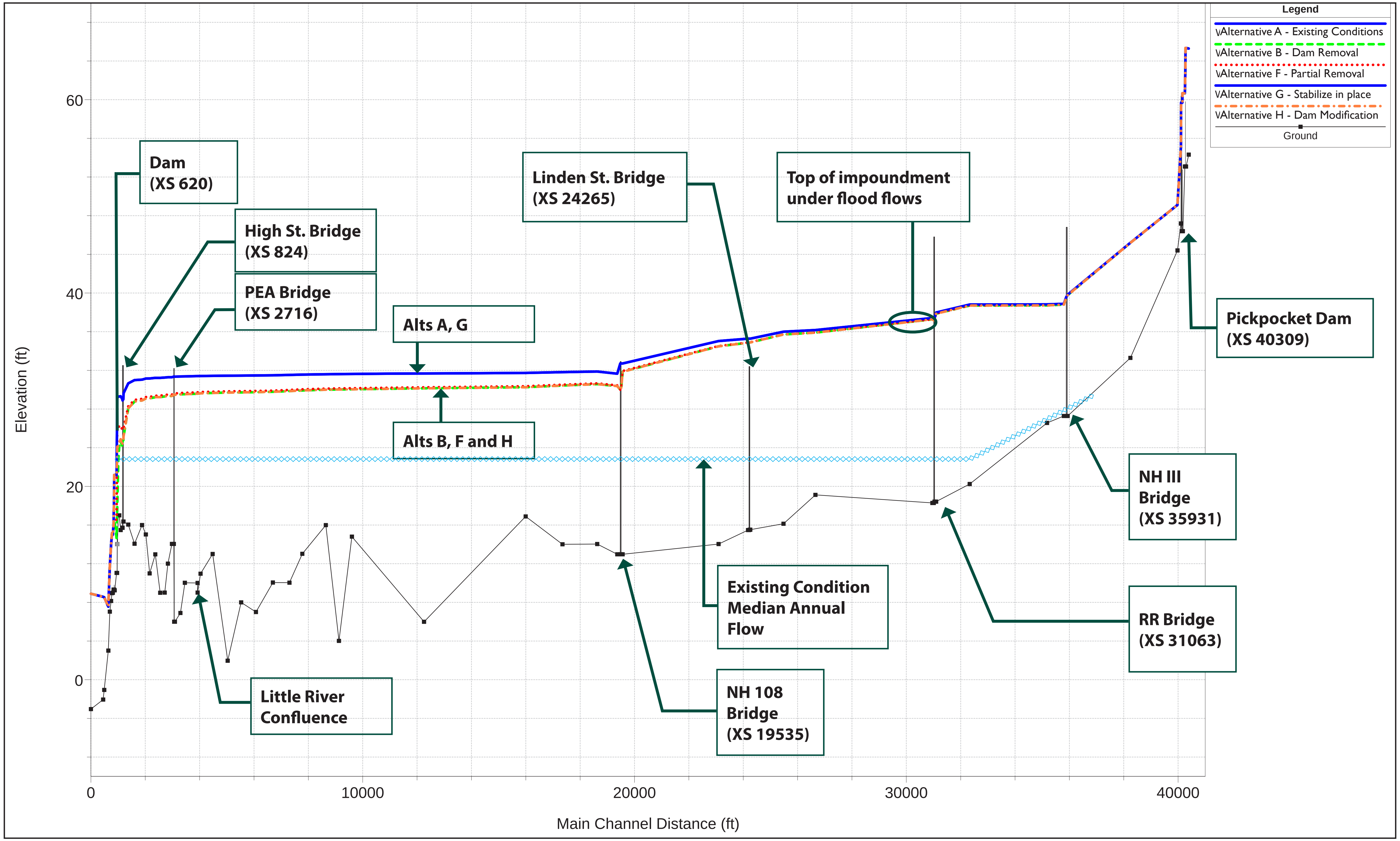
**Figure 3.2-3**
**Hydraulic Model Results, Exeter River, Median Annual Flows**

**Exeter Great Dam Removal Feasibility and Impact Study**
**Exeter, NH**




Notes:

1. This graph shows the water levels in the river for the 50-year flood flow of 5,858 cfs under each of the five alternatives. Note that this flow is equivalent to the Mother's Day Storm of 2006. Dam Removal, Partial Removal and Dam Modification would all have relatively similar effects on water levels, so the lines representing these water levels converge. The Stabilize in Place Alternative would not change flood levels compared to the existing condition.
2. Additional graphs for other river flows are contained in the appendices.
3. "XS" = River Cross-section in feet from the HEC-RAS model.

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**Figure 3.2-4**
**Hydraulic Model Results, Exeter River, 50-yr Flows**

**Exeter Great Dam Removal Feasibility and Impact Study**
**Exeter, NH**

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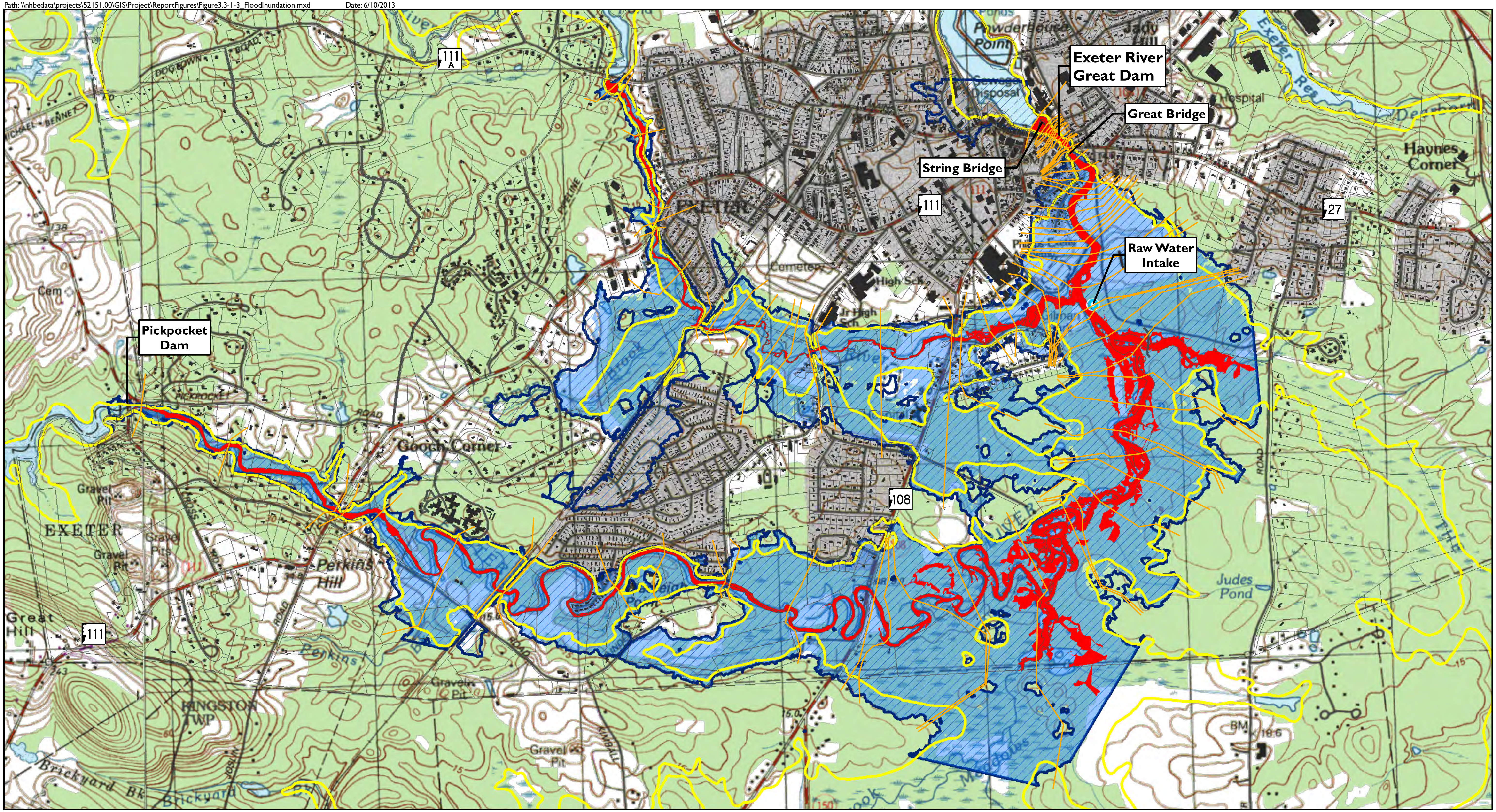


**Legend**

- Median Annual Storm - High Tide
- 50 Year Storm Profile - High Tide
- 100 Year Storm Profile - High Tide
- Cross-Section
- FEMA 100-Yr Floodplain

0 1,500 3,000 Feet

Source: USGS 7.5 Minute Quadrangles: Exeter, Kingston

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**Figure 3.2-5**
**Alternative A - Existing Conditions Flood Inundation Mapping**
**Exeter Great Dam Removal Feasibility & Impact Analysis**

**Exeter, NH**

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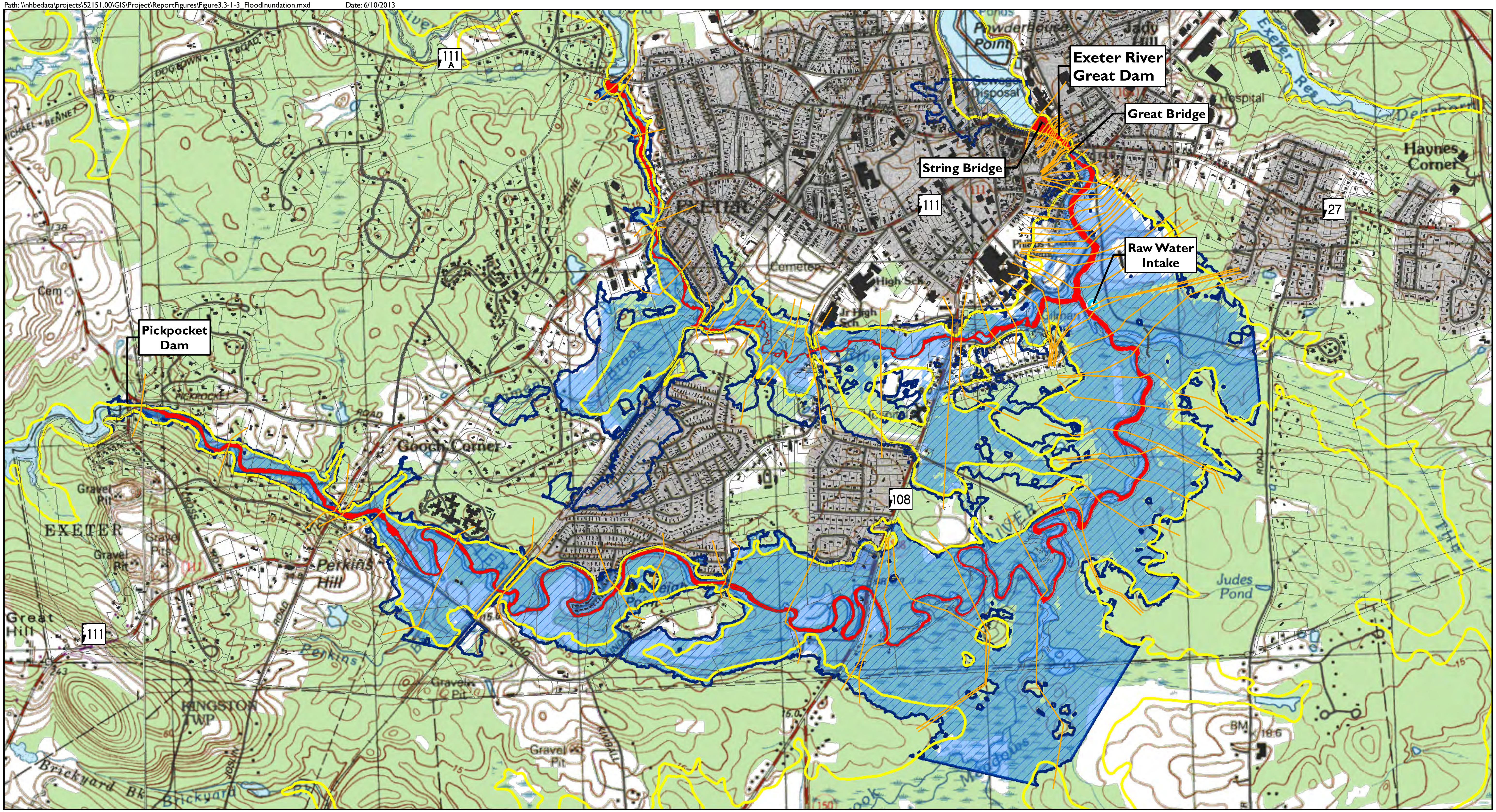


**Legend**

- Median Annual Storm - High Tide
- 50 Year Storm Profile - High Tide
- 100 Year Storm Profile - High Tide
- Cross-Section
- FEMA 100-Yr Floodplain

Source: USGS 7.5 Minute Quadrangles: Exeter, Kingston

0 1,500 3,000 Feet

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**Figure 3.2-6**
**Alternative B- Dam Removal Flood Inundation Mapping**

**Exeter Great Dam Removal Feasibility & Impact Analysis**

**Exeter, NH**

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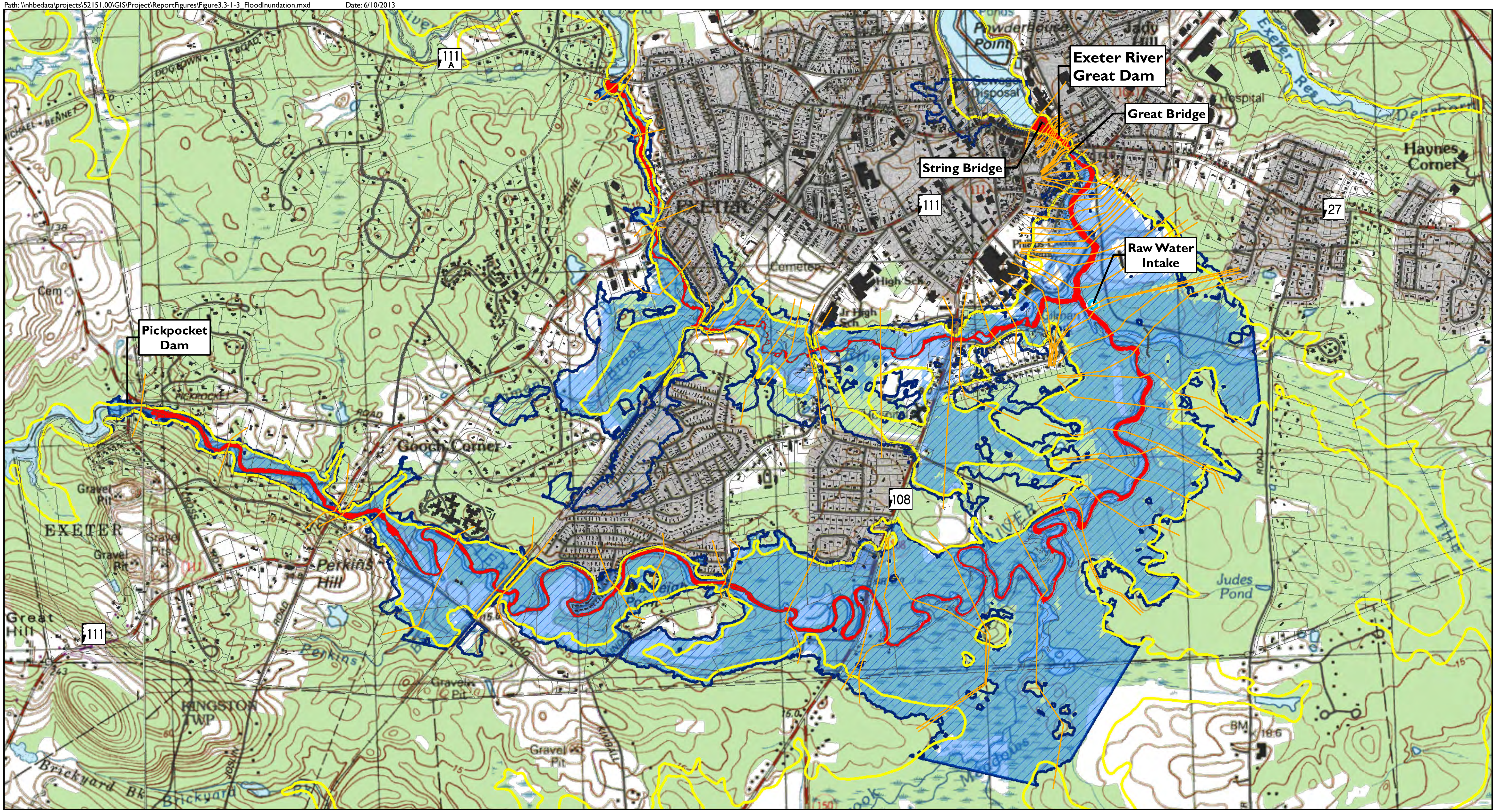


**Legend**

- Median Annual Storm - High Tide
- 50 Year Storm Profile - High Tide
- 100 Year Storm Profile - High Tide
- Cross-Section
- FEMA 100-Yr Floodplain

0    1,500    3,000 Feet

Source: USGS 7.5 Minute Quadrangles: Exeter, Kingston

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**Figure 3.2-7**
**Alternative F- Partial Removal**
**Flood Inundation Mapping**

**Exeter Great Dam Removal**
**Feasibility & Impact Analysis**

**Exeter, NH**

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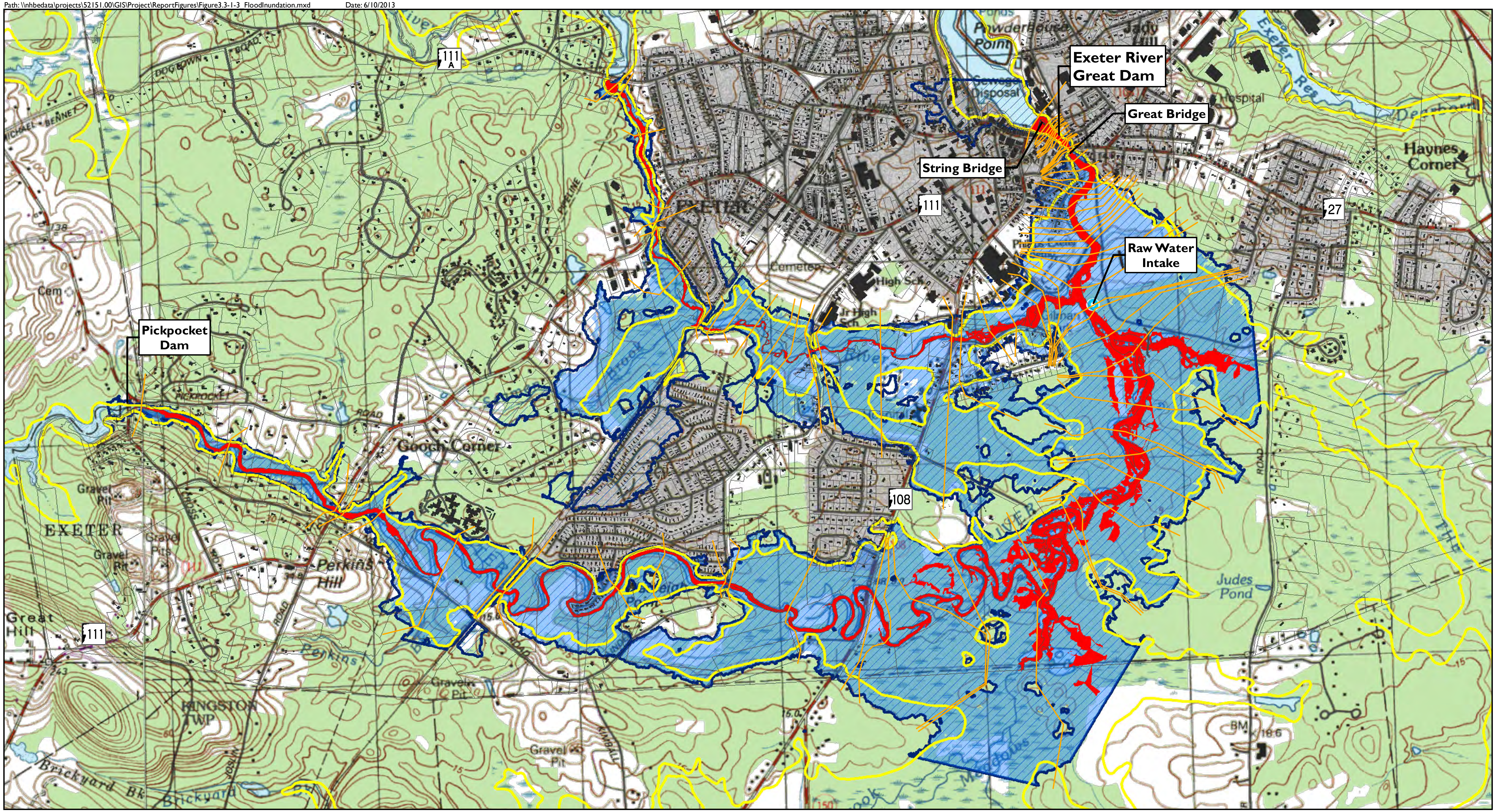


**Legend**

- Median Annual Storm - High Tide
- 50 Year Storm Profile - High Tide
- 100 Year Storm Profile - High Tide
- Cross-Section
- FEMA 100-Yr Floodplain

0 1,500 3,000 Feet

Source: USGS 7.5 Minute Quadrangles: Exeter, Kingston

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**Figure 3.2-8**
**Alternative G - Stabilize in Place**
**Flood Inundation Mapping**
**Exeter Great Dam Removal**
**Feasibility & Impact Analysis**

**Exeter, NH**

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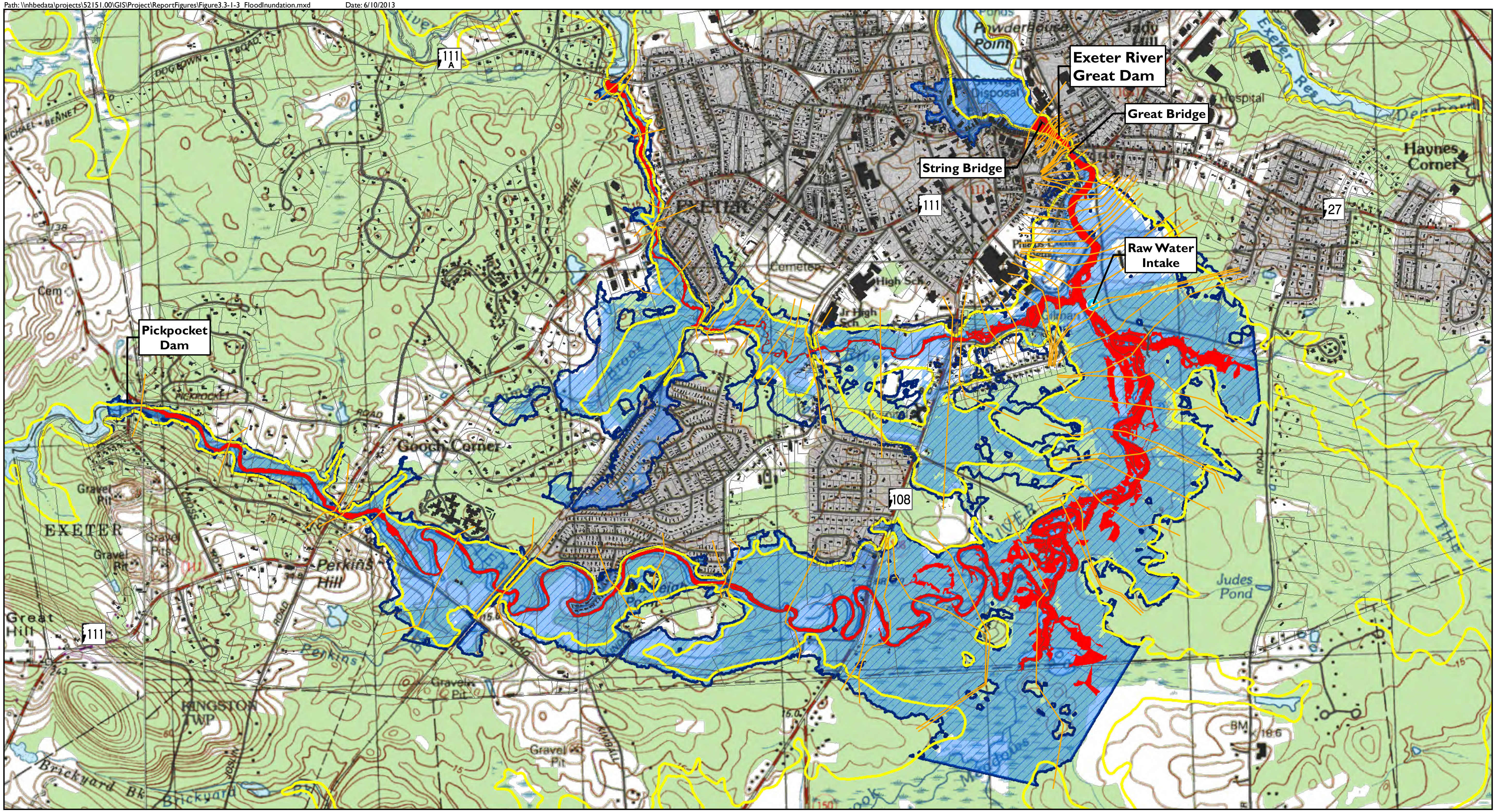


**Legend**

- Median Annual Storm - High Tide
- 50 Year Storm Profile - High Tide
- 100 Year Storm Profile - High Tide
- Cross-Section
- FEMA 100-Yr Floodplain

Source: USGS 7.5 Minute Quadrangles: Exeter, Kingston

0 1,500 3,000 Feet

VHB Vanasse Hangen Brustlin, Inc.

**Figure 3.2-9**
**Alternative H - Dam Modification**
**Flood Inundation Mapping**

**Exeter Great Dam Removal**
**Feasibility & Impact Analysis**

**Exeter, NH**

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would be no change in the impoundment volume or depth, or the median stream depths or widths under either of these two alternatives.

- **For normal flows, there would be a substantial decrease in the impoundment under *Alternative B – Dam Removal* and *Alternative F – Partial Removal*.** The removal of Great Dam would see the existing hydraulic control of the riverine impoundment, the crest of the dam's spillway at Elev. 22.5 feet, replaced by the natural bedrock outcroppings beneath the dam, generally at Elev. 17-19 feet. This 5.5-foot drop in the hydraulic control of the Exeter River would be accompanied by a substantial reduction in the impounded volume. The partial removal would drop this hydraulic control by about 4 ft. As shown in **Table 3.2-4**, during the median annual flow, the impounded volume would be expected to decrease from 290 ac-ft to 128 ac-ft if the dam were removed, a drop of 56%. The Partial Removal Alternative would also substantially reduce the impoundment volume, though not as much. Under the Partial Removal Alternative, the impoundment volume is expected to decrease to about 207 ac-ft, a 29% drop. Just as the hydraulic control of Great Dam decreases as flow increases, so too would the hydraulic control of the natural bedrock outcroppings. For instance, during the 10-year flood, the volume of water impounded in the Exeter River would decrease 36% with the Great Dam either fully or partially removed, down from a 56% or 29% reduction during the median annual flow or "normal conditions" for Alternatives B and F respectively. This pattern continues as flow increases further; during the 100-year flood, the impounded volume would decrease only 23-24% for the partial and full removal alternatives. Despite this pattern, the Great Dam impoundment would decrease a substantial amount if the dam were to be either fully or partially removed, regardless of the flow condition.

Table 3.2-4. Impoundment Volume by Alternative, Exeter River

| Flow Condition | River Flow (cfs) | Alt A Existing Condition (ac-ft) | Alt B Dam Removal (ac-ft) | Alt F Partial Removal (ac-ft) | Alt G Stabilize in Place (ac-ft) | Alt H Dam Modification (ac-ft) | Percent Change Relative to Existing Condition: Dam Removal Decrease (%) | Partial Removal Decrease (%) | Stabilize in Place Decrease (%) | Dam Modification Decrease (%) |
|---|---|---|---|---|---|---|---|---|---|---|
| Median Annual | 71 | 290 | 128 | 207 | 290 | 290 | 56% | 29% | 0% | 0% |
| 2-Year Flood | 1,481 | 1,799 | 847 | 843 | 1,799 | 855 | 53% | 53% | 0% | 52% |
| 10-Year Flood | 3,245 | 4,758 | 3,028 | 3,028 | 4,758 | 3,089 | 36% | 36% | 0% | 35% |
| 50-Year Flood | 5,858 | 9,296 | 6,723 | 6,756 | 9,296 | 6,925 | 28% | 27% | 0% | 26% |
| 100-Year Flood | 7,109 | 11,341 | 8,598 | 8,682 | 11,341 | 8,942 | 24% | 23% | 0% | 21% |

Source: HEC-RAS analysis

Table 3.2-5. Impoundment Surface Area by Alternative, Exeter River

| Flow Condition | River Flow (cfs) | Alt A Existing Condition (ac) | Alt B Dam Removal (ac) | Alt F Partial Removal (ac) | Alt G Stabilize in Place (ac) | Alt H Dam Modification (ac) | Percent Change Relative to Existing Condition: Dam Removal Decrease (%) | Partial Removal Decrease (%) | Stabilize in Place Decrease (%) | Dam Modification Decrease (%) |
|---|---|---|---|---|---|---|---|---|---|---|
| Median Annual | 71 | 63 | 31 | 47 | 63 | 63 | 51% | 26% | 0% | 0% |
| 2-Year Flood | 1,481 | 770 | 534 | 537 | 770 | 542 | 30% | 31% | 0% | 30% |
| 10-Year Flood | 3,245 | 1,134 | 913 | 913 | 1,134 | 931 | 19% | 19% | 0% | 18% |
| 50-Year Flood | 5,858 | 1,644 | 1,430 | 1,437 | 1,644 | 1,473 | 13% | 13% | 0% | 10% |
| 100-Year Flood | 7,109 | 1,768 | 1,559 | 1,574 | 1,768 | 1,621 | 12% | 11% | 0% | 8% |

Source: HEC-RAS analysis

Table 3.2-6. Average Channel Depths by Alternative, Exeter River

| Flow Condition | River Flow (cfs) | Alt A Existing Condition (ft) | Alt B Dam Removal (ft) | Alt F Partial Removal (ft) | Alt G Stabilize in Place (ft) | Alt H Dam Modification (ft) | Percent Change Relative to Existing Condition: Dam Removal Decrease (%) | Partial Removal Decrease (%) | Stabilize in Place Decrease (%) | Dam Modification Decrease (%) |
|---|---|---|---|---|---|---|---|---|---|---|
| Median Annual | 71 | 4.9 | 3.4 | 4.1 | 4.9 | 4.9 | 31% | 17% | 0% | 0% |
| 2-Year Flood | 1,481 | 7.5 | 6.1 | 6.1 | 7.5 | 6.2 | 19% | 19% | 0% | 18% |
| 10-Year Flood | 3,245 | 9.7 | 8.0 | 7.9 | 9.7 | 8.1 | 18% | 18% | 0% | 16% |
| 50-Year Flood | 5,858 | 11.8 | 10.2 | 10.2 | 11.8 | 10.5 | 14% | 14% | 0% | 12% |
| 100-Year Flood | 7,109 | 12.7 | 11.0 | 11.1 | 12.7 | 11.5 | 13% | 12% | 0% | 10% |

Source: HEC-RAS analysis

- **For flood flows,** ***Alternative B – Dam Removal, Alternative F – Partial Removal*** **and** ***Alternative H – Dam Modification*** **would have similar effects, reducing the depth of the flooding relatively substantially.** As discussed in previous sections, Alternative H – Dam Modification was developed to incorporate an adjustable flashboard and gate system that would allow the Town to maintain traditional river levels under "normal" flow conditions like the median annual flow, but could be opened to varying degrees to dramatically increase the discharge capacity of Great Dam during flood conditions. Due to the increased discharge capacity, the modified Great Dam envisioned in Alternative H, would be hydraulically similar to that of *Alternative B – Dam Removal* and *Alternative F – Partial Removal*. For instance, during a 2-year flood event, Alternative B is expected to see a 53% reduction in volume and a 19% reduction in average channel depth from existing conditions (**Tables 3.2-4** and **3.2-6**). Under those same flow conditions, Alternative F – Partial Removal is expected to see the same level of reductions: 53% and 19%, respectively. The same pattern is shown for Alternative H – Dam Modification. Further, these similarities between these three alternatives persist for other flow conditions. For instance, during the 100-year flood, Alternatives B, F and H impoundment volumes would be reduced by 24%, 23% and 21%, respectively, and 13%, 12% and 10% reductions in average channel depth, respectively.

### 3.2.3.2 Predicted Changes at Specific Reaches

Like many run-of-river dams on shallowly sloped coast rivers, the Great Dam impounds the Exeter-Little River system and its tributaries for several miles upstream. The removal or modification of Great 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 Exeter-Little River system to predict what, where, and when those impacts may occur. **Tables 3.2-7** through **3.2-12** present data for six different reaches of the Exeter and Little Rivers, as discussed below.

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 Exeter-Little River system will experience these changes differently. The hydraulic model results indicate that the type and magnitude of changes in the hydraulic characteristics of the Great Dam impoundment divide the Exeter-Little River system into six distinct sections or reaches, including:

- Exeter River, Squamscott River to Great Dam;
- Exeter River, Great Dam to Little River confluence;

- Exeter River, Little River Confluence to NH 108 Bridge;
- Exeter River, NH 108 Bridge to impoundment limit;
- Exeter River, upstream of impoundment limit; and
- Little River, mouth to impoundment limit.

Results of the hydraulic model for each of these reaches is provided in **Table 3.2-7 to 3.2-12**, and each is discussed in more detail below.

### Exeter River: Squamscott River to Great Dam

The Exeter River, from its tidal reaches in the Squamscott River to the Great Dam, resides in a deep, defined channel that drops steeply from the base of Great Dam to the tidal zone roughly 500 feet downstream. In this reach, the stream bed is typically about 10 feet lower than the surrounding land, but it is as much as 14 feet lower in some places. This is so deep and defined that the river is largely separated from its floodplain.

***None of the alternatives evaluated would permanently change the hydraulic conditions in this reach.*** The Great Dam is a run-of-river dam, meaning that whatever discharge enters the impoundment is quickly and fully discharged over the dam. Therefore the removal or modification of Great Dam will not change the magnitude of the seven design flows discussed in Section 3.2.1. The steep channel slope, fluctuation of the tides downstream in the Squamscott River, and the isolation of the river channel from its floodplain will all serve to maintain the existing hydraulic characteristics of this reach under all studied flow conditions. (See **Figure 3.2-10** for an illustration of the tidal range below the dam.)

The reach of the Exeter River from the tidal Squamscott River to Great Dam is typified by the area immediately upstream of the String Bridge. As shown in **Table 3.2-7**, the river width currently increases relatively little from "normal flow conditions" to flood conditions, increasing from 75 feet wide during the median annual flow to 190 feet wide during the 100-year flood. While this widening does represent a 250% change, it is a significantly smaller change than that experienced by most areas of the Great Dam impoundment, which see increases of 500-4000%. Even during the 100-year flood, the Exeter River is well within its deep and defined channel in this area. The removal or modification of Great Dam is not predicted to

Table 3.2-7. Hydraulic Model Results - Exeter River: Squamscott River to Great Dam

| River Flow | Existing Condition | | | Alternative B Dam Removal | | | Alternative F Partial Removal | | | Alternative G Stabilize in Place | | | Alternative H Dam Modification | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | River Depth (ft) | River Width (ft) | Velocity (ft/s) | River Depth (ft) | River Width (ft) | Velocity (ft/s) | River Depth (ft) | River Width (ft) | Velocity (ft/s) | River Depth (ft) | River Width (ft) | Velocity (ft/s) | River Depth (ft) | River Width (ft) | Velocity (ft/s) |
| Median Sept. | 1.2 | 75 | 0.1 | 1.2 | 75 | 0.1 | 1.2 | 75 | 0.1 | 1.2 | 75 | 0.1 | 1.2 | 75 | 0.1 |
| Median Annual | 1.2 | 75 | 0.9 | 1.2 | 75 | 0.9 | 1.2 | 75 | 0.9 | 1.2 | 75 | 0.9 | 1.2 | 75 | 0.9 |
| Median May | 1.2 | 75 | 1.4 | 1.2 | 75 | 1.4 | 1.2 | 75 | 1.4 | 1.2 | 75 | 1.4 | 1.2 | 75 | 1.4 |
| 2-Year Flood | 1.4 | 174 | 8.5 | 1.4 | 174 | 8.5 | 1.4 | 174 | 8.5 | 1.4 | 174 | 8.5 | 1.4 | 174 | 8.5 |
| 10-Year Flood | 2.2 | 180 | 11.4 | 2.2 | 180 | 11.5 | 2.2 | 180 | 11.4 | 2.2 | 180 | 11.4 | 2.2 | 180 | 11.4 |
| 50-Year Flood | 3.1 | 187 | 13.9 | 3.1 | 187 | 13.9 | 3.1 | 187 | 13.9 | 3.1 | 187 | 13.9 | 3.1 | 187 | 13.9 |
| 100-Year Flood | 3.4 | 190 | 14.8 | 3.4 | 190 | 14.8 | 3.4 | 190 | 14.8 | 3.4 | 190 | 14.8 | 3.4 | 190 | 14.8 |

Table 3.2-8. Hydraulic Model Results - Exeter River: Great Dam to Little River Confluence

| River Flow | Existing Condition | | | Alternative B Dam Removal | | | Alternative F Partial Removal | | | Alternative G Stabilize in Place | | | Alternative H Dam Modification | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | River Depth (ft) | River Width (ft) | Velocity (ft/s) | River Depth (ft) | River Width (ft) | Velocity (ft/s) | River Depth (ft) | River Width (ft) | Velocity (ft/s) | River Depth (ft) | River Width (ft) | Velocity (ft/s) | River Depth (ft) | River Width (ft) | Velocity (ft/s) |
| Median Sept. | 4.9 | 132 | 0.0 | 1.8 | 64 | 0.1 | 2.3 | 76 | 0.0 | 4.9 | 132 | 0.0 | 4.9 | 132 | 0.0 |
| Median Annual | 5.2 | 134 | 0.1 | 2.5 | 75 | 0.4 | 2.6 | 100 | 0.3 | 5.2 | 134 | 0.1 | 5.2 | 134 | 0.1 |
| Median May | 5.4 | 135 | 0.1 | 2.7 | 78 | 0.5 | 2.8 | 104 | 0.4 | 5.4 | 135 | 0.1 | 5.4 | 135 | 0.1 |
| 2-Year Flood | 8.0 | 221 | 1.3 | 5.1 | 133 | 2.2 | 5.2 | 134 | 2.1 | 8.0 | 221 | 1.3 | 5.1 | 133 | 2.2 |
| 10-Year Flood | 10.4 | 359 | 2.0 | 5.2 | 196 | 3.1 | 5.4 | 202 | 3.0 | 10.4 | 359 | 2.0 | 5.6 | 196 | 3.1 |
| 50-Year Flood | 13.5 | 503 | 2.6 | 5.6 | 357 | 3.7 | 5.6 | 360 | 3.6 | 13.5 | 503 | 2.6 | 5.2 | 358 | 3.7 |
| 100-Year Flood | 14.9 | 654 | 2.8 | 6.4 | 374 | 3.8 | 6.5 | 376 | 3.7 | 14.9 | 654 | 2.8 | 6.4 | 374 | 3.8 |

Table 3.2-9. Hydraulic Model Results - Exeter River: Little River Confluence to NH 108 Bridge

| River Flow | Existing Condition | | | Alternative B Dam Removal | | | Alternative F Partial Removal | | | Alternative G Stabilize in Place | | | Alternative H Dam Modification | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | River Depth (ft) | River Width (ft) | Velocity (ft/s) | River Depth (ft) | River Width (ft) | Velocity (ft/s) | River Depth (ft) | River Width (ft) | Velocity (ft/s) | River Depth (ft) | River Width (ft) | Velocity (ft/s) | River Depth (ft) | River Width (ft) | Velocity (ft/s) |
| Median Sept. | 5.8 | 63 | 0.0 | 1.9 | 36 | 0.1 | 3.1 | 53 | 0.1 | 5.8 | 63 | 0.0 | 5.8 | 63 | 0.0 |
| Median Annual | 6.2 | 67 | 0.2 | 3.8 | 42 | 0.3 | 3.8 | 60 | 0.4 | 6.2 | 67 | 0.2 | 6.2 | 67 | 0.2 |
| Median May | 6.4 | 82 | 0.3 | 4.3 | 45 | 0.3 | 4.1 | 62 | 0.5 | 6.4 | 82 | 0.3 | 6.4 | 82 | 0.3 |
| 2-Year Flood | 10.5 | 668 | 2.4 | 7.3 | 618 | 1.5 | 10.3 | 668 | 2.4 | 10.5 | 668 | 2.4 | 10.3 | 618 | 2.4 |
| 10-Year Flood | 12.4 | 1546 | 4.5 | 8.6 | 1272 | 2.1 | 11.7 | 1546 | 4.7 | 12.4 | 1546 | 4.5 | 11.7 | 1263 | 4.7 |
| 50-Year Flood | 14.9 | 1862 | 6.7 | 10.8 | 1800 | 1.9 | 13.7 | 1862 | 7.3 | 14.9 | 1862 | 6.7 | 13.6 | 1795 | 7.3 |
| 100-Year Flood | 16.2 | 1878 | 6.3 | 12.0 | 1860 | 1.9 | 14.7 | 1878 | 8.2 | 16.2 | 1878 | 6.3 | 14.6 | 1859 | 8.3 |

Table 3.2-10. Hydraulic Model Results - Exeter River: NH 108 Bridge to Impoundment Limit

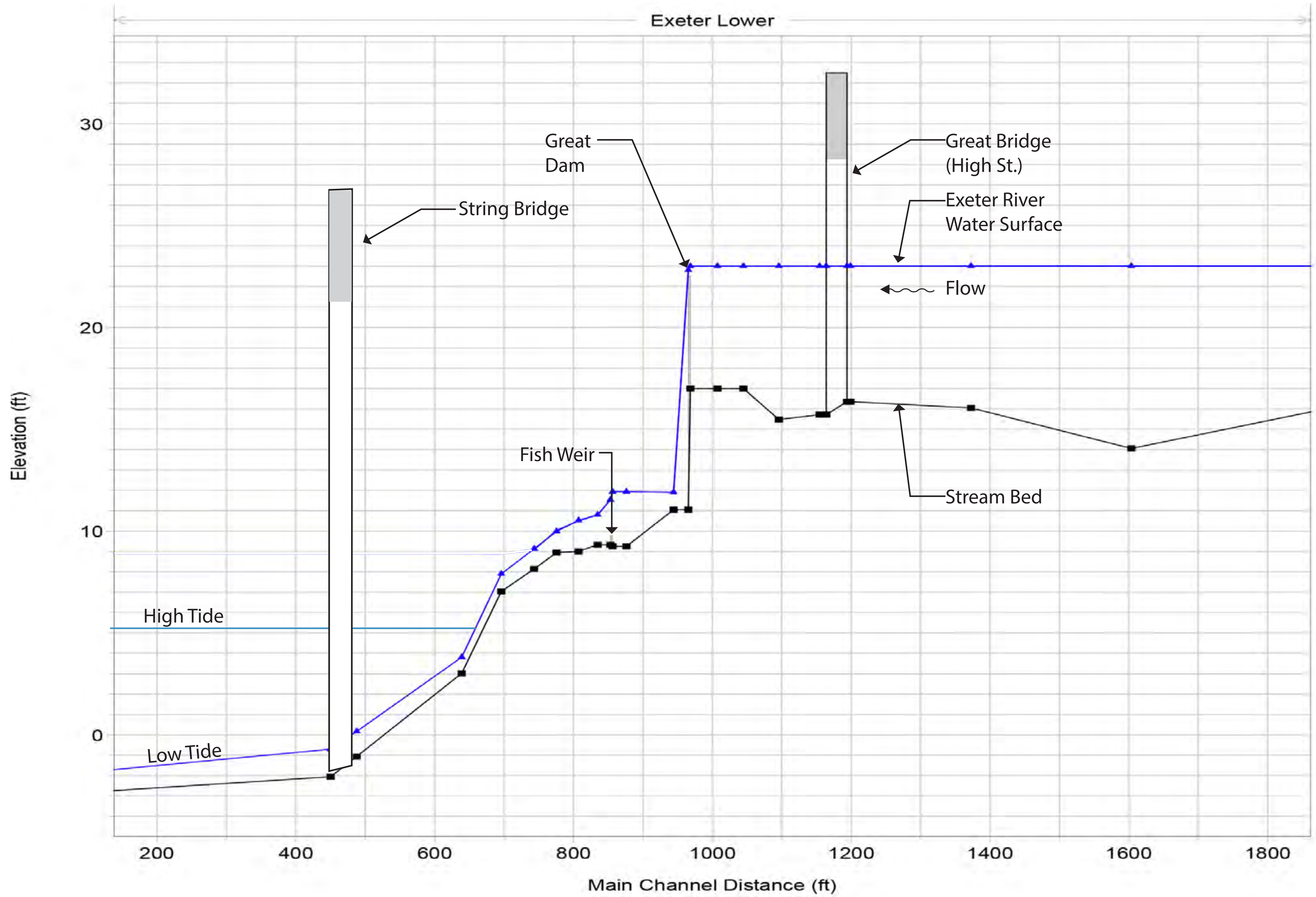
| | Existing Condition | | | Alternative B Dam Removal | | | Alternative F Partial Removal | | | Alternative G Stabilize in Place | | | Alternative H Dam Modification | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| River Flow | River Depth (ft) | River Width (ft) | Velocity (ft/s) | River Depth (ft) | River Width (ft) | Velocity (ft/s) | River Depth (ft) | River Width (ft) | Velocity (ft/s) | River Depth (ft) | River Width (ft) | Velocity (ft/s) | River Depth (ft) | River Width (ft) | Velocity (ft/s) |
| Median Sept. | 3.9 | 39 | 0.0 | 0.7 | 16 | 0.5 | 1.4 | 21 | 0.2 | 3.9 | 39 | 0.0 | 3.9 | 39 | 0.0 |
| Median Annual | 4.2 | 41 | 0.4 | 2.3 | 28 | 0.9 | 2.4 | 28 | 0.9 | 4.2 | 41 | 0.4 | 4.2 | 41 | 0.4 |
| Median May | 4.3 | 42 | 0.5 | 2.7 | 31 | 1.1 | 2.7 | 31 | 1.0 | 4.3 | 42 | 0.5 | 4.3 | 42 | 0.5 |
| 2-Year Flood | 3.4 | 198 | 2.2 | 3.6 | 177 | 2.3 | 3.6 | 177 | 2.3 | 3.4 | 198 | 2.2 | 3.6 | 177 | 2.3 |
| 10-Year Flood | 3.9 | 505 | 2.4 | 3.6 | 462 | 2.6 | 3.6 | 464 | 2.6 | 3.9 | 505 | 2.4 | 3.6 | 462 | 2.6 |
| 50-Year Flood | 6.3 | 620 | 2.4 | 6.1 | 613 | 2.5 | 6.1 | 614 | 2.5 | 6.3 | 620 | 2.4 | 6.1 | 613 | 2.5 |
| 100-Year Flood | 6.7 | 634 | 2.7 | 6.8 | 636 | 2.7 | 6.8 | 636 | 2.7 | 6.7 | 634 | 2.7 | 6.8 | 636 | 2.7 |

Table 3.2-11. Hydraulic Model Results - Exeter River: Impoundment Limit to Pickpocket Dam

| | Existing Condition | | | Alternative B Dam Removal | | | Alternative F Partial Removal | | | Alternative G Stabilize in Place | | | Alternative H Dam Modification | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| River Flow | River Depth (ft) | River Width (ft) | Velocity (ft/s) | River Depth (ft) | River Width (ft) | Velocity (ft/s) | River Depth (ft) | River Width (ft) | Velocity (ft/s) | River Depth (ft) | River Width (ft) | Velocity (ft/s) | River Depth (ft) | River Width (ft) | Velocity (ft/s) |
| Median Sept. | 0.5 | 16 | 0.7 | 0.5 | 16 | 0.7 | 0.5 | 16 | 0.7 | 0.5 | 16 | 0.7 | 0.5 | 18 | 0.6 |
| Median Annual | 1.2 | 35 | 1.5 | 1.2 | 35 | 1.5 | 1.2 | 35 | 1.5 | 1.2 | 35 | 1.5 | 1.2 | 36 | 1.4 |
| Median May | 1.4 | 38 | 1.7 | 1.4 | 38 | 1.7 | 1.4 | 38 | 1.7 | 1.4 | 38 | 1.7 | 1.5 | 39 | 1.6 |
| 2-Year Flood | 5.6 | 68 | 5.6 | 5.6 | 68 | 5.6 | 5.6 | 68 | 5.6 | 5.6 | 68 | 5.6 | 5.6 | 68 | 5.6 |
| 10-Year Flood | 8.2 | 85 | 8.4 | 8.2 | 85 | 8.4 | 8.2 | 85 | 8.4 | 8.2 | 85 | 8.4 | 8.2 | 85 | 8.4 |
| 50-Year Flood | 11.3 | 117 | 11.0 | 11.3 | 117 | 11.0 | 11.3 | 117 | 11.0 | 11.3 | 117 | 11.0 | 11.3 | 117 | 11.0 |
| 100-Year Flood | 12.5 | 154 | 12.1 | 12.5 | 154 | 12.1 | 12.5 | 154 | 12.1 | 12.5 | 154 | 12.1 | 12.5 | 154 | 12.1 |

Table 3.2-12. Hydraulic Model Results - Little River: Confluence with the Exeter to Little River Impoundment Limit

| | Existing Condition | | | Alternative B Dam Removal | | | Alternative F Partial Removal | | | Alternative G Stabilize in Place | | | Alternative H Dam Modification | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| River Flow | River Depth (ft) | River Width (ft) | Velocity (ft/s) | River Depth (ft) | River Width (ft) | Velocity (ft/s) | River Depth (ft) | River Width (ft) | Velocity (ft/s) | River Depth (ft) | River Width (ft) | Velocity (ft/s) | River Depth (ft) | River Width (ft) | Velocity (ft/s) |
| Median Sept. | 1.2 | 21 | 0.0 | 1.2 | 20 | 0.0 | 1.2 | 20 | 0.0 | 1.2 | 21 | 0.0 | 1.2 | 21 | 0.0 |
| Median Annual | 1.5 | 25 | 0.3 | 1.4 | 24 | 0.3 | 1.4 | 24 | 0.3 | 1.5 | 25 | 0.3 | 1.5 | 26 | 0.3 |
| Median May | 1.6 | 27 | 0.4 | 1.5 | 26 | 0.4 | 1.5 | 26 | 0.4 | 1.6 | 27 | 0.4 | 1.6 | 28 | 0.4 |
| 2-Year Flood | 2.9 | 192 | 1.3 | 2.5 | 166 | 1.6 | 2.5 | 165 | 1.6 | 2.9 | 192 | 1.3 | 2.5 | 166 | 1.6 |
| 10-Year Flood | 5.4 | 332 | 1.6 | 3.8 | 265 | 2.3 | 3.9 | 280 | 2.2 | 5.4 | 332 | 1.6 | 3.8 | 265 | 2.3 |
| 50-Year Flood | 8.4 | 643 | 1.9 | 7.0 | 373 | 2.3 | 7.1 | 374 | 2.2 | 8.4 | 643 | 1.9 | 7.0 | 373 | 2.3 |
| 100-Year Flood | 9.4 | 1176 | 2.1 | 8.3 | 624 | 2.3 | 8.4 | 638 | 2.3 | 9.4 | 1176 | 2.1 | 8.3 | 625 | 2.3 |




Notes:
Elevations are NGVD29.
The High Tide shown in this figure is Mean Higher High Water High (MHHW) at the Squamscott Bridge according to the National Geodetic Survey. MHHW at this location is Elev. 8.76 ft (5.33 ft NGVD29).

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**Figure 3.2-10**
**Exeter River Profile,**
**Great Bridge to Squamscott River,**
**with tides**

**Exeter Great Dam Removal**
**Feasibility and Impact Study**
**Exeter, NH**

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change the channel's containment of the Exeter River in this area. In fact, as shown in **Table 3.2-7**, no changes to river width are expected under any flow condition for any of the alternatives.

This reach of the Exeter River also currently experiences some of the highest velocities in the Exeter-Little River system even at relatively low flow depths, due to the defined channel walls and steep channel slope. For instance, under existing conditions, during the 50-year flood, the average flow depth is only 3.1 feet, but the water is moving at 13.9 feet per second (fps). Like river width, the hydraulic modeling results presented in **Table 3.2-7**, indicate that no change in river depth or velocity would occur.

### Exeter River: Great Dam to Little River Confluence

In sharp contrast to the short rocky channel downstream of Great Dam, the reach of Exeter River upstream of Great Dam to the confluence of the Little River is predicted to experience substantial changes in both river depths and velocities if the dam were removed or modified. This first reach of the Great Dam impoundment includes some of the deepest, slowest waters within the Exeter-Little River system, the top five feet of which are hydraulically controlled by Great Dam. If Great Dam were removed either partially or fully, this reach would experience considerable reductions in river depth and width under all flow conditions as well as an increase in average channel velocity, especially at lower flows. Modification of Great Dam, as envisioned in Alternative H, would result in similar changes under flood flows when the flashboard and gate were opened, though under low to normal flow conditions, Alternative H would be expected to behave similarly to existing conditions in this reach.

This reach of the Exeter River, from Great Dam to the Little River confluence, is typified by the area immediately upstream of the High Street Bridge. As shown in **Table 3.2-8**, under the existing conditions of Alternative A, this area contains a relatively wide channel, as indicated by a river width of 134 feet during the median annual flow, with a modest but not extensive floodplain that is accessible, as indicated by a river width of 503 feet during the 50-year flood, a widening of 375%. This reach is relatively deep, with an average depth of over five feet and maximum depths of roughly 10 feet under "normal flows." This reach is also quite slow-moving, flowing at only 2.8 fps even during the 100-year flood event.

These characteristics are predicted to change substantially for all flow conditions under *Alternative B – Dam Removal* and *Alternative F – Partial Removal* and for flood conditions under *Alternative H – Dam Modification*. During the median annual flow, for example, the predicted average depth would drop from 5.2 feet to 2.5 feet and the maximum depth would drop 4.6 feet if the Great Dam were removed entirely. Partial Removal would have a similar impact – dropping the average depth to about 2.6 ft. There would be no changes under normal flows for either the Stabilize in Place or the Dam Modification Alternatives.

As noted previously though, the magnitude of these changes associated with the Dam Removal and Partial Removal Alternatives is expected to decrease as discharge rates increase.

Velocities would increase substantially if the dam were to be removed or modified. As shown in **Table 3.2-8**, during the median annual flow, velocity is predicted to increase from 0.1 to 0.4 feet per second if the dam were to be removed, although these velocities are still quite modest. Increases in velocity are also expected for flood conditions, typified by increases of about 40% during the 50-year flood for Alternatives B, F and H, while there would be no change for Alternative G.

### Exeter River: Little River Confluence to NH 108 Bridge

Further up the Exeter River, in the reach extending from the Little River confluence to the NH 108 Bridge, similar changes are expected. Like the area between Great Dam and the Little River confluence, this reach is also relatively deep and slow, although this reach differs somewhat in its sinuosity and its extensive network of in stream and near-stream wetlands. These wetlands areas exist because of the exceptionally wide floodplains that characterize this reach. Changes to the river depth and width and to flow velocity tend to be similar but less substantial in this reach than those changes predicted immediately upstream of Great Dam.

This reach of the Exeter River, from the Little River confluence to NH 108, is typified by the area downstream of the NH 108 Bridge. As shown in **Table 3.2-9**, this reach experiences average depths quite similar to the reach downstream of the Little River confluence for all flow conditions and velocities that are quite similar during low to bankfull (2-year) flows. However, while the existing “normal” river width of 67-79 feet is narrower than the reach downstream of the Little River confluence, the dramatic increase in river width during flood conditions, nearly 40 times wider during the 100-year flood, highlights the extensive use of floodplains in this reach. These extensive floodplains also serve to maintain lower average velocities during flood conditions, as the plants, debris, and oxbows associated with those wetlands slow down the flood waters.

There would be no changes in river depth, width or velocities during normal flows for either *Alternative G – Stabilize in Place* or *Alternative H – Dam Modification.*

There would, however, be substantial changes for all flow conditions under *Alternative B – Dam Removal* and *Alternative F – Partial Removal*, and for flood conditions under *Alternative H – Dam Modification*. However, these changes are predicted to be less substantial than those predicted for the lower impoundment.

During the median annual flow, the average depth in this reach is predicted to drop from 6.2 ft to 3.8 feet if Great Dam were fully or partially removed.

Velocity is predicted to increase from 0.1 to 0.3 feet per second during the median annual flow under the Dam Removal or Partial Removal Alternatives, though it would still be quite slow-moving. Flood condition increases are less substantial, typified by increases of 48% and 45% during the 50-year flood, respectively. River width is predicted to decrease from 75 ft to about 42 feet during the median annual flow if Great Dam were removed or to about 60 ft wide for the Partial Removal Alternative.

Note that river width would decrease during flooding conditions. While these flood condition changes in river width are substantial, they represent only 12-13% of the existing 50-year flood width. In fact, no flood flow condition is predicted to decrease river width more than 25%, suggesting that much of the existing floodplain will continue to be inundated on a regular basis, although the flooding would be shallower and likely of shorter duration.

### Exeter River: NH 108 Bridge to Impoundment Limit[36]

In the upper reach of the Great Dam impoundment on the Exeter River, from NH 108 to the impoundment limit, the hydraulic control of the Great Dam steadily diminishes. The channel is somewhat steeper than in the lower and middle reaches of the impoundment, corresponding to a less sinuous channel with an accessible but not excessively wide floodplain. The upstream limit of the Great Dam impoundment varies by flow, but HEC-RAS model results indicate that the hydraulic control of Great Dam generally decreases to negligible levels in the vicinity of a natural cascade near the Boston & Maine Railroad Bridge. Just as the hydraulic control of Great Dam decreases over this reach, so too do the predicted impacts of dam removal or dam modification.

This reach of the Exeter River, from NH 108 to the upstream limit of the Great Dam impoundment, is typified by the area upstream of the Linden St. Bridge. As shown in **Table 3.2-10**, this reach has a "normal" width of about 40 feet, but a 2-year flood width of 198 feet and a 100-year flood width of 634 feet, indicating that the river can access its floodplain as needed but lacks the exceptionally wide flood areas of the middle reach downstream of NH 108. This reach does currently have areas of significant depth, particularly near its downstream end. The current average depth in this area is approximately 4 feet and 50-year flood depths are in can reach 6 feet, due in part to the backwatering effect from the NH 108 Bridge.

As with other reaches of the Great Dam impoundment, this reach is predicted to experience decreases in the depth and width of water as well as increased velocity for all flow conditions under *Alternative B – Dam Removal* and *Alternative F – Partial Removal* and for flood conditions under *Alternative H – Dam Modification*.

[36] The "Impoundment Limit" refers to the point on the river where the dam exerts no influence on water depths or velocities. In other words, the water flows freely under all flow conditions as if the dam were not in place.

Generally speaking, the expected changes would be similar for the Full and Partial Removal Alternatives. However, these changes are generally less than those predicted for downstream reaches and would decrease to negligible levels at the upstream limit of the impoundment. During the median annual flow, the average depth in this reach is predicted to drop from 4.2 feet to about 2.3 to 2.4 feet if Great Dam were removed fully or partially; during the 50-year flood, the average depth is predicted to drop only 0.2 feet under all alternatives. Velocity is predicted to increase from 0.4 to 0.9 feet per second during the median annual flow under Alternatives B and F, an increase of about 166%. Flood condition increases are less substantial, typified by increases of 4% during the 50-year flood. River width is predicted to decrease from about 41 feet to about 28 feet during the median annual flow if Great Dam were removed, and during the 50-year flood, river width is predicted to decrease just 7 feet for Alternatives B, F and H. As the model results presented in **Table 3.2-10** indicate, while changes due to dam removal or modification are predicted in the hydraulic characteristics of this reach, those changes are less significant than in downstream areas and are expected to diminish to negligible levels at the impoundment's upstream limit near the Railroad Bridge.

### Exeter River: Upstream of Impoundment Limit to Pickpocket Dam

By definition, Great Dam exerts no hydraulic control over the Exeter River reach upstream of the Great Dam impoundment; therefore, the removal or modification of Great would have no impact on this reach. Model results confirm that the hydraulic characteristics of the Exeter River are not impacted by the removal or modification of the Great Dam.

This reach of the Exeter River, from the upstream limit of the Great Dam impoundment to Pickpocket Dam, is typified by the area upstream of the NH 111 Bridge, represented in the HEC-RAS model as River Station 35975. As shown in **Table 3.2-11**, the differences among the alternatives are negligible under all flow conditions. River depth differences do not exceed 0.1 feet; river width differences do not exceed 1 foot; and velocity differences do not exceed 0.1 feet per second. Any minimal discrepancies are not indicative of actual impacts, but rather are modeling artifacts that the HEC-RAS model creates as it strives to represent a complex river with a small series of mathematical equations.

### Little River: Confluence with the Exeter River to the Little River Impoundment Limit

The Little River flows into the Exeter River near Gilman Park. Because this is relatively close to the Great Dam, the Little River is also influenced by the dam (not just the Exeter River). Under normal flows, the Great Dam has the greatest influence on the Little River downstream of the NH 108 (Court Street) Bridge, but does exert some influence all the way to the Linden Street Bridge, about one mile upstream of its confluence with the Exeter River.

The Little River is somewhat narrower and shallower than the nearby Exeter River as it conveys less flow, generally contributing about 15% of the total flow over the Great Dam. Given its smaller size, the Little River experiences the progression from a strong Great Dam hydraulic control near its mouth to negligible control at the impoundment's upstream limit over a significantly shorter distance than the Exeter River. The impounded reach of the Little River is currently characterized by a modest channel with relatively slow-moving water and an accessible and rather wide floodplain.

The impounded reach of the Little River is typified by the area downstream of its Linden St. Bridge crossing. As shown in **Table 3.2-12**, this reach has a "normal" width of 21-27 feet, but a 2-year flood width of 192 feet and a 100-year flood width of 1176 feet, indicating that the river can access its substantial floodplain as needed, though it lacks the exceptionally wide flood areas that exist on the Exeter River. The Little River does currently have areas of significant depth, particularly downstream of NH 108, though moderate depths, such as those near Linden St. are more typical. The average depth of the river in this area under normal flows is approximately 1.5 feet and the average flood depths range from 5-10 feet. Velocities in this reach are quite slow, and can be less than 0.1 to 0.4 feet per second during normal flows and 1 to 2 feet per second during flood conditions.

Dam Removal, Partial Removal or Dam Modification would decrease river depth and width as well as increase velocities for all flow conditions. There would be relatively little change noted for normal flows, but there would be substantial decreases in depth and width and increased velocities for high flood conditions. However, these changes would be generally less substantial than those predicted for the lower and middle reaches of the impoundment on the Exeter River and would decrease to negligible levels at the upstream limit of the impoundment near the Linden Street Bridge.

During the median annual flow, the predicted average depth of the Little River near the Linden Street Bridge would drop about 0.1 feet (i.e., about an inch) if Great Dam were removed either partially or fully. However during the 50-year flood, the average depth would drop from 8.4 ft to about 7 feet under the various alternatives.

A similar pattern is predicted for the width of the river. River width is predicted to decrease only 1 or 2 feet during the median annual flow if Great Dam were removed, but during the 50-year flood, river width is predicted to decrease from 643 ft to about 373 feet for Alternatives B, F and H. These changes in river width associated with dam removal and modification are significant, approximately 40% of the existing 50-year flood width. The 100-year flood width is predicted to experience decreases of 40-60% as well, suggesting that this reach of the Little River may experience substantial changes in floodplain hydraulics, and potentially, ecology.

Flow velocity is also expected to experience significant changes during flood conditions. As noted in **Table 3.2-12**, velocity is not predicted to increase significantly under "normal" flow conditions, but during flood events, increases of 20-50% are predicted. For instance, during the 50-year flood, velocity is predicted to increase from 1.9 feet per second to 2.3 feet per second.

Just as impacts of dam removal or modification on the hydraulic characteristics of the Exeter River are limited to the Great Dam impoundment, so too are the impacts to the Little River. While changes due to dam removal or modification are predicted in the hydraulic characteristics of this reach of the Little River, those changes would diminish to negligible levels at the impoundment's upstream limit.

### 3.2.3.3 Mother's Day Storm, 2006

Another way to consider the potential effects of the removal or modification of the Great Dam is to consider a flood event that is familiar and memorable to local residents and to examine how the effects of that flood would have differed under the project alternatives.

Most people in the area remember the "Mother's Day Flood," caused by as much as 14 inches of rainfall from May 13-17, 2006 in central and southern New Hampshire. A state-wide flood resulted and, for many residents of the region, this was the largest flood ever witnessed. Private and public infrastructure was damaged and numerous residential areas were evacuated for several days.

According to the USGS, peak flows at the Haigh Road stream gage on the Exeter River peaked at 3,520 cfs on May 15. (Olsen, 2007) This was the highest flow ever recorded at the gage, which had been in operation since 1996. This meant that the flow at the Great Dam was approximately 5,950 cfs, or roughly the equivalent to the 50-year design storm as discussed above. Therefore, by looking at the hydraulic results for this particular storm, we can begin to understand how the removal or modification of the dam would have changed flooding.

To be clear, dam modification or removal only has the potential to *decrease flood depths and the area subject to flooding* ***upstream*** *of the dam*. As discussed above, because the Great Dam is a "run of the river" dam, its removal or modification would not affect downstream flooding in a measureable way. However, removal of the dam, [or modification] would decrease the severity of upstream flooding. **Table 3.2-13** provides information on flood depths for several points of interest on the Exeter River.

Table 3.2-13. Mother's Day Flood Depths

| Location | River Depth (ft) | | | | | Flood Depth Decrease Relative to Existing Condition (ft) | | | |
|---|---|---|---|---|---|---|---|---|---|
| | Existing Condition | Dam Removal | Partial Removal | Stabilize in Place | Dam Modification | Removal | Partial Removal | Stabilize in Place | Dam Modification |
| Upstream of High Street | 29.6 | 25.1 | 26.0 | 29.6 | 25.2 | 4.5 | 3.6 | 0.0 | 4.5 |
| Franklin Street Neighborhood | 31.0 | 28.8 | 28.9 | 31.0 | 28.8 | 2.2 | 2.1 | 0.0 | 2.2 |
| PEA Athletic Fields | 31.3 | 29.4 | 29.5 | 31.3 | 29.4 | 1.9 | 1.8 | 0.0 | 1.9 |
| NH 108/Court Street Bridge | 31.7 | 30.4 | 30.5 | 31.7 | 30.4 | 1.3 | 1.2 | 0.0 | 1.3 |
| Linden Street Bridge | 35.3 | 34.9 | 34.9 | 35.3 | 34.9 | 0.4 | 0.4 | 0.0 | 0.4 |
| Robin Hood Drive | 36.0 | 35.7 | 35.7 | 36.0 | 35.7 | 0.3 | 0.3 | 0.0 | 0.3 |
| Amtrak RR Crossing | 38.0 | 37.9 | 37.9 | 38.0 | 37.9 | 0.1 | 0.1 | 0.0 | 0.1 |

As can be seen from this table, either Dam Removal or Dam Modification has the potential to decrease the overall depth of flooding relative to what occurred during the Mother's Day Flood. And, both alternatives would reduce flood depths similarly. For example, at the NH 108/Court Street Bridge across the Exeter River, Dam Removal would reduce flood depths approximately 1.3 ft, the same as Dam Modification. The Partial Removal Alternative also decreases flood depths by a similar amount. Note that this decrease in flood depths does not change the area that would be subject to flooding by a significant amount. This can be seen by comparing the areal limits of the 50-year flood for each of the alternatives in **Figures 3.2-5** through **3.2-9**.

## 3.2.4 Predicted Changes in Sediment Transport

A sediment transport analysis was performed for the Exeter River using the HEC-RAS model results that were developed for the project. The HEC-RAS model provides a means to predict changes in water surface elevations, velocities, shear stress and sediment transport under various alternatives.

### 3.2.4.1 Shear Stress Analysis

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 changed 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 modification.

Sediment sampling in the Exeter River indicates sedimentation of relatively uniform sand size particles is occurring within the Great Dam backwater. See **Table 3.2-14** and **Figure 3.2-11** for the location of six sampling stations where sediment data was collected in November 2011.

The particle size distributions determined by sediment samples for the six sampling locations represents conditions above and below the impoundment. (More information on sediment characteristics is contained in **Appendix I**.) These sampling stations were established in accordance with the *NHDES Policy on the Evaluation of Sediment Quality for Dam Removals* (NHDES, 2006). More information on the selection of these sampling sites can be found in Section 3.4.1.

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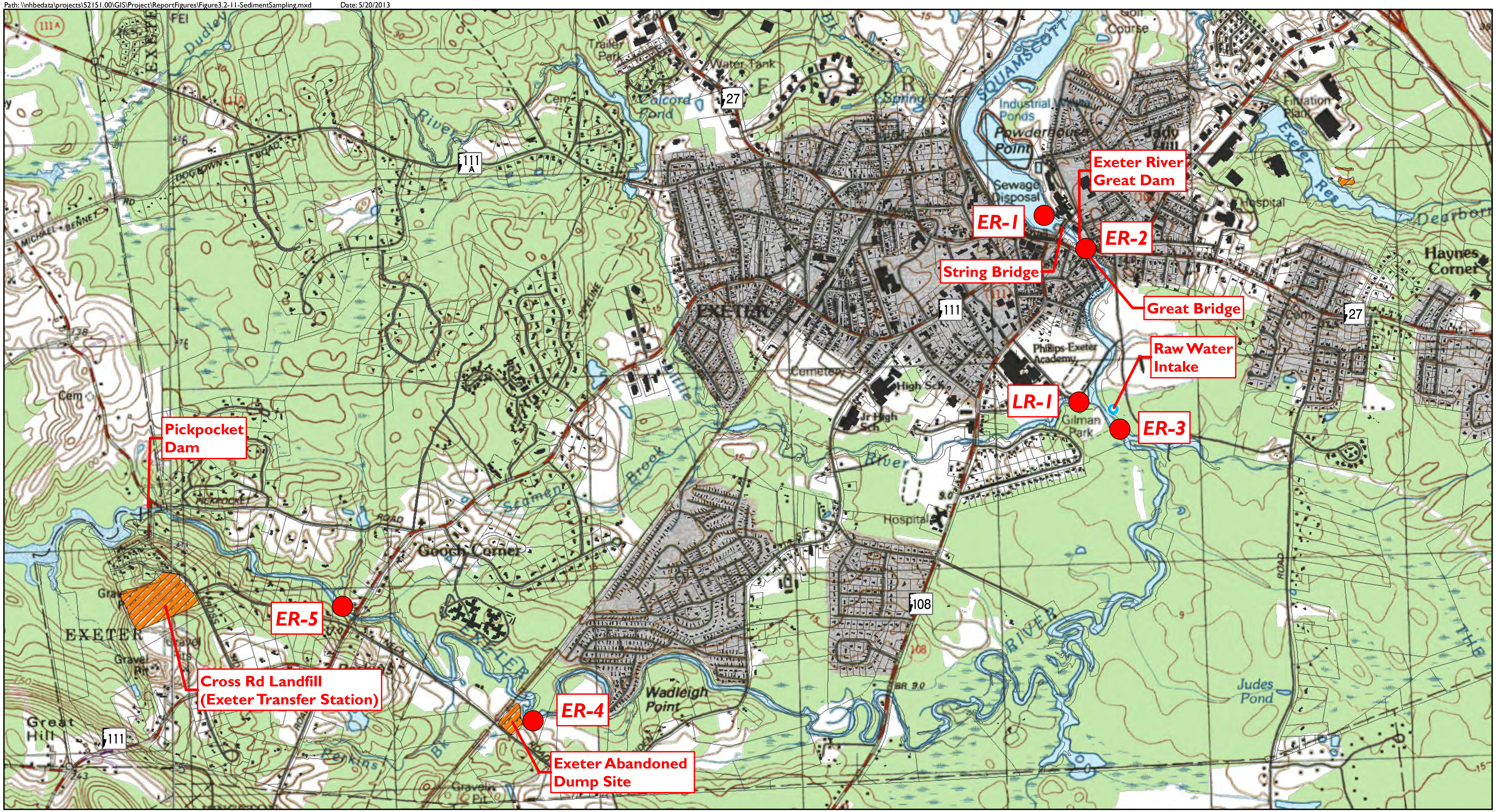


**Legend**

- Sediment Sampling Stations
- RAW Water Intake
- Potential Groundwater Contamination Area

0 1,500 3,000 Feet

Source: USGS 7.5 Minute Quadrangles: Exeter, Kingston

VHB Vanasse Hangen Brustlin, Inc.

**Figure 3.2-11**
**Sediment Sampling Stations**
**Exeter Great Dam Removal Feasibility & Impact Analysis**

**Exeter, NH**

Town of Exeter Founded 1638 New Hampshire

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Table 3.2-14. Sediment Sample Particle Size Distribution and Classification[1]

| Sample | Location Description | $D_{15}$ (mm) | $D_{50}$ (mm) | $D_{50}$ Material Class | $D_{85}$ (mm) |
|---|---|---|---|---|---|
| ER-1 | Downstream of Great Dam – pool | 0.2479 | 0.922 | coarse sand | 4.0996 |
| ER-2 | Just Upstream of Dam - pool | 0.1287 | 1.5156 | very coarse sand | 15.5138 |
| ER-3 | Just Upstream of Raw Water Intake - pool | 0.0027 | 0.0403 | coarse silt | 0.1791 |
| ER-4 | Upstream near former landfill - pool | - | 0.0192 | fine silt | 0.1858 |
| ER-5 | Just upstream of NH 111 - riffle | 0.08 | 0.2004 | fine sand | 0.4263 |
| LR-1 | Little River - pool | 0.0052 | 0.1617 | fine sand | 0.8675 |

Note:
1. Material classification follows the Wentworth Grade Scale. D15, D50 and D85 refer to the grain diameter (particle size) at the 15th, 50th, and 85th percentiles in the sample.

Channel aggradation has occurred within the impoundment due to the low velocities and high residence times of the water at most flow conditions. Post-dam removal channel geometry and bedslope would be such that sediment transport continuity would be restored.

The “bankfull discharge” is the flow that determines much of the channel formation and erosion occurs 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 or modification.

Data for the 2-year recurrence interval discharge ($Q_2$) was modeled for the project area. These data, a representative low flow ($Q_{low}$), a mean annual flow, $Q_2$, $Q_{10}$, and $Q_{100}$ were used to evaluate sediment transport and particle stability. Inspection of topographic maps of the Exeter River, in combination with an understanding of the regional physiography and stream channel patterns, guided the sediment transport and management assessment.

### 3.2.4.2 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 Great Dam. Particle stability was determined by shear stress assessment in accordance with ASCE Manual 54 and EM 1110-2-1418. Shear stress ($\tau$) 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).

Using the water surface slope and hydraulic radius from the HEC-RAS model results, to the project team calculated the shear stress at each cross section in the model. 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 3.2-15**.

By comparing the incipient diameters between the Existing Condition/No Action Alternative and the conditions predicted for the Dam Removal Alternative (Alternative B) and Dam Modification Alternative (Alternative H), inferences can be drawn regarding the potential for erosion and deposition as a result of modification or removal of the dam. 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 3.2-15. 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 |

### 3.2.4.3 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 a) existing conditions, b) dam modification, and c) full dam removal. **Table 3.2-16** below illustrates the calculated stable particle sizes for both the bankfull flow (Q2), and the 10-year recurrence interval flood (Q10) for the three alternatives evaluated at each of the six sampling locations.

**Table 3.2-16**, 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 member 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 flood plain 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 or modification, specifically in areas characterized by the sediment samples taken at location ER-2, ER-3, and LR-1. Results predicted substantial changes in the stable particle size under the various alternatives evaluated for these locations. Upstream of the confluence of the Exeter River with the Little River, most of the predicted changes would likely be insignificant, with the stable particle size after dam removal remaining as gravel or smaller.

Results predict the most significant increases in stable particle size at the ER-2 sampling location, located approximately 160 feet upstream of the Great Dam. The predicted stable particle size at this location increases from coarse gravel to cobbles between the existing and dam removal scenario. Within this reach, the predicted stable particle size after dam removal would be predominantly cobbles and boulders, as would be expected for a riffle.

Downstream of the Great Dam, the analysis indicates that stable particle size of the particles resting on bedrock would be mostly cobbles and boulders for all conditions. The correlates well with field observations which indicate that the river downstream of the dam containing gravel, cobbles and boulders resting on bedrock. This seems to indicate that the larger substrates (coarse gravels through boulders) as well as the bedrock downstream of the dam are acting as a relatively stable “pavement,” and are not highly mobile.

Table 3.2-16. Incipient Diameter Analysis

| Sample Location | Alternative | Q2 Ds (mm) Shields | Q2 Ds (mm) Colorado | Q2 Ds (mm) LWM | Q2 Ds Sediment Grade Class Range | | | Q10 Ds (mm) Shields | Q10 Ds (mm) Colorado | Q10 Ds (mm) LWM | Q10 Ds Sediment Grade Class Range | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| ER-1 | Existing Condition | 255.73 | 320.31 | 224.20 | Cobbles | - | Boulders | 405.87 | 449.89 | 362.80 | Boulders | - | Boulders |
| | Dam Modification | 255.73 | 320.26 | 224.20 | Cobbles | - | Boulders | 405.87 | 449.83 | 362.80 | Boulders | - | Boulders |
| | Full Removal | 255.73 | 320.26 | 224.20 | Cobbles | - | Boulders | 405.87 | 449.83 | 362.80 | Boulders | - | Boulders |
| ER-2 | Existing Condition | 5.63 | 19.36 | 4.21 | Fine Gravel | - | Coarse Gravel | 11.62 | 32.96 | 8.95 | Medium Gravel | - | V. Coarse Gravel |
| | Dam Modification | 207.31 | 274.45 | 180.15 | Cobbles | - | Boulders | 285.40 | 347.19 | 251.37 | Cobbles | - | Boulders |
| | Full Removal | 221.08 | 287.74 | 192.64 | Cobbles | - | Boulders | 285.40 | 347.19 | 251.37 | Cobbles | - | Boulders |
| ER-3 | Existing Condition | 1.00 | 5.43 | 0.70 | Coarse Sand | - | Fine Gravel | 0.75 | 4.38 | 0.51 | Coarse Sand | - | Fine Gravel |
| | Dam Modification | 2.11 | 9.40 | 1.51 | V. Coarse Sand | - | Medium Gravel | 5.63 | 19.34 | 4.20 | Fine Gravel | - | Coarse Gravel |
| | Full Removal | 2.77 | 11.47 | 2.01 | V. Coarse Sand | - | Medium Gravel | 5.63 | 19.35 | 4.21 | Fine Gravel | - | Coarse Gravel |
| ER-4 | Existing Condition | 13.99 | 37.79 | 10.86 | Medium Gravel | - | V. Coarse Gravel | 30.20 | 66.55 | 24.21 | Coarse Gravel | - | Cobbles |
| | Dam Modification | 14.25 | 38.30 | 11.07 | Medium Gravel | - | V. Coarse Gravel | 31.29 | 68.31 | 25.12 | Coarse Gravel | - | Cobbles |
| | Full Removal | 14.25 | 38.30 | 11.07 | Medium Gravel | - | V. Coarse Gravel | 31.53 | 68.69 | 25.32 | Coarse Gravel | - | Cobbles |
| ER-5 | Existing Condition | 74.40 | 129.16 | 61.93 | V. Coarse Gravel | - | Cobbles | 144.22 | 210.16 | 123.43 | Cobbles | - | Cobbles |
| | Dam Modification | 74.43 | 129.20 | 61.96 | V. Coarse Gravel | - | Cobbles | 145.69 | 211.73 | 124.74 | Cobbles | - | Cobbles |
| | Full Removal | 74.43 | 129.20 | 61.96 | V. Coarse Gravel | - | Cobbles | 145.98 | 212.05 | 125.01 | Cobbles | - | Cobbles |
| LR-1 | Existing Condition | 0.06 | 0.67 | 0.04 | Coarse Silt | - | Coarse Sand | 0.06 | 0.71 | 0.04 | Coarse Silt | - | Coarse Sand |
| | Dam Modification | 0.54 | 3.43 | 0.36 | Medium Sand | - | V. Fine Gravel | 0.38 | 2.65 | 0.25 | Medium Sand | - | V. Fine Gravel |
| | Full Removal | 0.56 | 3.53 | 0.38 | Medium Sand | - | V. Fine Gravel | 0.38 | 2.64 | 0.25 | Medium Sand | - | V. Fine Gravel |

Note: The values reported for Dam Modification are for Alternative E. Because of the nature of these calculations and the minor hydraulic differences between Alternative E and Alternative H, these results are considered valid for both alternatives.

### 3.2.4.4 Estimated Volume of Sediment Subject to Downstream Migration

The project team evaluated the potential total volume of sediment transported to the Squamscott River for the various alternatives 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 very low flow to "normal flows" to very high flows and from short duration events to very long duration events to establish a full understanding of the ramifications of dam removal or modification.

The HEC-RAS model uses a "Quasi-Unsteady State" flow routing for sediment transport simulations. Initially, the project HEC-RAS model was developed to support steady state 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, quasi-unsteady state, 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 revised the existing HEC-RAS model to include additional sediment depth and bed gradation input data required for quasi-unsteady state 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 quasi-unsteady state simulations modify during their iterative calculation process.

The project team prepared the HEC-RAS sediment data file based on information obtained during the sediment sampling effort conducted in support of this Feasibility Study. A total of six samples were taken near the waterline of the Exeter and Little Rivers in November 2011 as shown in **Figure 3.2-11**. In addition to collecting sediment samples for particle size distribution analysis during the November 2011 sampling effort, the project team also noted the depth of sediment at each of the six sample sites. Those observations are summarized in the **Table 3.2-17**.

Visual observations made during the November 2011 sampling effort and those made by the project team's fluvial geomorphologist, Dr. John Field, during a separate visit to the Exeter-Little River, suggest that sediment depth varies considerably both laterally across the Great Dam impoundment as well as longitudinally along the length of both the Exeter and Little Rivers. However, with the exception of areas immediately upstream and downstream of Great Dam, average sediment depths were consistently found to be approximately 24 inches. Immediately upstream of Great Dam, sediment depths appeared to be limited to approximately 6 inches. No direct observations were made of the transition from 6 inches immediately upstream of Great Dam to the average sediment depths of 24 inches observed elsewhere in the impoundment. However, given the wedge-shaped sediment deposition pattern typical in the impoundments of run-of-river dams, and the bathymetry of the Exeter River channel bottom, the project team expects that the deposited sediment would remain approximately 6 inches deep from Great Dam to approximately 200 feet upstream of the High Street Bridge. Upstream of that point, the channel bottom begins to drop considerably, decreasing the average flow velocity and the River's sediment-carrying capacity. Bathymetric data suggests that the transition of sediment depths from 6 to 24 inches would likely occur over a roughly 1200-ft. long reach extending upstream from a point 200 feet upstream of the High Street Bridge.

Table 3.2-17. Sediment Sampling Observations

| Sample ID | Estimated Avg. Sediment Sample Depth | General Sediment Description | Other Relevant Location/ Channel Notes |
|---|---|---|---|
| ER-1 | 0-6" | Cobble, rocky bottom, minimal sediment deposits | Below dam; high velocity area and tidal |
| ER-2 | 6" | Cobble, rocky bottom, minimal sediment deposits | Approx. 20 ft above dam, 20 ft off right bank |
| ER-3 | 24" | Silty-sand material, mucky, minimal stone or gravel | Evidence of marine clay was observed below 24" with hand auger – no refusal encountered |
| LR-1 | 24" | Medium-sand material some gravel over silt to dense clay material. Some organic material and debris | Dense marine clay observed below 24 inches in many areas; Overlying sediment depth was highly variable with deeper deposits in shoal areas and shallower depths in scour areas in the main channel |
| ER-4 | 24" | Very fine silty sand, some silt material, few rocks or stones, grayish in color at depth | No refusal encountered but firmer more dense material was noted near or below 24 inches in depth, perhaps marine clay. |
| ER-5 | 24" | Coarse to medium sand with some silt and organic material. | This location was in a depositional area above a pipe crossing acting as a small dam across the channel bottom: just downstream of pipe, a cobble/rocky bottom was noted extending several hundred feet downstream. |

The project team incorporated these observations and inferences into the HEC-RAS sediment data file. All cross-sections upstream in the Little River and all cross-sections in the Exeter River upstream of the transition area near High Street Bridge were assigned a sediment depth of 24 inches. Within the transition area, sediment depths were linearly interpolated based on distance along the channel centerline, ranging from 24 inches approximately 1,200 feet upstream of High Street to 6 inches approximately 200 feet upstream of the Bridge. Below the Great Dam, the project team applied a constant sediment depth of 3 inches to all cross-sections as suggested by observations made during the sampling effort and other site visits.

The HEC-RAS sediment data file also include information regarding bed gradations. The six known bed gradations derived from the November 2011 sampling effort were applied to the model cross-section nearest to each sampling location as shown in **Figure 3.2-11**. For intermediate cross-sections located between sampling locations ER-2, -3, -4, and -5, bed gradations were be assigned by linearly interpolating along the channel centerline using an interpolation tool built into HEC-RAS. A constant bed gradation, equivalent to the ER-1 sample, was assigned to all cross-sections downstream of Great Dam. Cross-sections upstream of ER-5 and LR-1 were assigned a bed gradation equivalent to that of the nearest sample site.

In addition to revising the HEC-RAS model geometry by developing a sediment data file to supplement the existing geometry files, the project team prepared a total of six 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, stream flow in the modeled cross-sections is constant within each individual steady-state simulation, but can vary between those steady-state simulations. The project team prepared the revised flow files required to drive six different “events” over which to compare the predicted sediment transport rates for each Alternative. Those six flow events included a very low flow event, a “normal” event, three flood events, and an extended period simulation.

The low flow event was modeled as a 6-day constant flow event equivalent to the median September flow at Great Dam. The magnitude of the median September event, 5.9 cfs at Great Dam, was determined from USGS stream flow data recorded at the Haigh Road gage. The constant flow of 5.9 cfs was simulated to enter the Great Dam impoundment at three locations – Pickpocket Dam (69%), Colcord Pond Dam (15%), and the Great Cove (16%), based on the relative size of their drainage areas. The normal flow event was modeled in a very similar manner, as a 6-day constant flow event equivalent to the median annual flow at Great Dam. Again the magnitude of that flow event, 71 cfs at Great Dam, was determined from USGS stream flow data and distributed among the three primary inflows to the Great Dam impoundment.

The three flood events, representative of the 2-, 10-, and 100-year floods, were developed somewhat differently. In contrast to the constant flow rates of the low and normal flow events, 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 Squamscott River varied over the 6-day simulation period. The shapes of the hydrographs used to define those three flood events were taken from a rainfall-runoff model of the Exeter River. The model is documented in detail in the July 2012 “Rainfall-Runoff Model Design Flow Report” (**Appendix E-2**), but ultimately the rainfall-runoff model was developed to simulate the 6-day runoff hydrograph produced in response to several 24-hour rainfall events, including the 2-, 10-, and 100-year events. The resulting runoff hydrographs for each of the three inflow locations were divided by their respective peak magnitudes to produce a unitless version of the hydrographs for each of the three flood events. The peak magnitudes of the 2-, 10-, and 100-year flow events, 1481, 3245, and 7109 cfs at Great Dam, respectively, were derived through statistical analysis of USGS stream flow data from the Exeter River and other nearby watersheds, as documented in the January 2012 memorandum from the project team to the Town of Exeter, titled "Exeter River Design Flows" (**Appendix E-1**). The project team combined those peak magnitudes with the unitless hydrographs derived from the rainfall-runoff model to prepare the flow files needed to drive quasi-unsteady-state sediment transport simulations of those three flood events.

In addition to the 6-day simulations of a constant low flow, a constant "normal" flow, and three flood events, the project team prepared a flow file representative of the historically observed conditions on the Exeter River from October 1, 2002 through September 30, 2007 (Water Years 2003-2007). In contrast to the five 6-day simulations, which consisted of 144 steady-state simulations of 1 hour each, the 5-year extended simulation consisted of 61 steady-state simulations of 30 days each (except for the final steady-state simulation of 25 days). The magnitude of the flow during each 30-day interval was estimated by averaging the daily mean stream flow data recorded by the USGS Haigh Road gage over that same period. This historical period encompasses a variety of wet, dry, and normal seasons. The Mother's Day and Patriot's Day flood events also occurred during this period. By evaluating changes in sediment transport over this extended period, the project team was able to estimate the magnitude of the potential changes that may occur in the years following dam removal or modification.

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 Great Dam impoundment. Given that the Great Dam impoundment is composed primarily of unconsolidated silt- and sand-sized particles and larger, bedload transport equations are 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 the manner in which 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 volume of sediment transported to the Squamscott River for Alternatives A, B, F and H[37] under a variety of flow conditions through a series of HEC-RAS simulations. In total the project team conducted 72 sediment transport simulations, one for every combination of the three alternatives, six flow conditions, and three transport methodologies. The results of those simulations are presented in **Tables 3.2-18** through **3.2-23** below.

These tables present the estimated volume of sediment simulated to move from the Great Dam impoundment, the reaches of the Exeter and Little River between the impoundment and the next upstream dam, and the short reach between Great Dam and the tidal waters of the Squamscott. The six tables represent the simulation results for each of the six flow events considered, presenting the average, minimum, and maximum sediment volumes estimated by the three transport methods for each of the three Alternatives.

As expected, under Alternative B – Dam Removal, Alternative F – Partial Removal and Alternative H – Dam Modification, substantially more sediment was simulated to move from the Exeter-Little River system than under Alternative A – Existing Conditions. With the dam removed or modified, hydraulic control of the Great Dam impoundment would be lowered several feet, which would cause decreased depth of flow and increased velocities, which in turn would increase shear stress on the riverbed and the sediment carrying capacity of the river. Across the five 6-day flow events evaluated, the predicted increase in sediment load between Alternatives A and B ranges from 35% during the 100-year flood to 151% during the 2-year flood, with an average increase of 81%. The simulated changes to sediment transport associated with Alternative H – Dam Modification are similar, ranging from 13% during the median Annual simulation to 120% during the 2-year flood, with an average increase of 56% over existing conditions.

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[37] Sediment transport calculations were originally developed for Alternative E. Given the time intensive nature of this modeling exercise and the fact that Alternative E and H are hydraulically similar, the results for Alternative E were determined to remain valid for Alternative H.

The results for 5-year simulations of historically observed stream flow produce a similar pattern as the 6-day events, but on a larger scale. The model predicts that over the significantly larger time period, the upward change in sediment load transported from the Exeter-Little River system to the tidal waters of the Squamscott River would increase. The Alternative B predicted sediment load, averaged across the three transport methods, represents a 366% increase over Alternative A and a 344%. Similarly, the average predicted Alternative H sediment load during the 5-year simulation represents a 337% increase over that of Alternative A. Presumably over a longer time period even than five years, the sediment available for transport from the Great Dam impoundment under Alternatives B, F and H would diminish until the transport rates dropped significantly closer to those of the existing conditions. However, the results of the HEC-RAS sediment transport simulations indicate that removing or modifying the dam would result in higher sediment loads being discharged to the Squamscott River for at least a 5 year period.

Section 3.3 contains a discussion of the likely river's geomorphic response to these changes, including a discussion of the possible fate of sediments released to the Squamscott River.

While all five 6-day flow events evaluated indicate a net outflow of sediment from the Exeter-Little River system to the Squamscott River that sediment is not derived uniformly from within the Great Dam impoundment and the rest of the Exeter-Little River system. The six tables below also provide an estimate of the net movement of sediment from seven different reaches within the system. As the summary tables indicate, sediment is generally predicted to move from those reaches upstream of the impoundment and sometimes from the upper reaches of the impoundment itself. The model predicts that some of that mobilized sediment load would deposit in the lower impoundment, and the remainder would combine with sediment mobilized from below the Great Dam before discharging into the Squamscott River.

Table 3.2-18. Total Sediment Volume Transported by Reach for the 100-year Flood Event

| Design Event | Alternative | | Total Volume Entering Squamscott | Exeter River: Squamscott to Great Dam | Exeter River: Great Dam to Exeter-Little Confluence | Exeter River: Exeter-Little Confluence to Rt. 108 | Exeter River: Rt. 108 to RR Bridge | Exeter River: RR Bridge to Pickpocket Dam | Little River: Exeter-Little Confluence to RR Bridge | Little River: RR Bridge to Colcord Pond Dam |
|---|---|---|---|---|---|---|---|---|---|---|
| | | | Total Sediment Volume (cubic yards) Transported from Reach (+ = lost, - = gained) | | | | | | | |
| 100-year Flood | *Existing Condition* | Max | 12,116 | 982 | 3,598 | -882 | 7,284 | 7,958 | -1,088 | 2,931 |
| | | Min | 3,831 | 764 | 660 | -8,414 | 168 | 857 | -1,951 | 1,971 |
| | | *Average* | *6,705* | *866* | *1,708* | *-3,637* | *3,284* | *3,554* | *-1,505* | *2,435* |
| | *Dam Removal* | Max | 17,788 | 1,018 | 6,059 | -665 | 8,309 | 8,587 | -1,055 | 3,104 |
| | | Min | 4,493 | 727 | 1,063 | -7,183 | 308 | 868 | -1,883 | 1,962 |
| | | *Average* | *9,035* | *841* | *2,802* | *-3,082* | *3,551* | *3,784* | *-1,373* | *2,512* |
| | | Change | 2,330 | -25 | 1,094 | 555 | 267 | 230 | 132 | 77 |
| | *Partial Removal* | Max | 16543 | 1,018 | 5695 | -625 | 8143 | 8501 | -1013 | 3073 |
| | | Min | 4089 | 727 | 904 | -6249 | 274 | 799 | -1864 | 1942 |
| | | *Average* | *10,316* | *841* | *3,300* | *-3,437* | *4,208* | *4,650* | *-1,438* | *2,508* |
| | | Change | 3,611 | -25 | -1592 | -200 | -924 | -1096 | -67 | -73 |
| | *Dam Modification* | Max | 16,847 | 921 | 5,650 | -869 | 8,198 | 8,546 | -1,071 | 3,058 |
| | | Min | 4,264 | 707 | 812 | -7,499 | 255 | 867 | -1,890 | 1,971 |
| | | *Average* | *8,569* | *815* | *2,601* | *-3,222* | *3,505* | *3,767* | *-1,393* | *2,497* |
| | | Change | 1,865 | -51 | 892 | 415 | 221 | 213 | 112 | 62 |

Table 3.2-19. Total Sediment Volume Transported by Reach for the 10-year Flood Event

| Design Event | Alternative | | Total Volume Entering Squamscott | Exeter River | | | | | Little River | |
|---|---|---|---|---|---|---|---|---|---|---|
| | | | | Squamscott to Great Dam | Great Dam to Exeter-Little Confluence | Exeter-Little Confluence to Rt. 108 | Rt. 108 to RR Bridge | RR Bridge to Pickpocket Dam | Exeter-Little Confluence to RR Bridge | RR Bridge to Colcord Pond Dam |
| | | | Total Sediment Volume (cubic yards) Transported from Reach (+ = lost, - = gained) | | | | | | | |
| 10-year Flood | *Existing Condition* | Max | 3,321 | 852 | 1,330 | -55 | -65 | 3,067 | -60 | 370 |
| | | Min | 1,068 | 570 | 54 | -1,063 | -849 | 257 | -105 | 85 |
| | | *Average* | *1,896* | *683* | *534* | *-418* | *-351* | *1,318* | *-76* | *206* |
| | *Dam Removal* | Max | 7,698 | 875 | 3,539 | 192 | -71 | 3,780 | 221 | 407 |
| | | Min | 1,925 | 623 | 751 | -26 | -1,065 | 253 | -32 | 93 |
| | | *Average* | *4,117* | *756* | *1,788* | *74* | *-436* | *1,611* | *97* | *227* |
| | | Change | 2,221 | 72 | 1,254 | 493 | -85 | 293 | 173 | 21 |
| | *Partial Removal* | Max | 7159 | 875 | 3,327 | 180 | -70 | 3,742 | 212 | 403 |
| | | Min | 1752 | 623 | 638 | -23 | -948 | 233 | -32 | 92 |
| | | *Average* | *4455* | *756* | *1,983* | *79* | *-509* | *1,987* | *90* | *248* |
| | | Change | 2,559 | 72 | -1,449 | -497 | 158 | -669 | -166 | -42 |
| | *Dam Modification* | Max | 7,022 | 631 | 3,196 | 41 | -71 | 3,764 | 197 | 406 |
| | | Min | 1,446 | 502 | 534 | -41 | -1,067 | 253 | -33 | 92 |
| | | *Average* | *3,592* | *579* | *1,526* | *8* | *-436* | *1,605* | *84* | *226* |
| | | Change | 1,696 | -105 | 992 | 427 | -85 | 288 | 160 | 20 |

Table 3.2-20. Total Sediment Volume Transported by Reach for the 2-year Flood Event

| Design Event | Alternative | | Total Volume Entering Squamscott | Exeter River: Squamscott to Great Dam | Exeter River: Great Dam to Exeter-Little Confluence | Exeter River: Exeter-Little Confluence to Rt. 108 | Exeter River: Rt. 108 to RR Bridge | Exeter River: RR Bridge to Pickpocket Dam | Little River: Exeter-Little Confluence to RR Bridge | Little River: RR Bridge to Colcord Pond Dam |
|---|---|---|---|---|---|---|---|---|---|---|
| | | | Total Sediment Volume (cubic yards) Transported from Reach (+ = lost, - = gained) | | | | | | | |
| 2-year Flood | *Existing Condition* | Max | 1,455 | 660 | 107 | -33 | -43 | 1,626 | 9 | 104 |
| | | Min | 759 | 451 | -6 | -287 | -555 | 176 | -41 | 37 |
| | | *Average* | *1,036* | *558* | *33* | *-137* | *-232* | *765* | *-13* | *61* |
| | *Dam Removal* | Max | 4,694 | 684 | 1,644 | 917 | -41 | 2,259 | 376 | 107 |
| | | Min | 1,335 | 431 | 328 | 121 | -1,039 | 147 | 34 | 38 |
| | | *Average* | *2,597* | *521* | *857* | *392* | *-394* | *964* | *195* | *63* |
| | | Change | 1,562 | -37 | 824 | 529 | -162 | 198 | 208 | 2 |
| | *Partial Removal* | Max | 4365 | 684 | 1545 | 862 | -40 | 2236 | 361 | 106 |
| | | Min | 1215 | 431 | 279 | 105 | -925 | 135 | 34 | 38 |
| | | *Average* | *2790* | *521* | *912* | *484* | *-482* | *1186* | *197* | *72* |
| | | Change | 1,754 | -37 | -879 | -621 | 250 | -421 | -210 | -11 |
| | *Dam Modification* | Max | 4,226 | 532 | 1,400 | 829 | -41 | 2,244 | 365 | 107 |
| | | Min | 1,086 | 316 | 280 | 84 | -1,036 | 147 | 34 | 38 |
| | | *Average* | *2,276* | *446* | *662* | *348* | *-393* | *959* | *191* | *63* |
| | | Change | 1,240 | -112 | 629 | 485 | -161 | 193 | 204 | 2 |

Table 3.2-21. Total Sediment Volume Transported by Reach for the Median Annual Flow Event

| Design Event | Alternative | | Total Volume Entering Squamscott | Exeter River: Squamscott to Great Dam | Exeter River: Great Dam to Exeter-Little Confluence | Exeter River: Exeter-Little Confluence to Rt. 108 | Exeter River: Rt. 108 to RR Bridge | Exeter River: RR Bridge to Pickpocket Dam | Little River: Exeter-Little Confluence to RR Bridge | Little River: RR Bridge to Colcord Pond Dam |
|---|---|---|---|---|---|---|---|---|---|---|
| | | | Total Sediment Volume (cubic yards) Transported from Reach (+ = lost, - = gained) | | | | | | | |
| Median Annual | *Existing Condition* | Max | 415 | 301 | -2 | -13 | -17 | 420 | 0 | 8 |
| | | Min | 315 | 266 | -16 | -104 | -154 | 50 | -4 | 0 |
| | | *Average* | *350* | *280* | *-7* | *-48* | *-69* | *193* | *-1* | *3* |
| | *Dam Removal* | Max | 728 | 293 | 61 | 119 | -3 | 293 | 93 | 8 |
| | | Min | 438 | 268 | 40 | 48 | -94 | 19 | 49 | 0 |
| | | *Average* | *567* | *277* | *48* | *89* | *-35* | *117* | *68* | *3* |
| | | Change | 217 | -3 | 55 | 138 | 33 | -75 | 69 | 0 |
| | *Partial Removal* | Max | 677 | 293 | 57 | 112 | -3 | 290 | 89 | 8 |
| | | Min | 399 | 268 | 34 | 42 | -84 | 17 | 49 | 0 |
| | | *Average* | *538* | *277* | *46* | *77* | *-43* | *154* | *69* | *4* |
| | | Change | 188 | -3 | -53 | -125 | -26 | 39 | -70 | -1 |
| | *Dam Modification* | Max | 489 | 303 | -7 | 2 | -4 | 287 | 86 | 8 |
| | | Min | 324 | 266 | -22 | -32 | -103 | 19 | 42 | 0 |
| | | *Average* | *396* | *279* | *-14* | *-13* | *-39* | *115* | *65* | *3* |
| | | Change | 46 | -1 | -6 | 36 | 30 | -78 | 66 | 0 |

Table 3.2-22. Total Sediment Volume Transported by Reach for the Median September Flow Event

| Design Event | Alternative | | Total Volume Entering Squamscott | Exeter River: Squamscott to Great Dam | Exeter River: Great Dam to Exeter-Little Confluence | Exeter River: Exeter-Little Confluence to Rt. 108 | Exeter River: Rt. 108 to RR Bridge | Exeter River: RR Bridge to Pickpocket Dam | Little River: Exeter-Little Confluence to RR Bridge | Little River: RR Bridge to Colcord Pond Dam |
|---|---|---|---|---|---|---|---|---|---|---|
| | | | Total Sediment Volume (cubic yards) Transported from Reach (+ = lost, - = gained) | | | | | | | |
| Median September | *Existing Condition* | Max | 62 | 62 | 0 | -1 | -6 | 48 | 0 | 336 |
| | | Min | 1 | 1 | 0 | -8 | -40 | 7 | -336 | 0 |
| | | *Average* | *31* | *31* | *0* | *-4* | *-20* | *24* | *-113* | *113* |
| | *Dam Removal* | Max | 64 | 60 | -4 | -8 | 2 | 125 | 17 | 336 |
| | | Min | 21 | -25 | -57 | -42 | -110 | 12 | -240 | 0 |
| | | *Average* | *44* | *20* | *-21* | *-19* | *-37* | *62* | *-73* | *113* |
| | | Change | 13 | -11 | -21 | -16 | -17 | 38 | 40 | 0 |
| | *Partial Removal* | Max | 60 | 60 | -4 | -8 | 2 | 124 | 16 | 333 |
| | | Min | 19 | -25 | -48 | -37 | -98 | 11 | -238 | 0 |
| | | *Average* | *39* | *20* | *-26* | *-22* | *-48* | *67* | *-111* | *166* |
| | | Change | 8 | -11 | 26 | 18 | 28 | -43 | -2 | -53 |
| | *Dam Modification* | Max | 0 | 61 | -1 | -7 | 8 | 133 | 9 | 336 |
| | | Min | 22 | -1 | -29 | -53 | -86 | 12 | -288 | 0 |
| | | *Average* | *40* | *30* | *-12* | *-34* | *-27* | *65* | *-93* | *113* |
| | | Change | 9 | -1 | -12 | -31 | -8 | 41 | 20 | 0 |

Table 3.2-23. Total Sediment Volume Transported by Reach for the Extended Period Event

| Design Event | Alternative | | Total Volume Entering Squamscott | Exeter River: Squamscott to Great Dam | Exeter River: Great Dam to Exeter-Little Confluence | Exeter River: Exeter-Little Confluence to NH 108 | Exeter River: NH 108 to RR Bridge | Exeter River: RR Bridge to Pickpocket Dam | Little River: Exeter-Little Confluence to RR Bridge | Little River: RR Bridge to Colcord Pond Dam |
|---|---|---|---|---|---|---|---|---|---|---|
| | | | Total Sediment Volume (cubic yards) Transported from Reach (+ = lost, - = gained) | | | | | | | |
| Water Years 2003-2007 | *Existing Condition* | Max | 2,739 | 509 | 505 | -498 | -7,033 | 12,370 | 130 | 1,666 |
| | | Min | 1,838 | 107 | -7 | -1,066 | -10,083 | 9,664 | -1,425 | 391 |
| | | *Average* | *2,251* | *255* | *310* | *-827* | *-8,681* | *10,851* | *-538* | *881* |
| | *Dam Removal* | Max | 12,646 | 476 | 2,701 | 1,985 | -9,759 | 16,922 | 8,376 | 1,665 |
| | | Min | 9,051 | 168 | -4,962 | 1,535 | -10,465 | 11,719 | 945 | 287 |
| | | *Average* | *10,492* | *291* | *-140* | *1,724* | *-10,083* | *14,352* | *3,546* | *801* |
| | | Change | 8,241 | 36 | -450 | 2,552 | -1,402 | 3,500 | 4,084 | -79 |
| | *Partial Removal* | Max | 11,761 | 476 | 2,539 | 1,866 | -9564 | 16,753 | 8,041 | 1,648 |
| | | Min | 8,236 | 168 | -4,218 | 1,335 | -9314 | 10,781 | 936 | 284 |
| | | *Average* | 9,999 | *291* | -839 | 1,601 | -9439 | 13,767 | 4,488 | 966 |
| | | Change | 7,748 | 36 | 1,149 | -2,428 | 758 | -2,916 | -5,026 | -85 |
| | *Dam Modification* | Max | 12,522 | 450 | 2,359 | 1,823 | -5,817 | 18,892 | 5,409 | 1,662 |
| | | Min | 7,634 | 38 | -3,464 | 1,129 | -14,265 | 12,122 | 786 | 287 |
| | | *Average* | *9,848* | *176* | *185* | *1,432* | *-9,990* | *14,768* | *2,477* | *801* |
| | | Change | 7,597 | -79 | -125 | 2,259 | -1,309 | 3,916 | 3,015 | -80 |

## 3.3 Geomorphic Assessment

### 3.3.1 Geomorphic Setting

Field inspections of the Exeter River were conducted in September and December 2011 to gather information on the geomorphic setting of the impounded reach of the Exeter River. Information was also garnered from current aerial photographs and by comparing recent and historical topographic maps. The site visits included a partial reconnaissance of an area 6.6 mi upstream and 0.5 mi downstream beyond the head-of-tide to the downstream end of Clemson Pond. The upstream most 0.9 mi assessed was beyond the upper limit of the impoundment behind the dam and thus provided information on river processes unaffected by the dam. In addition, the lower 0.5 mi of the Little River below the NH 108 Bridge was also assessed (see **Figure 3.3-1**).

In the immediate vicinity of the Exeter Dam, bedrock and rock walls protecting foundations of downtown buildings line the river channel. The river in the vicinity of the dam is inset into higher terrain approximately 20 ft above the river bottom and what little floodplain is present is constrained by buildings or retaining walls designed to prevent flooding of buildings (**Figure 3.3-2**). Fine-grained glacial sediments may underlie the upper portion of the terrace, but bedrock, as seen exposed in the banks of the channel, is present at depth. (See **Figure 3.3-3**.) Downstream of the dam the river flows over bedrock ledges before opening up into a tidally influenced portion of the river that is more than 40 times wider than the channel at the dam.

Visual observations during a drawdown of the impoundment corroborate geotechnical information. At the dam, bedrock ledge extends across the channel at a height of the present channel bottom. Based on field observations and the results of hydraulic modeling, the impoundment upstream of the dam extends for more than 5.0 mi upstream. The confinement by higher terrain extends only 0.2 mi upstream of the dam with a wide floodplain present for much of the remaining 4.5 mi of the impoundment. Given the lack of confinement in concert with fine-grained bank material and low gradient valley, the channel is a highly sinuous channel with evidence of oxbows along the channel margins (**Figure 3.3-1**). Bank heights are very low to nonexistent where the river flows across the marshy floodplain. Despite the wide floodplain, the channel occasionally flows against the higher banks at the outer margins of the floodplain, increasing the potential for slumping. However, both these high banks and low banks along the floodplain are largely stable and well vegetated. The conditions on the lower Little River are very similar with low stable banks present in the impounded area and the channel flowing against higher banks only within 300 ft of the NH 108 Bridge. Upstream of the impoundment, the floodplain is narrower and channel steeper, but a meandering planform with oxbows is still present. The slumping along higher floodplain and terrace banks may be more prevalent beyond the impoundment (**Figure 3.3-4**), but the banks are still largely stable and well forested.

In addition to the geomorphic assessment completed as part of this study, a geomorphic assessment of the Exeter River watershed was completed in 2009 for the NH Department of Environmental Services and Town of Exeter (Bear Creek Environmental, 2009). The assessment was completed independently of this dam removal feasibility and impact study, but a review of the assessment was completed to further inform investigations into the potential impacts of dam removal on geomorphic conditions and bank stability. The 2009 geomorphic assessment subdivided the study area into seven geomorphic reaches with each reach morphologically distinct from adjacent reach due to significant variations in slope, valley confinement, or drainage area.

Many of the reaches have several common characteristics such that unimpounded reaches upstream can provide clues as to potential conditions that might develop in impounded reaches if Great Dam is removed. Five of the eight reaches are classified as Rosgen E-type channels characterized by broad low gradient valleys with highly sinuous channels. Four of these five reaches are within the impoundment upstream of Great Dam and show very little bank erosion (Reaches LE01-LE04).[38] The E-type channel in an unimpounded portion of the Lower Exeter River Reach (Reach LE07) has considerably more erosion present.

### 3.3.2 Geomorphic Response to Dam Removal or Modification

One of the key concerns with regard to a river's response to dam removal is the possibility that the removal would create a "headcut." A headcut is 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 erode and collapse. A headcut migrates upstream; its uppermost point is called a nickpoint. Where a headcut forms, a large amount of sediment is transported downstream relatively rapidly, which can impact downstream river reaches. An example of a classic headcut can be seen in New Hampshire on the Suncook River in response to the Mother's Day Flood in 2006.

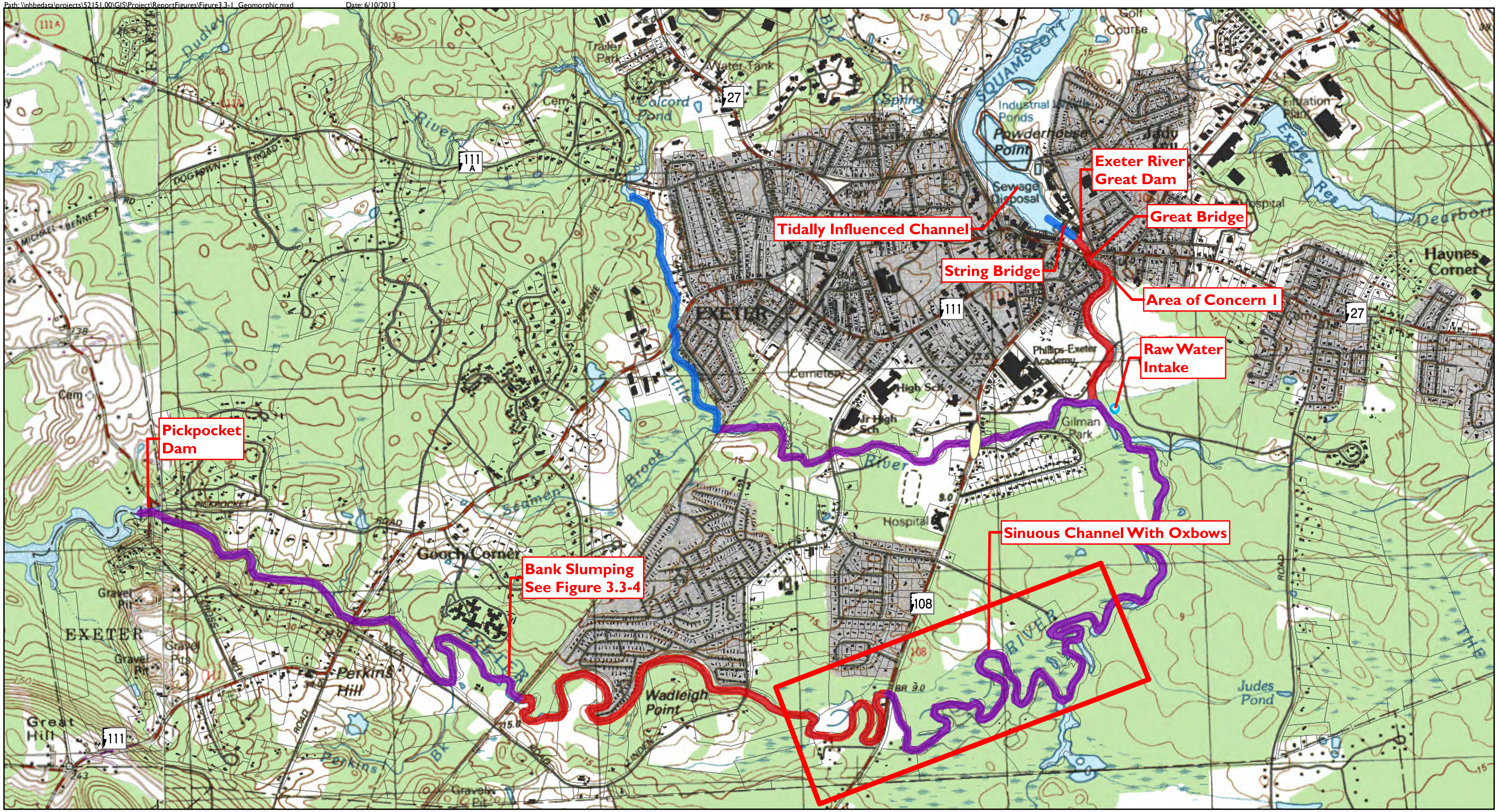
However, in this case, removal or modification of the Exeter Dam is unlikely to initiate a significant upstream migrating headcut, because of the presence of ledge across the channel at the dam.

Dam removal would obviously lead to lower water levels as compared to the currently-impounded river. Removal would also increase flow velocities near the to

▼

[38] Reach codes (e.g., "LE-1" etc.) are taken from Bear Creek Environmental's 2009 report. See **Appendix D** for more information.

Path: \\nhbedata\projects\52151.00\GIS\Project\ReportFigures\Figure3.3-1_Geomorphic.mxd Date: 6/10/2013




**Legend**

- Predicted net gain of sediment in reach
- Net loss of sediment in reach
- No net change in reach

Source: USGS 7.5 Minute Quadrangles: Exeter, Kingston

0 1,500 3,000 Feet

*Vanasse Hangen Brustlin, Inc.*

**Figure 3.3-1**
**Geomorphic Assessment**

**Exeter Great Dam Removal Feasibility & Impact Analysis**

**Exeter, NH**

TOWN OF EXETER FOUNDED 1638 NEW HAMPSHIRE

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A. Downstream of dam – Left Bank of Kimball Island

B. Upstream of Great Bridge – The banks are protected by a) rock walls and b) retaining walls

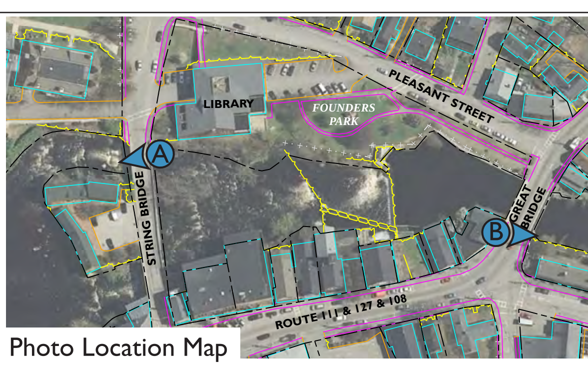


Photo Location Map

Vanasse Hangen Brustlin, Inc.

**Figure 3.3-2**

**Floodplain Immediately Upstream and Downstream of the Dam**

**Exeter Great Dam Removal Feasibility and Impact Study Exeter, NH**


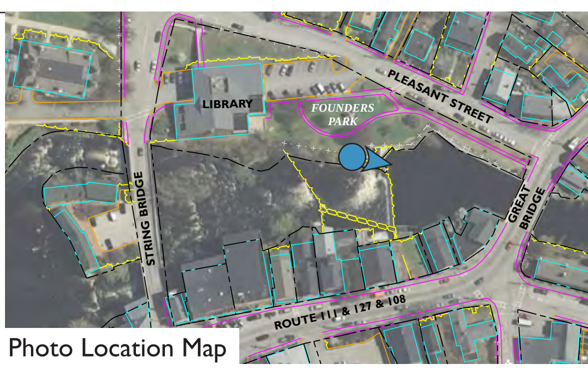


Photo Location Map

Vanasse Hangen Brustlin, Inc.

**Figure 3.3-3**

**Bedrock Outcrops at the Great Dam Site**

**Exeter Great Dam Removal Feasibility and Impact Study**
**Exeter, NH**

A. A view of bank slumping located west of the Amtrak Railroad Line, beyond the upper limit of the impoundment. This type of slumping may become more prevalent in the impoundment area following dam removal. (See Figure 3.3-1 for photo location.)

B. Sharp right angle bend in the Exeter River upstream of the dam may be prone to increased erosion after dam removal. Note: This photo location is shown as Area of Concern 1 labeled in Figure 3.3-1.

Vanasse Hangen Brustlin, Inc.

**Figure 3.3-4**

**Geomorphic Areas of Concern**

**Exeter Great Dam Removal Feasibility and Impact Study Exeter, NH**

dam and, therefore, potentially lead to increased erosion in areas that may be prone to bank instability. The area immediately adjacent to the dam is unlikely to experience major problems, because of the bedrock banks or rock walls at the base of the buildings (**Figure 3.3-2**). However, additional studies of these foundations are recommended to determine if reinforcement of the rock walls and foundations along the channel may be required in areas. See Section 3.7.1 of this report for more information on structural analysis and recommendations.

The geomorphic assessment of the Exeter River watershed indicates that the upstream end of the Great Dam impoundment is just upstream of the Linden Street crossing. The elevation change within this reach reduces the likelihood for backwater effects from the dam extending upstream even during high flows.

However, increased flow velocities are likely to increase channel migration along the meandering channel in the unconfined portion of the impoundment where a wide floodplain is present (see **Figure 3.3-1**). Data collected during the Bear Creek Environmental (2009) geomorphic assessment indicates that the river reach upstream of these impounded meander bends (i.e., Reach LE07) shows more bank erosion than the impounded E-type channel. Thus, the removal of the Great Dam and the return of more natural riverine flows could lead to greater erosion consistent with the levels seen in Reach LE07. This is consistent with the findings of the geomorphic reconnaissance completed as part of the dam removal feasibility study that concluded increased erosion might accompany dam removal in the meandering sections of the river. With little infrastructure in this marshy area, the increase in channel dynamics that might accompany dam removal or modification could have a positive impact on aquatic habitat with little risk of property damage.

Slumping of the higher banks where the river impinges on the higher terrace is likely to increase due to the higher flow velocities and greater bank slope that will result from the drop in water level. While this slumping is unlikely to be problematic throughout much of the undeveloped impoundment area, one location of note may be potentially at risk. Where the floodplain narrows and becomes confined by the terrace when entering the village, the river encounters the high terrace banks at a sharp right angle bend labeled as Area of Concern 1 in **Figure 3.3-1**. The greater energy expenditure at the hard bend will increase the potential for the erosion at this location (**Figure 3.3-4**). Although the erosion will likely only threaten open space and no buildings, improved bank stabilization where a rock wall already exists may be warranted. Further investigation of other unprotected bends in the first 0.3 mi upstream of the dam should be considered to determine the need for bank protection, but the banks tends to be lower than Area of Concern 1 and no bank protection would likely be necessary.

Downstream of the dam no significant permanent adverse impacts are anticipated because of the ledge control before reaching the much wider tidally influenced channel. Tidal forces within the much wider portion of the channel will continue exert a much greater influence on channel morphology than changes in hydraulics and sediment inputs associated with dam removal.

While tidal forces below the head-of-tide are likely to disperse increases in sediment load thereby preventing long-term impacts, four areas have been identified where short-term sediment accumulation is possible as the result of dam removal (**Figure 3.3-5**). The first location is just downstream of String Bridge where a sand bar is already present. The bar may grow in size immediately following dam removal but is likely to return to its current condition over time as tidal forces transport the sediment downstream and sediment loads from the Exeter River equilibrate following dam removal. The second location of possible sediment accumulation is in the embayed area where the Phillips Exeter Academy boat house is located. The residence time of sediment accumulating in the embayment is likely greater than the sand bar upstream, so efforts to prevent deposition in this area may be warranted. The third location of possible sediment accumulation is on the inside bend of the meander at the downstream end of Clemson Pond. Flow velocities on the inside bends of meanders tend to be lower, promoting formation of point bars. However, tidal forces may be sufficient to prevent significant bar growth, especially over the long term. A final location of possible sediment accumulation is immediately upstream of the NH 101 Bridge if the bridge is constricting the channel. The bridge is beyond the limits of the geomorphic assessment, so the bridge's impact on channel morphology is unknown. However, sediment accumulation is common upstream of bridges that severely constrict the channel. Aerial images suggest the bridge is not constrictive, so significant sediment accumulation is unlikely, but this conclusion was not confirmed in the field.

The proposed Dam Modification Alternative envisions impounding flows at normal low flow conditions but will allow high flows to pass in a more unrestricted manner similar to dam removal alternative. The Dam Modification Alternative has the potential to disrupt the transport of fine sediments (e.g., sand and finer sediments) through the system. While coarse sediment (e.g., gravel and larger particles) is usually entrained during high flows, fine sediment can be transported during low flows, particularly during the tail end of a flood discharge when the river may continue to carry substantial suspended sediments for a period of days after a storm. If, under the Dam Modification Alternative, flow was impounded while fine sediment was still suspended in the water column this sediment would be deposited behind the dam and not allowed to pass through the dam site as would occur under the complete dam removal scenario. The accumulated sediment would then be entrained during the next flood when the dam crest is again lowered, potentially releasing a pulse of fine sediment downstream. While the total volume of fine sediment transported downstream over time in both scenarios would be roughly equivalent, the sediment pulses potentially created by the Dam Modification Alternative could impact sensitive habitats in the head-of-tide area immediately downstream of the dam. These impacts could be mitigated by ensuring that the gates are not closed for a length of time following a storm sufficient to allow the river to once again run "clean." Fine sediment transport on the Exeter River during low flow periods is likely minimal at all other times.

In summary, the fluvial geomorphological reconnaissance of the Exeter River indicates that:

- Dam Removal will not likely cause an upstream migrating headcut and channel incision. This is the most serious form of erosion associated with dam removals. Fortunately, it appears very unlikely in the case of the Great Dam.
- However, Dam Removal could cause some increased channel migration in the wider floodplain areas of the Exeter and Little Rivers. Based on the location of these areas, this possible increased channel migration would not impact human infrastructure. It should be noted that channel migration is often a result of normal river processes.
- Dam Removal could also increase the potential for slumping of high banks where the river impinges against higher terrain with one area of potential concern associated with this erosion.
- Dam Removal should not impact downstream conditions over the long term due to the strong influence of tidal forces below the dam. However, short-term sediment accumulations may occur in certain areas.
- Dam Modification would have a similar impact on the likelihood of future channel migration because most channel migration occurs at higher flows. Dam Modification could also have an adverse downstream effect similar to Dam Removal.

## 3.4 Sediment Quality

As discussed in Section 3.3, rivers move not only water, but also sediment. Due to the history of industrial uses within and adjacent to New England rivers, contaminated sediments are sometimes found in rivers and streams. Because the modification or removal of the Great Dam is expected to return sediment transport in the Exeter River to normal conditions (relative to the currently-impounded condition), it is important to understand whether any of the sediment that might be mobilized could pose a risk to the downstream aquatic environment. Therefore, a screening level analysis of sediment quality was conducted to characterize existing sediment quality conditions in select locations. This analysis was conducted in accordance with the recommended guidance included with NHDES' Policy on Evaluation of Sediment Quality for Dam Removals (NHDES, 2006).

As part of this analysis, a literature search and review of existing sediment quality was conducted to determine whether there was any existing data that could be used to help characterize existing conditions. Relevant sediment quality data was found to exist in the downstream tidal portion of the Squamscott River below the Great Dam. Sediment quality data was collected by a consultant (AECOM) in the area of a

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**Legend**

Potential Depositional Areas

0 500 1,000 Feet

*Vanasse Hangen Brustlin, Inc.*

**Figure 3.3-5**
**Squamscott River Potential Depositional Areas**

**Exeter Great Dam Removal Feasibility & Impact Analysis**
**Exeter, NH**

Source: NHGRANIT, NH Fish & Game, Town of Exeter GIS

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historic coal to gas manufacturing facility along Swasey parkway. This data revealed elevated levels of various Polycyclic Aromatic Hydrocarbons (PAH's) in tidal river sediments as discussed further below. Additional sediment quality data was collected as part of the National Coastal Assessment Program (NCAP) at downstream locations in the Squamscott River (Trowbridge and Jones, 2005). However, no existing sediment quality data was discovered for locations upstream of the Great Dam. The downstream NCAP data was used to compare to upstream sediment quality data collected in this study to the downstream sediment quality data as a means to assess the potential for adverse risks to water quality and aquatic life from the potential upstream sediment migration. The published ecological risk guidance levels for both freshwater and saltwater organisms were also used in this analysis to assess potential adverse effects downstream as a result of dam removal.

This section summarizes the sediment quality sampling program, including the protocols used to collect and analyze sediment samples collected upstream of the dam and a discussion of the potential risk posed by sediment quality associated with dam removal. More specific details on the sampling and testing protocols can be found in the Exeter River/Great Dam Removal Feasibility and Impact Analysis Quality Assurance Project Plan (QAPP) that was prepared, reviewed and approved by the project partners and US EPA prior to sampling. In addition, a separate discussion and analysis on the bioaccumulation potential for various parameters detected was included in a Sediment Quality Technical Report, which was submitted and reviewed by NHDES in the fall of 2012. Representatives from both the 401 Water Quality Certification Program and Environmental Health Program reviewed and accepted the results of this report. The results of this bioaccumulation analysis are summarized herein in Section 3.4.4 below.

### 3.4.1 Sampling Locations

The NHDES Policy on the Evaluation of Sediment Quality for Dam Removals (NHDES, 2006) recommends that a minimum of four (4) sampling locations be established as follows:

- At a location immediately downstream of the dam,
- At a location in the impoundment immediately upstream of the dam,
- At a second location within the impoundment, and
- At a location upstream of the effects of the impoundment.

NHDES' policy generally suggests that a downstream sample be used as a reference station or to represent background conditions as it is typically not exposed to the same upstream contaminant sources and sediment deposition processes that occur within the impoundment. The upstream sample locations are generally targeted to cover different segments within the impoundment with one sample taken just above the dam and one sample collected just upstream of the impoundment.

For this study, a total of six sampling locations were included with five sediment samples collected within or upstream of the impoundment and one sample collected just downstream of the dam in the tidal portion of the Squamscott River. Sampling locations are shown in **Figure 3.2-11**.

The following six (6) locations were established to meet or exceed the minimum number of samples recommended by the NHDES Policy:

- ER-1: Downstream of the dam
- ER-2: Immediately upstream of the dam
- ER-3: Approximately 100 feet upstream of the Town's raw water intake.
- ER-4: Upper impoundment (near old town landfill off Powder Mill Rd.)
- ER-5: Upstream of the effects of the impoundment (lower riffle area)
- LR-1: Impounded portion of the Little River.

Sample station (ER-3) was selected to represent sediment quality conditions at a location just upstream of the municipal raw water intake used as a drinking water supply source for the Town. The station will be useful in assessing whether any sediment contaminants are located in the vicinity of the raw water intake. The additional sampling station located in the Little River (LR-1) was used to provide sediment quality data and sediment grain size data for the impounded portion of the Little River just upstream of its confluence with the Exeter River. This sampling location will help to assess whether the sediment grain size distribution and sediment chemistry properties are different than that in the Exeter River.

Following the initial round of sampling conducted in November 2011, a second limited round of sampling was conducted in Nov. 2012 just in the Little River near Station LR-1 to verify and confirm the presence of mercury levels in sediment. The results of both these sampling events are discussed below.

### 3.4.2 Analytes and Lab Methods

Consistent with the NHDES Policy (2006), sediment quality and particle size distribution data were analyzed for the following parameters:

- Total Organic Carbon (TOC) Method 9060
- Polynuclear Aromatic Hydrocarbons (PAHs) by USEPA Method 8270D
- Polychlorinated Biphenyls (PCBs) by USEPA Method 8082A
- Pesticides by USEPA Method 8081B
- Select Metals (arsenic, barium, cadmium, chromium, copper, lead, nickel and zinc USEPA Method 6010C) and Mercury (USEPA Method 7471B)
- Volatile Organic Compounds (VOCs) by USEPA Method 8260B
- Grain Size Distribution Analysis via sieve and hydrometer (silt and clay) by ASTM Method D-422, or comparable method

A more detailed description of the laboratory methods can be found in the previously submitted and approved QAPP.

### 3.4.3 Field Sampling Methods

Prior to sample collection, an approximate depth of unconsolidated sediment deposits was estimated using manual sediment probing techniques with stainless steel rods. As described in the project sampling QAPP, reviewed and approved by the project team prior to sampling, each sample consisted of a grab sample taken from the upper six to eight inches of the streambed using a hollow-stem stainless steel auger. A core sample from the upper six to eight inches of sediment was considered sufficient for a screening level analysis. The sampling program focused on the upper sediment layer (i.e., 6 to 8 inches) because these sediments are generally considered to be the most vulnerable to move during major flood events. This assumption is supported by the sediment transport analysis results presented earlier in Section 3.2.4.

The general sample locations are described above. While in the field, field samplers targeted the deepest portion of the channel that contained the greatest flow volume and made sure that there was sufficient sediment material available to enable analysis of all parameters including grain size distribution.

### 3.4.4 Sediment Quality Results

**Table 3.4-1** presents a summary of the analytical results for the various parameters tested that had levels above detection or method reporting levels (MRLs). These include various metals and polycyclic aromatic compounds (PAHs). The sediment samples were tested for other pollutants including volatile organic compounds (VOCs), pesticides and PCBs, as noted in Sec. 3.4.2 above. However, none of the samples had levels above detection or MRLs for these pollutants and, thus, are not reported here but are included in the lab reports provided in **Appendix I**.

Consistent with the NHDES Policy on Evaluating Sediment Quality (2005), the measured sediment concentrations were compared to published Threshold Effect Concentrations (TECs) and Probable Effect Concentrations (PECs) to evaluate whether the sample results may pose an environmental risk to aquatic organisms, and sediment-dwelling, freshwater organisms for the various parameters analyzed.

- TEC/Threshold Effects Concentration: Represents the estimated chemical concentration threshold that may pose an adverse risk to sediment dwelling organisms if exposed to higher levels.
- PEC/Probable Effects Concentration: Represents the estimated chemical concentration threshold that is likely to result in an adverse risk or effect on sediment dwelling organisms if exposed to higher levels.

The TECs and PECs used in this study were based on either the NOAA SQuiRT Tables for metals (Buchman, 2008) or the EPA Region 3 Freshwater Sediment Screening Benchmarks for Toxicological Assessment Guidance (BTAG) values (USEPA Region III, 2006). The NOAA SQuiRT Tables also have threshold guidance levels for sediment dwelling marine organisms. Since the aquatic environment below the dam is tidally influenced, these marine guidance levels were also used in the analysis, where data was available. For the marine environment, however, the published threshold effect concentrations and probable effect concentrations are expressed as threshold effect levels (TELs) and probable effect levels (PELs) instead of TECs and PECs but essentially represent the same threshold. For purposes of this analysis, the terms TEC and PEC were used to represent both freshwater and marine guidance levels and the comparison relied on the lower of the two thresholds.

To produce a TEC-Hazard Quotient (TEC-HQ) and PEC-Hazard Quotient (PEC-HQ), the observed concentration for each parameter was divided by the appropriate TEC and PEC value, respectively. If the TEC-HQ for a particular parameter is greater than 1.0 (meaning the observed concentration is higher than the TEC), then the sample results would indicate a Moderate Risk to sediment organisms for that parameter. If the PEC-HQ for a particular parameter is greater than 1.0, then the sample results would indicate a potential High Risk to sediment organisms for that parameter. Stations ER-1, ER-2, LR-1 and ER-4 had reported concentrations of metals and/or PAH compounds that were above TEC or PEC levels. None of the parameters analyzed in sediment samples from Stations ER-3 or ER-5 had observed concentrations above TEC or PEC levels. A more detailed description of the results for each sampling station is provided below.

It is important to note that not all of the parameters had published TEC and PEC values. In addition, for the VOCs, PCBs and pesticides where the analytical results were all below method reporting limits (aka detection levels), the method reporting limits were typically below the available TEC and PEC levels with the exception of three VOC compounds. This discrepancy for the three VOC compounds is not likely to change the overall results of this risk assessment since no VOC compounds were detected in any of the sediment samples, and the potential for these compounds to be at levels exceeding TEC or PEC levels is considered to be extremely low.

Overall, the potential risk that the proposed dam removal or modification alternatives may have on freshwater and/or marine benthic organisms depends both on sediment chemistry data and the estimated likelihood that sediment may move downstream with the dam removed or modified. As discussed in detail below, the chemistry data for sediments collected bottom sediments upstream of the dam present no greater toxicological risks to downstream aquatic life than what currently exists in the downstream sediment. The sediment transport analysis, presented in Section 3.2.4, indicates that a relatively limited amount of sediment material is expected to move downstream and primarily from only the lower reaches of the impoundment. The sediment chemistry analysis, as further discussed below, indicates that the observed parameter levels at the upstream sampling stations were generally less than the existing observed parameter levels in the downstream sediments as documented in other studies.

### Station ER-1

This station is located approximately 750 ft downstream of the dam in the tidal Squamscott River. Since this Station is located in a tidally influenced area below the dam, published TEC and TEL levels for freshwater and marine organisms, respectively, were used in analyzing the results for this station. The TEL-HQ and PEL-HQ values were based on the lower of the two values (freshwater or marine) and typically the marine TEL and PEL levels were lower.

This station had the greatest number of compounds that exceeded TEL or PEL levels and these primarily related to PAH compounds. There were two metals, chromium and nickel, that were just above published TEL levels with TEL-HQ values of 1.9 and 1.6. There were 15 PAH compounds with concentrations above the TEL threshold (i.e., TEL-HQ > 1.0). Three of the PAH compounds were also equal to or exceeded the PEC criteria. Concentrations of several PAH compounds were also significantly greater than the sediment concentrations measured downstream in the Squamscott River as part of the NCAP program.

The TEL-HQ levels ranged from 1.1 to 40.1 with all but three compounds having TEL-HQ values above 10. (See Appendix I.) These TEL-HQ values are generally higher than the computed TEL-HQ values for the other stations, which were all less than 5 and closer to 1. This suggests a much higher degree of contamination and potential risk to benthic organisms in the downstream sample compared to the above-dam samples. The elevated PAH levels at Station ER-1 are consistent with other sediment chemistry findings from sediment samples collected within the tidal area along Swasey Parkway as reported in previous technical reports focused on site remediation of remnant coal-tar deposits associated with a former coal to gas manufacturing plant that was once located along Water Street (AECOM, 2009).

The results of the hydraulic and sediment transport analysis suggests that the flow velocity, shear stress, incipient diameter and bedload rates downstream near Station ER-1 would essentially be the same with dam removal or modification. (See Section 3.3.4.) Essentially, the bed substrate is already very coarse in nature and subject to extensive sheer stress and high flow velocities under existing conditions. Thus, even though the sediments at ER-1 contain relatively high concentrations for several chemical constituents, the limited potential for sediment movement suggests that no sediment management actions are considered necessary at this station in relation to the potential dam modification or removal.[39]

[39] Findings presented in this section relative to the need for additional sampling or actions were reviewed with NHDES Watershed Management Bureau and Environmental Health Program staff on October 22, 2012 and represent a consensus recommendation.

Table 3.4-1. Summary of Sediment Quality Results by Sampling Station, Exeter River[1]

| | Threshold/Probable Effect Concentrations[2] | | | | Exeter River Sampling Results[2] | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|
| | Freshwater Criteria | | Saltwater Criteria | | ER-1 | ER-2 | ER-3 | LR-1 | ER-4 | ER-5 |
| | Consensus Effect Concentration | Probable Effect Concentration | Threshold Effects Level | Probable Effects Level | D/S Dam, Squamscott R. | U/S Dam, D/S Great Bridge | Near Gilman Park | Little River Confluence | D/S Former Landfill | U/S NH 111 |
| Metals | (mg/kg) | (mg/kg) | (mg/kg) | (mg/kg) | (mg/kg) | (mg/kg) | (mg/kg) | (mg/kg) | (mg/kg) | (mg/kg) |
| **Arsenic** | **9.79** | **33** | **7.24** | **41.6** | **3.1** | **5.2** | **4.0** | 13.0 | 12.0 | **1.7** |
| **Chromium** | **43.4** | **111** | **52.3** | **160** | 97 | **29** | **33** | **42** | 45 | **13** |
| **Copper** | **31.6** | **149** | **18.7** | **108** | **18** | **18** | **4** | 19 | 32 | **< 4** |
| **Lead** | **35.8** | **128** | **30.2** | **112** | **11** | 43 | **9.2** | **30** | **15** | **3.4** |
| **Mercury** | **0.18** | **1.06** | **0.13** | **0.70** | **0.110** | **0.110** | **< 0.05** | 1.30 | **< 0.05** | **< 0.05** |
| **Nickel** | **22.7** | **48.6** | **15.9** | **42.8** | 25 | 19 | **13** | 23 | 26 | **5** |
| PAHs | (ug/g) | (ug/g) | (ug/g) | (ug/g) | (ug/g) | (ug/g) | (ug/g) | (ug/g) | (ug/g) | (ug/g) |
| **Acenaphthylene** | **na** | **na** | **0.0059** | **0.13** | 0.07 | 0.01 | **<0.01** | 0.02 | **<0.01** | **<0.01** |
| **Acenaphthene** | **na** | **na** | **0.0067** | **0.089** | 0.04 | **<0.01** | **<0.01** | **<0.01** | **<0.01** | **<0.01** |
| **fluorine** | **0.0774** | **0.536** | **0.0021** | **0.536** | 0.04 | **< 0.03** | **< 0.03** | **< 0.03** | **< 0.03** | **< 0.03** |
| **Phenanthrene** | **0.204** | **1.17** | **0.087** | **1.17** | 1.17 | **0.07** | **< 0.03** | **0.04** | **< 0.03** | **< 0.03** |
| **Anthracene** | **0.0572** | **0.845** | **0.049** | **0.845** | 0.21 | **< 0.03** | **< 0.03** | **< 0.03** | **< 0.03** | **< 0.03** |
| **Fluoranthene** | **0.423** | **2.23** | **0.113** | **2.23** | 2.19 | 0.2 | **< 0.03** | 0.14 | **< 0.03** | **< 0.03** |
| **Pyrene** | **0.195** | **1.52** | **0.153** | **1.52** | 1.87 | 0.18 | **< 0.03** | **0.12** | **< 0.03** | **< 0.03** |
| **benzo(a)anthracene** | **0.108** | **1.05** | **0.075** | **1.05** | 1.07 | 0.11 | **< 0.03** | **0.05** | **< 0.03** | **< 0.03** |
| **Chrysene** | **0.166** | **1.29** | **0.108** | **1.29** | 1.06 | 0.11 | **< 0.03** | **0.07** | **< 0.03** | **< 0.03** |
| **benzo(b)fluoranthene** | **0.0272**[4] | **na** | **na** | **na** | 0.92 | 0.09 | **< 0.01** | 0.07 | **< 0.01** | **< 0.01** |
| **benzo(k)fluoranthene** | **0.0272**[4] | **na** | **na** | **na** | 1.09 | 0.13 | **< 0.01** | 0.05 | **< 0.01** | **< 0.01** |
| **benzo(a)pyrene** | **0.15** | **1.45** | **0.089** | **1.45** | 0.93 | **0.1** | **< 0.03** | **0.05** | **< 0.03** | **< 0.03** |
| **indeno(1,2,3-cd)pyrene** | **0.017**[4] | **na** | **na** | **na** | 0.22 | 0.03 | **< 0.01** | 0.02 | **< 0.03** | **< 0.01**[5] |
| **dibenzo(a,h)anthracene** | **0.033** | **na** | **0.006** | **0.33** | 0.11 | 0.01 | **< 0.01** | **< 0.01** | **< 0.01** | **< 0.01**[5] |
| **benzo(g,h,i)perylene** | **0.17** | **na** | **na** | **na** | 0.19 | **< 0.03** | **< 0.03** | **< 0.03** | **< 0.03** | **< 0.03**[5] |

Notes:

1. Sampling date November 7, 2011.
2. Bold values indicate that the sample exceeded the suggested TEC/TEL levels. Shaded cells indicate that the sample exceeded the suggested PEC/PEL levels. See Appendix I for complete sampling results including TEC-HQ and PEC-HQ values.
3. The Freshwater and Saltwater Threshold Effect Concentrations (TEC's) and Probable Effect Concentrations (PEC's) are primarily based on the 2006 EPA Region III Sediment Screening Benchmarks at http://www.epa.gov/reg3hwmd/risk/eco/btag/sbv/screenbench.htm or those listed in the NOAA SQuiRT Tables, with a few exceptions as noted.
4. The TEC levels used for three PAHs were published separately by the International Association of Great Lakes Research.
5. The percent recovery for surrogate parameters for laboratory control matrix spike duplicate were outside previously specified acceptance criteria. The data is still considered valid, however, the margin of error or confidence limits tends to be greater for the parameters where % recovery was outside the desired lab criteria for spike duplicates.

### Station ER-2

This station is located approximately 20 feet upstream of the dam spillway and below the Great Bridge. Station ER-2 had nine (9) PAH compounds and two (2) metals, lead and nickel, with observed concentrations that were above the fresh and/or saltwater TEC criteria (i.e., TEC_HQ > 1.0). None of the parameters exceeded the fresh or saltwater PEC criteria. The highest TEC-HQ value was 4.8 for a PAH compound known as benzo(k)fluoranthene and the TEC-HQ values for the metals were 1.2 and 1.4 for nickel and lead, respectively. This sampling location was generally described as having a cobbly/rocky bottom, some boulders and limited sediment. During the sediment sampling, it was noted that there was very little unconsolidated sediment available for sampling and the approximate depth of sediment generally ranged between 0 and 6 inches. The presence of large boulders and even ledge were encountered during sampling. The grain size analysis results indicate that approximately 25 percent of the collected sediment material was greater than 3/8 inch in diameter (see **Appendix I**).

The measured parameters concentrations at the ER-2 location were comparable or less than parameter concentrations measured downstream based on National Coastal Assessment Program (NCAP) data as provided by NHDES. Thus, any sediment movement downstream with the dam removed is not expected to pose any greater toxicological risk to aquatic organisms than what currently exists based on the existing downstream sediment quality data. In addition, even though the sediment transport analysis presented in Section 3.2.4, indicates that the flow velocities at this location may change significantly with the dam removed or modified, the limited amount of unconsolidated sediment that currently exists at this location (i.e., ~6 inches of material observed in the field) suggests that only relatively minor amounts of material may move downstream during high flow events. No additional sampling is considered necessary at ER-2 with respect to this feasibility study.

### Station ER-3

This station is located in the main stem of the Exeter River approximately 0.7 mile upstream of the dam and just upstream of the Town of Exeter's drinking water intake. None of the observed parameter concentrations at this sample location exceeded the available TEC or PEC levels. The bottom material was described as sandy/silty material with very little cobble or rock. The grain size analysis indicates that the bottom sediment at this location had some of the finest grained material relative to the other stations with more than 55 percent of the material considered to be silt/clay particles. Only Station ER-4, the next station upstream, had a higher percentage of silt and clay material.

Since none of the measured concentrations exceeded the TEC or PEC criteria and the concentrations of all the measured parameters at this site were comparable or less than sediment concentrations measured downstream either as part of this feasibility assessment or the NCAP data, the potential impact of any sediment movement from this site is not expected to cause any greater toxicological risk to bottom dwelling organisms downstream. Although the sediment transport analysis in Section 3.2 4 indicates that there is potential for sediment to move from ER-3 if the dam was removed, no additional sampling or future sediment management measures are considered necessary at ER-3.

### Station LR-1

Station LR-1, is located in the Little River just above the confluence with the Exeter River and is also approximately 0.7 miles above the dam. The sediment sampling at the location showed four (4) metals including arsenic, copper, mercury and nickel that had observed concentrations that were equal to or above TEC levels, In addition, there were five (5) PAH compounds with concentrations above TEC levels. The observed mercury concentration of 1.3 mg/kg was well above the published PEC level of 0.7 mg/kg, with a computed PEC-HQ value of 1.9 using saltwater criteria. This was the only above-dam location that had a parameter concentration above a PEC level. The computed TEC-HQ value was close to 10 which was much higher than any of the other parameters including arsenic, copper and nickel, which had TEC-HQ values of 1.8, 1.0 and 1.0, respectively. The TEC-HQ values for the PAH compounds ranged from 1.2 to 3.4. With the exception of mercury, all of the measured parameters were comparable or less than the NCAP sediment concentrations measured downstream in the Squamscott River.

Following review and discussions with DES on the initial sampling results, additional sampling was conducted at the LR-1 location to confirm and verify the presence of mercury in the sediment at this location. As part of the additional sampling, five different samples were collected in close proximity to and at the same mid-channel location that was previously sampled. This additional sampling focused on mercury only since it was the only parameter that was detected to be much higher than the reported levels in the downstream NCAP data. (**Table 3.4-2.**)

Table 3.4-2. Additional Little River Sediment Sampling for Mercury near Station LR-1 following Initial Sampling Phase

| Field ID/Sample | Relative Location | Reported Mercury Concentration (mg/kg) | Freshwater (mg/kg) | | Saltwater (mg/kg) | |
|---|---|---|---|---|---|---|
| | | | TEC | PEC | TEL | PEL |
| LR-A | ~ 75 ft Upstream | < 0.04 | 0.18 | 1.06 | 0.13 | 0.70 |
| LR- B/ LR-B-dup | Near LR-1 | 0.06/0.06 | 0.18 | 1.06 | 0.13 | 0.70 |
| LR-C | ~25 ft Upstream | < 0.09 | 0.18 | 1.06 | 0.13 | 0.70 |
| LR-D | ~ 50 ft Upstream | < 0.04 | 0.18 | 1.06 | 0.13 | 0.70 |
| LR-E | ~ 50 ft Downstream | 0.24 | 0.18 | 1.06 | 0.13 | 0.70 |

The additional sampling revealed much lower mercury concentrations, with four of the five samples having mercury concentrations that were well below the TEC and PEC levels. One sample, identified as Sample LR-E, had a mercury concentration that was above the TEC level at 0.24 mg/kg. The results of this additional sampling from multiple locations in the Little River suggest that the relatively high mercury concentrations observed in the initial sampling may have been an anomaly. These additional sampling results have been reviewed and discussed with NHDES and as a result of these discussions, no further sampling or action was considered necessary.

The substrate material at this location was described as being composed of fine sand with some gravel and silt material. The grain size analysis results indicate that the substrate had a relatively high percentage of fine sand particles as well as silt and clay-sized particles.

Although the sediment transport analysis, provided in Section 3.2.4 indicates that the sediment incipient diameter is likely to increase due to increased flow velocities during high flow conditions with the possible dam removal or modification, no further sediment management actions are considered necessary since the measured parameter concentrations are considered less or similar to the measured downstream concentrations in Squamscott River as part of the NCAP assessment.

### Station ER-4

The next upstream location, Station ER-4, is located approximately 5.7 miles upstream of the dam and adjacent to a former landfill that was located off Powder Mill Road. This station had four (4) metals (arsenic, chromium, copper and nickel) with reported concentrations above TEC levels. However, the observed chromium and copper concentrations were just slightly above the TEC level with a TEC-HQ of 1.05 and the estimated TEC-HQ for nickel and arsenic were 1.10 and 1.20, respectively. There were no PAH compounds detected in the ER-4 sample. The substrate material was described in the field notes as very fine sandy silt, tight material that showed some greyish coloring that could be indicative of buried marine clay deposits or perhaps due to reduced oxygen conditions. The grain size analysis also demonstrates a relatively high percentage of silt and clay material.

Although several parameters exceeded the TEC criteria, no additional sampling or mitigation activities are considered necessary at ER-4, since the concentrations of all measured parameters at this site were comparable or less than typical downstream sediment concentrations based on a comparison to NCAP sediment data and, based on the sediment transport analysis, little to no additional sediment is expected to move downstream from this location if the dam were to be removed or modified.

### Station ER-5

This station is located approximately 6.7 miles upstream of the dam in the Exeter River, downstream of the Cross Road Transfer Station, in a riffle area above the limits of the impoundment. Sampling results indicate no concentrations above the published TEC and PEC levels of any of the parameters. Further, all of the measured parameters were comparable or less than sediment concentrations measured downstream in the Squamscott River for the NCA program. The substrate material at this location was described as coarse sandy deposits with some cobble/rock material nearby. Because hydraulic modeling demonstrates that this location is above the influence of the dam, no additional sediment transport would occur under either the dam removal or dam modification alternatives. Additional sampling at this location is therefore not considered necessary for this feasibility study.

In addition to comparing observed concentrations to TEC and PEC values, as discussed above, a limited bioaccumulation analysis was conducted to preliminarily assess the bioaccumulation risk for specific parameters that TEC-HQ or PEC-HQ values above 1.0. The specific parameters evaluated include three metals (arsenic, mercury, nickel) and two PAH compounds (benzo(a)anthracene and indeno(1,2,3-cd)pyrene). The analysis focused on estimating potential tissue concentrations in a saltwater mussel species (*Mytilus galloprovincialis*) using published Biota Sediment Accumulation Factors (BASFs) as there was limited published data available for other marine and freshwater organisms. This information was included in a separate Sediment Quality and Transport Analysis Technical Report that was submitted to DES in August 2012 for review and comment. DES has provided written response that concurred with the general conclusion of this analysis in that the bioaccumulation risk does not appear to be of significant concern given that the bioaccumulation risk ratio was less than 1.0 for the various parameters evaluated and the relatively limited risk and volume of sediment material predicted to move during major flow events with the proposed dam removal.

## 3.5 Sediment Management

One of the primary functions of a river is to convey not only water, but to also transport sediment, nutrients and woody debris. The presence of the Great Dam has interrupted this normal process in the Exeter River. Removal or modification of the dam would restore this process to varying degrees, as discussed in Section 3.2.4.

Based on the sediment transport results, it is expected that a volume of currently-impounded sediment would move downstream following the project. It is important to consider downstream resources and anticipate what effect this sediment migration may have on ecological and human resources. This section provides a discussion of what type of sediment management measures may be needed to mitigate any potential impacts relative to the downstream resources and to consider the measures that could be implemented to manage this potential impact.

### 3.5.1 Sediment Volumes

As presented in Section 3.2.4 and 3.3, with the exception of the *No Action* and *Stabilize in Place Alternatives*, all alternatives would either fully or partially restore normal sediment transport processes to the river. While the presence of bedrock at the dam site would limit the potential for rapid changes in the river, the restoration of normal sediment transport would increase the sediment load to downstream reaches of the Squamscott River.

Some of the key conclusions that can be drawn from the sediment transport analysis are as follows:

- **Sediment transport into the Squamscott River could increase substantially – perhaps as much as 2.5 to 6.5 fold.** The most meaningful data are provided in Table 3.2-23, which shows that, over a five year simulation period, the total amount of sediment delivered to the Squamscott River would increase from about 2,000 to 3,000 cubic yards under the existing condition to about 8,000 to 13,000 cubic yards under the dam removal or dam modification alternatives.

- **Most of the sediment that is predicted to move downstream will come from the Exeter River and Little River downstream of their crossing of NH 108.** The sediment transport analysis divided the river into seven different reaches which provides some understanding of which reaches may degrade and which may aggrade. This information indicates that sediment will move from the reach between the Little River confluence to the NH 108 on both the Exeter River as well as the Little River. These data also indicate that, perhaps counter-intuitively, material will be deposited in the reach below the Little River confluence to the Great Dam – i.e., material will move from reaches far upstream of the dam to the reach closest to the dam.

- **Chemical analysis of the sediment upstream of the dam shows that these sediments contain metals and PAHs, however, the levels detected should not present a risk to ecological or human health.** Sampling for potential hazardous contaminant was conducted during this study (see Section 3.4). Certain chemicals were detected in sediments within the impoundment. However, further analysis shows that the levels of contaminants in these sediments are not high enough to pose a significant risk to aquatic organisms or human health. This means that no remedial activities would need to occur prior to removal or modification of the dam to ecological risk from contaminants.

- **Full Dam Removal, Partial Dam Removal and Dam Modification would all have similar effects.** As shown by the sediment transport calculations reported in Section 3.2, all of these alternatives would increase sediment transport to a similar degree. Thus, unless the Stabilize in Place Alternative is selected by the community, a sediment management plan is warranted.

- **Only** ***Alternative G – Stabilize in Place*** **would maintain the current sediment transport regime.** Because Alternative G would maintain the dam spillway at its current height, there would be no change to the rate of sediment transport from the Exeter River into the Squamscott River.

- **Tidal flushing in Squamscott River is likely to remain the dominant process downstream**. The volume of water that is carried up and downstream in the Squamscott River on a daily basis as a result of tidal influences is much greater than the flow of water from the river. Tidal dynamics are complex phenomena, but the geomorphological analysis suggests that the delivery of additional sediment to the Squamscott River should not create substantial permanent impacts.

### 3.5.2 Downstream Resources & Likely Depositional Areas

Based on geomorphic analysis and a consideration of resources in the Squamscott River, four areas of concern were identified as follows (See **Figure 3.3-5**):

- **Sandbar Below String Bridge.** There is an existing sand bar just below the String Bridge. The bar has been in place for some time, but has apparently grown in size over the last decade. This bar is significant because it is located at the head of tide and is therefore within an area used as spawning habitat by smelt. In fact, the NHF&GD has planned a habitat restoration project which would remove some of the deposited material in this location. Because this is already a depositional area, it is likely that some of the new sediment would be deposited in this location which could further impact smelt spawning.

- **PEA Boat Basin.** Phillips Exeter Academy maintains a boathouse and boat basin on the west side of the Squamscott River near the southern end of Swasey Parkway. This basin has been recently dredged and requires periodic maintenance. Because of its position relative to the head of tide, and because it is an artificially maintained basin, it is possible that sediment could be deposited in this area, which could impact recreational activity associated with the facility and require more frequent maintenance dredging.

- **Meander Bar and Salt Marsh downstream of Clemson Pond.** Another area of potential deposition is on the inside of a large radius bend in the Squamscott River, located downstream of Clemson Pond. This area is currently relatively shallow, and velocities are lower than the adjacent river. These factors suggest that sediment could be deposited in this area.

- **NH 101 Bridge Crossing.** While the opening of the NH 101 highway bridge across the Squamscott River is relatively large, under certain conditions, this bridge may serve as a constriction to outgoing tides. This suggests that sediment might also be deposited here.

Predicting the timeline and spatial extent of sediment deposition in the Squamscott River is complicated by many factors. It is currently unknown exactly how long it would take for sediments to be moved out of the Exeter/Little River system and into the Squamscott. The sediment transport simulations suggest that this process should reach equilibrium within 5 to 10 years, although this will be dictated by future flows, which cannot be known at this time. If large floods occur in the period immediately following dam removal or modification, sediment could move rapidly and equilibrium achieved in a relatively short period of time. However, if floods are not experienced, then the period of sediment transport would be extended. Similarly, the location of downstream deposition cannot be predicted precisely based on the tools and data available at this time.

In order to understand the potential impact, calculations were performed to attempt to predict a best and worst case scenario with regard to the depth of downstream sediment deposits. For example, if the predicted volume of sediment is deposited in the area from the String Bridge to the NH 101 Bridge, then average sediment depths would be approximately one inch. If, however, sediments were deposited over a much more limited area (e.g., the four areas of concern identified above), then sediments could be as much as one foot deep in some areas.

### 3.5.3 Management of Downstream Sediment Deposits

There are two main strategies that could be employed to manage sediments during and following dam removals:

- **Active Management.** Active management would entail dredging sediments prior to dam removal or modification in order to prevent the sediment from being transported downstream. This is most appropriate when the spatial extent of at risk sediment is limited, or where sediments are known to be contaminated.

- **Passive Management.** This strategy would involve allowing sediments to migrate downstream as flows dictate following removal. Natural sediment transport processes would resume, and the river would move the sediment downstream without substantial intervention.

***For the Great Dam project, it is recommended that a passive management approach be followed for the following reasons:***

- **The source of at risk sediments is significantly upstream of the dam and is spread over a wide area.** As reported elsewhere in this report, very little sediment has accumulated at the dam site, where river processes have continued to carry sediments over the dam. Rather, the sediments most likely to move are located a distance upstream in the Exeter and Little Rivers.

- **Dredging of sediments over a large area would be very costly.** Dredging would involve excavation by large machinery, trucking, and disposal costs. The cost of dredging is expected to be as much or more than the modification or removal of the dam itself.

- **Dredging would also create significant ecological impacts that would be mitigated by allowing sediment to move naturally.** When material is removed from a river system, animals and plant life are not able to adapt to the changed conditions. Oftentimes, extensive turbidity is generated, which can impact downstream resources. These factors suggest that dredging would not mitigate the environmental impacts of potential sediment movement.

While a passive management strategy is recommended, there are other measures which could be employed to minimize the possible effects.

- **Early and Controlled Drawdown.** Opening the existing low-level outlet well in advance of the project would drawdown the impoundment which would limit water quality impacts, and allow some sediment to be transported downstream in a controlled manner. This drawdown would need to be conducted in coordination with NHDES and NHF&D to prevent unintended impacts to water quality or fish migration.

- **Vegetate Exposed Streambed and Banks.** Immediately following the drawdown, areas of bare soil will be exposed in the impoundment. These areas could be seeded with native vegetation in an attempt to stabilize the soils and prevent excessive erosion. This measure would have other benefits as well – it would limit the potential for invasive or non-native plant species and would create wildlife habitat value.

- **Consider Installation of a Sediment Curtain at the PEA Boat Basin.** It is noted that the basin will likely fill eventually due to the fact that it is artificially maintained. However, dam removal or modification could accelerate this process – at least temporarily. Therefore, the installation of a turbidity curtain or other structure should be considered. A variety of "turbidity curtains" are available on the market. These devices are intended to limit turbidity impacts during in stream excavation work and are generally considered a temporary measure. However, a semi-permanent system could be designed and installed at the boat basin, which would help to direct migrating sediments away from the basin and thereby preserve its depth.

- **Delay the Smelt Restoration Project.** As discussed above, NHF&GD is considering lowering the sand bar deposit just downstream of the String Bridge in an effort to improve fisheries habitat for smelt. Because this is an area that could see increased sediment deposition following the project, it is recommended that this project be delayed for a period of at least one year.

- **Monitoring.** Monitoring of upstream and downstream reaches is recommended. This monitoring effort would help to identify any potential ecological or infrastructure impacts, and allow for efficient remediation if needed. The monitoring data would also contribute to a better understanding of sediment transport dynamics which could be useful in planning future dam infrastructure project.

## 3.6 River Ice

### 3.6.1 Documented Ice Jams on the Exeter River

As discussed above, rivers carry water and sediment. In cold climates, ice can also be an important factor. An ice jam is a stationary accumulation of fragmented ice that restricts river flow. Ice jams are a common, natural process in northeastern rivers, and usually do not cause any problems except when combined with floodplain encroachment by buildings, roads, or bridges. Research by the US Army Corps of Engineers Cold Regions Research & Engineering Laboratory (CRREL) in Hanover, NH has shown that dams in the Northeast can affect ice dynamics in certain rivers.

A review of databases maintained by CRREL determined that no documented ice jams have occurred in Exeter. The closest documented ice jams occurred in Dudley Brook, a tributary of the Exeter River outside of the project vicinity.

### 3.6.2 Field Survey for Ice Jamming

The CRREL methodology states that a site visit investigating probable locations of historical ice jams provides valuable information to predict the impact of dam removal on river ice dynamics (ERDC/CRREL TR-07-18). Therefore, a site survey was conducted in September 2011 to search for field evidence of ice jamming at locations likely to be subject to ice jamming. (See **Figure 3.6-1**.)

The Exeter River was canvassed from above the Pan Am Railways/Amtrak bridge downstream to the Great Dam via canoe, vehicle and on foot. At the time of the field survey, the river was in a low flow condition (50 cfs at the USGS Exeter River at

Haigh Road, near Brentwood, NH Gage, 01073587), with the impoundment drawn down about 2-3 ft from current pool elevation. Each specific observation location was geo-referenced with a WAAS-enabled Garmin Map-76 handheld GPS unit. Evidence of ice jamming included scarring or de-barking of stream bank trees at or above the normal high water mark, and/or evidence of broken tree limbs at similar elevations.

#### Upper Impoundment

The upper impoundment was represented by Survey Locations 1 and 2 (the southeastern section along the Exeter River near Wadleigh Point). The river passes through a wooded, undeveloped area in with steeply-sloped banks, and riparian wetlands. The river channel is approximately 50-75 ft wide in this reach. Although there is evidence of some trees fallen into the river, this appears due to normal attrition rather than a result of extensive erosion or ice damage. No evidence of ice jamming was found in this reach.

#### Mid- Impoundment

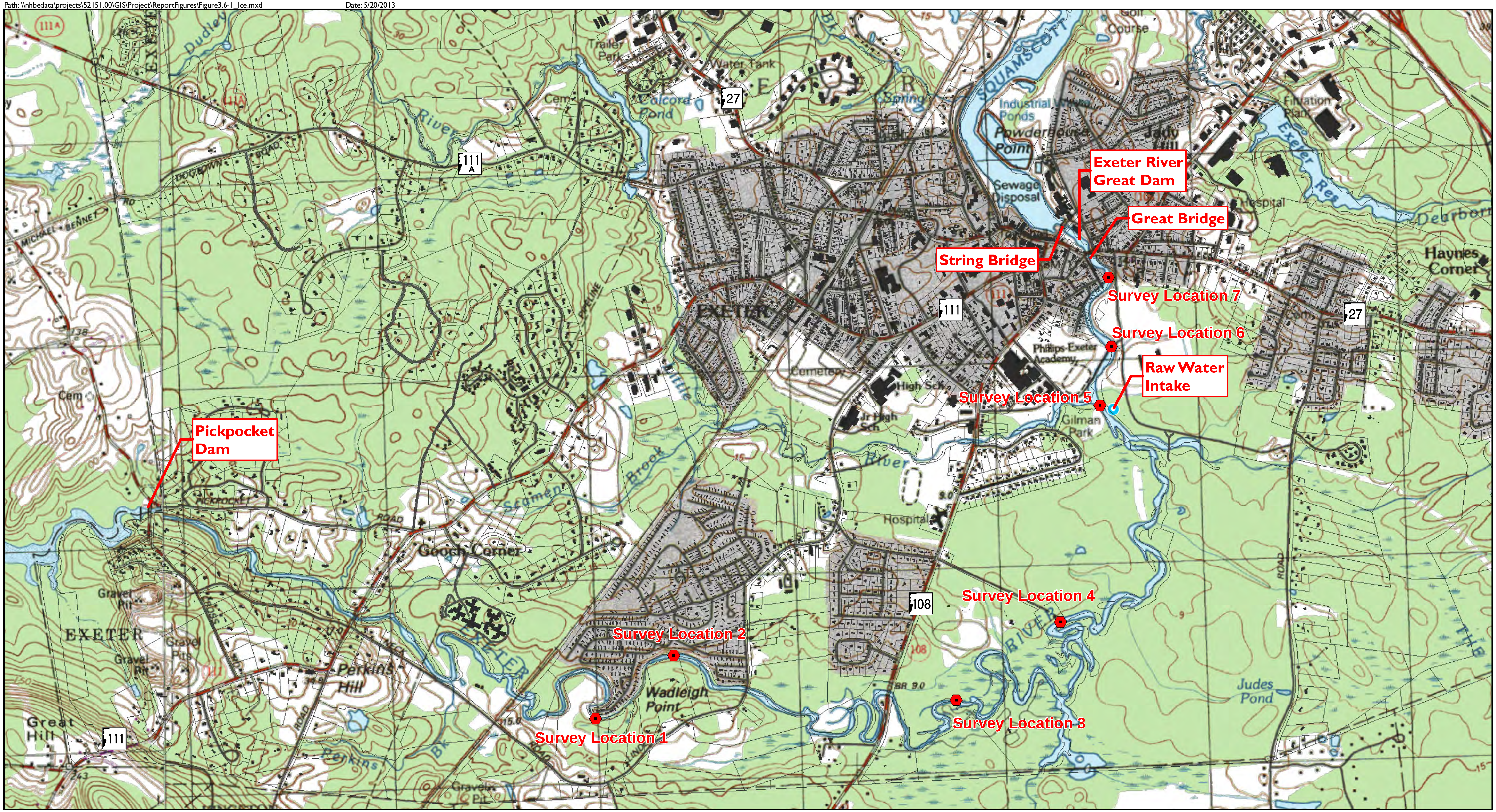
The middle impoundment was represented by Survey Locations 3 and 4 (south of the Raw Water Intake and east of Route 108 on the Exeter River). The river passes in large meanders through a wooded, generally undeveloped area in moderately-banked, forested area with riparian wetlands and alders fringing the shoreline. The river channel is approximately 100 ft wide in this reach with stable embankments. No evidence of ice jamming was found in this reach.

#### Lower Impoundment

The lower impoundment was represented by Survey Locations 5, 6 and 7 (north of the Raw Water Intake to the Great Dam). The river enters a densely-settled residential area that includes Phillips Exeter Academy. The river channel is approximately 100-125 ft wide in this reach with stable embankments. The shoreline generally is stable with woody riparian vegetation, but is also developed with landscaping and shrub removal along the banks in residential areas. There are structures such as electric substations and pump-houses located directly along the banks in this reach. Like other reaches, no evidence of ice jamming was found in this reach.

### 3.6.3 Discussion of Potential Effects

Based on the lack of documented ice jams on the Exeter River and the lack of field evidence of ice jamming in the impoundment of the Great Dam, the modification or removal of the Great Dam should have no effect of river ice dynamics.




**Legend**

Ice Jamming Field Survey Locations

0 1,500 3,000 Feet

Source: USGS 7.5 Minute Quadrangles: Exeter, Kingston

*Vanasse Hangen Brustlin, Inc.*

**Figure 3.6-1**
**Ice Jamming Field Survey**
**Exeter Great Dam Removal**
**Feasibility & Impact Analysis**

**Exeter, NH**

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## 3.7 Infrastructure[40]

The Great Dam is surrounded by several businesses, roads and bridges. Some of the foundations for these buildings are located in the river, both upstream and downstream of Great Dam. Several bridges cross the Exeter River both upstream and downstream of the dam, including the String Bridge directly downstream, the Great Bridge directly upstream of the dam and the Phillips Exeter Academy footbridge approximately 2,000 feet upstream of the dam. Additionally, several water withdrawals are located in the 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 dam removal or modification. The structures with potential for being affected are further discussed below.[41]

### 3.7.1 Bridges, Walls and Foundations

A field evaluation of bridges, walls and foundations in the impoundment was performed in September 2011. During the field visit, some of the basements of the buildings along the river were accessed, drawings were reviewed as available, photographic documentation was collected and field observations were noted. The HEC-RAS model (developed to assess a variety of changes to the Exeter River hydraulics) 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 two year, ten year, fifty year, and one hundred 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 various cross-sections of the impoundment 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 either Dam Removal, Partial Removal or Dam Modification, the water surface elevations would be lower and the velocities would be higher than

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40 Discussions herein are intended to be preliminary in nature with the objective of informing interested parties regarding some, but not necessarily all, possible effects of proposed alternatives, and these discussions should be used as such.

41 Based on the results of the hydraulic analysis, there would be no effects on river depths, velocities or shear stresses downstream of the dam site. Therefore, downstream structures such as the String Bridge or the retaining walls along Kimball Island are not at risk and not discussed further in this analysis.

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 the Stabilize in Place or Dam Modification Alternatives would remain very similar to the Existing Condition due to the proposed crest gate operations.

However, during flood events the proposed gates will be opened such that the dam maintains a minimum of one foot of freeboard per NHDES safety requirements. Under Dam Modification (Alternative H) it is predicted water velocities in the vicinity of the dam would significantly increase during the 50-year flood event, varying from 11 ft/sec near the bridge to 6 ft/sec near the dam. These velocities are approximately 50 percent higher than the current conditions under similar flows. Dam Removal (Alternative B) and Partial Removal (Alternative F) would have similar results to Dam Modification (Alternative H) under flood flows. For example, the model indicates that 50-year flood water velocities vary from 13 ft/sec at the bridge to 8 ft/sec at the dam for Alternative B.

The increased velocities, coupled with the lower water depths for both alternatives, may create scouring conditions. Scour is defined as erosion of streambed or bank material caused by flowing water, usually being localized.[42] 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.

#### 3.7.1.1 Structures Reviewed but Not Impacted

There are several structures upstream of the Great Bridge, including the PEA/Stadium Bridge and the NH 108/Court St Bridges on the mainstem of the Exeter and the Little River. Additionally, the String Bridge and adjacent retaining walls are located a relatively short distance downstream.

Based on the hydraulic model results and their locations, these structures *are not* likely to be adversely affected by implementation of either Alternative B (Dam Removal) or Alternative H (Dam Modification). The water levels would be lower during flood events and therefore less likely to impact the structures with hydraulic loading. The water velocities are slightly higher for both alternatives than current

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42 Evaluating Scour at Bridges, Fourth Edition, US Department of Transportation Federal Highway Administration, Publication No. FHWA NHI 01-001, 2001

conditions; however the velocities do not exceed 3–4 ft/sec under normal conditions, which indicates low scour potential. Due to the low scour potential, the foundations of the PEA/Stadium Bridge and the NH 108/Court St Bridge will not likely experience deterioration due to the proposed modifications. Downstream, the model shows that there would be no meaningful change in velocities.

#### Recommendation:

- No further action is required for structures upstream of the Great Bridge because the effects of the alternatives are considered relatively minor
- No further action is required for the String Bridge or associated retaining walls because the Dam Removal, Partial Removal or the Dam Modification Alternatives will not change hydraulic conditions downstream. As discussed in Section 3.2, the Great Dam is a run-of-the-river dam, which has little influence on depths and velocities downstream.

### 3.7.1.2 Loaf and Ladle Restaurant (1-9 Water Street, Map 72, Lot 41)

The foundation of the Loaf and Ladle is located on the river's edge, and includes a concrete slab on grade, indicating the rocks visible from the exterior are cosmetic (**Figure 3.7-1**). The exterior of the foundation was visually observed, photographed and documented. The building owner stated that there were concrete piers supporting the slab, which was not confirmed, but if verified would indicate the structure is supported by means other than the river bank material.

Based on the hydraulic model results, some of the potential effects of the Dam Removal or Dam Modification Alternatives on the Loaf and Ladle are as follows:

- The higher scour potential under the proposed Dam Removal or Modification Alternatives may affect the foundations if it is not adequately founded on ledge. It was not possible to determine the current condition of the foundation bearing during the field visit and no drawings are currently available, leaving the foundation details for this structure unknown.

- Another condition specific to Dam Removal (Alternative B) and Partial Removal (Alternative H) is that the water surface elevations under normal flow conditions will be lower than the foundation bearing elevations of some of these structures. The foundations would then be exposed to different types of erosion. For example the water surface may fluctuate above and below the foundation bearing elevation, thereby introducing wave action, debris and ice loading to unprotected soils.

\\nhbedata\PROJECTS\52151.00\graphics\FIGURES\support\52151_fig_51713.indd

Exterior of Loaf and Ladle

Interior Basement of Loaf and Ladle

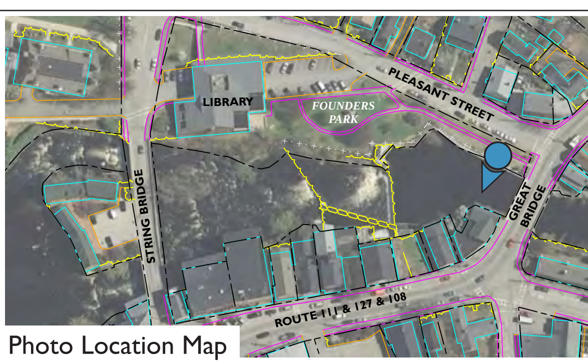


Photo Location Map

Vanasse Hangen Brustlin, Inc.

**Figure 3.7-1**

**Views of Loaf and Ladle Foundation**

**Exeter Great Dam Removal Feasibility and Impact Study**
**Exeter, NH**

Also, due to the absence of the water buffer there may be a potential for freeze-thaw and upheaval of the foundation bearing material during the winter months.

## Recommendations:

- Perform geotechnical investigations to determine foundation bearing conditions and capacity to resist the potential scour.
- If the dam is removed or modified, visually monitor the foundation for excessive freeze thaw, ice and debris loading damage after floods and winter conditions.

### 3.7.1.3 11 Water Street Restaurant (Map 72, Lot 42)

The owner of the restaurant installed a concrete wall against the outside face of the existing foundation wall (**Figure 3.7-2**). The foundation for the building adjacent to the river appears to be concrete; however the foundation for the larger structure appears to be concrete masonry unit blocks and brick with concrete infill sections.

Based on the hydraulic model results, some of the potential effects of the Dam Removal or Dam Modification Alternatives on the 11 Water Street Restaurant are as follows:

- The higher scour potential may affect the foundations that are not soundly founded on ledge. It was not possible to determine the current condition of the foundation bearing during the field visit and no drawings are currently available leaving the foundation details for this structure unknown.

- Another condition specific to Dam Removal (Alternative B) is that the water surface elevations under normal flow conditions will likely be lower than the bearing elevations of some of these structures. The foundations would then be exposed to different types of erosion. For example the water surface may fluctuate above and below the foundation bearing elevation, thereby introducing wave action, debris and ice loading. Also, due to the absence of the water buffer there may be a potential for freeze-thaw and upheaval of the foundation bearing material during the winter months.

## Recommendations:

- Perform geotechnical investigations to determine foundation bearing conditions and capacity to resist the potential scour.

A. Concrete wall adjacent to foundation wall

B. General view of Water Street Restaurant

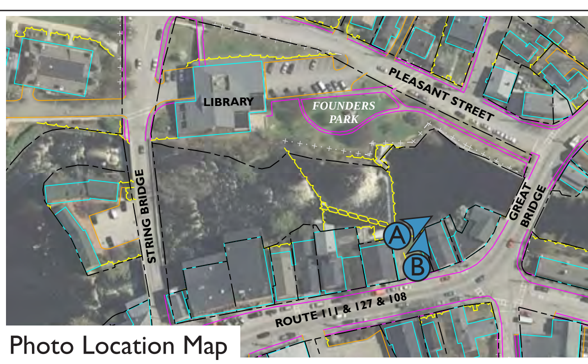


Photo Location Map

Vanasse Hangen Brustlin, Inc.

**Figure 3.7-2**

**Views of 11 Water Street Foundation**

**Exeter Great Dam Removal Feasibility and Impact Study Exeter, NH**

- If the dam is removed or modified, visually monitor the foundation for excessive freeze thaw, ice and debris loading damage after floods and winter conditions.

### 3.7.1.4 Retaining Wall at Empty Lot (23 Water Street, Map 72, Lot 39)

During the site inspection conducted as part of this study, the lot at 23 Water Street was being used as access for the construction of a replacement retaining wall on the adjacent lot to the north. The intent of the new retaining wall is to bypass the existing stone retaining wall that seems to be sliding (**Figure 3.7-3**). The conditions causing the sliding will not likely change based on the proposed alternatives. However, the fish passage structure serves as a retaining wall support and therefore, additional structures may be needed if the dam and associated fish passage structures are removed (Alternative B). The need for these additional structures would be evaluated during the final design if the Dam Removal Alternative is selected.

Based on the hydraulic model results between the Great Dam and the Great Bridge (High Street), some of the potential effects of the Dam Removal or Dam Modification Alternatives on the Retaining Wall at the Empty Lot are as follows:

- The higher scour potential may affect the foundations that are not soundly founded on ledge. It was not possible to determine the current condition of the foundation bearing during the field visit and no drawings are currently available leaving the foundation details for this structure unknown.

- Another condition specific to Dam Removal (Alternative B) and Partial Removal (Alternative F) is that the water surface elevations under normal flow conditions will likely be lower than the bearing elevations of some of these structures. The foundations would then be exposed to different types of erosion. For example the water surface may fluctuate above and below the foundation bearing elevation, thereby introducing wave action, debris and ice loading. Also, due to the absence of the water buffer there may be a potential for freeze-thaw and upheaval of the foundation bearing material during the winter months.

#### Recommendations:

- Perform geotechnical investigations to determine foundation bearing conditions and capacity to resist the potential scour.
- If the dam is removed or modified visually monitor the foundation for excessive freeze thaw, ice and debris loading damage after floods and winter conditions.

A.  Left bank downstream of Great Dam.
Rock retaining walls that appear to be sliding and have recently been stabilized.

B. Looking upstream at the retaining walls at the Great Bridge.

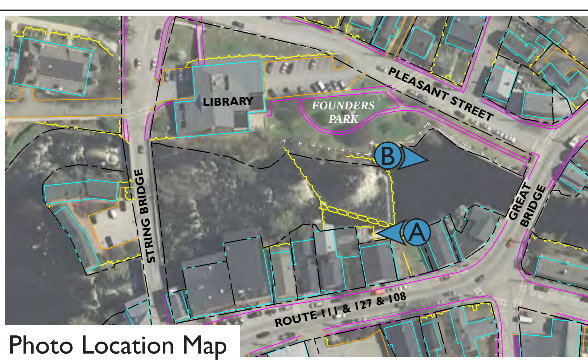


Photo Location Map

Vanasse Hangen Brustlin, Inc.

**Figure 3.7-3**

**Retaining Walls at the Great Dam**

**Exeter Great Dam Removal Feasibility and Impact Study**
**Exeter, NH**

### 3.7.1.5 Great Bridge

The Great Bridge is located immediately upstream of the dam and is supported by stone abutments on each side of the river (**Figure 3.7-3**). The bridge was rehabilitated around 2003, including a new bridge deck and new wing walls; however, the stone abutments remained. Drawings of this rehabilitation were obtained and available elevations were used as a reference.

Based on the hydraulic model results at the Great Bridge, some of the potential effects of the Dam Removal or Dam Modification Alternatives on the bridge's foundation are as follows:

- The higher scour potential may not affect the structures that are soundly founded on ledge, such as the southeast wing-wall of the Great Bridge as design drawings provided by the NH Department of Transportation (NHDOT) show they are doweled into the ledge. (See **Appendix J**). However, the foundation details for the bridge abutments are unknown; the design drawings also indicate the bridge's southwest wing-wall is not located on bedrock and the northeast wall is not doweled into the ledge.

- Another condition specific to Dam Removal (Alternative B) and Partial Removal (Alternative F) is that the water surface elevations under normal flow conditions will likely be lower than the bearing elevations of some of these structures. The foundations would then be exposed to different types of erosion. For example the water surface may fluctuate above and below the foundation bearing elevation, thereby introducing wave action, debris and ice loading. Also, due to the absence of the water buffer there may be a potential for freeze-thaw and upheaval of the foundation bearing material during the winter months.

#### Recommendations:

- Perform geotechnical investigations to determine foundation bearing conditions of the abutments, and northeast and southeast wing-walls and their capacity to resist the potential scour.
- If the dam is removed or modified visually monitor the foundation for excessive freeze thaw, ice and debris loading damage after floods and winter conditions.

### 3.7.1.6 Founders Park Retaining Wall

The retaining wall northeast of the Great Bridge extends downstream from the bridge (**Figure 3.7-3**) along Founders Park. The foundation is located on the river bank and therefore may be affected by altered river hydraulics. Drawings of the retaining wall were obtained and available elevations were used as a reference herein.

Based on the hydraulic model results between the Great Dam and the Great Bridge (High Street), some of the potential effects of the Dam Removal or Dam Modification Alternatives on the Founders Park Retaining Wall are as follows:

- The higher scour potential may affect the foundations that are not soundly founded on ledge. It was not possible to determine the current condition of the foundation bearing during the field visit. Although the drawings were made available, the foundation bearing was not clearly detailed and portions of the foundation details for this structure remain unknown.

- Another condition specific to Dam Removal (Alternative B) and Partial Removal (Alternative F) is that the water surface elevations under normal flow conditions will likely be lower than the bearing elevations of some of these structures. The foundations would then be exposed to different types of erosion. For example the water surface may fluctuate above and below the foundation bearing elevation, thereby introducing wave action, debris and ice loading. Also, due to the absence of the water buffer there may be a potential for freeze-thaw and upheaval of the foundation bearing material during the winter months.

#### Recommendations:

- Perform geotechnical investigations to determine foundation bearing conditions and capacity to resist the potential scour.
- If the dam is removed or modified visually monitor the foundation for excessive freeze thaw, ice and debris loading damage after floods and winter conditions.

## 3.7.2 Surface Water Withdrawals

In its impounded state, the Exeter River serves as a supply for the Town's drinking water supply, as well as providing water to several other riparian property owners. A full analysis of the potential effects on the Town's water system that could result from removal of the Great Dam was conducted prior to this study and can be consulted for more information (Weston & Sampson, 2010a and 2010b). The study

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0 400 800 Feet

Vanasse Hangen Brustlin, Inc.

**Figure 3.7-4**
**Location of Water Withdrawals**
**Exeter Great Dam Removal Feasibility & Impact Analysis**

**Exeter, NH**

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included an evaluation of the impact to river water elevations as well as the groundwater elevation in the river corridor. Estimates of changes to surface water and groundwater elevations were calculated based upon observations of changes in surface water and groundwater elevations as the result of a month long river 'drawdown' completed in November 2009. The results of this study provided an understanding of the potential changes to the river elevation and associated groundwater elevation as a result of dam removal. This information was used to estimate the impact to the various surface water and groundwater withdrawals identified within the potentially impacted area. This section addresses water withdrawals that could be affected by either the Dam Removal or Dam Modification alternatives.

#### 3.7.2.1 Withdrawals Potentially Affected

Withdrawals from the Exeter River that would be impacted by the lowering of the impoundment were investigated during this study. This work continued previous efforts and investigations by Weston & Sampson as part of the Water Supply Alternatives Study performed for the Town in 2009. That study revealed three primary withdrawals other than the Town's surface water withdrawal from their river pump station that may be impacted by dam removal or modification. **Figure 3.7-4** shows the general location of these withdrawal points. They include:

- The Exeter River Pump Station which withdraws water from the Exeter River to supply the Exeter water supply reservoir.
- The Phillips Exeter Academy which utilizes the river for their steam heating system and irrigation.
- The Exeter Mills Apartments which utilizes the river for cooling, irrigation and fire suppression.
- The Town of Exeter's Fire Department which has a hydrant and intake at Founders Park and supplemental hydrant connections located on the town's library.

Field site visits and other reconnaissance were performed by the project team as part of this study. The following is a discussion of the current infrastructure and operational characteristics of these withdrawal points.

##### Exeter River Pump Station

The Exeter River Pump Station consists of a pipe intake in the bank of the river and an adjacent pump house which provide the suction to withdraw water from a wet well. The Pump Station is located on the right bank of the Exeter River, across from the Gilman Park boat launch and approximately 1,000 feet upriver of the Great Dam. The Pump Station does not supply the water system directly; rather it pumps water to the Exeter Reservoir approximately one mile to the northeast. The water is then withdrawn and enters the municipal drinking water treatment facility.

The river intake has an invert of Elev. 15.0 ft and requires a water surface elevation in the impoundment of approximately Elev. 16.0 to maintain gravity-fed flow to the wet well of the adjacent Pump Station. Two pumps located in the River Pumping Station convey raw water from the wet well to the water treatment facility via a 10-inch diameter raw water transmission main. There are two vertical turbine pumps installed above the wet well. One pump is equipped with a 50-hp variable frequency drive, the other is a fixed 75-hp pump capable of delivering approximately 1,000 gallons-per-minute to the water treatment facility. The pumps are operated as needed to supplement the supply at the water treatment plant reservoir. Typical daily pumping volume is approximately 1.5 million gallons per day, but the variable speed pump can be operated at a rate as low as 0.6 million gallons per day.

### Phillips Exeter Academy Withdrawal

The Phillips Exeter Academy utilizes surface water from the Exeter River for their boiler makeup water and also for irrigation of their ball fields. The withdrawal points consist of an intake on the western side of the river adjacent to their track stadium. The Academy's makeup water intake for the central heating plant is located adjacent to Lovshin Track, where there is a shallow well that is approximately 10.5 feet deep (Mark Leighton, Phillips Exeter Academy, personal communication, December 16, 2011). This is also the same source to irrigate the soccer, baseball, and softball fields. River water is also used to irrigate the athletic fields adjacent to Phelps Stadium located on the East side of Exeter River. The source is also a shallow well located on the East side.

The Academy provided updated water use information on their water withdrawals as part of this study. Those data show that the Academy draws between 10,000 to approximately 35,000 gallons per day.[43] According to this data, water use from the river varies seasonally with a daily average withdrawal ranging from 0.01 to 0.05 cfs.

The Academy has the ability to utilize water from the Town's water system in the event they have mechanical problems with their pumps or need to perform other maintenance. Other mitigating approaches to satisfying the Academy's water needs as the result of the river and groundwater level lowering would be to deepen the river intake / wells such that sufficient head remains above the pumps.

### Exeter Mill Apartments

The former Exeter Manufacturing Company facilities were converted into housing in the 1987. Since that time, additional buildings have been converted and a few new ones added. Currently, there are ten different buildings on the site, nine of which are

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[43] These averages are based on records from April 2010 to August 2011 provided by Phillips Exeter Academy.

housing units that range from studio apartments to townhouses. All of the residential buildings get their domestic water from the Town's municipal water system. Overall, the average water use for the Mill is 120 gallons per day per unit from the Town's water system.

The Exeter Mill Apartments utilize the river for some of their fire suppression needs as well. The larger buildings rely on a dry system that can obtain water from both the Town system and via booster pumps that derive water from the river. Some of the hydrants on Mill property are apparently connected to the Town's system; however it is currently not known exactly which ones (Bill Hally, Exeter Mills Apartments, personal communication).

The Exeter Mill Apartments also utilize water from the upstream side of the Great Dam for cooling, fire suppression and irrigation. The Mill obtains water from the river via the penstock at the dam. The use of river water for cooling purposes dates back to 1955 when the first air conditioning system was installed in the main mill building. The current cooling system takes water from the Exeter River into a closed-loop, non-contact cooling water system which provides air conditioning to 134 units of the 161 unit multi-family apartment complex.[44] The return flow from the cooling system goes into the former Mill wastewater lagoons, now called Clemson Pond. The other buildings are cooled by units that do not rely on river water (Bill Hally, Exeter Mills Apartments, personal communication).

In order to mitigate this potential loss, the Exeter Mill Apartments may need to access the Exeter public water distribution system or investigate the possibility of retrofitting the existing intake such that it remains submerged. No drawings of the existing penstock are currently available to assess the precise impact of dam removal.

### Fire Hydrants Located in Founders Park and at the Public Library

The Town owns and maintains three dry fire hydrants located on the east side of the Exeter River near the Great Dam. The Town's Fire Department has the ability to withdraw water from the river to supplement their firefighting capabilities in the downtown area. A fire truck equipped with pumps can connect to these hydrants during a fire.

When contacted, a Fire Department representative stated that the hydrant at Founders Park was adequate for their system; however, the hydrants at the library often get air entrained. No as-built plans of these systems exist. The Founders Park hydrant simply has a pipe that extends into the river. It is assumed that the two

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44 A Notice of Intent for Non-Contact Cooling Water General Permit associated with the facility's use of the river water for cooling was submitted to the United States Environmental Protection Agency on May 18, 2010. Information from this application was used to develop the description of the Mill's use of river water for this study.

hydrants located at the library obtain their water from the penstock that flows under the library and parking area. Therefore, flow into these hydrants is assumed to be dependent on how open the penstock at the dam is and whether or not its screen has debris that might be impeding flow.

The same mitigation options apply to the fire hydrants in Founders Park and at the Public Library that apply to the Exeter Mill Apartments.

## 3.7.3 Wells

### 3.7.3.1 Existing Groundwater Conditions

Extensive research and testing conducted by Weston & Sampson as part of the reactivation of the Gilman and Stadium water supply production wells in 2009 provided valuable insight into the surficial geology and aquifer deposits of Exeter River corridor. Existing United States Geologic Survey mapping was used as a starting point and supplemented by extensive well drilling to further characterize the area. This work was focused primarily in the Gilman Park area (the confluence of the Little River and the Exeter River); however additional investigations were also performed in the vicinity of Lary Lane. This testing found that the regional surficial geology of the study area is characterized by coarse stratified drift overlain by glaciolacustrine silt and clay deposits. As the glaciers advanced, the bedrock surface (Eliot Formation) was scraped clean of its surficial deposits and eroded in areas of weak rock, exploiting deep preglacial valleys. One of these preglacial valleys is located approximately 4,000 feet to the southeast of Gilman Park. This valley represents a glacial drainage that was to the south southeast towards the Atlantic Ocean. Current drainage is to the north with the ultimate discharge location being Great Bay.

Once the glaciers began to recede, deltaic sands and gravels were deposited in these valleys in what was a glacioestuarine environment. With continued deglaciation of the region, the area was inundated by sea level rise subsequently modifying the surface of the deltaic deposits and depositing tens of feet of glaciomarine silts and clays. The water table aquifer is located in this thin sand and silt horizon. The highly transmissive lower aquifer is overlain by tens of feet of low permeability silts and clays of the Presumpscot Formation.  This lower aquifer has been tapped for use as a public water supply source for the Town of Exeter but the water supply wells (Gilman Well and Stadium Well) have remained inactive since 1973.  The two wells are both currently off-line and considered to be approved drinking water sources listed as ‘inactive’ by the New Hampshire Department of Environmental Services.

### 3.7.3.2 Municipal Wells

The Gilman Park Well and the Stadium Well are located on either side of the Exeter River, approximately 500 feet upstream (south) of the confluence of the Exeter River and the Little River. These wells have recently been permitted through the Department of Environmental Services but remain inactive at the time of this writing. These two wells represent a potential of up to 1.2 million gallon per day (mgd) withdrawal and are the only two municipal wells that could be impacted by dam removal.

Both aquifer pumping tests as well as a river drawdown test were conducted and extensively monitored. It was determined through both tests that the confining nature of the marine clay deposit isolated the lower transmissive aquifer from significant impact and that only a minor change in estimated safe yield was expected if the dam were to be removed.

The impact of lowered groundwater levels on the safe yield of these production wells was estimated using the pumping test and river drawdown data and was found to represent an 80 gpm or 0.12 mgd reduction in the estimated safe yield of Gilman and Stadium production wells due to the potential removal of Great Dam. This represents an impact or drop of approximately 11% in capacity. Combined, the two wells are still projected to produce approximately 1.08 million gallons-per-day of safe yield under post-dam removal conditions.

As cited above, the Gilman and Stadium Wells were originally estimated to yield a combined 820 gallons per minute or up to 1.2 million gallons per day. Estimates of both individual and combined withdrawal rates are summarized in **Table 3.7-1** below.

These original safe yield estimates were adjusted to account for the drop in groundwater level due to the potential removal of Great Dam. The greatest anticipated drop in static water level in the deep aquifer due to the potential dam removal is approximately 3.15 feet. Lowering the static water level ultimately lowers the availability of water to the pumping wells and, in turn, changes the estimated safe yield to approximately 740 gpm or 1.1 mgd (**Table 3.7-2**).

Table 3.7-1. Municipal Well Safe Yields, With Dam

| Individual Safe Yields | gpm | gpd |
|---|---|---|
| Gilman | 580 | 835,200 |
| Stadium | 840 | 1,209,600 |
| | | |
| Combined Safe Yields | | |
| Gilman | 330 | 475,200 |
| Stadium | 490 | 705,600 |
| **TOTAL** | **820** | **1,180,800** |

Table 3.7-2. Municipal Well Safe Yields, Dam Removal

| Individual Safe Yields | gpm | gpd |
|---|---|---|
| Gilman | 540 | 777,600 |
| Stadium | 760 | 1,094,400 |
| | | |
| Combined Safe Yields | | |
| Gilman | 300 | 432,000 |
| Stadium | 440 | 633,600 |
| **TOTAL** | **740** | **1,065,600** |

Finally, this change represents an 80 gpm or 0.12 mgd reduction in the estimated safe yield of Gilman and Stadium production wells due to the potential removal of Great Dam, or a drop of approximately 11%. These changes are tabulated in **Table 3.7-3** below.

Table 3.7-3. Municipal Well Safe Yields, Impact

| **Summary Table - Change** | | |
|---|---|---|
| Individual Safe Yields | gpm | gpd |
| Gilman | 40 | 57,600 |
| Stadium | 80 | 115,200 |
| | | |
| Combined Safe Yields | | |
| Gilman | 30 | 43,200 |
| Stadium | 50 | 72,000 |
| **TOTAL** | **80** | **115,200** |

### 3.7.3.3 Private Wells

As discussed previously, all surface water bodies are presumed to be hydraulically disconnected from the lower aquifer. As the Town's water distribution system supplies homes in the vicinity of the river with drinking water, very few private water supply wells are located in the Exeter River corridor. As part of a previous study, the NHDES (OneStop database), the NH Geological Survey, and the Town of Exeter database were queried for a list of private wells in the area. These databases were re-queried for this study and found to reveal that all registered private water supply wells in the vicinity of the Exeter River are drilled in bedrock. Since these withdrawals are from the deep bedrock aquifer and the bedrock is hydraulically isolated from the river, no impact to private wells are expected as a result of dam removal. Public meetings associated with this project have sought to query the public to determine if any unregistered wells exist within the river corridor. No unregistered wells are known at this time. If any shallow driven or dug wells used for irrigation or drinking water supply are located within the potential groundwater impact zone resulting from the Dam Removal, there is a potential for impact. The impact to each well would have to be assessed individually to determine the extent of impact based upon the well's distance from the river and construction depth.

### 3.7.4 Water Supply Summary and Conclusion

As discussed in Sections 3.7.2 and 3.7.3, some impact to both public drinking water supplies and infrastructure is expected if the Dam Removal or Partial Removal Alternative is selected. These impacts can be summarized by the following:

- Seasonal impact to surface water withdrawal in Exeter River.
- 0.12 Million Gallon Per Day Impact to permitted (inactive) groundwater supply wells (Gilman & Stadium)
- Need to retrofit Phillips Exeter Academy Heating and Irrigation
- Need to retrofit Exeter Mills Apartments cooling, irrigation and fire suppression.
- Need to retrofit the Town of Exeter's Fire Department fire hydrants and intake at Founders Park

## 3.8 Water Quality

Generally speaking, removal of a dam from a formerly free-flowing river will have a substantial net benefit on water quality in the river. This section discusses the issues surrounding the current water quality of the Exeter River and provides a discussion of the effects of the removal or modification of the Great Dam.

### 3.8.1 Existing Conditions

Since 2006, New Hampshire Department of Environmental Services (DES) has listed the entire lower Exeter River from the Great Dam upstream to the Pickpocket Dam, consisting of approximately 7.5 river miles, as being impaired due to several declining or poor water quality conditions as discussed further below. Data from the NHDES "water quality report card" for each assessment unit in the study area is included in **Appendix K**.

The Exeter River is classified as a Class B waterway according to the State's surface water classification system. Class A waters are considered to be the highest quality and best for use as drinking water supplies, while Class B waters are considered acceptable for recreational purposes, supporting aquatic life and for water supply purposes with adequate treatment.

NHDES has classified water quality standards under the Clean Water Act. Since 1991 NH surface waters have been classified as Class A or Class B. Class A are considered to be the highest quality and best for use as water supplies. Class B waters are considered acceptable for recreational purposes, supporting aquatic life and water supply after adequate treatment.

New Hampshire Department of Environmental Services (DES) has also adopted surface water quality standards that specify certain narrative and numerical thresholds for various water quality parameters and constituents to assess whether the various designated uses for both Class A and B waters such as supporting aquatic life, recreational uses are being fully supported. If these narrative or numerical thresholds are not being met based on sufficient water sampling and/or field measurement results, then the subject water body would be considered "impaired" or not supporting their designated uses. Water bodies designated as impaired are listed on the DES's 303(d) list which is updated every two years as required by the federal Clean Water Act (CWA). When the causes for the impairment are known to be related primarily to human activity or influences, as opposed to a naturally occurring conditions, the CWA specifies that future activities cannot further degrade water quality conditions and that a Total Maximum Daily Load (TMDL) study needs to be conducted to identify the principal sources of the impairment and the relevant control measures that would limit the maximum daily load to be no greater than what the water body can assimilate without exceeding the water quality standards.

As described below, the entire lower Exeter River impoundment from the Great Dam upstream to the Pickpocket Dam, consisting of approximately 7.5 river miles, has been listed as impaired since 2006 due primarily to occasional low dissolved oxygen levels, which can adversely affect fish population and other aquatic life. Data from the NHDES "water quality report card" for each assessment unit in the study area is included in **Appendix K**.

As future activities are proposed that may affect water quality conditions within this impaired segment, NHDES may require as part of any permitting approval process related to such activities, including the proposed dam removal or modification alternatives, that certain mitigation measures be undertaken to prevent any further contribution to the impairment and improve water quality conditions. Dam removal, and to a lesser extent, partial dam removal can potentially alleviate some of the contributing factors that can lead to lower dissolved oxygen levels. These factors include increased water temperature and limited water circulation patterns and aeration potential that can result from temperature stratification. See additional discussion of the potential effects below. Nonetheless, the Town of Exeter could be required to take additional steps as part of the future permitting process associated with a dam removal or modification proposal in order to further alleviate low dissolved oxygen conditions.

Section Env-Wq-1703.19 of the state water quality standards also address aquatic habitat and biological community integrity and specify that water bodies "*support and maintain a balanced, integrated, and adaptive community of organisms having a species composition, diversity, and functional organization comparable to that of similar natural habitats of a region*." Thus, as part of any future wetland permit application process for dam removal or modification, especially if a 401 water quality certificate is issued as part of the permitting process, DES may include additional conditions to address fish passage and mobility, especially if full dam removal (which has the greatest potential for improving fish passage and mobility) is not the preferred alternative. These conditions could include future monitoring to evaluate changes in fish passage/mobility and possibly additional structural improvements that may be contingent on the results of this monitoring.

It is important to also mention that EPA's Draft 2013 MS4 Stormwater General Permit includes provisions that require municipalities subject to the MS4 Permit requirements to develop Water Quality Response Plans (WQRPs) to address stormwater discharges that outlet to impaired water bodies to prevent further contributions and to rectify existing impairments. The thermal gain potentially caused by warmer stormwater runoff released from paved surfaces may be issue that the Town may need to address when the MS4 permit requirements are finalized later this year.

The impaired river reaches include the impounded sections of both the Exeter River and the Little River primarily due to low dissolved oxygen levels and dissolved oxygen saturation, as well as low pH and occasional elevated chlorophyll *a* concentrations. Elevated chlorophyll *a* concentrations are indicative of high levels of nuisance algae growth, which can adversely affect primary contact recreation uses while the low dissolved oxygen and pH can adversely affect aquatic life protection. The low pH is attributed to atmospheric deposition or acid rain whereas the sources for chlorophyll *a* and low dissolved oxygen are listed as unknown. Periods of low dissolved oxygen primarily occur during summer months because warmer water temperatures hold less dissolved oxygen as compared to colder waters. Low dissolved oxygen levels can also be attributed to both natural processes and human influences, as discussed further below.

In 2010, DES also listed the Exeter and Little Rivers as being impaired due to occasional elevated levels of *E. coli* bacteria, which could adversely affect primary and secondary recreation uses. In 2011, NHDES developed a statewide Total Maximum Daily Load (TMDL) Study for bacteria, which outlines various potential sources and control measures that can be used to reduce bacteria contributions. With the TMDL study completed, NHDES no longer includes *E.coli* bacteria on the 2012 303 (d) list, as it is intended that this issue will be addressed as part of the implementation of the statewide TMDL study.

With regard to dissolved oxygen, for Class B waters, a minimum dissolved oxygen concentration of 5 mg/L and a minimum average daily saturation level of 75 percent must be sustained in order to support designated aquatic life uses. Since dissolved oxygen can be highly variable on a daily basis particularly during summer months, NHDES generally requires that several measurements be taken over the course of a day in order to calculate an average daily saturation level. Measuring saturation level compensates for the fact that warmer waters have a lower capacity to store dissolved oxygen as compared to cooler waters due to the physical properties of water. In other words, warmer water will almost always have lower dissolved oxygen levels than colder water, but in either case the percent saturation should be closer to 100 percent when there are minimal oxygen demands from oxygen consuming processes or due to flow modifications that limit aeration and circulation. Thus, the measurement of percent saturation can often be an important indicator in determining whether natural decay processes or human activities are potential causes for low dissolved oxygen levels beyond that associated with warmer temperatures and diminished capacity.

Low dissolved oxygen conditions tend to be more prevalent in slower moving impoundments as opposed to free-flowing streams due to the thermal gain or temperature increases attributed to solar heating of a larger surface water area and greater retention time (i.e., slower travel time) in impounded segments. The longer residence time allows the same volume of water to greater solar exposure resulting in higher water temperatures at the surface. In deeper waters, thermal stratification can occur where the temperature differential between the cooler water and the warmer surface water impedes the mixing of upper and lower layers and, thus, further adds to the oxygen deficit problem because oxygen exchange between the surface and bottom layers is limited.

In addition, dissolved oxygen can often be consumed by decomposition of organic matter and plant material that accumulates along the stream bottom as well as any organic contaminants that are introduced from human activities. Moreover, heated runoff discharged from impervious surfaces associated with developed areas along the stream corridor can further add to the problem.

The previous Wright-Pierce study (2005) collected bi-weekly measurements of dissolved oxygen (DO) levels (mg/L and % saturation) and water temperature collected at various locations within the lower Exeter River and Little River during summer and fall of 2005. These measurements revealed occasional low DO concentrations and percent saturation that were below Class B standards at various locations and on multiple sampling events. The low readings were generally reported in deeper waters and associated with warmer temperatures. In late August and mid-September, DO readings at times in the Little River and Exeter river (near drinking water intake) were below 2.0 mg/L, which represent highly anoxic conditions. This data may have been used in determining the dissolved oxygen impairment for these river segments.

Subsequent dissolved oxygen measurements collected as part of the Volunteer River Assessment Program (VRAP) have also recorded occasional low DO concentrations and percent saturation levels in the lower reaches of the Exeter River and Little River. The most recent data collected in the summer of 2012 as part of the VRAP Program, as presented in **Table 3.8-1** below, shows fewer incidences of violations of the water quality standards suggesting perhaps some improvement in water quality conditions.

Table 3.8-1 Dissolved Oxygen and Temperature Measurements Collected in 2012 in the Exeter and Little Rivers[1]

| | 22-June | | | 13-July | | | 9-Aug | | | 30-Aug | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|
| Station | DO Conc. (mg/L) | %Sat[2] | Temp ºC | DO Conc. (mg/L) | %Sat[2] | Temp ºC | DO Conc. (mg/L) | %Sat[2] | Temp ºC | DO Conc. (mg/L) | %Sat[2] | Temp ºC |
| 09-EXT, Exeter River at Great Bridge | 7.09 | 87.1% | 25.6 | 7.83 | 96.7 | 25.9 | 7.13 | 89.8% | 26.8 | 6.18 | 77.1% | 22.3 |
| 12 EXT,- Exeter River at Court St | 6.95 | 83.4% | 24.5 | 6.29 | 76.6% | 25.2 | 6.11 | 74.2% | 25.0 | 5.96 | 66.4% | 20.8 |
| 12A-EXT, Little River at Linden St | 7.66 | 91.1% | 23.9 | 6.46 | 76.9% | 24.1 | 7.45 | 89.3% | 24.4 | 7.30 | 82.1% | 21.1 |
| 00 -LTE, Little River at Gilman Bridge | 5.06 | 61.0% | 25.0 | nd | nd | 26.0 | 7.12 | 88.1% | 26.2 | 7.71 | 87.8% | 21.7 |
| 02-LTE, Little River at Linden St Bridge | 5.47 | 65.7% | 24.6 | 5.14 | 58.3% | 21.5 | 6.5 | 73.4% | 20.7 | 4.92 | 53.8% | 19.7 |

Notes:

1. Underlined values indicate violations of the Class B water quality standards for dissolved oxygen concentrations or percent saturation levels.
2. Percent Saturation readings represent instantaneous readings and not daily average readings similar to the water quality standards. nd = no data

The previous dissolved oxygen measurements suggest that there can be brief periods of low dissolved oxygen levels in certain locations, which could be attributed to both decomposition of organic matter in the river bottom and perhaps thermal gain within impoundment particularly during warm and low flow periods. The data also indicates that the Little River (near Linden Street) generally has lower dissolved oxygen levels compared to that measured in the Exeter River on the same sampling date. This could potentially be due to the greater dissolved oxygen demands associated with the organic debris contained in the larger wetland complex located just upstream of the Court Street bridge.

## 3.8.2 Discussion of Potential Effects

The likelihood for changes in water quality, especially as they relate to dissolved oxygen, will depend mostly on the extent to which residence time and the surface water area or the volume of water in the impoundment might change under each alternative. The residence time is a general estimate of time it takes for the volume of water within the impoundment to be fully exchanged with new water flowing into the impoundment. The residence time is estimated by dividing the estimated impoundment volume divided by the inflow rate. A decrease in residence time and impoundment volume will likely result in a net benefit for dissolved oxygen levels by reducing the potential thermal gain that currently occurs in the riverine reaches above the dam. Lower residence times and quicker travel times will generally result in greater likelihood for improved water quality conditions.

**Table 3.8-2** below provides a comparison of the estimated changes in impoundment volume and residence time under various flow conditions for each alternative. The estimated difference in residence time are perhaps most important for the mean annual and 2-year flow conditions since these conditions would occur much more frequently than the higher flood flow conditions. Under the No Action Alternative (Alternative A) and the Stabilize in Place Alternative (Alternative G), no significant changes in residence time or impoundment volume are expected. Thus, dissolved oxygen conditions would remain the same.

Full dam removal, as proposed under Alternative B, would result in the greatest reduction in residence time and, would therefore have the greatest potential to improve dissolved oxygen levels relative to the other alternatives. Removing the dam is estimated to reduce the residence time by 53-56 percent during the mean annual and 2-year flood conditions. This is a fairly substantial reduction that would reduce the potential for thermal gain and any thermal stratification that currently occurs within the impoundment. For larger flood events, the estimated differences in residence time are not as dramatic, but low dissolved oxygen conditions are not typically prevalent during flood events given the greater turbulence and mixing that occurs. In addition to the estimated reduction in residence time, the shallower water depths that would result from dam removal would allow for greater mixing and less temperature stratification at lower flows. Faster flow velocities could also lessen the accumulation of oxygen-consuming organic material and debris within the channel, and thus, reduce a source of oxygen demand.

While the Partial Removal Alternative would have some benefit, it is estimated that the decrease in residence time for the annual flow would be about 29%, about half as much benefit at the full dam removal.

Table 3.8-2. Residence Times by Alternative

| Flow | Flow (cfs) | Impoundment Volume (ac-ft) | | | | Residence Times (Days) | | | | Residence Times (Percent Decrease Relative to Existing Condition) | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | | Alt A | Alt B | Alt F | Alt H | Alt A | Alt B | Alt F | Alt H | Alt B | Alt F | Alt H |
| | | (ac-ft) | (ac-ft) | (ac-ft) | | | | | | | | |
| Median Annual | 71 | 290 | 128 | 207 | 290 | 2.06 | 0.91 | 1.47 | 2.06 | 56% | 29% | 0% |
| 2-Year Flood | 1,481 | 1,799 | 847 | 843 | 855 | 0.61 | 0.29 | 0.29 | 0.29 | 53% | 53% | 52% |
| 10-Year Flood | 3,245 | 4,758 | 3,028 | 3,028 | 3,089 | 0.74 | 0.47 | 0.47 | 0.48 | 36% | 36% | 35% |
| 50-Year Flood | 5,858 | 9,296 | 6,723 | 6,756 | 6,925 | 0.80 | 0.58 | 0.58 | 0.60 | 28% | 27% | 26% |
| 100-Year Flood | 7,109 | 11,341 | 8,598 | 8,682 | 8,942 | 0.80 | 0.61 | 0.62 | 0.63 | 24% | 23% | 21% |

Note: Alternatives A and G are not included because there would be no change in impoundment and therefore no water quality benefit.

The modified dam scenario proposed under Alternative H is estimated to result in minimal change in the residence time for the mean annual flow conditions but could reduce the residence time by more than 50 percent under the 2-year flood condition. The installation of an adjustable spillway under this alternative would essentially maintain the current water levels under normal flow conditions but would be lowered under higher flow conditions to release greater flow and thus would reduce the impoundment volume under flood conditions. It may be possible, however, to use the flexible gate to occasionally increase the flushing or lower the residence time during critical warm and/or dry periods to improve dissolved oxygen levels if the lowering of the gate was timed appropriately ahead of significant forecasted rain event that would replenish the impoundment. The timing and criteria for this type of water level management or water release would most likely need to be discussed and reviewed by various environmental resource agencies as well as the citizens of Exeter.

### 3.8.2.1 Water Quality and Fish/Aquatic Life

Fishing is popular on the Exeter River as a whole, especially in the upper reaches of the River that are annually stocked with American shad and with brook, brown and rainbow trout by the New Hampshire Fish and Game Department (NHFGD). Fish are released annually in an effort to restore populations and stabilize spawning stocks, as return numbers are declining in the past five years. The River supports both cold and warm water native species such as smallmouth and largemouth bass, brown bullhead, chain pickerel, American eel, yellow perch and sunfish. A fish ladder at Great Dam supports ongoing restoration efforts for river herring and shad and facilitates access to upstream spawning and nursery habitat for alewife and blueback herring. (See Section 3.11.1.)

Any improvement in dissolved oxygen levels as a result of the proposed alternatives could enhance aquatic habitat for fish populations and other aquatic organisms that are essential to the ecological food web cycle. A free flowing river with cooler temperatures could increase the recreational fishing opportunities within the Exeter and Little Rivers. It is conceivable that the cold water species could potentially expand their habitat, especially spawning habitat, and possibly develop sustaining populations with adults at least temporarily utilizing the lower reaches of the river with higher dissolved oxygen levels and cooler water temperatures as a result of the dam removal.

### 3.8.2.2 Drinking Water

The Town of Exeter's drinking water supply was previously studied by Weston & Sampson (2010a and 2010b). Notably, the town withdraws water to supply their reservoir with drinking water from a river bank intake structure located opposite of Gilman Park. This study determined that the Town would still be able to utilize the river as a water supply source even if the dam were to be removed, but that some modifications to the existing river intake may be necessary to allow for withdrawals under very low flow conditions.

In terms of potential changes in water quality, it is reasonable to conclude that the proposed removal or modification of the dam would result in a net benefit in drinking water quality by eliminating or reducing the potential for extended periods of anoxic or low oxygen conditions. Eliminating the anoxia could prevent certain trace metals and nutrients that are held in the bottom sediment from being released into the water column. Releases of phosphorus from bottom sediments may in part be responsible for the existing algal growth and increase chlorophyll *a* levels, which could lead to taste and odor issues. Iron and manganese also become more available under anoxic conditions, which can result in greater water treatment demands. In a more free-flowing river, there is generally greater potential for well oxygenated conditions due to added mixing and turbulence.

Conversely, it is also possible that higher flow velocities in the river with the dam removed could occasionally increase turbidity levels for brief periods during high flow periods. These potentially short periods of higher turbidity represent a potential trade-off for the potential water quality benefits of eliminating or minimizing the more favorable conditions for higher algal growth and phytoplankton abundance during the summer months under the existing impounded condition.

### 3.8.2.3 Recreational Uses

The reported trend of increased chlorophyll *a* levels and related nuisance algae can adversely affect the recreational uses of the River, particularly with respect to canoeing and kayaking. Increased nuisance algae growth in freshwater systems is typically the result of increased availability of phosphorus. The availability of phosphorus in this riverine system is most likely due to a combination of nonpoint source inputs within the watershed and internal releases from bottom sediments during periods of anoxia in deeper water areas. If the occurrence and duration of anoxic conditions can be diminished as a result of the proposed dam removal and modification, as discussed above, this could potentially reverse or slow the trend of future nuisance algae growth and chlorophyll *a* levels. Alternative B, with the full dam removal, has the greatest potential to reduce anoxic conditions while Alternative H has much more limited potential to change conditions to reduce anoxia but could be an improvement over existing conditions.

Similarly, occasional elevated bacteria levels can present a potential human health risk for secondary contact recreation uses (e.g., kayaking, canoeing other small craft use). The elevated bacteria levels are more likely related to stormwater runoff and inputs from various sources within the watershed rather than any influence of the impoundment created by the dam. It is unlikely that removal of the dam and the related impoundment would result in any dramatic change in bacteria levels, but a free-flowing river could flush out elevated bacteria levels more quickly following runoff events thereby reducing the potential exposure to higher levels. Dam removal or modification is expected to lower water levels in the future during flood events, which could result in a net benefit because developed areas, and particularly septic systems, are less likely to be inundated which could reduce the amount and occurrence of bacteria entering into the river. Given the requirements contained in the Draft 2013 MS4 Stormwater General Permit, the Town of Exeter will likely need to develop an approach to identifying and prioritizing sources of bacteria within the downtown urbanized areas and measures to reduce these bacteria contributions over time as part of the permit compliance activities.

## 3.9 Cultural Resources

### 3.9.1 Historic (Above-Ground) Resources

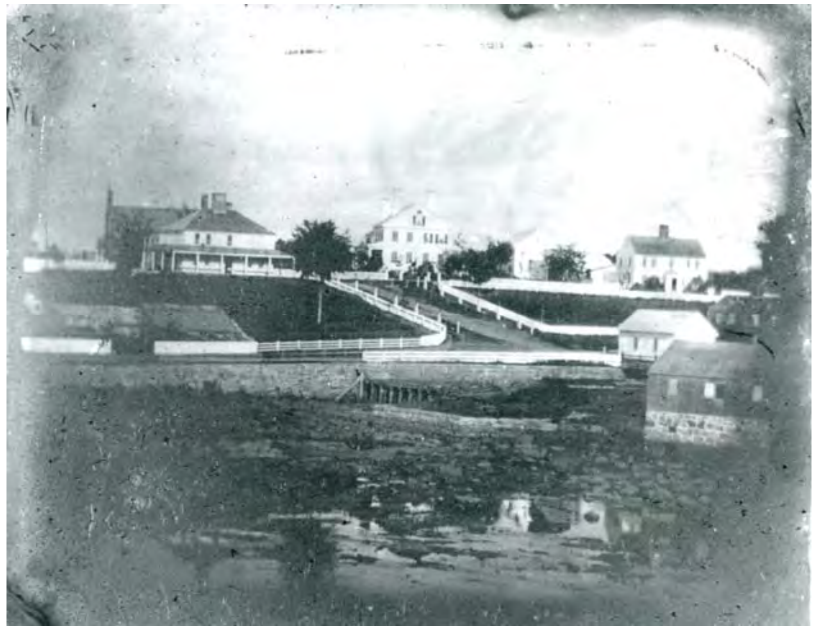
The Great Dam located in the heart of Exeter's central business district, and has served an important role in the town's industrial history for almost 100 years. Its location just upstream of the Great Falls has been the site of a dam since the 1640s,[45] which provided the source of water power for numerous mills that lined the banks of the Exeter River until 1828. In that year, the incorporators of the newly-formed Exeter Manufacturing Company and the Exeter Mill and Water Power Company, who were already the holders of the dam/flowage rights, transferred those rights to the corporations. The corporations agreed to build a new dam within nine months. The specific completion date for this new dam and what type of dam it was is unknown. The dam from the late 1820s served the Exeter Manufacturing Company, presumably until its replacement in 1914 with the existing concrete gravity dam.

The dam lies within the Exeter Waterfront Commercial Historic District, which was originally listed in the National Register of Historic Places in 1980, with a boundary increase that added the former Exeter Manufacturing Company property in 1986. The dam has been determined eligible as a contributing resource to this district. (**Figure 3.9-1**)

The district was recognized for its association with important events associated with Exeter's early industrial and commercial growth, with an emphasis on the 18th century through the early 20th century period and its intact and sophisticated array of mostly 18th and 19th century residential, institutional, commercial, and industrial architecture. The original district nomination recognized the district's significance in Architecture, Commerce, Military, Transportation, Industry, and Invention. Industry

[45] A dam is assumed to have been built by Edward Gilman near or at this location for his mills built in the late 1640s.

and architecture were noted as the areas of significance in the second nomination, which recognized the importance of the Exeter Manufacturing Company buildings to the district's significance and architectural character.



*Photograph of Great Falls area facing north, ca. 1857. String Bridge and Kimball's Island on right; Great Falls and Great Dam just out of frame on right. This image is often referred to as the earliest known photograph of Exeter, an ambrotype copy of a daguerreotype (Aten 1896, 9). Exeter Historical Society, MSS10 Box3_1996.26.2 Dennis Waters collection.*

Throughout Exeter's nearly 400-year history, the area around the Great Falls (also referred to as "Squamscott Falls" in town histories) has served as the town's municipal and commercial town center. Great Falls has also served as the town's industrial center for much of its history. The earliest Euro-American settlement in the town was adjacent to the falls, which became the site of the town's first mills. In 1828-1830 the Exeter Manufacturing Company constructed a large mill on the east side of the falls, gradually taking over the various smaller mills along Great Falls as well as a 40-mile-stretch of the Exeter River. The mill dominated Exeter's employment base for decades, and the steady availability of jobs attracted immigrants who settled nearby throughout the 19th and early 20th centuries. In 1842, the establishment of the Boston & Main Railroad, more than ½ mile west of the town center at Great Falls, drew focus away from the Exeter Manufacturing Company mill as the industrial heart of the town, adding a new industrial center along the railroad. By the 1930s, most of the other factories had closed down, once again leaving the Exeter Manufacturing

Company mill near Great Falls as the primary industrial enterprise in the town. Shifts in production sustained the Exeter Manufacturing Company throughout much of the 20th century, but by the 1960s the mill was facing stiff competition from factories located in southern states. In addition, the increased use of private

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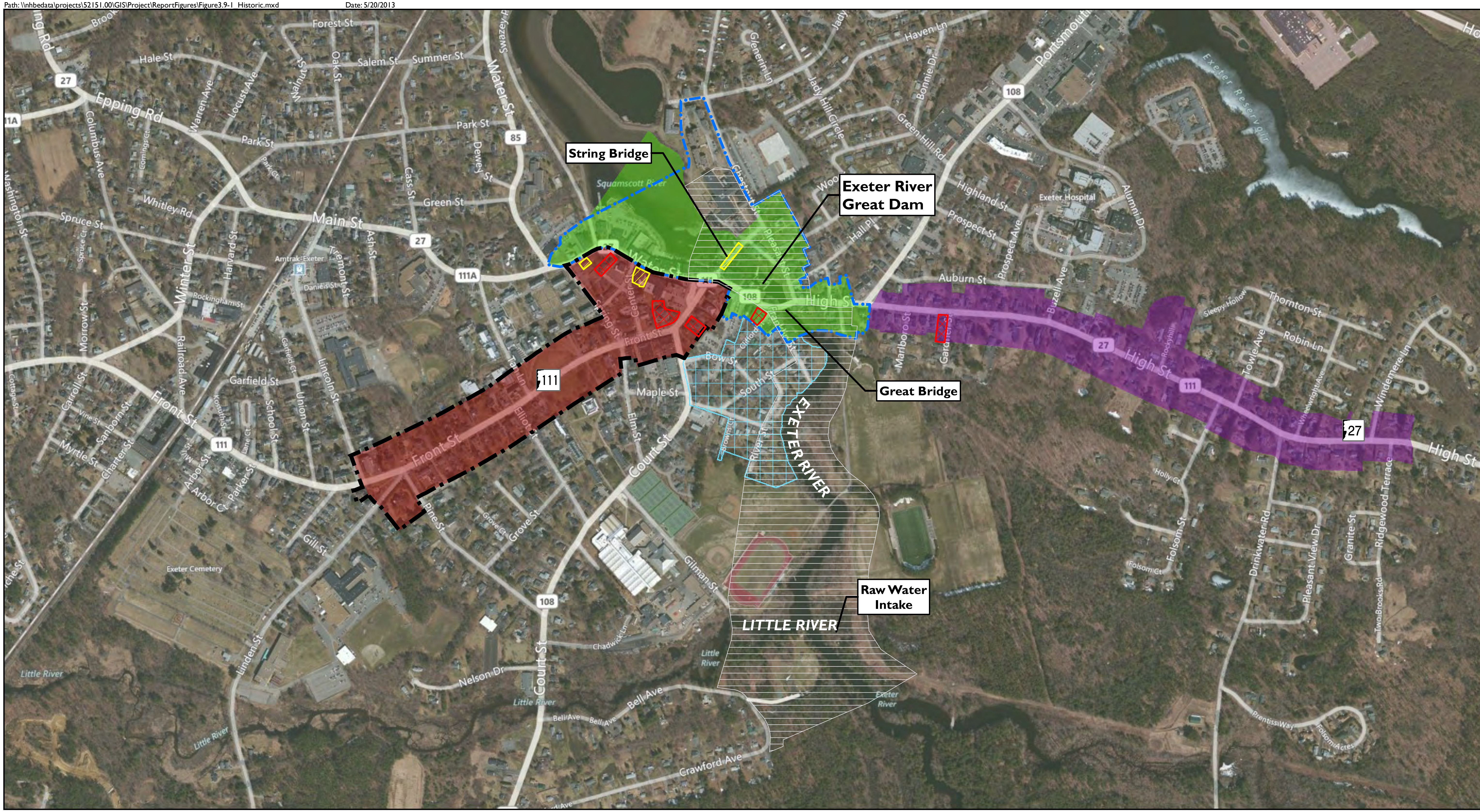


**Legend**

National Register Historic Districts:
- Front Street
- Waterfront Commercial
- NR Listed Property
- Inventoried Property
- Area Form Boundary

- Area Recommended for Further Survey

Local Historic Districts
- Front Street
- High Street
- Waterfront Commercial

0 700 1,400 Feet

Vanasse Hangen Brustlin, Inc.

**Figure 3.9-1**
**Exeter Historic Districts**
Exeter Great Dam Removal
Feasibility & Impact Analysis

Exeter, NH

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automobiles allowed residents to live in Exeter but work in the Boston or Portsmouth areas. After the Exeter Manufacturing Company mill was sold in 1966, the new owners of the factory continued production for another two decades, after which time the Great Falls area's prominence as the industrial heart of the town ended. However, the area's role as the commercial and municipal center of Exeter has continued unabated to the present.

The National Register nomination for the Exeter Waterfront Commercial District, in which the northern sections of the project area are included, divides the immediate area around the Exeter Great Dam as the Lower Block, the Upper Block, and the Residential Area. The Lower Block lies west of the intersection of Water and Front Street, on the west side of the Exeter River. This area contains the impressive brick commercial buildings from the late 19th and early 20th centuries. The Upper Block, east of the Water and Front Street intersection and the northern tip of Franklin Street, is mostly composed of smaller scale wood frame gable front buildings which have been converted to commercial use; this area escaped the late 19th fire that destroyed most of the Lower Block, so retains its smaller scale and mid-to-late 19th century buildings. The Residential Area, which includes west end of High Street, and Pleasant and Chestnut Streets, is characterized by mostly early 19th century residences, mainly from the Federal period, although there are several Georgian style houses as well.

*Photograph of String Bridge facing north, Exeter Manufacturing Company mill in background. J.S. Mitchell, identified by Aten (2003) as 1882-1884. Exeter Historical Society, MSS91.*

The project area is focused on Exeter's earliest area of settlement at the Great Falls on the Exeter River, which provided water power for industrial enterprises soon after the town was established. The ledge outcroppings in the river which produced the falls and formed the base of the dams which have been located here since the 1640s and that of Kimball's Island downstream of the falls are prominent features in the project area. Granite retaining walls line both sides of the river downstream of the High Street bridge, with more sporadic instances of retaining walls upstream within the river's impoundment area. On the west side of the Exeter River within the project area, the land is mainly level; the topography east of the river, especially along Pleasant Street is much higher, with a relatively gentle incline down to the river from these streets. As a result, the early 19th century houses on these streets, within the Residential Area described above, have a more imposing appearance and elevated front view of the river and Great Dam. The 1987 brick public library and open space to the south, known as Founders' Park, established in 1988, provide a more tranquil and open setting for the Pleasant Street houses; the area was previously filled with tenement houses and, even earlier, mills. The buildings on the west side of the river, along Water Street and Franklin Streets, in contrast, face away from the river with their rear elevations closest to the river. Two low-scale concrete bridges – the 2003 High Street (or Great Bridge, which replaced the one built in 1934) and the 1935 String Bridge – cross the river on both the upstream and downstream sides of the Great Dam.

The north end of the project area, which includes both the Lower and Upper Blocks defined above, where these bridges are located, is characterized by a dense arrangement of masonry commercial blocks and wood frame former residences, now used commercially, on Water Street. The houses, still serving as residences, fronting on Pleasant Street on the east bank are generally larger and less densely spaced. Just to the south, at the intersection of Pleasant and High Streets, a tight cluster of early 19th century brick and wood frame buildings characterize Hemlock Square. To the southeast along High Street, a series of wood frame, mostly early 19th century houses densely line the street, most with shallow setbacks from the street.

Franklin Street, which begins south of the intersection of Water and High Street, on the west side of the river, holds a number of early to mid-19th century double and single sided gable houses. Two automotive-related buildings at the north end of the street are the 20th century successors to the former carriage factory activities that dominated this area in the mid-19th century. South of the Franklin Street area, on both sides of the Exeter River, the land is undeveloped, dominated by the expansive athletic fields of the Philips Exeter Academy. An early 20th century concrete arch bridge connects the fields to the north, while a simple metal footbridge, likely from the mid to late 20th century, leads from Gilman Street on the west bank to Gilman Park, the southern boundary of the project area.

Trees and vegetation within the project area are relatively sparse in the northern end, except for along the east bank in the vicinity of Founders' Park and on Kimball's Island at String Bridge. South of the High Street bridge, trees line the west bank of the river behind Franklin Street. Further south, larger clusters of trees line both banks of the river, which curves several times before branching into the Little River on the west at Gilman Park.

The condition of buildings and structures in the project range from excellent to poor; a direct correlation can be observed regarding the condition of the buildings within the three local historic districts that converge on the north end of the project area and those seen in the Franklin Street area to the south.

Information for the historical study was compiled from a variety of sources. The holdings at the Exeter Historical Society served as the primary source of information, including photographs, maps, histories, town records, books, and a number of subject files. Barbara Rimkunas, the curator of the historical society, provided a great deal of research on the background of the residents of the area identified locally as "Franklin Street," located south of the central business district on the west side of the Exeter River. A site file search was conducted at the New Hampshire Division of Historical Resources in September 2011, in order to identify previously recorded resources in the area as well as properties and districts listed in the National Register. The New Hampshire Department of Environmental Services' Dam Safety Bureau has a large file of documents relating to the history and condition of the dam, which were extensively used. The Exeter Public Library provided a large collection of town directories and local histories. Online resources, such as the Town of Exeter's website and indexed historical records available via Google Books, were also utilized as references.

Fieldwork consisted of a pedestrian review of every street in the project area, including the identification of any previously unidentified districts or areas that could be considered potentially eligible for the National Register. Photographs consisted of both individual buildings and streetscapes in order to capture all buildings and structures within the project area. The extent of the field survey was defined by the understanding that the primary impact of the project would be the removal of the existing dam, fish ladder and concrete weir, which are all within both a local and National Register district. The removal of the dam may also lower the level of the Exeter River upstream, possibly by up to five feet, with the impacts possibly extending south to Gilman Park. There are no impacts anticipated at the head of the tidal Squamscott River, at Kimball's Island and String Bridge.
The New Hampshire Fish and Game Department added a fish ladder and concrete weir on the west side of the Great Dam in 1968 as part of a fish passage and spawning restoration initiative. Since the late 19$^{th}$ century experts have associated the construction of dams with the decline of diadromous fish. Fish ladders that allow migrating fish to pass through dams at falls and rapids originally were thought to mitigate the effects of dams on spawning fish populations, but recent research suggests that fish passage structures at dams do not necessarily guarantee efficient passage of fish around a dam (Kennebec Estuary Land Trust). Researchers conclude that human impacts, including the construction of river dams, have contributed to a staggering decline in diadromous fish populations (Chesapeake Bay Journal 2010). At the dam site, there would be direct impacts associated with reconstruction/deconstruction of the dam and fish ladder and concrete weir.

Additional information on cultural resources is contained in **Appendix L**.

## 3.9.2 Archaeological Resources

Both Native Americans and early European settlers were drawn to Exeter by the presence of the Exeter River and its rich resources. Archaeologists have noted a clear association between seasonally-occupied sites at the falls of rivers where settlements focused on the riverine resources, particularly the spring run of alewives and Atlantic salmon (Starbuck 2005). There are, however, no previously reported sites within the project's Area of Potential Effect (APE) at the dam site. There are two previously reported sites within the potential impact area. [redacted]

Note: Information on archaeological sites redacted at the request of the NH Division of Historic Resources.

Based on historical and environmental review, and information gathered from the NHDHR archaeological site files, the APE at the Great Dam should be considered archaeologically sensitive for Pre-Contact and Euro-American archaeological sites, if soil cores indicate intact soil horizons beneath contemporary landscaping and historical fill. Until soil cores are available, the entire APE around the dam should be considered archaeologically sensitive.

In addition to the APE at the dam site, landforms along the Exeter and Little rivers suggest some potential for archaeological sites. Until archaeologists can walk over and visually inspect the entire potential impact area the following areas should be considered archaeologically sensitive for Pre- and Post-Contact period sites.

### Pre-Contact Period Sites

- On both banks of the Little and Exeter rivers, on intact, relatively level terrain within 200 meters of the water, particularly elevated river terraces with well-drained sandy to silty sandy soils.

- Particularly sensitive areas are the elevated terraces adjacent to the western bank of the Exeter River in the vicinity of the Gilman's Racetrack; and along the elevated terrace extending northeastward from Lary Lane

### Post-Contact Sites

- On the western bank of the Exeter River, on intact, relatively level, well-drained terrain north of South Street, between Franklin Street and the river,

- On the western bank of the Exeter River, on intact, relatively level, well-drained terrain south of South Street, at the bend in the river at the end of Franklin Street,

- On the western bank of the Exeter River, on intact, relatively level, well-drained terrain between South River Street and the river

- On the eastern bank of the Exeter River, at High Street.

If the Town of Exeter decides to remove the dam, then archaeologists can refine this assessment when they have permission to walk over and visually inspect all potential impact areas. At that time archaeologists also will be able to rank impact areas according to high, moderate, and low potential and create a research design for subsurface testing targeted to that ranking. Soil core testing throughout the APE at the dam site is recommended to determine whether there are intact soil horizons below grade and whether those soil horizons could have hosted archaeological sites. Hydraulic modeling results also should be reviewed to determine whether monitoring of archaeologically sensitive areas along upstream river banks is warranted to evaluate the long term effects of changes to the stream flow and to determine whether lowering the water level will expose archaeologically sensitive areas to erosion.

### 3.9.3 Discussion of Potential Effects

Adverse effects would occur to historic resources, both above-ground and archaeological (if the latter exist), regardless of whether Alternative B – Dam Removal, Alternative F - Partial Removal or Alternative H – Dam Modification is selected.

Alternative B - Dam Removal would eliminate the dam, while Alternative F - Partial Removal Alternative would create a substantial change to the structure, which is a contributing element of the surrounding historic district. Both options would essentially eliminate the impoundment, which would change the setting of the historic district and therefore likely be considered an adverse effect, albeit an indirect effect. Under the current conceptual design, however, portions of the dam abutments would remain in place, which may mitigate the adverse effect of its modification or removal.

Under Alternative H – Dam Modification, very significant modifications would need to be made to the dam in order to meet safety regulations, including removal of the top 5 feet (vertical) of the dam spillway and the installation of a highly-engineered mechanical automated crest gate and slide gate configuration. The modified dam would not resemble the current dam. Thus, the modified dam would change in its appearance significantly, which would have an adverse effect on the structure and the surrounding historic district.

Consideration and review of these impacts has begun with the initiation of the Section 106 review (Section 106) of the National Historic Preservation Act of 1966 (NHPA). Section 106 Section 106 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 federal agency involved in the undertaking, which for this project is NOAA, identifies the historic properties in consultation with the New Hampshire Division of Historical Resources (the State Historic Preservation Office) and other consulting parties and consults on the effects of the undertaking on these historic properties. NOAA has identified the consulting parties and has provided them with the inventory forms for the dam and the project area for review. The New Hampshire Division for Historical Resources has recommended that the Great Dam is a contributing resource to the existing Exeter Waterfront Commercial Historic District, NOAA, the lead federal agency concurs with the finding. The project area form has recommended further investigation on certain areas upstream of the dam that may be affected by Dam Removal or Modification, which include the Franklin Street area on the west side of the Exeter River, Gilman Park, and the granite and other walls lining the Exeter River immediately upstream of the dam. The archeological assessment calls for additional walk-overs by an archaeologist and soil coring along the banks of the Exeter River in the anticipated area of lower water levels, should the Town decide to remove the dam. Once the Town determines whether or not to remove the dam, the Section 106 process would continue with these additional investigations and subsequent consultation regarding effects.

## 3.10 Recreation

The purpose of this analysis is to review the extent to which recreation on the Exeter River in the vicinity of the Great Dam will be affected by Alternatives A (Existing Conditions/No Action) and Alternative B (Dam Removal). While Alternatives G and H were considered in other resources areas, the assessment of effects to recreation does not include these alternatives. Effectively, stabilizing or modifying the dam would result in no change to the dam impoundment under normal inflow conditions and would only affect flows in excess of the 50-year design flood, during which recreational activities are unlikely to occur.

### 3.10.1 Existing Conditions

The Exeter River begins in the town of Chester and flows east and north to the town of Exeter. Below the Great Dam, the river becomes the tidal Squamscott River, before emptying into Great Bay (NHDES, 2012). Beyond the developed area surrounding the Great Dam, the River is bordered by wetlands and forested riverbanks with gently-flowing waters characterizing this reach (ESRLAC, 2012). The stretch of the Exeter River in the town of Exeter impounded by the Dam provides such water-based recreation opportunities as boating, angling, and swimming. Lands surrounding the Exeter River in this reach provide complimentary land-based opportunities such as hiking, camping, bird-watching, sightseeing and field sports.

### 3.10.1.1 Recreation Activities

Fishing is popular on the Exeter River as a whole, especially in the upper reaches of the River that are annually stocked with American shad and with brook, brown and rainbow trout by the New Hampshire Fish and Game Department (NHFGD) (NHDES, 2011). Fish are released annually in an effort to restore populations and stabilize spawning stocks, as return numbers are declining in the past five years. The River supports both cold and warm water native species such as smallmouth and largemouth bass, brown bullhead, chain pickerel, American eel, yellow perch and sunfish. A fish ladder at Great Dam supports ongoing restoration efforts for anadromous fish.  river herring and shad and facilitates access to upstream spawning and nursery habitat for alewife and blueback herring. (Patterson, et al. 2012.)

The impounded nature of the Exeter River provides excellent flatwater non-motorized boating opportunities such as canoeing, kayaking, and rowing. Quickwater and whitewater boating opportunities are limited to high water conditions and generally to reaches upstream of the stretch impounded by the Great Dam (NHDES, 2012). Motorized boating opportunities are generally limited to deeper areas of the River impounded by Great Dam (ESRLAC, 2008). Downstream of Great Dam, the tidal reach of the Squamscott River is available for motorized and non-motorized boating (NHDES, 2011).

Scenic views of the river for sightseeing, nature study and bird watching are afforded from the various shoreline access sites and the bridge crossings at NH 108/Court Street, Gilman Street, and NH 108/High Street and the String Bridge from which Great Dam is visible. Over eighty percent of respondents to surveys of riverfront landowners and municipal officials conducted by the Exeter Squamscott River Local Advisory Committee (ESRLAC) in 1997 indicated that they value the scenic beauty of the watershed (ESRLAC, 2008).

### 3.10.1.2 Recreation Facilities

The stretch of the River impounded by Great Dam is accessible from Gilman Park, which is owned and operated by the Town of Exeter and provides a hand-carry boat launch, shoreline angling access, open space for walking, picnic tables, a baseball diamond and a basketball court (NHDES, 2012; Town of Exeter, 2012a). Gilman Park is also a popular spot for bird watching and provides scenic views of the River (NHDES, 2011; NHDES, 2012). The town of Exeter also owns conservation land adjacent to the river which provides opportunities for hiking and fishing (NHDES, 2012).

Phillips Exeter Academy provides shoreline access to the River adjacent to the Academy forest and athletic fields (NHDES, 2011). Hiking, jogging, and skiing opportunities are available on a trail system through the forest (NHDES, 2012) and a hand-carry launch is located adjacent to the Academy track off of Gilman Street.

Informal angling and canoe/kayak launching areas can be found at many bridge crossings in the watershed including the NH 108/Court Street and PEA/Stadium Bridge (ESRLAC, 2012). Founders Park provides benches from which people can view the falls and fish ladder at Great Dam (NHDES, 2011; Town of Exeter, 2012b).

Two privately-owned campgrounds are located adjacent to the river, upstream of Great Dam, in Exeter. The Green Gate Campground provides sites for tents and RVs, a playground, swimming pool, and shuffleboard courts. While it is located adjacent to the River, no access is available from the campground (GGC, 2012). Exeter Elms Campground likewise provides seasonal sites for tents and RVs, as well as a swimming pool, pavilion, and two playgrounds. The Exeter River can be accessed from the campground for non-motorized boating and angling activities (EEC, 2012). Downstream of the Dam, concrete boat launches providing motorized and non-motorized access to this reach are provided by the Exeter Town Landing on Water Street; Stratham Town Landing on River Road; NHFGD Chapman's Landing off of NH 108; and the Newfields Town Landing on River Road. Saltonstall boathouse, provides a boat launch on the Squamscott River and is used regularly by rowers (Marianne Barbin, Phillips Exeter Academy Athletic Department, Personal Correspondence, October 23, 2012).

Swasey Parkway, owned and operated by the Town of Exeter, provides a walking trail along the Squamscott River, a pavilion for concerts and performances, and is also popular for fishing, picnicking and bird watching (NHDES, 2011). Fishing along the Squamscott River also takes place from String Bridge in downtown Exeter, just downstream of Great Dam (NHDES, 2011).

Great Bay Campground, located at the mouth of the Squamscott River, provides access to the Squamscott River and Great Bay (NHDES, 2011). The campground provides seasonal bare tent and full hook up RV sites, a swimming pool, sport fields, dock and boat launch (GBC, 2012).

The locations of these sites are shown on **Figure 3.10-1**.

### 3.10.2 Discussion of Potential Effects

Aspects of each alternative that could affect recreation are summarized below. Additional details about each alternative are provided in Chapter 2 of this report.

Under Existing Conditions (Alternative A), Stabilize in Place (Alternative G) and Dam Modification (Alternative H), there would be no change to the river and recreation opportunities and facilities that exist now, as described above, would persist under this alternative.

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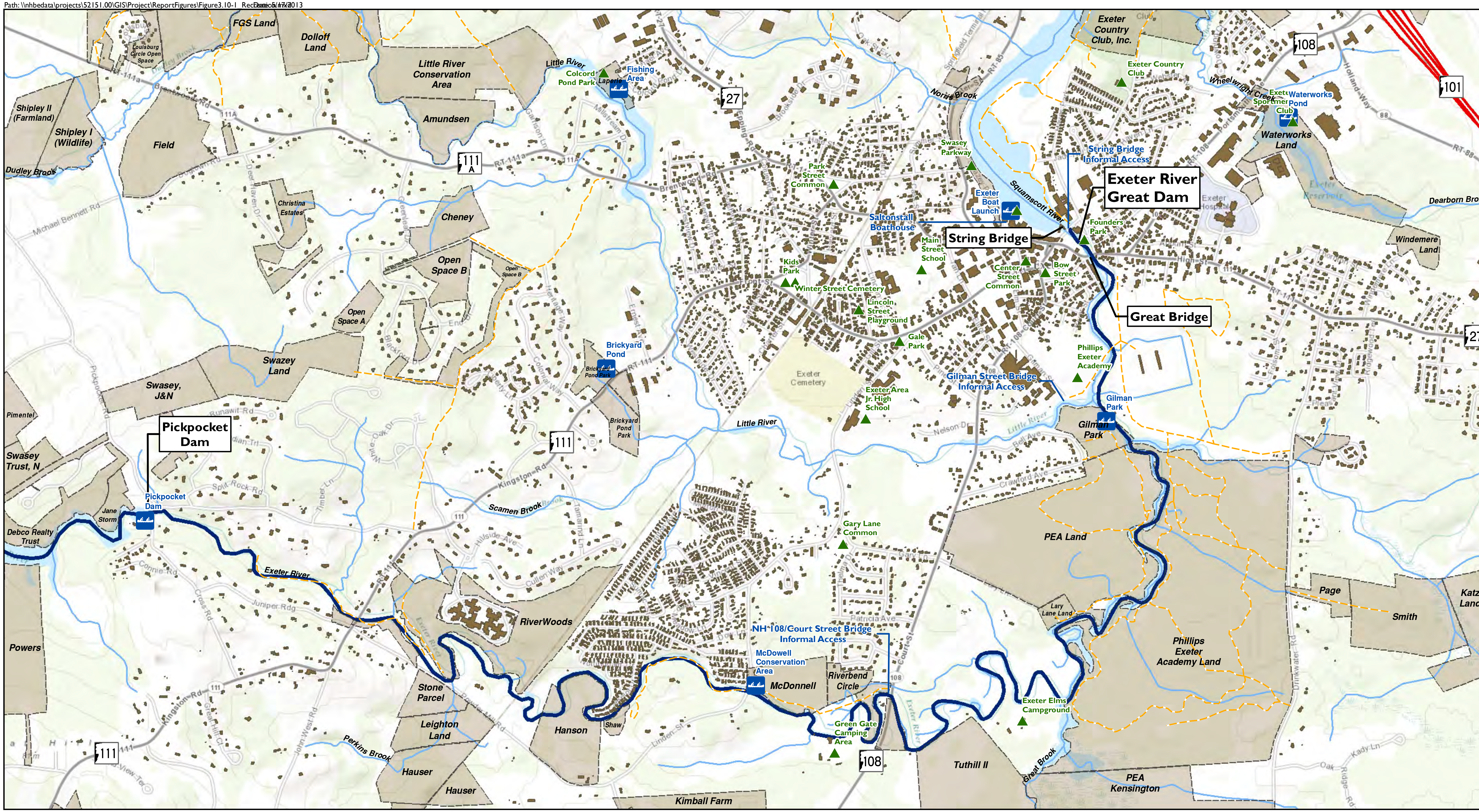


## Legend

- Recreation Site
- Recreation Trail
- Public Access Site
- Conservation/Public Land (NHGRANIT)
- Exeter River
- Stream (NHD)
- Buildings
- Highway

0 1,500 3,000 Feet

Vanasse Hangen Brustlin, Inc.

**Figure 3.10-1**
**Recreational Resources in the Study Area**

**Exeter Great Dam Removal Feasibility & Impact Analysis**

**Exeter, NH**

Town of Exeter Founded 1638 New Hampshire

Source: NHGRANIT, NH Fish & Game, Town of Exeter GIS

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Dam Removal (Alternative B), however, involves the removal of the entire existing dam structure. Partial Removal (Alternative F) would lower the dam spillway elevation by 4 ft. These alternatives would substantially change river elevations upstream from the existing dam site under low, normal and flood flows which may impact recreational opportunities as discussed below. From a recreation perspective, only Alternatives B and F would alter the stream channel and river characteristics upstream of the dam that may result in effects to recreational use. As such, Alternative B was evaluated with respect to the following potential effects to recreation as a "worst case" scenario:

- Access - for existing public and commercial boat launches, docks and fishing piers. The effect of Alternative B on the availability of access under post-removal conditions and what modifications might be necessary to ensure continued access (i.e. extension of boat ramps, dredging, etc.).
- Navigability - for existing boating opportunities. The effect of Alternative B on the availability of motorized and non-motorized boating under post-removal conditions with respect to sufficient depth, obstructions, hazards, velocities, etc.
- Fishing Opportunities - for existing resident and migratory species upstream and downstream of the dam. A change from an impounded to free-flowing habitat may change the composition of the fishery which, in turn, may affect recreational fishing opportunities. The overarching effects to fishing are summarized.

The HEC-RAS model (developed to assess a variety of changes to the Exeter River hydraulics) was employed to simulate hydraulic conditions in the river channel that would result under the implementation of Alterative B, from the dam to the head of the impoundment. Because the focus was primarily on access and navigability, this assessment focuses on modeling results obtained in the vicinity of existing formal and informal public access sites and known areas of constriction and shallow depth within the mainstem of the Exeter River (excluding the side channels). Specifically, we relied on modeling data for the following locations:

- Downstream extent of the model (interface of tidal influence)
- String Bridge - downstream of Great Dam
- Between Great Dam and String Bridge (dam tailrace)
- High Street Bridge
- Mid-point of Reach between High Street Bridge and Phillips Exeter Academy Stadium Bridge
- Just downstream of Phillips Exeter Academy Stadium Bridge
- Approximately 200 feet downstream of Phillips Exeter Hand-Carry Launch
- Approximately 200 feet upstream of Phillips Exeter Hand-Carry Launch
- Gilman Park
- Existing shallow Upper Exeter River

- Existing shallow and constriction Upper Exeter River
- Existing constriction Upper Exeter River
- Just downstream of the NH 108/Court Street Bridge

Hydraulic simulation through the study site was performed based on the median May flow, which would represent best recreation conditions under a post-removal scenario, as May is a high flow month, the month of peak fish passage activity, and generally the start of the summer recreation season. The median flow for the month of May was calculated to be 104 cfs for the reach downstream of Gilman Park to the Great Dam (Lower Exeter River) and 88 cfs in the reach extending from the confluence with the Little River at Gilman Park upstream to the NH 108/Court Street Bridge (Upper Exeter River). Hydraulic simulation was also conducted for the median September flow, which would represent worst case recreation conditions under a post-removal scenario. The median flow for September was calculated to be 5.9 cfs for the Lower Exeter River and 5 cfs for the Upper Exeter River (see Section 3.2.1).

**Table 3.10-1** summarizes the mean channel depths, wetted area (dewatered shoreline) and velocities that can be expected at each cross-section discussed above, under dam removal conditions (Alternative B), for May median and September median flow in comparison with Existing Conditions (Alternative A).

Under Alternative B, the average cross-sectional water depths for access points and areas having a potential effect on navigation will range from 0.13 ft or 1.6 inches (at the Great Dam during September median flow) to 7.71 ft (near the Phillips Exeter Academy Stadium Bridge during May median flow). The largest drop in cross-sectional water depth for the considered cross-sections will near the High Street Bridge during September median flows for a total drop in water depth of 4.73 feet.

Depths from Great Dam to the tidal influence of the Squamscott River will generally be the shallowest continual stretch, having an average depth of only approximately 2.5 inches over the course of the approximately 550 ft long reach. This reach is comprised of steeply descending ledge drops exposed by the dam removal, and not conducive to safe recreation under average inflow conditions. Two other locations having known shallow depths in the Upper Exeter River will see a drop in depth from 3.62 ft and 3.03 ft, respectively under existing September median flow conditions to 1.08 ft and 0.40 ft (4.8 inches), respectively under September median flow conditions if the Dam is removed.

During September median flow in post-removal conditions (Alternative B), wetted width will range from 7.76 ft to 125.89 ft (just upstream of the Phillips Exeter launch). The largest change to exposed shoreline area during September median flow conditions will occur at an existing shallow area of the River upstream of the confluence with the Little River. In this location, the existing wetted width of the River during September median flows is 142.85 ft. Under Alternative B, the River is expected to be 49.20 ft wide in this location resulting in approximately 94 ft of

Table 3.10-1. Hydraulic Effects of Alternative B in Comparison with Existing Conditions (Alternative A)

| Location | Alternative A - Existing Conditions | | | | | | Alternative B - Dam Removal | | | | | | Difference | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | May Median Flow | | | September Median Flow | | | May Median Flow | | | September Median Flow | | | May Median Flow | | | September Median Flow | | |
| | Hydraulic Depth (ft) | Wetted Area Width (ft) | Channel Velocity (ft/s) | Hydraulic Depth (ft) | Wetted Area Width (ft) | Channel Velocity (ft/s) | Hydraulic Depth (ft) | Wetted Area Width (ft) | Channel Velocity (ft/s) | Hydraulic Depth (ft) | Wetted Area Width (ft) | Channel Velocity (ft/s) | Hydraulic Depth (ft) | Wetted Area Width (ft) | Channel Velocity (ft/s) | Hydraulic Depth (ft) | Wetted Area Width (ft) | Channel Velocity (ft/s) |
| Downstream Extent | 0.38 | 172.36 | 3.55 | 0.26 | 10.15 | 2.24 | 0.38 | 172.36 | 3.55 | 0.26 | 10.15 | 2.24 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 |
| String Bridge | 0.41 | 31.15 | 8.14 | 0.15 | 10.22 | 3.76 | 0.41 | 31.15 | 8.14 | 0.15 | 10.23 | 3.76 | 0.00 | 0.00 | 0.00 | 0.00 | 0.01 | 0.00 |
| Between Dam and String Bridge | 0.78 | 88.88 | 1.50 | 0.28 | 20.89 | 1.00 | 0.78 | 88.88 | 1.50 | 0.28 | 20.89 | 1.00 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 |
| Great Dam | 4.87 | 115.56 | 0.18 | 4.41 | 113.66 | 0.01 | 0.50 | 51.26 | 4.03 | 0.13 | 26.42 | 1.77 | -4.37 | -64.30 | 3.85 | -4.28 | -87.24 | 1.76 |
| High St Bridge | 5.92 | 68.91 | 0.30 | 5.39 | 68.10 | 0.02 | 1.39 | 53.09 | 1.41 | 0.66 | 40.35 | 0.22 | -4.53 | -15.82 | 1.11 | -4.73 | -27.75 | 0.20 |
| Between High Street and PEA/Stadium Bridge | 6.14 | 175.23 | 0.10 | 6.10 | 161.63 | 0.01 | 3.51 | 127.33 | 0.23 | 2.49 | 113.45 | 0.02 | -2.63 | -47.90 | 0.13 | -3.61 | -48.18 | 0.01 |
| PEA/Stadium Bridge | 9.84 | 131.16 | 0.08 | 9.52 | 128.26 | 0.00 | 7.71 | 101.27 | 0.13 | 7.11 | 91.54 | 0.01 | -2.13 | -29.89 | 0.05 | -2.41 | -36.72 | 0.01 |
| PE Launch | 8.24 | 174.76 | 0.07 | 7.95 | 164.05 | 0.00 | 5.70 | 132.46 | 0.14 | 4.61 | 125.89 | 0.01 | -2.54 | -42.30 | 0.07 | -3.34 | -38.16 | 0.01 |
| PE Launch | 7.09 | 141.82 | 0.11 | 6.89 | 131.33 | 0.01 | 5.26 | 92.89 | 0.21 | 4.32 | 85.24 | 0.02 | -1.83 | -48.93 | 0.10 | -2.57 | -46.09 | 0.01 |
| Gilman Park | 8.00 | 116.39 | 0.09 | 7.67 | 113.37 | 0.01 | 5.98 | 82.78 | 0.18 | 5.22 | 74.52 | 0.01 | -2.02 | -33.61 | 0.09 | -2.45 | -38.85 | 0.00 |
| Gilman Park | 7.20 | 151.41 | 0.08 | 6.83 | 147.77 | 0.00 | 5.04 | 104.78 | 0.17 | 4.38 | 90.39 | 0.01 | -2.16 | -46.63 | 0.09 | -2.45 | -57.38 | 0.01 |
| Upstream of Gilman Park | 3.98 | 153.72 | 0.15 | 3.62 | 142.85 | 0.01 | 1.99 | 67.88 | 0.65 | 1.08 | 49.20 | 0.09 | -1.99 | -85.84 | 0.50 | -2.54 | -93.65 | 0.08 |
| Upstream of Gilman Park | 3.08 | 55.49 | 0.52 | 3.03 | 46.83 | 0.04 | 1.14 | 14.39 | 5.37 | 0.40 | 7.76 | 1.59 | -1.94 | -41.10 | 4.85 | -2.63 | -39.07 | 1.55 |
| Meander Bends, Downstream of Court St. | 3.77 | 45.43 | 0.51 | 4.53 | 32.48 | 0.03 | 2.92 | 27.01 | 1.11 | 2.23 | 11.16 | 0.20 | -0.85 | -18.42 | 0.60 | -2.30 | -21.32 | 0.17 |
| Court St Bridge | 6.45 | 85.03 | 0.27 | 5.81 | 63.45 | 0.02 | 4.11 | 44.47 | 0.48 | 2.56 | 29.73 | 0.07 | -2.34 | -40.56 | 0.21 | -3.25 | -33.72 | 0.05 |

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exposed shoreline. Exposed shoreline in the vicinity of the Phillips Exeter Launch will average approximately 42 ft under September median flows for Alternative B while exposed shoreline in the vicinity of Gilman Park will average approximately 50 ft.

Water velocity would generally be slack in the reach between the Phillips Exeter Academy Stadium Bridge and upstream of Gilman Park under the low flow conditions of September median flow for Alternative B. In areas generally corresponding with constriction of the river channel (Lower Exeter River reach in the vicinity of the dam and Upper Exeter River reach near Lary Lane), velocities would be higher under the low September median flow conditions, generally exceeding 1 ft/sec up and ranging up to 3.76 ft/sec at the rapids exposed at String Bridge. Under May median flow conditions, the reach between the Phillips Exeter Academy Stadium Bridge and Gilman Park would still be generally slow (less than 0.25 ft/sec). Velocities would be expected to exceed 5 ft/sec at the shallowest and narrowest part of the river downstream of the Court Street Bridge. The fastest current would be experienced at the String Bridge, with 8.14 ft/sec expected post-removal under May median flow conditions, however, depths would only be approximately 0.41 ft (4.9 inches) in this location under these conditions due to the steep falls.

### Access

Removal of the Great Dam and appurtenant facilities will result in a lowering of the existing water level of the impoundment. This drop in elevation will result in exposure of approximately 20 feet of previously inundated shoreline in the vicinity of the existing Gilman Park boat launch during the highest seasonal flows (May) and approximately 25 feet of previously inundated shoreline during the lowest seasonal flows (September). The boat launch at Phillips Exeter Academy off Gilman Street would likewise experience dewatering of the shoreline by approximately 23 feet during median May flows and 21 feet during median September flows. Because these boat launches are hand-carry/shoreline access launches, they will still be usable under Alternative B. As such, dam removal is expected to have no effect to public access to this reach of the Exeter River for non-motorized boating.

Likewise, pedestrian access to the impoundment for angling, bird watching and other purposes will continue to be provided by Gilman Park, the Phillips Exeter hand-carry launch, and where the various bridges cross the River. At the High Street Bridge, just upstream of the Dam, the shoreline will dewater by approximately 8 feet on either side of the shore during May median flows and 14 feet on either side of the shoreline during September median flows. The PEA/Stadium Bridge will experience an average dewatering of either shoreline by 15 feet during May median and by approximately 18 feet during September median flows. The upstream extent of the impoundment at the NH Route 108/Court Street Bridge will experience approximately 20 feet of dewatering on either shoreline, on average, during May median flows and 17 feet during September median flows. Again, because this access would persist, though the distance to the water would be greater, dam removal is expected to have no effect to informal public access at road crossings along the Upper and Lower Exeter River.

## Navigation

For the upstream reach extending from Great Dam to the NH Route 108/Court Street Bridge, the shallowest sections of the River under existing conditions is located in the reach upstream of Gilman Park. At these locations, existing depth under September median flow conditions is in excess of 3 ft. Under the Dam Removal Alternative, the shallowest river depths would be only 4.8 inches in a short portion of the channel (i.e., corresponding to the reemergence of a riffle area), though other areas will retain as much as 2 ft of river depth. About ¼ mile downstream of the NH 108/Court Street bridge, the depth under September median flows is predicted to drop to 2.23 ft under Alternative B. The Great Bridge at High Street has an existing depth of 5.39 ft under September median flows. However, under post-removal conditions, this would drop to 0.66 ft (approximately 8 inches). Because non-motorized watercraft comprise the majority of the boating use of the reach of the Exeter River upstream of the dam, given the existing riverine nature of the impoundment and the lack of adequate motorized boat access, Alternative B will have limited effects to navigation. In areas where median September flows result in river depths of less than 1 foot, there may be locations where portaging or carrying over shallow riffles and sandbars may be necessary. However, as non-motorized boats are typically able to traverse flowed waters with a minimum depth of 6 inches, the overall effect to navigation in this reach is negligible.

For the reach immediately downstream of and including Great Dam, post-removal depths under September median flow conditions will generally be too low to navigate. Specifically, the depths in this approximately 550 ft long reach will range from 0.13 ft (1.6 inches) to 0.28 ft (3.36 inches). As such, this section of the River would be unavailable for through boating under low flow conditions. Under higher May median flow conditions, depths in this reach do increase. However, several locations within the reach would be less than 6 inches and therefore, unfavorable to through navigation for non-motorized boats.

Removal of the Dam will support a continuous riverine environment for non-motorized boating for the length of the Exeter River currently impounded by the Great Dam, possibly enhancing the attractiveness of the river for extended trips. Furthermore, existing ledges located immediately downstream of the existing dam may, at higher flow-levels, provide riffles, waves, and other current features that may be favored by non-motorized boaters. Where the hydraulic model predicts that depths and velocities will vary among areas within a particular reach, this may indicate turbulent erratic flow typical of rapids. As such, there is the potential for whitewater features in areas where flow is constricted by the river channel or obstructions. In the reach from Great Dam to the String Bridge, the river channel bottom drops in elevation approximately 14.5 feet over the course of the approximate 370 foot long reach, resulting in an average gradient of approximately 4% or 207 ft/mi. Under 2 year flood flow conditions for Alternative B, corresponding to 1,481 cfs in the Lower Exeter River and 1,257 cfs in the Upper Exeter River, depths would range from approximately 1.3 feet to over 5 feet. Sufficient depth and gradient for whitewater boating opportunities would potentially be afforded by this reach under 2 year flood flow conditions.

### Angling

Dam removal is identified as a viable option for improving fish passage and habitat in the project area and would restore upstream passage to approximately 13 river miles on the mainstem of the Exeter River and over 2 river miles on the Little River. Species composition in the immediate vicinity of Great 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. Enhanced habitat connectivity resulting from dam removal; may facilitate the spawning migration of American shad and river herring (alewives and blueback herring) and contribute to increases in their population abundance. The juvenile fish of these species travel in schools and provide a valuable source of forage to other aquatic predators including game fish such as bass and pickerel, and also avian birds such as kingfisher, osprey, heron and eagles.

Both the adult and juvenile life stages of river herring provide forage for marine and estuarine predators, including game fish such as striped bass during both the spring adult spawning run and again in the late summer and early fall when the juvenile herring exit the Exeter River.

American shad historically were harvested during the late spring during the adult upstream spawning run. However, the current population does not provide a fishery in the Exeter River. Dam removal may simultaneously promote improved access for shad to riverine spawning habitat, and the currently impounded river reach would likely become more suitable for shad spawning and juvenile rearing. Over time this may promote increases in shad abundance that can provide a potential future fishery.

Cooler and faster flowing water may enhance opportunities for coldwater fishing for trout species and provide more insect forage for all game species. As these activities contribute to improved sport fish populations in the area, increases in angling may result. Because fish passage currently exists at Great Dam, no significant change to the overall composition of the fishery upstream is expected. Where shallower areas of the River present themselves under post-removal conditions, there may be an increase in wading angling in these locations.

# 3.11 Natural Resources

## 3.11.1 Fisheries

The Exeter River provides habitat for a number of ecologically important native diadromous fish species, including the anadromous alewife (*Alosa pseudoharengus*), blueback herring (*A. aestivalis*), and rainbow smelt (*Osmerus mordax*) and the catadromous American eel (*Anguilla rostrata*) (Eipper, et al., 1982). The New Hampshire Fish and Game Department (NHFGD) owns, operates, and monitors the fish ladder at the Great Dam and has documented that, in addition to these diadromous fish species, American shad and sea lamprey also use the fish ladder. Anadromous fish species such as shad and sea lamprey spawn in fresh water and then migrate to the sea to grow to maturity. 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 migrate to estuarine and freshwater rivers and rely on the river to provide for nursery habitat. Eels live in the fresh and brackish water system for upwards of 20 to 30+ years before returning to the ocean to spawn. These two groups are referred to collectively as diadromous 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 Great Dam between the marine and freshwater ecosystem to complete their life cycles.

NH Fish and Game has been actively working to restore both river herring and American shad in the Exeter River since the late 1960s 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 the first two dams from the head-of-tide during spring months only. Fish ladders at Pickpocket Dam in Brentwood and Great Dam in Exeter allow for upstream passage of diadromous fish to reach spawning and nursery habitat. However, there are not specific passage facilities for American eels from the tidal portion of the river, Squamscott River, to the Exeter River upstream. The fish ladders are not designed to provide downstream passage for emigrating diadromous fish. By enhancing upstream fish passage at Great Dam, diadromous fish can volitionally access approximately 13 miles of spawning and nursery habitat on the Exeter River, and over two miles on Little River.

The Exeter River watershed is home to ten fish species of "special conservation concern" as identified in the New Hampshire's Wildlife Action Plan (**Appendix N**) prepared by the NHFGD. These include both diadromous and freshwater species: American eel, alewife, blueback herring, sea lamprey, American shad, rainbow smelt, bridle shiner, redfin pickerel, banded sunfish and swamp darter. A designation of "special concern" indicates that the species has the potential to become threatened if no conservation actions are taken. There is an ongoing anadromous fish restoration effort for river herring and shad, and the river serves as a spawning area and juvenile habitat for alewife, blueback herring, sea lamprey, American eel, rainbow smelt and American shad.

Blueback herring and alewife are presently under consideration by the Department of Interior (DOI) as candidates for protection under the Endangered Species Act (ESA). An ESA listing may determine that the population is imperiled unless threats to the population identified at the time of the listing are addressed and the population recovers to a defined level. If such a listing occurs, any federal action concerning the dam will be subject to review by NOAA under Section 7 of the ESA. Continued operation of the dam and fish ladder may require that the federal agencies issue an Incidental Take Permit. Issuance of an ITP will be contingent on a finding that the lawful operation of the fish ladder and/or dam will not materially impact species recovery.

Anadromous species rely on gaining access to upstream habitat for spawning, and nursery life cycle functions during the spring and summer. The catadromous American eel relies on the river to provide habitat for juvenile eels growing to maturity and feeding up to approximately 25 years, until at maturity they undertake a seaward migration to spawn. Under existing conditions, Great Dam has a denil fish ladder to facilitate the migration (**Figure 3.11-1**).[46] The fish ladder was operational in 1970. The fish ladder system was designed based on the existing headwater and tailwater elevation and hydrologic conditions at the site.

NHFGD records show a decline in river herring, American shad, and rainbow smelt in the past decade in the river corridor. According to Patterson et al. (2012), two factors affecting recruitment of adults in the Exeter River are poor water quality and impediments to downstream migration. Problems with closing the floodgate at the Exeter River dam, water withdrawals from the river by the Town of Exeter, or a combination of both, have resulted in prolonged periods of limited or no flow over the Great Dam at various times of the year. 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 Exeter River. Therefore, low annual returns of spawning river herring may be due to poor survival of river herring due to extended periods of poor water quality from June through October. (C. Patterson, NHFGD, personal communication). Patterson et al. (2012) summarizes monitoring data from the Exeter fish ladder from 1972 through 2011 (**Figure 3.11-2**). Counts of river herring have ranged as high as 15,626 fish (1981). However, in some years no river herring have been recorded, due to a variety of factors such as when the fish trap was inoperable in 1994 or when high spring flows have interrupted migratory fish ascending the fish ladder and/or fish count monitoring. River herring were present and were observed spawning below the Great Dam and String Bridge

▼

[46] A denil ladder has 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.

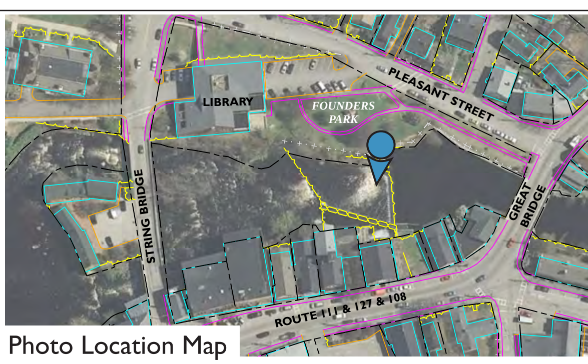



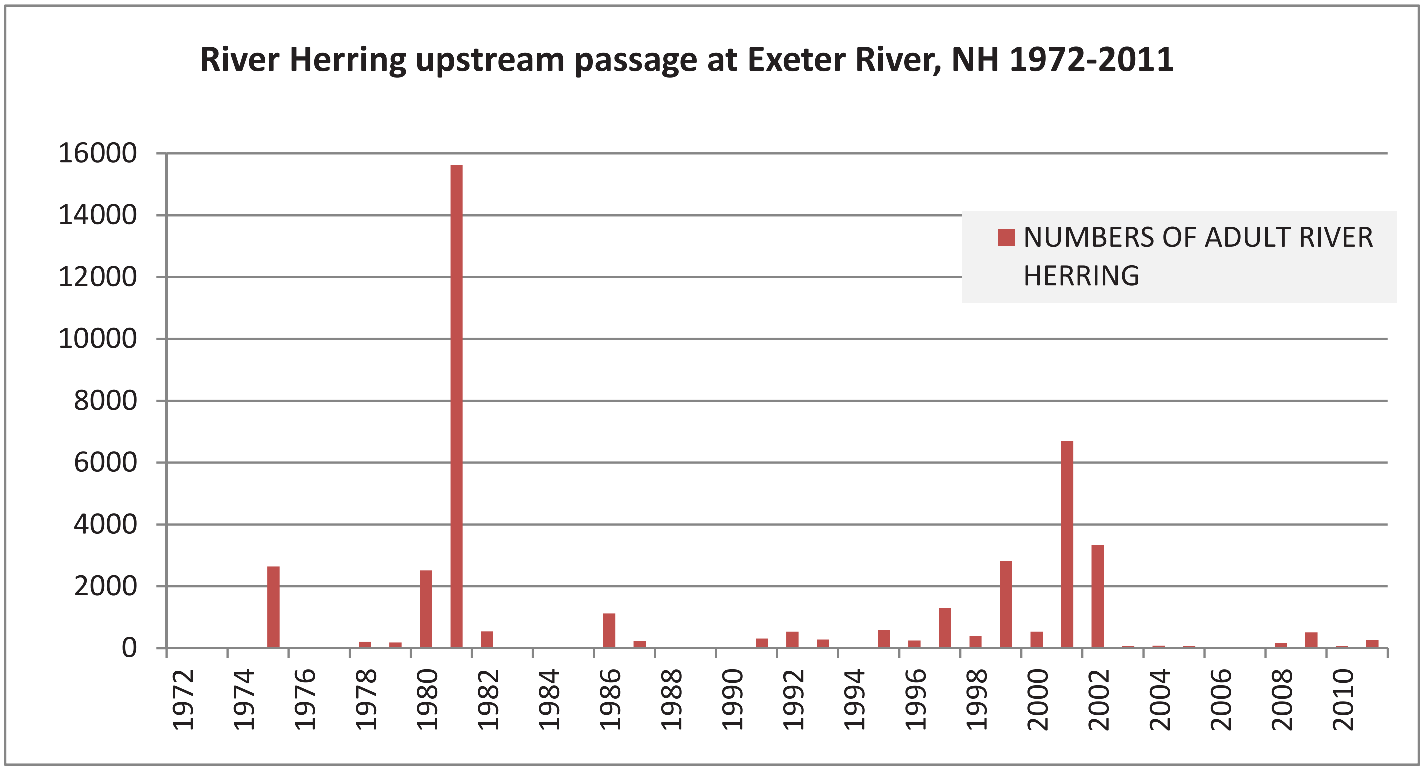
Photo Location Map

Vanasse Hangen Brustlin, Inc.

**Figure 3.11-1**

**Fish Ladder at the Great Dam**

**Exeter Great Dam Removal Feasibility and Impact Study**
**Exeter, NH**




Vanasse Hangen Brustlin, Inc.

**Figure 3.11-2**

**River Herring Data, Exeter River**

Exeter Great Dam Removal
Feasibility and Impact Study
Exeter, NH

Source: C. Patterson, NH Fish and Game Department in those years but not documented (C. Patterson, NHFGD, personal communication). In addition to river herring, a total of 10,395 fish of at least 22 other species have ascended the fish ladder since 1980 (**Table 3.11-1**) (C. Patterson, NHFGD, personal communication), with lamprey consisting of 79% of the species composition, followed by brook trout (10%), white sucker (6%), and rainbow trout (1%). Many of these species are not diadromous (e.g., common white suckers, bass, etc.). Rather, these fish during their in-river movements fall over the dam and use the fish ladder to ascend back into freshwater.

Rainbow smelt spawn in low gradient habitat at the freshwater-saltwater interface, and do not inherently migrate very far up streams. They would be unlikely to have ascended the historic natural falls at the Great Dam**.** Rather they are known to spawn in the gravel and cobble substrates at the head of tide below the dam.

Table 3.11-1. Fish species (*other than river herring*) recorded as passing upstream at the Exeter River fish ladder at Great Dam, 1980-2012.

| Species | number of individuals | |
|---|---|---|
| lamprey | 8,249 | 79% |
| brook trout | 1,077 | 10% |
| white sucker | 636 | 6% |
| rainbow trout | 87 | 1% |
| fallfish | 70 | 1% |
| brown trout | 51 | 0.49% |
| creek chub | 47 | 0.45% |
| common sunfish | 47 | 0.45% |
| largemouth bass | 39 | 0.38% |
| common shiner | 21 | 0.20% |
| golden shiner | 20 | 0.19% |
| bluegill | 16 | 0.15% |
| eastern chain pickerel | 6 | 0.06% |
| trout spp. | 5 | 0.05% |
| redbreast sunfish | 5 | 0.05% |
| Atlantic salmon | 5 | 0.05% |
| banded sunfish | 4 | 0.04% |
| brown bullhead | 3 | 0.03% |
| American eel | 3 | 0.03% |
| smallmouth bass | 2 | 0.02% |
| yellow perch | 1 | 0.01% |
| tiger trout | 1 | 0.01% |
| TOTAL | 10,395 | |

Source: NHFGD records

NHFGD staff have observed that under some high flows, most river flow is along the right bank (looking downstream) in the vicinity of String Bridge and river left has barriers like logs and other river debris. This creates conditions such that fish cannot easily find the entrance to the fish ladder. This may delay or otherwise undermine upstream fish passage effectiveness (*C. Patterson, NHFGD, personal communication)*. So, while no quantitative fish passage efficiency studies have been performed on the fish ladder, it appears that a number of factors contribute to impacting its effectiveness. The fish ladder is operational but requires routine maintenance (C. Patterson, NHFGD, personal communication).

### 3.11.1.1 Fish Passage Characteristics of the Project Alternatives

Aspects of each alternative that could affect fish passage are summarized below. Additional details about each alternative are provided in Section 2 of the report.

- **Alternative A – Existing Conditions**. Under this scenario, the existing dam and fish ladder would remain as is, with no modifications. As discussed in Chapter 2, this alternative is not viable due to safety and regulatory issues. It is included here to provide a basis for comparison.

**Alternative B – Dam Removal**. This alternative involves the removal of the entire existing dam structure, including the fish ladder and lower dam, and restoring the original slope, and exposing the natural stream bed by removing accumulated sediment and submerged debris that has accumulated upstream of the spillway within the footprint of the existing dam and immediately upstream and downstream. This alternative substantially changes river elevations upstream from the existing dam site and river hydraulics both upriver and at the former dam site. Under this alternative, migratory fish species would need to migrate upstream through rapids and ledges no longer submerged by the impoundment created by the two dams rather than via the existing fish ladder. From a fish passage perspective only Alternative B would alter the stream channel and passage characteristics below the dam in ways affecting upstream fish passage migration. This alternative would entail removing the existing fish ladder allowing fish to ascend the river through the natural river channel of exposed bed rock ledges and rapids.

- **Alternative F – Partial Removal.** Under Alternative F, the dam crest would be lowered to reduce flood hazard. Because the structure would still remain blocking upstream fish passage, an upstream fish ladder would be required. Under this scenario, the existing denil fish ladder (river left shoreline) would be removed along with the angled weir and a new more compact denil fish ladder would be constructed on the river right shoreline (looking downstream), to include attraction flow.

Removal of the angled weir, and discontinued use of the slide gates should eliminate cross-hydraulics that reduces the effectiveness of the existing fish ladder, and enable river herring to access the new fish ladder entrance more readily than under the existing fish passage arrangement. Because the net head will be reduced by lowering the dam crest, the net rise of this new fish ladder will be less than the existing ladder, allowing the ladder to be a shorter run, which should also reduce the amount of potential fallback and delay of fish entering and ascending a longer and steeper fish passage such as that which currently exists.

- **Alternative G – Stabilize in Place**. Under this scenario, the dam and fish ladder would remain essentially as is, with no significant modifications. Thus, the fish ladder would not be directly affected.

- **Alternative H – Dam Modification.** Under this alternative the dam would remain but would be modified sufficiently to pass the 50-year flood event by lowering the spillway and replacing it with a 75-ft long adjustable flashboard and gate system to provide an "effective" spillway crest of Elev. 18.5 when fully opened. Downstream river channel and fish ladder structures would remain essentially the same as under existing conditions. Alternative H would retain the existing fish ladder, and would not change the inlet or outlet elevations thereby allowing it to be functionally unchanged. However, operation of the gates and spillway could potentially influence the effectiveness of the fishway, as gate discharges could provide flows that make finding the fishway entrance difficult for fish. This could delay or reduce the spawning run. Therefore, fish approaching the Exeter River from downstream would experience the same fish passage conditions as at present. Upstream fish passage is not likely to occur during flood events. Therefore although Alternative H would redirect flood flow hydraulics through the structure and downstream fish passage area differently than the existing spillway, fish passage would not be affected. For purposes of this analysis it was assumed that non-flood event hydraulics below the dam would be similar to those under existing conditions, as the river channel and fish ladder entrance geometry will not be altered.[47]

## 3.11.1.2 Fish Passage Analysis Methods

The HEC-RAS model (developed to assess a variety of changes to the Exeter River hydraulics) was employed to simulate hydraulic conditions in the river channel that would dictate upstream fish passage conditions resulting from implementation of

▼

[47] Although beyond the scope of this analysis, improvements to the existing fish ladder may be required due to existing conditions that may provide sub-optimal fish passage efficiency. These may include repairs to the fish ladder, and/or channel modifications near the fish ladder entrance to enhance attraction flow hydraulics.

Alterative B. Although the HEC-RAS model extends from the dam upstream 7.5 miles to the Pickpocket Dam, the fish passage assessment focused on modeling results obtained in the immediate vicinity of the dam so that hydraulics expected to exist after dam removal could be simulated. (See **Figure 3.11-3.**) Specifically, we relied on modeling data obtained from eight transects (148.4 through 251.2) that span the river reach from downstream from the existing fish weir upstream to the Great Bridge (High Street). This is a distance of 97 ft, which is where removal of the dam would expose the steepest sloped portion of the Exeter River.

Hydraulic simulation through the study site was performed based on the median May flow, as May is both a high flow month and also the month of peak fish passage activity. The stream channel velocities derived from the model were then evaluated using SprintSwim (Haro, et al., 2004) against the ichthyomechanics of representative migratory fish to evaluate the likelihood that such fish would be able to successfully ascend the exposed ledges and rapids that would exist after dam removal. For purposes of this model, the average alewife and blueback herring length was assumed to be approximately 12 inches long, and water temperature during migration was conservatively assumed to be 10°C (50°F).

### .11.1.3 Analysis Results

The median flow for the month of May was calculated to be 104 cfs (W&S, 2012). **Table 3.11-2** summarizes mean channel depths and velocities predicted at each cross-section in the vicinity of Great Dam, should it be removed. The hydraulic model predicts that depths and velocities will be variable among transects throughout the 97 ft reach, for which modeling data are available. This is to be expected in the turbulent erratic flow typical of natural rapids. The average cross-sectional water depths will range from 0.4 ft (at transect 181.7) to 1.2 ft (transect 245.8) and that water velocity would range from 1.5 ft/sec (transects 161.0 and 148.3) to 6 ft/sec (transect 212.4). The overall mean velocity for the reach is 3.9 ft/sec.

**Table 3.11-2** shows average channel depths and velocities under median May river flow, projected to occur at the Exeter River at the present site of the Great Dam, should the dam be removed.

The SprintSwim model indicates (through interpolation) that a fish such as a blueback herring ascending a stream 98 ft in length (approximately the distance of rapids that would be exposed by dam removal) against an average velocity of 3.9 ft/sec would have approximately a 88% probability of ascending the rapids (**Table 3.11-3** and **Figure 3.11-4**). This is likely a conservative estimate, as the average cross-sectional velocity generated by the HEC-RAS model does not account for the spatial variability in velocities that are inherent in complex rapids. In most cases there are velocity shelters formed behind rocks, boulder and in pocket pools, and along the stream margin that form pathways that fish can utilized and/or rest in, that are not reflected in this hydraulic model.

Table 3.11-2. Exeter River Depths & Velocities, Dam Out, Median May Flows

| Cross-section (From HEC-RAS) | Hydraulic Depth (ft) | Channel Velocity (ft/sec) |
|---|---|---|
| 245.8 | 1.2 | 2.0 |
| 227.9 | 0.9 | 5.5 |
| 212.4 | 1.0 | 6.0 |
| 201.0 | 1.0 | 5.9 |
| 181.7 | 0.4 | 4.9 |
| 161.0 | 0.9 | 1.5 |
| 148.3 | 0.8 | 1.5 |
| | Mean Velocity | 3.9 |

Source: Kleinschmidt Associates

**Table 3.11-3** shows the percentage of 12-inch long river herring successfully ascending various distances at various water velocities, at a water temperature of 50°F, based on Haro, et al. (2004). At a mean velocity of 3.9 ft/sec, fish would have approximately an 88% percent chance of ascending the rapids a distance of 98 ft. However the rapids would extend about an additional 100 ft. Although the model does not directly account for the added distance, it can be assumed that a lower percentage of fish would ascend a longer distance. For purposes of this analysis we conservatively assume this to be 55%.

### 3.11.1.4 Findings Relative to Fish Passage

Under existing conditions and also under Alternative H, river herring and other anadromous fish would continue to pass upstream via the existing fish ladder as they presently do, given the inherent site limitations of entrance location and gate operations. The fish ladder is a standard design that is used throughout New England to successfully pass such fish upstream. However, as discussed, under existing conditions, water depths and hydraulics in and around the existing fish ladder entrance are not optimal under certain flows and gate settings, and may not provide optimal upstream fish passage. The modifications proposed under Alternative H would not alter the function or hydraulics of the existing fish ladder unless additional modifications were pursued as part of the overall project specifically to correct the existing localized hydraulic conditions in the vicinity of the fish ladder entrance. This may include items such as modifications to slide gates and reinforcement of the lower portion of the fish ladder where it is subjected to river flow.

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Legend

HEC-RAS Model X-Section

0 100 200 Feet

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**Figure 3.11-3**
**HEC-RAS Cross-sections at Fish Ladder**

Exeter Great Dam Removal
Feasibility & Impact Analysis

Exeter, NH

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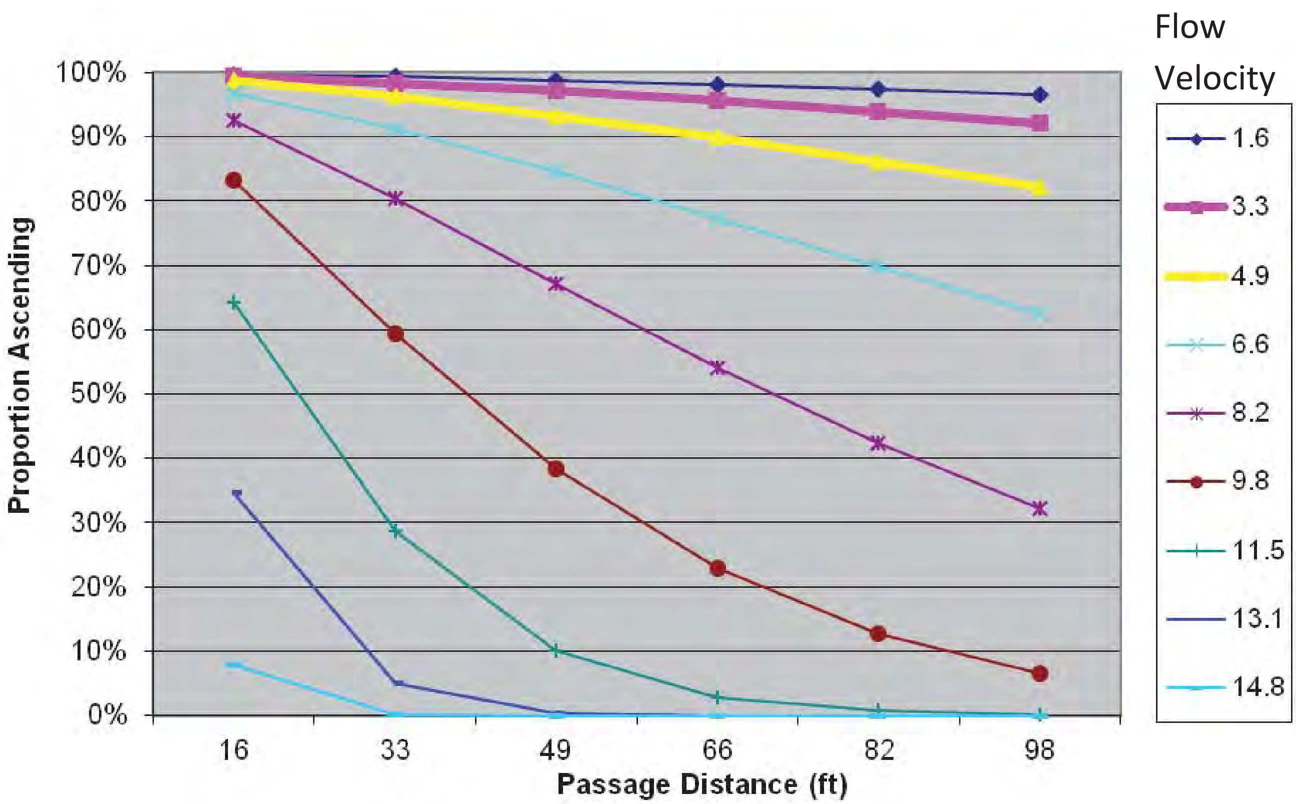


Percentage of 12-inch long river herring successfully ascending various distances at various water velocities, at a water temperature of 50 °F, based on Haro, et al. (2004).

Table 3.11-3. River Herring Passage Probabilities

| | Distance upstream (ft) | | | | | |
|---|---|---|---|---|---|---|
| velocity (ft/sec) | 16 | 33 | 49 | 66 | 82 | 98 |
| 1.6 | 100% | 99% | 99% | 98% | 97% | 97% |
| 3.3 | 99% | 98% | 97% | 96% | 94% | 92% |
| 4.9 | 99% | 96% | 93% | 90% | 86% | 82% |
| 6.6 | 97% | 91% | 85% | 77% | 70% | 62% |
| 8.2 | 93% | 80% | 67% | 54% | 42% | 32% |
| 9.8 | 83% | 59% | 38% | 23% | 13% | 7% |
| 11.5 | 64% | 29% | 10% | 3% | 1% | 0% |
| 13.1 | 35% | 5% | 0% | 0% | 0% | 0% |
| 14.8 | 8% | 0% | 0% | 0% | 0% | 0% |

Source: Kleinschmidt Associates, after Haro, et al. (2004)

The probability of river herring being capable of ascending the exposed rapids in the absence of the dam (Alternative B) is 55% probability. This alternative involves restoring the original slope and natural profile of the stream at the rapids below and immediately above the dam that existed prior to its construction. This suggests that approximately six out every 10 river herring will successfully ascend the rapids that would be exposed following dam removal. Such an upstream spawning escapement factor should be adequate for a self-sustaining river herring (alewife or blueback herring) run. For example, Maine alewife runs are commonly self-sustaining with as little as 15% upstream spawning escapement (Squiers, 1988). This ability of anadromous fish to readily ascend the exposed rapids and ledges is consistent with the historic evidence that these species commonly ascended the river prior to dam construction.

The model assumptions used in this analysis are conservative as they rely on average cross-sectional velocities and do not account for pocket velocity shelters that would enable fish to readily pass upstream with even greater ease. Furthermore, the model conservatively assumes a continuous 50°F water temperature, which, although typical for early in the passage season, would continuously warm as the season progresses. As ambient water temperature increases, the corresponding swim speed ability of the fish also increases, and would contribute to increased ability to ascend against prevailing velocities (Haro, et al., 2004).

## 3.11.2 Wildlife and Natural Communities

This section describes the ecological resources present along the Exeter, Little and Squamscott River and the connectivity between these rivers and the forested and floodplain shoreline adjacent to them. Information in this discussion is based on field review of the project area, review of existing published information such as the NH Wildlife Action Plan, and consultation with state and federal resource agencies such the NH Natural Heritage Bureau (NHNHB), the NH Fish and Game Department, US Fish and Wildlife Services and the University of New Hampshire. GIS data was developed and reconnaissance level wildlife observation surveys were performed by boat and on foot in 2010 and 2011 to review wildlife and habitat features along the

Exeter River. These observations focused on the Great Dam impoundment below the NH 108 Bridge, but landscape level data was collected using GIS to assist with this discussion.

### 3.11.2.1 Existing Conditions

The Exeter River corridor provides a variety of landscapes including large undeveloped blocks of habitat, which are present in the middle and upper reaches of the Great Dam impoundment. These blocks lie directly adjacent to the Exeter River or its tributaries and are influenced by periodic flooding. Flooding represents an important factor in determining community dynamics in floodplain areas. The disturbance created by flooding creates structural diversity in the habitat and tends to create a diversity of niches which can be exploited by a rich faunal community.

A variety of wildlife species were observed within the survey area, including species that are dependent upon wetland/aquatic habitats and those that use these communities opportunistically. The use by other species can be inferred by the presence of specific habitat types. **Figure 3.11-5** show the NHFG Wildlife Action Plan Habitat types. NHFGD's Wildlife Action Plan use available habitat data with GIS analysis of landscape characteristics to rank habitat throughout the state. **Figure 3.11-6** shows that a portion of the study area is ranked as some of the most valuable habitat in New Hampshire, while other areas are considered highly valuable on a regional basis.

The Exeter River and its habitats are also identified with species of concern in New Hampshire. Fish species and habitat are identified in Section 3.11.1 Fisheries. **Table 3.11-4** provides information on wildlife habitat from the NHFGD's Wildlife Action Plan. The data represents habitats directly adjacent to the impoundment. As can be seen, the area adjacent to the river is dominated by Appalachian Oak-Pine Forest. However, a substantial amount of floodplain forest is also located along the river.

Table 3.11-4. Habitat Types adjacent to the Exeter River, Great Dam Impoundment

| Habitat Type | Size (ac) |
|---|---|
| Appalachian Oak-Pine Forest | 1,709 |
| Floodplain Forest | 922 |
| Grasslands | 89 |
| Hemlock-Hardwood Pine Forest | 107 |
| Marsh/Wet Meadow Shrub Swamp | 85 |

The following includes descriptions of the habitat type and incorporates both observed species and inferred species occurring in the various communities in the study area. Agency correspondence and available data is contained in the appendices to this report.

Appalachian Oak-Pine Forest

The Appalachian oak-pine forest is upland, drier soil forest. Vegetation includes oak, white pine, shagbark and pignut hickories, black birch and aspen. The understory can sometimes be dominated by mountain laurel shrubs (Clyde, 2009).

Appalachian oak-pine forest is the dominant habitat type adjacent to the Exeter River, specifically the southern and western reaches of the river, around Little River and Great Brook. Southeast of Great Bridge is dominated by Appalachian oak-pine Forest, south surrounding the Raw Water intake and Great Brook. Another large portion of Appalachian oak-pine forest along the Exeter River is east of the NH 108/Court Street Bridge and smaller sections occur west to Pickpocket Dam.

Many species uses this forest type for part or all of their life cycle. Appalachian oak-pine forest is home to species such as, American woodcock, Canada warbler, Cooper's hawk, ruffed grouse, wild turkey, white-tailed deer, chipmunk and squirrels. The oak and hickory vegetation of this forest type provide significant food source for the identified species, as well as nesting sites.

Floodplain Forest

Floodplain forests occur in low laying reaches along the Exeter River and are prone to flooding. It is typical to find vernal pools, oxbows, open meadow and/or dense shrub thickets within the floodplains. Floodplains are important to water quality, as well as, erosion and sediment control. Large undeveloped blocks of habitat are present in the middle and upper reaches of the Great Dam impoundment. These blocks lie directly adjacent to the Exeter River or its tributaries and are influenced by periodic flooding. Flooding represents an important factor in determining community dynamics in floodplain areas. The disturbance created by flooding creates structural diversity in the habitat and tends to create a diversity of niches which can be exploited by a rich faunal community. Thus, the habitat value of these areas must be considered to be quite high relative to the northern portion of the study area in the lower impoundment.

Typically, vegetation in the floodplain forest consists of silver and red maple, with some black ash and ironwood among thick shrubs and occasionally wildflower and fern ground cover (Clyde, 2009).

Floodplain forest or riparian forests span the entire Exeter River, south of the dam. A location considered the Great Meadow Conservation area is located east of NH 108 and the Exeter River and to the south of NH 27 in Exeter. Great Meadow is a significant portion of the floodplain forest associated with the Exeter River and contains lush habitat for many species.

The floodplain is an important breeding habitat for many species of birds, such as warblers and the veery. It is also common habitat for many other species at one period during the year and provides a corridor for many species as they move

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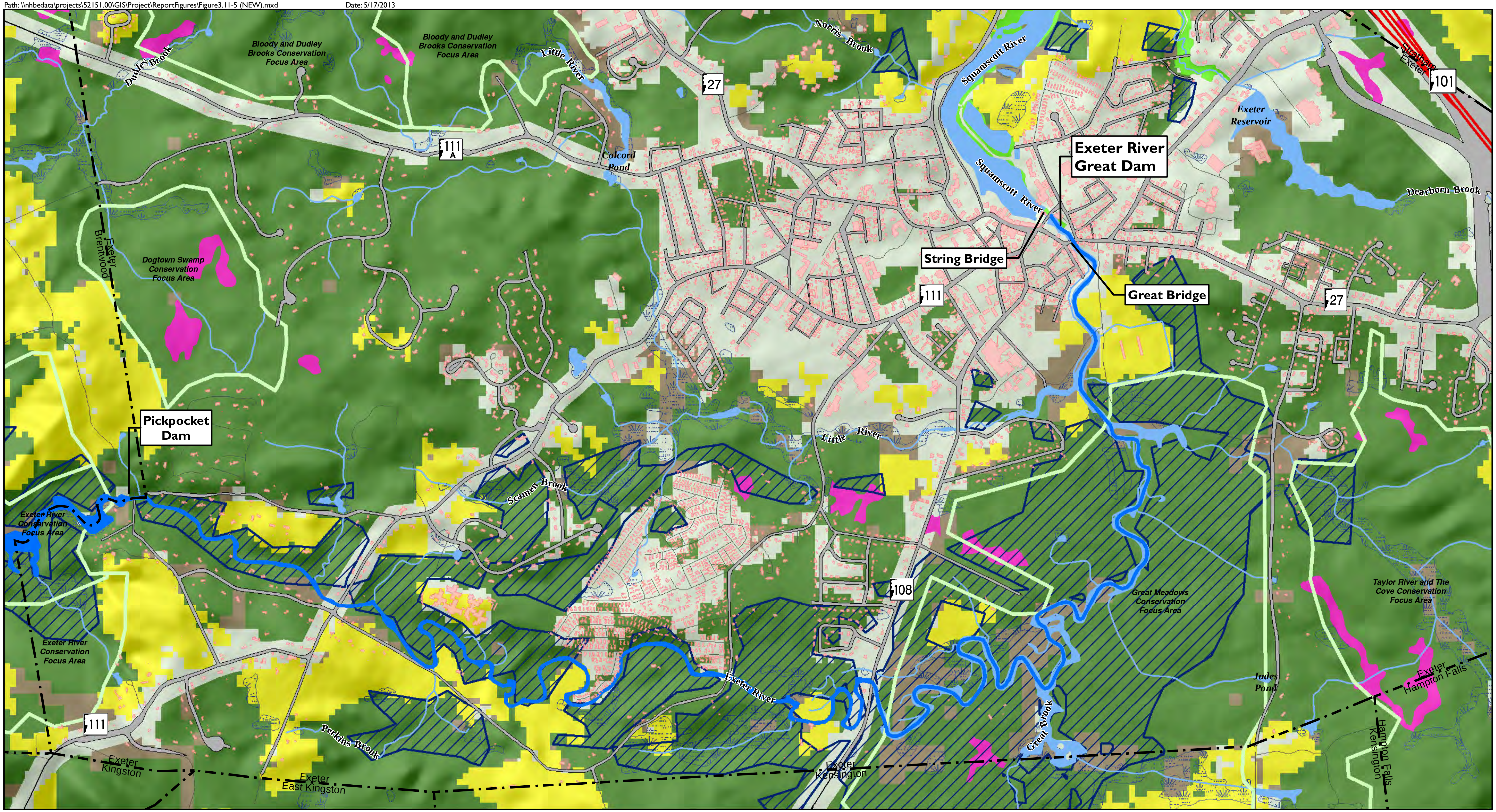


**Legend**

- Exeter River
- Town Boundary
- Buildings
- Highway
- Secondary State Road
- Local & Private Roads
- Lake/Pond
- Stream (NHD)

NHFG Wildlife Action Plan Habitat Types

- Floodplain forest
- Marsh/Wet Meadow/Shrub Swamp
- Peatland
- Grasslands
- Hemlock-hardwood-pine
- Salt marsh
- Appalachian oak-pine
- Non-habitat Area/Developed
- Conservation Focus Area (Land Conservation Plan for NH's Coastal Watersheds)

0 1,500 3,000 Feet

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**Figure 3.11-5**
**NH Fish & Game Wildlife Action Plan Habitat Types**
**Exeter Great Dam Removal Feasibility & Impact Analysis**

**Exeter, NH**

TOWN OF EXETER FOUNDED 1638 NEW HAMPSHIRE

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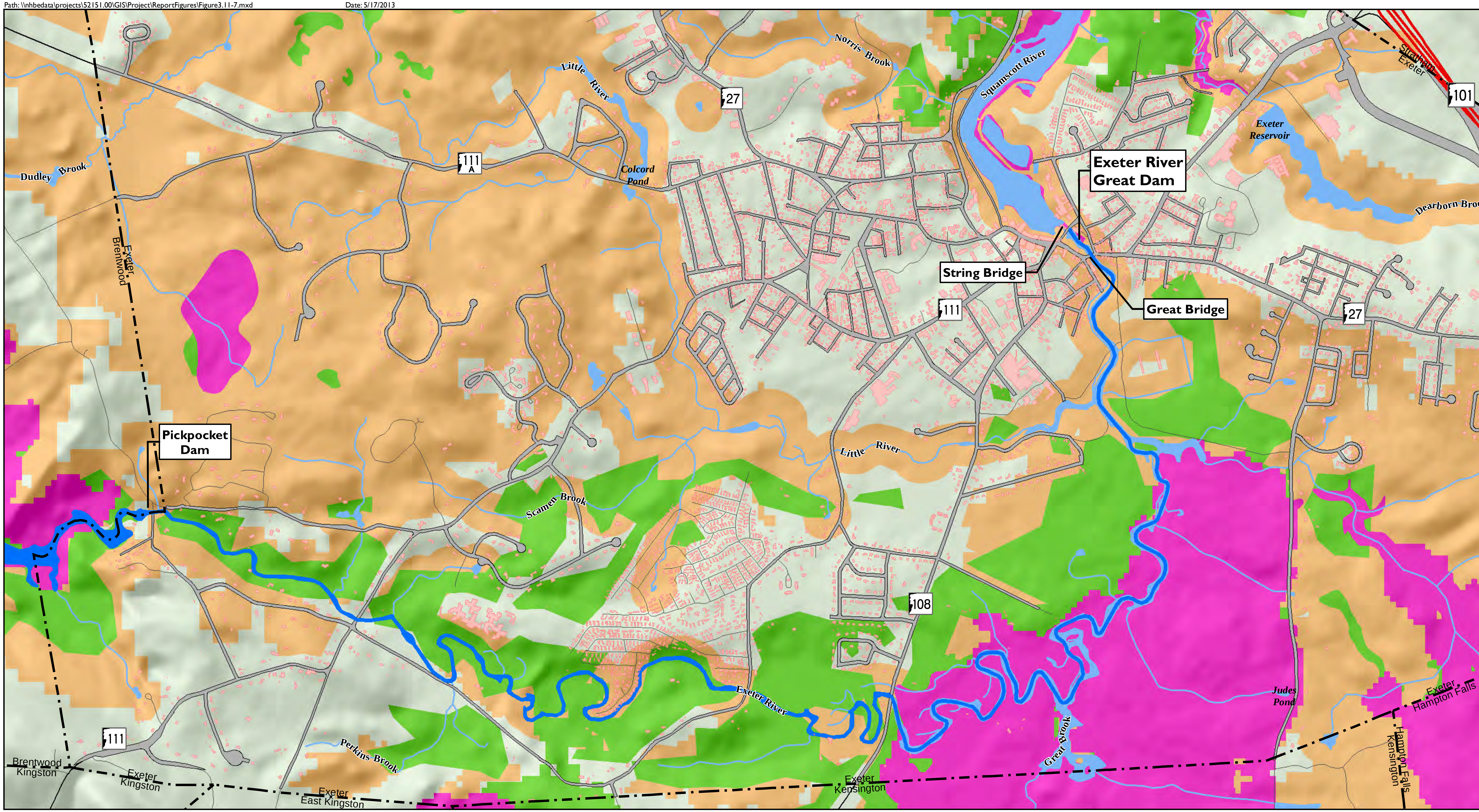


**Legend**

- Exeter River
- Town Boundary
- Buildings
- Highway
- Secondary State Road
- Local & Private Roads
- Lake/Pond
- Stream (NHD)

NHFG Ranked Habitat

- Highest Ranked Habitat in NH
- Highest Ranked Habitat in Biological Region
- Supporting Landscapes
- Non-habitat Area/Developed

0 1,500 3,000 Feet

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**Figure 3.11-6**
**NH Fish & Game Wildlife Action Plan**
**Ranked Habitat**
**Exeter Great Dam Removal**
**Feasibility & Impact Analysis**

**Exeter, NH**

TOWN OF EXETER FOUNDED 1638 NEW HAMPSHIRE

between habitats. A few of the species found in the floodplain forest include, American black duck, Baltimore oriole, belted kingfisher, Jefferson/Blue-spotted salamander complex, otter and wood turtle. The Blanding's turtle which is identified as a state endangered species also occupies the floodplain forest.

Grassland

This habitat type includes both pastures and mowed fields with well drained soils. Structural diversity is characteristically low in this habitat with the mowing diminishing both the cover and wildlife food value. Nonetheless, the edge created between this and other habitats, particularly forested areas, is very valuable. Grasslands were historically created by beaver activity and Native Americans. Ponds created above beaver dams became grassy meadows as water drained and Native Americans burned the land for improved agricultural purpose. More recently the grasslands are mostly agricultural areas.

The largest portion of grassland habitat occurring near the dam impoundment is located southeast of Great Bridge, adjacent to Appalachian oak-pine forest and floodplain forest. Other grassland along the Exeter River is associated with Great Meadows, southeast of Great Brook. Another larger portion is located south of the Exeter River, between Pickpocket Dam and Perkins Brook at NH 111.

Species typical of this habitat and its edge include bobolink, red-tailed hawk, American robin, American goldfinch, song sparrow, wood turtle, woodchuck, meadow vole, and red fox (Clyde, 2009). White-tailed deer may also be observed feeding in the open fields during warm summer evenings.

Hemlock-Hardwood-Pine Forest

Hemlock-Hardwood Pine Forest is comprised mostly of eastern hemlock, white pine, American beech and oak trees. It is a dominant habitat type within NH, considered a transitional forest to Appalachian oak-pine (Clyde, 2009). The understory commonly has smaller trees or shrubs including, witch hazel, black birch and Canada mayflower.

This habitat type is dominant south of Great dam along Little River. Traveling south to Great brook, Great Meadow and west to NH 108 pockets of hemlock-hardwood-pine occur. These locations represent this habitat type as transition habitat between the Exeter River and Appalachian oak-pine forest. Smaller pockets occur to the west along the Exeter River, mostly on the southern side of the river.

Many species that use this type of habitat require large spans of un-fragmented forested (Clyde, 2009). **Figure 3.11-5** depicts the habitat types and most of the blocks identified, and described above, are small sections. Typical species are, wood turtle, purple finch, American woodcock, Blackburnian warbler, barred owl, broad-winged hawk, eastern red bat, fisher, white-tailed deer and wild turkey.

Marsh/Wet Meadow Shrub Swamp

Seasonally this habitat (like forested wetlands) is frequently flooded by an adjacent stream or runoff from surrounding uplands. Scrub-shrub swamps in the study area are dominated by species such as highbush blueberry, willow, alder, dogwood and northern arrowwood. Structural diversity is low because of the lack of multiple vegetation layers. Nonetheless there is typically dense shrub growth, along with dense herbaceous growth in spots.

Amphibians and reptiles commonly found in shrub swamps include spring peepers and wood frogs, while the presence of open water enhances the attraction for snapping turtles and painted turtles. Scrub shrub swamps also provide habitat for spotted turtle and Blanding's especially if part of a larger wetland complex.  Bird species commonly found in this habitat include American woodcock (*Philohela minor*), song sparrow, alder flycatcher (*Empidonax aluorum*), and tree swallow (*Iridoprocne bicolor*). Mammalian species include white-footed mouse, meadow jumping mouse (*Zapus hudsonius*), and raccoon.

Species found in marshes include mallard, American bittern, great blue heron, red-winged blackbird, muskrat and common snapping turtle. During the dry summer months, meadow vole, meadow jumping mouse and American kestrel will be observed in shallow freshwater marshes or emergent marshes.

The occurrence of wildlife species and habitat use in the study area are heavily influenced by the geographic location of the habitats and surrounding land uses. The study area is located in coastal New Hampshire with the large Great Bay estuary to the north. Extensive residential, commercial and industrial land uses in the northern-most part of the study area have fragmented most of the natural habitats in that part of the study area. The high density of development in the northern portion of the study area limits movement of large, highly mobile mammalian species. In contrast, the presence of small and medium-sized mammalian species having smaller home ranges is predictable from the types and sizes of habitats present. Since much of the study area is highly developed or residential, many small and medium-sized mammalian species characteristic of these urban-like habitats are present.

Relative to bird species, the position of the study area near the Great Bay Estuary increases the seasonal variability in both species diversity and numbers. During the spring and fall migration periods, habitats in the area serve as resting or stopover areas for neotropical migrants as they move north or south. During the breeding season (spring and early summer), bird species' diversity and numbers are more directly related to the specific types of habitat present as well as their size and carrying capacity (*i.e.*, quality). Species diversity during the winter, although influenced by anthropomorphic factors like bird feeders, is uniquely affected by the climatic characteristics of the coastal location of the study area. Temperatures tend to be more moderate along the coast in the winter, and the presence of open water adjacent to the shore attracts a wide variety of overwintering waterfowl species and top predators.

## Wetland Wildlife Species

Wetlands are a particularly important habitat for wildlife (see Section 3.11.3). All amphibians require freshwater or wet areas for breeding, so their occurrence is dependent on wetlands. Described below are the major wetland types found in the study area along with representative species of each.

### Forested Wetlands (Forested Swamps)

Forested wetlands in the study area are typically dominated by red maples with varying amounts of swamp white oak, hemlock, and white pine intermixed. The typical interspersion of water and trees creates high structural diversity that enhances this habitat's value for wildlife. Common species include a variety of amphibians such as spring peeper (*Pseudacris crucifer),* gray treefrog (*Hyla versicolor)*, wood frog, bullfrog (*Rana catesbeiana)*, green frog (*Rana clamitans)*, mole salamanders and reptiles including eastern ribbon snake (*Thamnophis sauritus)*, ringneck snake (*Diadophis punctatus)*, painted turtle (*Chrysemys picta)*, snapping turtle (*Chelydra serpentina*).

The avian community found in area swamps is typically comprises facultative species, those which are found in upland forests as well, *e.g.*, black-capped chickadee, gray catbird (*Dumetella carolinensis*), ovenbird (*Seiurus aurocapillus*), wood thrush (*Hylocichla mustelina*), American robin (*Turdus migratorius*) and blue jay (*Cyanocitta stelleri*). Other bird species appear to be attracted to this habitat because of the presence of water, *e.g.*, wood duck (*Aix sponsa*), American black duck (*Anas rubripes*), and mallard (*Anas platyrhynchos*). Among raptors, red-shouldered hawks are probably most characteristic of forested wetlands where they both nest and hunt. Characteristic mammalian species include beaver (*Castor canadensis*), raccoon (*Procyon lotor*), mink (*Mustela vison*), woodland jumping mouse (*Napaeozapus insignis*), and white-footed mouse.

### Scrub-Shrub Swamp

Scrub-shrub swamps in the study area are dominated by species such as highbush blueberry (*Vaccinium australe*) , willow (*Salix* spp.), alder (*Alnus* spp.), dogwood (*Cornus* spp.), and northern arrowwood, (*Vibernum dentatum*). Structural diversity is low because of the lack of multiple vegetation layers. Nonetheless there is typically dense shrub growth, along with dense herbaceous growth in spots. Seasonally this habitat (like forested wetlands) is frequently flooded by an adjacent stream or runoff from surrounding uplands. Amphibians and reptiles commonly found in shrub swamps include spring peepers and wood frogs, while the presence of open water enhances the attraction for snapping turtles and painted turtles. Bird species commonly found in this habitat include American woodcock (*Philohela minor*), song sparrow, alder flycatcher (*Empidonax aluorum*), and tree swallow (*Iridoprocne bicolor*). Mammalian species include white-footed mouse, meadow jumping mouse (*Zapus hudsonius*), and raccoon.

Emergent Marsh

Species found in marshes include mallard, sora rail (*Porzana carolina*), American bittern (*Botarus lentiginosus*), great blue heron (*Ardea herodias*), red-winged blackbird (*Agelaius phoeniceus*), muskrat (*Ondatra zibethica*), foraging white-tailed deer, and common snapping turtle. During the dry summer months, meadow vole, meadow jumping mouse and American kestrel will be observed in shallow freshwater marshes and sedge meadows.

### 3.11.2.2 Potential Effects on Habitat and Wildlife

Implementation of either the Dam Removal (Alternative B) or Dam Modification (Alternative H) would not result in any substantial direct impacts to 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.

Minor indirect effects could occur based on changing flood regimes or hydrology of wetland adjacent to the impoundment which could create shifts in plant communities. (See Section 3.11.3 for more discussion.)

Whatever minor indirect impacts may occur would likely be offset by beneficial impacts. Beneficial impacts associated with this resource result from the presence of increased numbers of forage fish, as represented by adult and juvenile river herring, in the Exeter River upstream of the Great Dam. Changes to the fish populations and species assemblages within the river would likely benefit wetland-dependent species such as otter, osprey, and kingfisher by providing a larger and more diverse forage base.

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

The Appalachian oak-pine forest and hemlock-hardwood pine forest are upland, dry forested areas. Removal or modifications to the Great Dam would have negligible impacts on locations of Appalachian Oak-Pine Forest, hemlock-hardwood pine forest or grasslands. Under normal flow these habitats are not impacted by the flows of the Exeter River.

The change in flow generated by the removal or modification of the dam would not adversely impact the wildlife within this community. The overlapping locations of Appalachian oak-pine and hemlock-hardwood pine forest with floodplain forest, directly adjacent to the Exeter River, are the only locations were a minimal impact to the upland forest would occur.

Floodplain Forest

The floodplain forests would be the most significantly altered habitat. Removing the dam would benefit floodplain forest and its wildlife, with restored natural flow and seasonal flood patterns. The dam currently restricts the natural flooding potential and alters the natural community type.

Marsh/Wet Meadow Shrub Swamp

Marsh/wet meadow shrub swamp would not be greatly impacted by Alternative B or Alternative H. Some of area of marsh/wet meadow would be altered by lowering the surface water elevations within the Exeter River, therefore affecting the adjacent wetlands.

Open water habitat for waterfowl could decrease slightly, but not enough to eliminate the use of the area by this group of wildlife 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 have significant change. Upstream of the NH 108 Bridge, the drawdown resulting from the dam removal or modification is not likely to translate into wildlife habitat impacts. These benefits would not be expected to persist upstream of the dam because the exposed shoreline areas would become densely vegetated. 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.

### 3.11.3 Wetlands

According to the National Wetlands Inventory (NWI), the Exeter River watershed contains about 10,155 acres of wetlands representing about 15% of the watershed. In actuality, there is almost certainly even more wetland acreage because many forested wetlands are not effectively mapped through the NWI. There are three predominant "NWI systems" occurring in the Exeter River basin:

- **Palustrine** wetlands include all nontidal wetlands dominated by trees, shrubs, emergent grasses and sedges, mosses or lichens in freshwaters. This is the most common wetland type in the Exeter River watershed.

- **Lacustrine** wetlands include wetlands and deepwater habitats associated with lakes, dammed river and stream channels, and large ponds (typically >20 acres), which lack trees, shrubs, persistent emergents, emergent mosses or lichens with greater than 30% areal coverage. There are approximately 200 acres of lacustrine wetlands in the watershed.

- **Riverine** wetlands include all wetlands and deepwater habitats contained in channels periodically or continuously containing flowing water or which form a connecting link between two bodies of standing water. Riverine wetlands are the least common wetland type within the watershed.

### 3.11.3.1 Existing Conditions

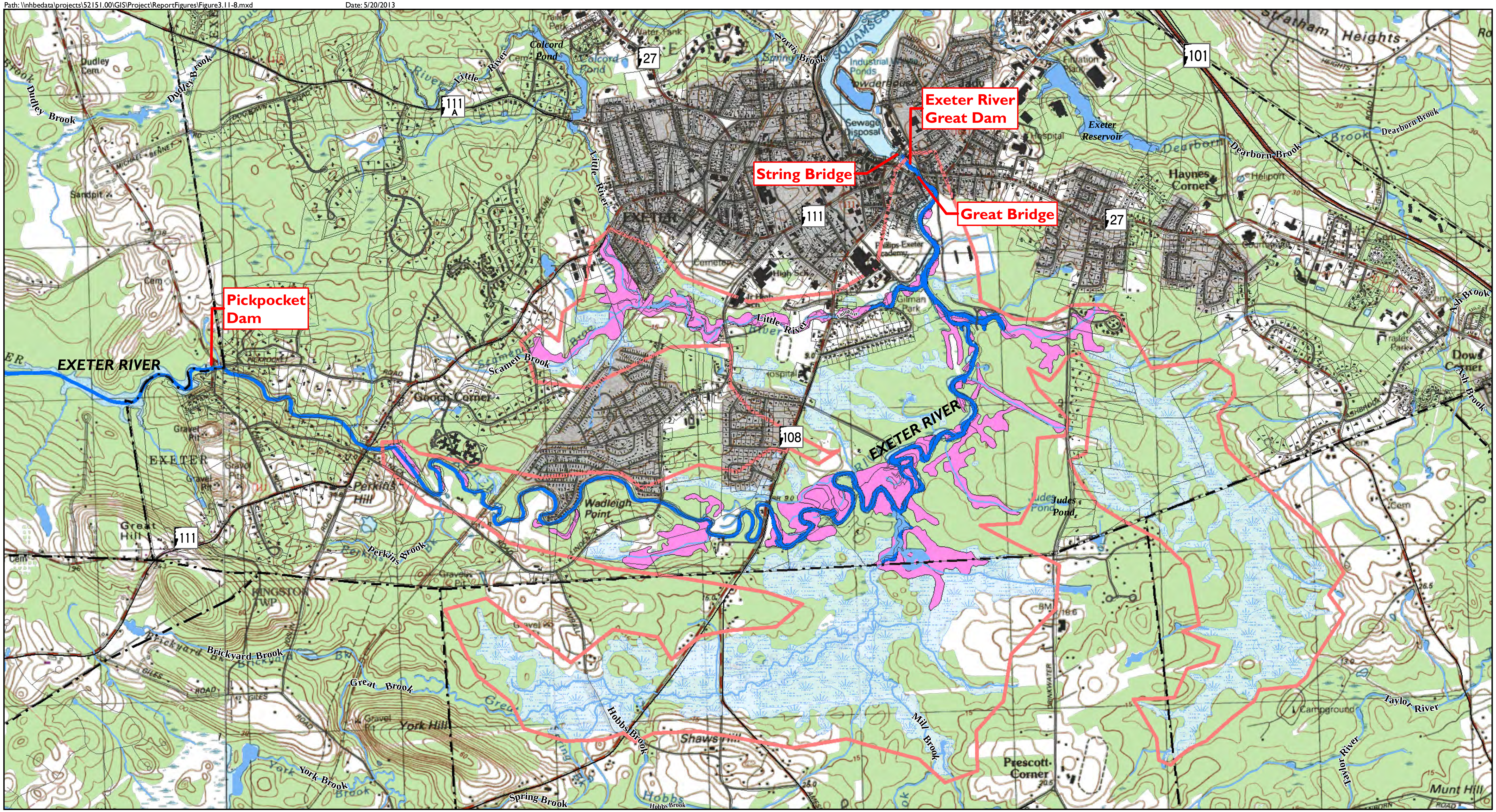
GIS data was developed and field inspection by boat and on foot were performed in 2010 and 2011 to review major wetland systems (>1 acre) along the Exeter River impoundment. For purposes of the discussion, terrestrial freshwater systems directly adjacent to (*i.e.,* touching or hydraulically connected in some way) the river are considered. **Table 3.11-5** provides a list of wetland types that are adjacent to the river, including their Cowardin classification, and **Figure 3.11-7** depicts their distribution along the river. Descriptions are provided below for each of the three general categories of wetlands within the study area.

Table 3.11-5. Wetlands Adjacent to the Great Dam Impoundment, by Cowardin Classification

| Cowardin Classification | Corresponding Wetland Description |
|---|---|
| PFO1E | Forested, broad-leaved deciduous, seasonally flooded/saturated |
| PSS1E | Scrub-shrub, broad-leaved deciduous, seasonally flooded/saturated |
| PFO1C | Forested, broad-leaved deciduous, seasonally flooded |
| PEM1/SS1E | Emergent and scrub-shrub wetlands, dominated by broad-leaved deciduous plants, seasonally flooded/saturated |
| PEM1E | Emergent wetlands, broad-leaved deciduous, seasonally flooded/saturated |
| PFO4/1E | Forested, dominated by needle-leaved evergreen and broad-leaved deciduous plants, seasonally flooded/saturated |
| PEM1F | Emergent wetlands, broad-leaved deciduous, semi permanently flooded |
| PFO1A | Forested, broad-leaved deciduous, temporarily flooded |
| PSS1F | Scrub-shrub, broad-leaved deciduous, semi permanently flooded |

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.

Path: \\nhbedata\projects\52151.00\GIS\Project\ReportFigures\Figure3.11-8.mxd    Date: 5/20/2013




**Legend**

- Exeter River
- Town Boundary
- Secondary State Road
- Local & Private Roads
- Lake/Pond
- Stream (NHD)
- Potential Groundwater Effect Zone (W&S)
- Wetlands with Hydraulic Connection to River (NWI)
- Other Wetlands Potentially Affected

Source: USGS 7.5 Minute Quadrangles: Exeter, Kingston
Potential Groundwater Effect Zone developed by Weston & Sampson.
NWI wetland boundaries.
Hydrography taken from the National Hydrography Dataset (NHD) as archived in NHGRANIT.

0    2,000    4,000 Feet

VHB Vanasse Hangen Brustlin, Inc.

**Figure 3.11-7**
**Wetlands and Floodplain Forests Habitat Types**
**Exeter Great Dam Removal Feasibility & Impact Analysis**

**Exeter, NH**

TOWN OF EXETER FOUNDED 1638 NEW HAMPSHIRE

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## Forested Wetlands (PFO)

Freshwater wetlands with at least 30 percent tree areal coverage are classified as PFO. Forested wetlands adjacent to the Exeter River consist of deciduous forested swamps including floodplain forests as well as a one example of a mixed deciduous/coniferous forested swamp.

Deciduous forested swamps in the study area are generally seasonally saturated and occur in isolated depressions or within the floodplain of the river. Dominant vegetation in the deciduous forested swamps typically consists of red maple *(Acer rubrum)* and white ash *(Fraxinus americana)* overstory; common winterberry *(Ilex verticillata)*, highbush blueberry *(Vaccinium corymbosum)*, and glossy buckthorn *(Rhamnus frangula)* shrub layer. Cinnamon fern *(Osmunda cinnamomea)*, jewelweed *(Impatiens capensis),* sensitive fern *(Osmunda sensibilis)*, royal fern *(Osmunda regalis),* poison ivy *(Toxicodendron radicans)*, skunk cabbage *(Symplocarpus foetidus)*, and sphagnum moss (*Sphagnum* sp.) provide herbaceous ground cover.

Importantly, much of the floodplain forested wetlands along the middle of the impoundment is co-dominated by swamp white oak (*Quercus bicolor),* which is considered a rare community type in New Hampshire due to the fact that it is largely restricted to the coastal plain.[48] Overstory species in this community type include swamp white oak, red maple, and green ash *(Fraxinus pennsylvanica*). Understory species include American hornbeam (*Carpinus caroliniana* ssp. *virginiana*), sensitive fern, smooth arrowwood (*Viburnum dentatum* var. *lucidum*), nannyberry (*V. lentago*), common winterberry and poison-ivy in canopy gaps and along streambanks. Herbaceous species observed in these floodplain forests include fringed sedge (*Carex crinita*), sweet wood-reed *(Cinna arundinacea*), and marsh fern (*Thelypteris palustris* var. *pubescens)*.

Mixed deciduous/coniferous forested swamps typically occur in seasonally flooded pit-and-mound topography, consisting of saturated loamy/sandy/gravelly soils in topographic depressions. Dominant vegetation in the mixed deciduous/coniferous forested swamp consists of red maple, white pine, eastern hemlock (*Tsuga canadensis*), American elm *(Ulmus americana)*, white ash, and yellow birch *(Betula alleghaniensis)* in the tree canopy; glossy buckthorn, northern arrow-wood *(Viburnum recognitum)*, highbush blueberry, and nannyberry in the shrub layer; and cinnamon fern, sensitive fern, skunk cabbage, goldthread (*Coptis groenlandica*), poison ivy, and sphagnum moss in the herbaceous layer.

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48 More information on the occurrence of the swamp white oak floodplain forest is presented in Section 3.11.5.

### 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.

Shrub wetlands within the study area generally occur as seasonally flooded, densely vegetated, fringing habitats bordering forested and emergent wetlands and along the edges of the river and small tributary drainages. Field verification confirmed that shrub wetlands typically consist of northern arrow-wood, 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.

### Emergent Wetlands (PEM)

Wetlands in the study area identified as PEM are grouped into the emergent wetland category. PEM 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. Freshwater marshes are seasonally flooded wetlands commonly saturated at or near the surface when not flooded, and are dominated by grasses or grass-like plants. Freshwater wet meadows are seldom-flooded wetlands that are saturated throughout the growing season, and are dominated by herbaceous vegetation.

In the study area, freshwater emergent marshes are 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.) are also found in some emergent marsh areas. Two exotic invasive species, common reed *(Phragmites australis)* and purple loosestrife *(Lythrum salicaria)* are also found in certain wetlands. (See Section 3.11.4 for more information on invasive species.)

## 3.11.3.2 Discussion of Potential Effects

As discussed in Section 3.3, removal or modification of the Great Dam will affect the depth of water in the river and the frequency of overbank flooding. These changes are likely to affect wetlands which have a direct hydraulic connection to the Exeter or Little River. Many of the wetland systems depicted in **Figure 3.11-7** depend to some degree on the backwater conditions created by dam. Other wetlands rely in part or entirely on the artificially high surface water levels that are created by the impoundment.

Elimination of the impoundment could affect the existing wetlands within and adjacent to the impoundment by lowering surface water elevations such that wetlands with a direct hydraulic connection to the river would be affected. While quantifying the amount of wetland thus affected is not possible at this level of study, a preliminary inventory of wetlands was completed to develop information on the population of wetlands that could be affected by the removal or modification of the Great Dam. We found that a total of 51 individual wetland areas are directly connected to the river. The amount of wetlands directly adjacent to the river total 244.6 acres.

Indirect effects to wetlands could also occur by falling local groundwater levels that are predicted to occur with removal or modification of the dam. Lower groundwater contours could reduce or eliminate the depth or duration of soil saturation or inundation. Since wetland hydrology is a driving influence of wetland plant communities, changes in groundwater or surface water contours could lead to changes in affected wetlands. Some information on the hydraulic connection between the river and adjacent wetlands was presented in Weston & Sampson (2010a) that provides some understanding for the potential for groundwater impacts to wetlands.

Weston & Sampson (2010a) examined the response of groundwater elevations as the river was drawn down artificially for a one-month period in 2009. They found that water levels in both a shallow and deep aquifer closely tracked water levels in the Exeter River. However, surface and shallow groundwater levels measured in two wetlands near the Stadium Well showed relatively little movement in response to changing river levels. Water level response in each wetland did not exceed 0.5 feet or more than 10% of the change in river level. Any response that was observed showed a significant lag time and occurred over many days.[49] However, Weston & Sampson (2010b) also suggested that the period of observation may have been too short to capture wetland response to lowered river water elevations. They hypothesized that if the dam were to be removed, shallow aquifer water levels near the river would drop as much as 7 ft, which could eventually cause water from the wetland to move downward into the shallow aquifer system, thereby reducing inundation or saturation of the wetland.

Using an understanding of the geology of the area, combined with observations made through previous studies on the nature of the shallow and deep aquifers in the study area, a "Potential Groundwater Effect Zone" was developed in order to inventory all wetlands that could be affected by some change in groundwater contours. This boundary is shown on **Figure 3.11-7**. The number and acreage of wetlands within this zone, shown in **Table 3.11-6**, is substantially greater than the population with a direct hydraulic connection to the River. Based on this analysis, as

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49 See *Figure 8, Groundwater Reaction to Drawdown in Sensitive Receptors*, in Weston & Sampson (2010b).

many as 141 wetlands totaling more than 1,000 acres could have some change in groundwater hydrology.

Small changes to the hydrologic regime may result in the conversion of one wetland type into another, or in the migration of a particular wetland type downslope towards the new, lowered water surface. For example, fringes of shrub wetland may be converted into forested wetland; emergent wetlands may be converted to shrub wetland; shallow aquatic wetland may be converted to emergent wetland; and shallow aquatic wetland habitat may shift toward the channel and replace deep aquatic habitat or unvegetated aquatic areas. Depending on the vertical extent of permanent drawdown of the shallow aquifer, draining of wetlands could result in the conversion of wetland habitat into upland habitat.

Field observations found evidence that some supplemental surface flow enters the wetlands from the surrounding hillsides. However, this flow is likely inadequate to supply sufficient water to maintain the current hydrological regimes in all cases.

The majority of potentially affected wetland is classified as Palustrine forested (PFO) areas along the banks of the river, with scrub-shrub and aquatic bed/emergent marsh areas also present. In general, it can be predicted that removal of the Great Dam would shift wetland cover types such that aquatic bed communities would develop characteristics of emergent marsh systems. Scrub-shrub wetlands could likely acquire an overstory of red maple and perhaps silver maple and swamp white oak, and understory species would shift to those characteristic 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. The exact quantity of affected wetland cannot be determined based on existing information. One should not interpret the data in **Table 3.11-6** to mean that there will be an overall loss of wetlands. Rather, the data show the approximate extent of wetlands where hydrological changes may induce observable plant community changes. However, these changes would 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 partially offset by the development of new riparian aquatic bed, emergent, and scrub-shrub systems within the Exeter River channel. That is, 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, it is expected that new beaver activity would occur in wetlands adjacent to the river which is likely to offset some of these wetland shifts.

Table 3.11-6. Wetlands within the Potential Groundwater Effect Zone, by Cowardin Classification

| Cowardin Classification | No. | Size (ac) |
|---|---|---|
| PFO1E | 47 | 331.9 |
| PEM1E | 14 | 120.5 |
| PSS1E | 26 | 117.6 |
| PSS1/EM1E | 1 | 60.9 |
| PFO5Fb | 1 | 50.5 |
| PFO1/SS1E | 2 | 45.5 |
| PFO5Eb | 1 | 37.2 |
| PFO1/4E | 3 | 36.2 |
| PFO1C | 12 | 33.8 |
| PFO4E | 7 | 33.4 |
| PEM1Fb | 1 | 32.8 |
| PEM1/SS1E | 3 | 31.5 |
| PFO4/1E | 3 | 25.5 |
| PEM1Ed | 1 | 22.4 |
| PFO1A | 4 | 11.6 |
| PEM1F | 2 | 7.2 |
| PSS1F | 3 | 5.0 |
| PEM1B | 1 | 2.8 |
| PSS1/FO4E | 1 | 2.3 |
| PFO5/EM1E | 1 | 2.0 |
| PUBHh | 4 | 1.1 |
| PUBHb | 1 | 0.9 |
| PUBF | 2 | 0.7 |
| Grand Total | 141 | 1013.2 |

## 3.11.4 Invasive Species

Field review for populations of existing stands of purple loosestrife (*Lythrum salicaria*) and common reed (*Phragmites australis*) was conducted along the impoundment to identify areas that may be impacted by colonization by these aggressive species. Fortunately, with the exception of a portion of the emergent marshes along the Little River, relatively little purple loosestrife or common reed was found. Other invasive species such as Japanese knotweed (*Polygonum cuspidatum)*, an aggressive invasive species that prefers sunny upland areas, is also found along the banks of the impoundment near the dam. Oriental bittersweet (*Celastrus orbiculatus*) was also determined to be relatively common, particularly along the banks of the lower impoundment below the confluence of the Little River. Specifically, areas that have currently been inundated by water and will become dried out if the dam removal were chosen are the locations that would most likely be impacted by new populations of invasive species.

Neither Alternative G – Stabilize in Place nor Alternative H - Dam Modification are expected to provide opportunity for the expansion of invasive species in the study area. This is because these alternatives are designed to maintain the current pool elevation under normal flow conditions.

However, Alternative B - Dam Removal Alternative would lower the impoundment level by several feet, with Alternative F – Partial Removal also dropping water levels substantially compared to current conditions particularly in the lower reaches above the dam. This decreased water surface elevation would expose currently flooded lands. These areas would initially have no vegetation and will resemble mud flats. Vegetation is expected to quickly grow on this bare ground; typically within the first growing season these mudflats will become fully vegetated. It should be noted, though, that invasive species are often "pioneer species"— ones that tend to quickly colonize disturbed or bare soils. Thus, 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 in any further development of this alternative, it is important to realize that it is not reasonable to expect the complete control or eradication of invasive species. This is because some species, such as purple loosestrife, are already well established in coastal New Hampshire. 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 methods have been used to control and reduce the spread and presence of invasive species in wetland communities. The first three methods include mechanical, chemical and environmental control. Biological control of purple loosestrife is also possible, although no such biological control exists for common reed or other invasive species in New Hampshire's flora.

**Herbicides** can be effective, and have been used to control common reed and other 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 commercially available and known to control common reed effectively when used properly. These two herbicides are currently considered safe to use in an aquatic environment, although recent data indicates potential adverse effects on amphibian populations, suggesting that this methods be used very conservatively.

**Mechanical removal** involves cutting, or plowing, or grading of the impacted wetland. It is generally most practical and effective in areas with small pockets or stands of purple loosestrife or common reed. Prior to 1997, mechanical removal was 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. When burning is not feasible, mechanical treatment is recommended.

**Prescribed fire** is a tool that can be used after an herbicide treatment to remove excess biomass, to potentially kill any living rhizomes, and to promote native plant growth. In situations where prescribed fire can be implemented it is easier to locate *Phragmites* regrowth and spot-treat those plants with herbicides once a site has been cleared of the thick, dead stems. In situations where it can be implemented safely and effectively, prescribed fire is a cost-effective and ecologically sound tool to help control *Phragmites*. Prescribed fire is recommended where *Phragmites* exists in large dense stands. Use of prescribed fire without first treating with herbicides does not control *Phragmites*, and instead may encourage rhizome growth and cause *Phragmites* populations to become more vigorous (Michigan DEQ, 2008).

**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 loosestrife in two NHDOT mitigation sites in the state (Littleton and Nashua), but it must be used in combination with other techniques to be successful in controlling *Phragmites* and purple loosestrife.

**Biological control** of purple loosestrife 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. In 1992, the US Department of Agriculture (USDA) approved four insects native to Europe to use in the United States that solely rely on purple loosestrife for their food source. These include two species of beetle (*Galerucella calmariensis* and *G. pussilla*) and two species of weevils (*Hylobius transversovittatus* and *Nanophyes marmoratus*). Stunting purple loosestrife by feeding on foliage, terminal buds, and stem tissue; preventing sexual reproduction and seed production; and causing extensive root damage are all characteristic of these species feeding regimes, thus allowing native species and wildlife habitat to be restored.

In 1997, NHDOT and New Hampshire Department of Agriculture, Market, and Food (NHDAMF) worked together to start a pilot study on using biological methods to control purple loosestrife in New Hampshire. Sites were selected among NHDOT mitigation areas based on purple loosestrife population size and density, lack of standing water for the growing season, and accessibility. Both species of beetle (*Galerucella calmariensis* and *G. pussilla*) were selected due to previous success rates in other states, cost, and easy establishment at sites. Monitoring occurred during the growing season and developmental stages of the beetles and included visual assessments of plant populations, quantifying percent-feeding damage, documenting any negative impacts that the beetles have upon native plant species, noting any predation of the leaf-feeding beetles. In the spring of 1999, an Integrated Pest Management (IPM) grant was awarded to NHDAMF to develop a Community Purple Loosestrife IPM Project (Durkis 2003). As of 2004, the project had resulted in approximately 217,000 beetles being purchased for release into wetlands invaded with purple loosestrife throughout the state, including all ten counties with the incorporation of the NHDOT mitigation sites. More information on this approach can be obtained by contacting Mr. Doug Cygan at the NHDAMF.

### 3.11.5 Rare Species and Natural Communities

State-listed protected species and community types exist within the Exeter River watershed. 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 NHFGD. The NHNHB maintains 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, in a GIS-based database. This database provides information on the present, past, or probable existence of such species for improved land use planning and environmental impact assessment. Subject to a confidentiality agreement, portions of the NHNHB geodatabase were made available to project scientists to review the location of these occurrences in relation to the impoundment. The results of this review are presented below.

#### 3.11.5.1 Existing Conditions

**Table 3.11-7** identifies the rare plants, rare animals, and exemplary natural communities that the NHNHB has on record within the project study area. **Appendix M** contains descriptions of the animals and exemplary natural communities to supplement the basic descriptions below.

According to the NHNHB database, there are six rare plants, four rare animals, and four exemplary natural communities found within the project study area. Because the data within the NHNHB is confidential, the precise location of these occurrences cannot be disclosed. However, each of the species or communities is briefly described, and its general location above or below the Great Dam is provided, as well as an impact assessment.

#### 3.11.5.2 Discussion of Potential Effects

The primary effect of the removal or modification of the Great Dam would be a reduction in surface water depths and the frequency of overbank flooding upstream of the dam. The likelihood of impacts from these changes are discussed below for each of the populations or communities located within the study area.

Table 3.11-7. Rare Species and Exemplary Natural Communities Located within Project Study Area[1]

| Common Name | Scientific Name | Viability[2] | State Listing[3] | Global Rank[4] | State Rank[4] | Location[5] |
|---|---|---|---|---|---|---|
| **Animal Species** | | | | | | |
| Great Blue Heron (Rookery) | *Ardea herodias* | | -- | Secure | Secure | AD |
| Common Moorhen | *Gallinula chloropus* | | SC | Secure | Imperiled | BD |
| Least Bittern | *Ixobrychus exilis* | | SC | Secure | Imperiled | BD |
| Osprey | *Pandion haliaetus* | | SC | Secure | Vulnerable | BD |
| **Plant Species** | | | | | | |
| Little-headed spikesedge | *Eleocharis parvula* | F | T | Secure | Imperiled | BD |
| Climbing hempvine | *Mikania scandens* | | E | Secure | Critically Imperiled | AD |
| Stout dotted smartweed | *Eleocharis parvula* | | E | Apparently Secure | Critically Imperiled | AD |
| Great bur-reed | *Sparganium eurycarpum* | G | T | Secure | Imperiled | AD |
| Peat moss | *Sphagnum contortum* | | T | Secure | Imperiled | AD |
| Spongy-leaved arrowhead | *Sagittaria montevidensis* ssp. *spongiosa* | | E | Apparently Secure | Critically Imperiled | BD |
| **Exemplary Natural Communities** | | | | | | |
| Hemlock - cinnamon fern forest | | G | -- | -- | Apparently Secure | AD |
| Swamp white oak floodplain forest | | E | -- | -- | Critically Imperiled | AD |
| Semi-rich oak - sugar maple forest | | G | -- | -- | Imperiled | AD |
| Tall graminoid meadow marsh | | G | -- | -- | Apparently Secure | AD |

Notes:

1 Data is from the New Hampshire Natural Heritage Bureau

2 Viability is a measure of how likely the population or community is to persist in the future. F = Fair; G = Good; E = Excellent

3 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.

4 State Rank and Global Rank indicates the species degree of rarity within New Hampshire and throughout its global range. Critically imperiled represents the rarest species/communities, while

5 Location refers to whether the species population or community is located below or above the impoundment of the Great Dam. BD = Below Dam; AI = Above Dam.

### Potential Impacts to Populations Downstream of the Dam

Section 3.3 of this study presents a detailed discussion of the hydraulic changes associated with Dam Removal (Alternative B) and Dam Modification (Alternative H). As demonstrated in the hydraulic modeling results, and as expected for a run-of-the-river dam, there would be no change in flow depths, velocities or other river flow parameters downstream of the dam site. The steep channel slope immediately below the dam, the isolation of the river channel from its floodplain in this location and the tidal influence of the Squamscott River will all serve to maintain the existing hydraulic characteristics of this reach under all flow conditions. Thus, there is not expected to be any permanent impacts to populations downstream of the dam. There is some potential for aggradation of sediments in the tidal portion of the river, but this is not expected to affect any of the species identified by the NHNHB in the Squamscott River.

Thus, there are no expected impacts on the following species:

#### Plant Species

**Little-headed Spikesedge - *Eleocharis parvula* (Roem. & Schult.) Link ex Bluff, Nees & Schauer**
A population of the little-headed spikesedge is located downstream of the dam on the tidal Squamscott River. Spikesedges are emergent herbs, often found in wetlands and aquatic habitats, particularly in the shallows of permanently inundated areas. Little-headed spikesedge is listed as Threatened in NH, but is not federally-listed and is ranked as globally secure.

**Spongy-leaved Arrowhead - *Sagittaria montevidensis* ssp. *spongiosa* (Engelm.) Boivin**
Spongy-leaved arrowhead occurs in freshwater to brackish intertidal mud flats. A population of this annual herbaceous plant is located on the tidal portion of the Squamscott River downstream of the Great Dam. Spongy-leaved arrowhead is listed as Endangered in NH, but is not federally-listed and is ranked as globally secure.

#### Animal Species

**Common Moorhen *(Gallinula chloropus)***
The common moorhen is a small- to medium-sized bird with an almost worldwide distribution. The moorhens live around well-vegetated, permanently flooded freshwater marshes, ponds, canals or brackish shallow ponds or deep marshes. The common moorhen is tracked in NH as a Species of Special Concern. Removal or modification of the dam would not significantly impact the habitat of the moorhen.

**Osprey *(Pandion haliaetus)***
The Osprey is a diurnal, fish-eating bird of prey. It is a large raptor, reaching more than 24 in long and 70 in across the wings. The Osprey tolerates a wide variety

of habitats, nesting in any location near a body of water providing an adequate food supply. The Osprey's diet consists almost exclusively of fish and has been observed using the tidal portion of the Squamscott River. Removal of the dam would improve fish passage, benefitting the Osprey's food source. The Osprey is tracked in NH as a Species of Special Concern.

**Least Bittern *(Ixobrychus exilis)***
The Least Bittern occupies a range of freshwater wetlands that contain tall emergent vegetation. Suitable habitats thus include cattail (*Typha* sp.) marshes associated with the shores of the Exeter River, and the impoundment, beaver ponds, and fens. Nests of the Least Bittern are occasionally found in hayfields and dense emergent vegetation near open water (Hunt, 2005). The Least Bittern is tracked in NH as a Species of Special Concern. Floodplain forest and locations such as the Great Meadow are a significant habitat for the Least Bittern, impact to this area and other emergent wetlands would potentially pose a threat to the Least Bittern.

## Potential Impacts Upstream of the Dam

As discussed throughout this study, the modification or removal of the Great Dam would change the depth and velocities of the river upstream of the dam, as well as the frequency of overbank flooding. Because these hydrological parameters can be crucial in maintaining community structure, the potential effects of each alternative must be considered carefully. Below, a discussion of each of the populations or communities above the dam is included.

### Plant Species

**Climbing Hempvine - *Mikania scandens* (L.) Willd.**
Climbing hempvine grows in swampy thickets and along streams or in moist woods. It is one of the very few climbing vines of the composite family and may grow from 5 to 15 ft in length. A population of this plant is reported to occur close to the Great Dam. Climbing hempvine is a listed Endangered species in NH, but is globally secure.

Of the species and communities identified by the NHNHB, only this one population could be directly impacted by construction activities at the dam site, and this risk would apply equally to all of the build alternatives. To mitigate this potential impact, it is recommended that a field survey for this species be conducted prior to construction. The survey should census the entire existing population. A plan should be developed to protect the plant from direct impacts during construction, or to rescue the population if direct impacts are unavoidable.

**Stout-dotted Smartweed - *Persicaria robustior* (Small) E.P. Bicknell**
The stout dotted smartweed is a perennial forb in the buckwheat (Polygonaceae) family which is an obligate wetland plant. The stout-dotted smartweed is listed as an Endangered Species in NH, but is globally ranked as Apparently Secure.

A population of the stout-dotted smartweed is located on the Little River. The plant is an obligate wetland species, and its location close to the river suggests that its presence may depend to some degree on the hydrology provided by the impounded river. In order to determine the degree to which Alternative B or Alternative H might change conditions near this population, the results of the HEC-RAS hydraulic model were examined. **Table 3.11-8** shows the predicted depth of the river under the existing condition, along with the predicted width of the river flow.

Table 3.11-8. Predicted Changes in the Little River at Smartweed Population

| | | | Decrease Relative to Existing Condition | | | |
|---|---|---|---|---|---|---|
| | Existing Condition | | Alternative B (Removal) | | Alternative H (Modification) | |
| Flow | Max. Depth[1] (ft) | Width[2] (ft) | Max. Depth (ft) | Width (ft) | Max. Depth (ft) | Width (ft) |
| Median Sept. | 1.2 | 21.2 | 0.1 | 1.6 | 0 | 0 |
| Median Annual | 1.5 | 25.8 | 0.1 | 1.8 | 0 | 0 |
| Median May | 1.6 | 27.5 | 0.1 | 1.8 | 0 | 0 |
| 2-year | 3.8 | 216.4 | 0.9 | 50.8 | 0.9 | 51.0 |
| 10-year | 6.5 | 358.5 | 2.2 | 93.4 | 2.1 | 78.6 |
| 50-year | 9.3 | 980.1 | 1.8 | 607.0 | 1.7 | 605.7 |
| 100-year | 10.7 | 1435.8 | 1.9 | 811.5 | 1.8 | 790.5 |

Notes:
1. WSE = Water Surface Elevation, the predicted elevation of the water in the channel in feet (NGVD29) under various flow conditions.
2. The width of the river, in feet, under various flow conditions including the channel and the left and right floodplains.

From these data, it can be seen that Alternative H would have no effects under normal flows, while Alternative B would create minor changes to the depth and width of the river. For example, under the median annual flow, removal of the dam (Alternative B) would decrease the depth of the Little River from 1.5 ft to 1.4 ft, a difference of only about 1.2 in. The magnitude of change in river width would be similar, decreasing from 25.8 ft wide under the existing condition to about 24.0 ft wide. For higher flows, i.e., the 2-year flow or greater, Alternative B and Alternative H would have similar effects. However, typical conditions are likely far more important for the viability of this smartweed population than high flood flows. Therefore, on the basis that the Little River at this location would experience relatively minor changes under typical flows, it is unlikely that this plant population would be significantly impacted by either the dam removal or modification.

**Great Bur-reed - *Sparganium eurycarpum* Engelm.**

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 individual flowers are small and occur in separate male (staminate) or female (pistillate) globular clusters on the same plant. The plant is listed as Threatened in NH, but is globally secure.

The population of great bur-reed identified by the NHNHB is located within a swamp white oak floodplain forest Exemplary Natural Community in the reach of the river between the Little River confluence and the NH 108 Bridge. Impacts to this population are included in the discussion of the swamp white oak community on the following page.

**Peat Moss - *Sphagnum contortum* Schultz**
The species of peat moss, an obligate wetland species, is a medium-sized moss, and generally found as small stands or scattered stems. Plants are characteristically pale orangey-brown, but can be yellowish-green or green-brown. The branches are curved when viewed from above, with leaves that stick out away from the branch stems. *Sphagnum contortum* is listed as a Threatened Species in NH, but is globally secure.

The population of *S. contortum* identified by the NHNHB is located within a swamp white oak floodplain forest Exemplary Natural Community in the reach of the river between the Little River confluence and the NH 108 bridge. Potential impacts to this community are discussed below.

Animal Species

**Great Blue Heron (Rookery)**
The Great Blue Heron (*Ardea herodias)* is a large wading bird in the heron family Ardeidae, common near the shores of open water and in wetlands over most of North and Central America. Great blue herons nest colonially near creeks, rivers, lakes and wetlands. The Great Blue Heron is not protected in NH, but its rookeries are tracked due to their relative scarcity and importance in maintaining the species population in the northeast.

A great blue heron rookery has been reported to occur in a forested swamp known as "The Cove" which covers portions of Exeter and Kingston. The NHNHB database indicates that this rookery, which was observed to be active in 1979, 1980 and 1983, was found to be inactive during a field survey in 1985.[50] Additionally, this resource is located well south of the area potentially affected by the dam. Therefore, it is expected that neither the Dam Removal Alternative nor the Dam Modification Alternative would have any discernible effect on the rookery.

Exemplary Natural Communities

Exemplary natural communities (ENCs) are either rare natural community types or high quality examples of more common community types. Exemplary natural communities represent the best remaining examples of New Hampshire's biological

50 According to the NHNHB database, in June 1985 no nests were occupied, and the rookery was assumed to be abandoned. In 1983, 10 total nests were observed, but there was no record for active nests. In 1980, at least 7 nests were active, and in 1979, 5 to 8 nests were observed.

diversity. Although ENCs are not formally protected under state law, the NHNHB identifies and tracks exemplary natural community occurrences to inform conservation decisions. Four such communities were identified by the NHNHB as occurring within the study area above the Great Dam.

- Hemlock - cinnamon fern forest
- Swamp white oak floodplain forest
- Tall graminoid meadow marsh
- Semi-rich oak - sugar maple forest

**Appendix M** contains descriptions of each of these communities from Sperduto and Nichols (2011). Potential impacts to each of these communities are discussed in this section.

**Tall Graminoid Meadow Marsh**

This community is a common marsh type (State Rank S4, Apparently Secure). The example identified by the NHNHB occurs in an open basin, with dominant plant species including a mixture of bluejoint (*Calamagrostis canadensis*), tussock sedge (*Carex stricta*) and cattail, as well as other tall grasses and sedges. Based on aerial photography, historical efforts have been made to drain this wetland through construction of a series of ditches.

This ENC is located relatively far to the south of the Exeter River. Its landscape position suggests strongly that it does not depend on hydrology provided by the river. Therefore, it is reasonable to conclude that neither the Dam Removal nor Dam Modification alternative would have any measureable impact on this ENC. However, see Section 3.11.3.2 of this report for a discussion of potential indirect impacts to wetland groundwater hydrology, which cannot be entirely ruled out.

**Semi-rich Oak - Sugar Maple Forest**

Review of topographic mapping indicates that this forest community is located on a landscape feature significantly higher in elevation than the surrounding floodplain and wetland communities. This forest is an upland community, whose structure is determined by factors other than periodic saturation or flooding, and which is located in an area above the floodplain. Therefore, it is expected that the Dam Removal or Dam Modification would have no effect on this occurrence.

**Floodplain Forests**

Two floodplain forest types are mapped by the NHNHB as Exemplary Natural Communities in the same general area of the impoundment, including:

- **Hemlock - Cinnamon Fern Forest, and**
- **Swamp White Oak Forest.**

In particular, intact floodplain forests dominated by swamp white oak (*Quercus bicolor)* are state and regionally rare. In New Hampshire, these forests are limited to the coastal plain, but were frequently drained and cleared for farmland in the past. The swamp white oak forest along the Exeter River is one of the larger examples in New Hampshire.

The potential impact to these floodplain communities can be assessed based on the results of the hydrologic and hydraulic modeling. The results of the hydrogeological analysis suggest that effects on the floodplain forests from changes in groundwater levels cannot be ruled out entirely. (See Section 3.11.3.2.) However, community dynamics in floodplain forests are largely driven by surface water flood events. Floods between the 2-year event and the 50-year event are the most important in driving community composition. Thus, by looking at the magnitude of change associated with these flow events in the vicinity of the floodplain forests, we can develop some understanding of likely impacts. **Table 3.11-8** shows predicted water surface elevations under the Existing Condition, Alternative B (Dam Removal) and Alternative H (Dam Modification). Data from a cross-section relatively close to the dam but in the vicinity of the floodplain forests identified by the NHNHB as exemplary natural communities was intentionally chosen for this discussion in order to represent a conservation approach to potential impacts.

Currently, this reach of the Exeter River is relatively deep and slow, with an extremely sinuous channel. As shown in **Table 3.11-9**, this reach is typically about 6 ft deep during normal flows, but is as deep at 15 ft under 100-year flood conditions. Similarly, the width of the river channel is between 100 and 140 ft wide during typical flows, but increases even more dramatically during flood conditions, growing to nearly 25 times wider during the 100-year flood. This highlights the extensive width of the floodplain in this reach.

## Table 3.11-9. Predicted Changes at Floodplain Forests, Exeter River

| | Existing Condition | | Alternative B (Removal) | | Alternative H (Modification) | |
|---|---|---|---|---|---|---|
| Flow | Max. Depth[1] (ft) | Width[2] (ft) | Max. Depth (ft) | Width (ft) | Max. Depth (ft) | Width (ft) |
| Median Sept. | 6.2 | 100.6 | 5.3 | 60.0 | 6.2 | 100.6 |
| Median Annual | 6.3 | 113.7 | 5.5 | 61.3 | 6.3 | 113.7 |
| Median May | 6.2 | 136.4 | 4.6 | 55.4 | 6.2 | 136.4 |
| 2-year | 8.1 | 727.0 | 6.2 | 212.2 | 6.3 | 242.0 |
| 10-year | 10.7 | 1193.4 | 8.1 | 729.7 | 8.3 | 734.5 |
| 50-year | 13.8 | 2377.6 | 11.3 | 1419.8 | 11.4 | 1464.5 |
| 100-year | 15.1 | 2526.3 | 12.6 | 2118.7 | 12.8 | 2153.0 |

Note: Data is from HEC-RAS Sta. 6732

The hydraulic model results predict that there would be a decrease in backwater flooding if the Great Dam were to be removed or modified. Flood events would be shallower and would inundate less of the floodplain forests compared to the Existing Condition.[51]

Substantial changes to the key hydraulic parameters provided in **Table 3.11-9** are predicted for all flow conditions under Alternative B – Dam Removal and for flood conditions under Alternative H – Dam Modification.

- During the median annual flow, the average depth of the river at the floodplain forests would drop about 1.0 ft if the Great Dam were removed (Alternative B), but would not change if the dam were modified (Alternative H).
- During the 2-year flood, average river depth is predicted to drop about 3.0 ft or 2.9 ft under Alternatives B and H, respectively, from about 8.1 ft to about 5.1 ft or 5.2 ft.
- During the 50-year flood, the average depth is predicted to drop 2.5 and 2.4 feet under Alternatives B and E, respectively, from about 13.8 ft to about 11.3 or 11.4 ft.
- River width is predicted to decrease fairly substantially, from about 114 ft to about 45 ft during the median annual flow if Great Dam were removed, whereas there would be no change if the dam were modified.
- During the 2-year flood event, river width would decrease dramatically, from about 727 ft to 212 ft or 240 feet for Alternatives B and H, respectively.
- For larger floods, the decrease in river width would be proportionally smaller. The 50-year flood width is 2,377 ft under Existing Conditions, but 1,419 ft or 1,464 ft respectively for Alternatives B and H, respectively.
- In other locations, the magnitude of change would be relatively less substantial. For example, further upstream the change in river width would represent only 12-13% of the existing 50-year flood width. In fact, no studied flow condition is predicted to experience a decrease in river width of more than 25% for either Alternative B or H, suggesting that much of the existing floodplain will continue to be inundated on a regular basis.

It is impossible to quantify precisely the effects that these changes might have on forest community dynamics. However, it seems unlikely that these changes would cause a sudden shift away from the floodplain community types. Rather, gradual changes in community composition may occur which could allow plant species typically occurring in drier sites to colonize the forest.

▼

51 Although Alternative B and Alternative H would decrease the backwater relative to the existing dam, there is substantial evidence that indicates that the frequency of high flow events has been increasing historically within southeastern New Hampshire due to climate changes. See Section 3.3 for more detail. This factor should be considered in assessing likely effects on these floodplain forests.

## 3.11.6 Mussels

### 3.11.6.1 Existing Conditions

Freshwater mussels are important to the ecology of river ecosystems and are important indicators of ecosystem health (Nedeau 2008). NHFGD and the Lamprey River Advisory Committee have been actively working to update records of the state-endangered brook floater (*Alasmidonta varicosa*) and establish baseline conditions for mussel populations in the Exeter and Lamprey River watershed. Historically, the Exeter River may have supported up to seven freshwater mussel species, including eastern elliptio (*Elliptio complanata*), creeper (*Strophitus undulatus*), triangle floater (*Alasmidonta undulata*), brook floater, eastern lampmussel (*Lampsilis radiata*), eastern floater (*Pyganodon cataracta*), and alewife floater *(Anodonta implicata*). However, based on recent surveys, it is believed that the brook floater has been extirpated from the Exeter River watershed (Michael Marchand, NHFGD, personal communication.) After consultation with the NHFG and NHNHB, it was determined that there are no concerns regarding state or federally-protected mussel species within the study area. However, freshwater mussels occur upstream of the dam, and marine mussels occur downstream, as discussed below.

The most recent work on freshwater mussels in the Exeter River watershed was conducted by Nedeau (2010). During the survey conducted by Nedeau (2010), only three of the six identified species were found in the Exeter River, including several thousand eastern elliptios (*Elliptio complanata*), approximately 350 eastern lampmussels (*Lampsilis radiata*), and six triangle floaters (*Alasmindonta undulata*). Triangle floater was widely distributed in the Exeter Rivers watershed, but at very low densities.

The survey included six locations along the Exeter River. One site in Exeter, two in Brentwood, two in Fremont and one in Chester. The surveyed locations are mostly far upstream of the Great Dam, well above its influence. However, one survey location known as "E-1" was located within the study area just below the Pickpocket Dam, above the influence of the Great Dam. Here, Nedeau (2010) found a total of 50 eastern lampmussels. (See **Figure 3.11-8.)**

Downstream of the dam, ribbed mussels *(Geukensia demissa)* are abundant in the lower portions of the Squamscott River, near the railroad bridge at the confluence of the river and the Great Bay (Dr. Raymond Grizzle, University of New Hampshire, personal communication). Populations of ribbed mussels have been identified among a natural reef, on both banks of the Squamscott River and north and south of the bridge.

### 3.11.6.2 Discussion of Potential Effects

Dams and flow alterations affect mussel species in a variety of ways. Dams create of deep impoundments which change habitat conditions, fragment rivers by inhibiting movement of animals, and alter thermal regimes in impoundments and downstream areas. Drawdowns for maintenance can cause high mortality in mussels that occupy the impoundment if they cannot move to deeper water fast enough.

Because dams are generally considered to adversely impact mussel populations, Alternative B – Dam Removal can be expected to benefit freshwater species upstream of the dam. Dam removal would benefit the mussel habitats, removing the impoundments and fragmented section of the Exeter River at Great Dam therefore, possibly increasing the mussel populations.

Alternative H- Dam Modification would generally not have these same beneficial effects. The intent of the Dam Modification Alternative is to maintain the existing impoundment in its current condition under normal flow regimes. While this would not create new impacts to aquatic habitat or existing mussel populations any more than the existing dam, Dam Modification would not benefit the aquatic habitat either.

One concern related to mussels is the potential for increased downstream sedimentation. As discussed in Sections 3.2 and 3.3, additional sediment is likely to be dispersed downstream if the dam were to be removed as impounded sediments are released. This additional sediment could potentially bury downstream salt water mussel populations. At the present time, the only known mussel population exists approximately six miles downstream. At this distance, it is unlikely that this known population would be impacted due to the effects of attenuation as newly released sediment migrates downstream.

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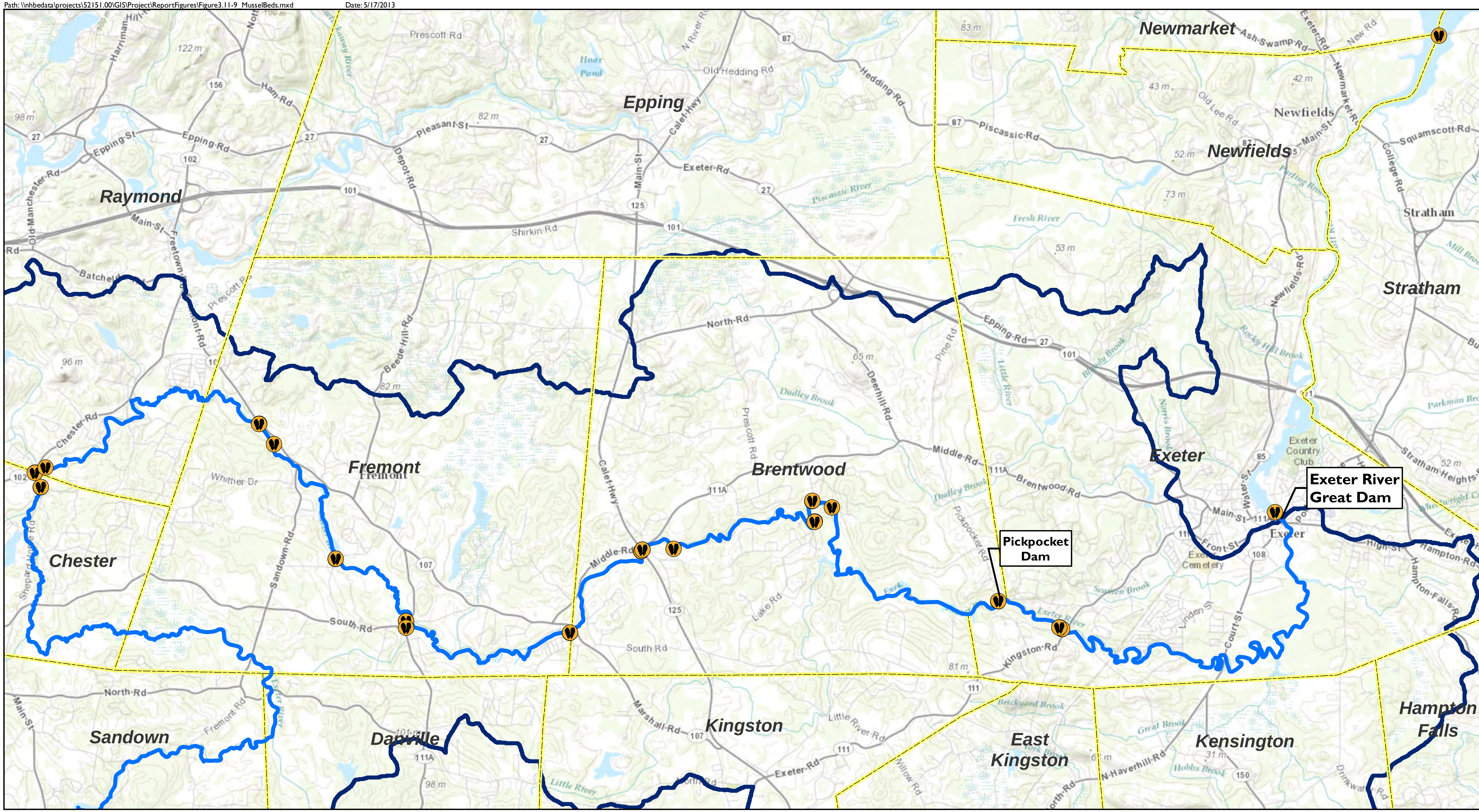


**Legend**

- Mussel Bed Survey Locations
- Exeter River
- Exeter River Watershed Boundary
- Municipal Boundary

Source: NHFG, LRAC

0 5,000 10,000 Feet

Vanasse Hangen Brustlin, Inc.

**Figure 3.11-8**
**Known Mussel Populations on the Lower Exeter River**
**Exeter Great Dam Removal Feasibility & Impact Analysis**

**Exeter, NH**

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## 3.12 Visual Impacts

A set of three visual simulations were prepared to help to understand the potential visual impacts associated with the removal of the Great Dam. These simulations are shown in **Figures 3.12-1 to 3.12-3**.

The sites of the three renderings were chosen based on points of interest to the public and results of the hydraulic model. The sites include:

- A view of the dam site, looking west from Founders Park.
- A view looking upstream, towards the Great Bridge (High Street Bridge), from the Great Dam site.
- A view looking upstream (south) from the boat launch at Gilman Park.

These renderings were produced by reviewing digital photographs of the river, particularly photographs taken during the recent draw down in November 2011. The digital images were brought into an engineering CAD platform so that water levels from the hydraulic model could be simulated. Digital image editing software was used to digitally superimpose a depiction of the alternative and/or the predicted water levels from each of the vantage points.

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Before

After

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**Figure 3.12-1**
**Photosimulation of the Dam Site from Founder's Park**
**Exeter Great Dam Removal Feasibility and Impact Study**
**Exeter, NH**

Vanasse Hangen Brustlin, Inc.

**Figure 3.12-2**
**Photosimulation looking upstream from the Dam**
**Exeter Great Dam Removal Feasibility and Impact Study**
**Exeter, NH**

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**Figure 3.12-3**
**Photosimulation looking upstream from Gilman Park**
**Exeter Great Dam Removal Feasibility and Impact Study**
**Exeter, NH**

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# Literature Cited

AECOM. 2009. Unpublished Technical Report entitled "Squamscott River Sediment Investigation on behalf of Unitil Corp." http://www.town.exeter.nh.us/ sites/default/files/fileattachments/sediment_analysis_report.pdf. Accessed October 31, 2012.

Barnes, Harry. 1967. Roughness characteristics of natural channels. USGS Water Supply Paper No. 1849.

Bear Creek Environmental, 2009. Exeter River Geomorphic Assessment and Watershed-based Plan, Fordway Brook, Upper Exeter River, Dudley-Bloody Brook, and Lower Exeter River. Technical Report to the NHDES and the Town of Exeter, issued March 20, 2009.

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.

Brown, C. B. 1950. Sediment Transportation. In Engineering Hydraulics, H. Rouse, ed., Wiley, New York, 769– 857.

Buchman, M.F., 2008. NOAA Screening Quick Reference Tables, NOAA OR&R Report 08-1, Seattle, WA Office or Response and Restoration Division, National Oceanic and Restoration Division, National Oceanic and Atmospheric Administration.

Burack, T.S., M. J. Walls, H. T. Stewart, and S. M. Couture. 2011. The Lower Exeter and Squamscott rivers - A Report to the General Court. New Hampshire Dept. of Env. Serv., Water Division – Watershed Management Bureau Concord, NH Rept. No. R-WD-11-5. 21 pp.

Burmaster, D. E., C. A. Menzie, J. S. Freshman, J. A. Burns, N. I. Maxwell, and S. R. Drew. 1991. Assessment of methods for estimating aquatic hazards at Superfund type sites: A cautionary tale. Environ. Toxicol. Chemistry 10: 827-842.

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.

Dillon, T.M. 1977. Mercury and the estuarine marsh clam, *Rangia cuneata* Gray. I. Toxicity. Arch. Environ. Contam. Toxicol. 6:249-255.

Durkis, T. 2003. Biological Control of Purple Loosestrife, 1997-2001. New Hampshire Department of Agriculture, Markets & Food, Plant Industry and the New Hampshire Department of Transportation. FHWA-NH-RD-12323Q. 59 pp +

Eipper, A., W. Knapp, and C. Lafflin., 1982. Anadromous fish streams of New England. Upstream migratory routes. Porfolio NE-1. US Fish and Wildl. Serv., Newton Corner, MA 02158

Exeter Elms Campground (EEC). 2012. Exeter Elms Campground. [Online] URL: http://www.exeterelms.com/index.html. Accessed October 25, 2012.

Exeter Squamscott River Local Advisory Committee (ESRLAC). 2012. Scenic and Recreational Resources. [Online] URL: http://www.exeterriver.org/histrec.html. Accessed October 25, 2012.

Exeter Squamscott River Local Advisory Committee (ESRLAC). 2008. Exeter River Corridor and Watershed Management Plan. [Online] URL: http://des.nh.gov/organization/ divisions/water/wmb/rivers/documents/management_plan_exeter.pdf. Accessed October 25, 2012.

FERC. 2013. Engineering Guidelines for the Evaluation of Hydropower Projects. [Washington, DC]: Federal Energy Regulatory Commission, Office of Hydropower Licensing, 2013.

FHWA. 1999. Geotechnical Engineering Circular No. 4. (FHWA-IF-99-015) Ground Anchors and Anchored Systems U.S. Department of Transportation Federal Highway Administration, 1999.

Great Bay Camping (GBC). 2012. About Us. [Online] URL: http://greatbaycamping.com/about1.htm. Accessed October 25, 2012.

Green Gate Campground (GGC). 2012. Facilities. [Online] URL: http://www.thegreengatecampground.com/facilities.php. Accessed October 25, 2012.

Haro, A., T. Castro-Santos, J. Noreika, and M. Odeh. 2004. Swimming performance of upstream migrant fishes in open-channel flow: a new approach to predicting passage through velocity barriers. Can. J. Fish. Aquat. Sci. 61: 1590–1601

Helsel, D.R. and R. M. Hirsch, 2002. Statistical Methods in Water Resources Techniques of Water Resources Investigations, Book 4, Chapter A3: U.S. Geological Survey, Reston, Virginia.

Houkal, D., B. Rummel, and B. Shephard. 1996. Results of an *in situ* mussel bioassay in the Puget Sound. Abstract, 17th Annual Meeting, Society of Environmental Toxicology and Chemistry, Washington, DC. November 17-21, 1996.

Hunt, P. 2005. NH Wildlife Action Plan, Appendix A, Species Profiles, Part Five: Birds, Least Bittern. New Hampshire Fish and Game Department, 2005.

Leopold, Luna. 1994. A View of the River. Harvard University Press.

McCarty, L.S., D. MacKay, A.D. Smith, G.W. Ozburn, and D.G. Dixon. 1992. Residue-based interpretation of toxicity and bioconcentration QSARs from aquatic bioassays: Neutral narcotic organics. Environ. Toxicol. Chem. 11:917-930.

Meyer-Peter, E. and R. Mueller. 1948. Formulas for bed-load transport. Proc., 2d Meeting Int. Assoc. for Hydraulic Research, Delft, The Netherlands, 39– 64.

Michigan Department of Environmental Quality. 2008. A Guide to the Control and Management of Invasive Phragmites. Office of the Great Lakes, Aquatic Invasive Species Program, 37 pp.

National Institute of Standards and Technology. 1995. NIST Handbook 135. Life-Cycle Costing Manual for the Federal Energy Management Program. U.S. Department of Energy. 1995

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, 2012

New Hampshire Department of Environmental Services (NHDES). 2010. New Hampshire Volunteer River Assessment Program, 2009 Exeter

River Watershed Water Quality Report. NHDES Publication NHDES R-WD-10-IL, January, 2010.

New Hampshire Department of Environmental Services (NHDES). 2011. The Lower Exeter and Squamscott Rivers: A Report to the General Court. [Online] URL: http://des.nh.gov/organization/commissioner/pip/publications/wd/documents/wd-11-5.pdf. Accessed October 25, 2012.

New Hampshire Department of Environmental Services (NHDES). 2012. Designated Rivers: The Exeter River. [Online] URL: http://des.nh.gov/organization/divisions/water/wmb/rivers/exeter_river.htm. Accessed October 25, 2012.

New Hampshire Office of Energy and Planning (NHOEP). 2007. New Hampshire Statewide Comprehensive Outdoor Recreation Plan (SCORP). [Online] URL http://www.nh.gov/oep/resourcelibrary/referencelibrary/s/scorp/documents/complete_report.pdf. Accessed October 25, 2012.

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

Olson, S.A., 2007, Flood of May 2006 in New Hampshire: U.S. Geological Survey Open-File Report 2007–1122, 32 p.

Olson, S.A., 2009. Estimation of flood discharges at selected recurrence intervals for streams in New Hampshire: U.S. Geological Survey Scientific Investigations Report 2008–5206: U.S. Geological Survey, Reston, Virginia.

Parker, G. 1990. Surface-based bedload transport relation for gravel rivers. Journal of Hydraulic Research 28(4): 417-436.

Patterson, C. K Sullivan, M. Dionne, R. Heuss, J. Fischer, 2012, R. Eckert, and S. Beirne. 2012. Progress Report: Anadromous fish investigations; Job 1: anadromous alosid restoration and evaluation. 19 pp. NHFGD, Concord, NH.

Rosgen, Dave and L. Silvey, 1996. Applied River Morphology. Wildland Hydrology.

Siegal, L. 2005. Technical Report entitled, Draft Evaluation of Sediment Quality Guidance. NH Department of Environmental Services, Publication NHDES-WD-04-9, April 2005

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

Sloth, J. J. and K. Julshamn. 2008. Survey of Total and Inorganic Content in Blue Mussels (*Mytilus edulis* L.) from Norwegian Fjords: Revelation of Unusual High Levels of Inorganic Arsenic. Journal of Agricultural and Food Chemistry. 56: 1269-1273.

Sperduto, D.D. and William F. Nichols. 2011. Natural Communities of New Hampshire. 2nd Ed. NH Natural Heritage Bureau, Concord, NH. Pub. UNH Cooperative Extension, Durham, NH.

Squiers, T.S. 1988. Anadromous Fisheries of the Kennebec River Estuary. Maine Dept. of Marine Resources. National Oceanic & Atmospheric Administration, National Marine Fisheries Service Management Division, State Federal Relations Branch.

Starbuck, David R. 2005. Unlocking the Past, Celebrating Historical Archaeology in North America. The Society for Historical Archaeology, 2005.

Thomann, R. V., J. P. Connolly, and T. F. Parkerton. 1992. An equilibrium model of organic chemical accumulation in aquatic food webs with sediment interaction. Environ. Toxicol. Chemistry. 11: 615-629.

Town of Exeter. 2012a. Gilman Park. [Online] URL: http://www.town. exeter.nh.us/recreation/gilman-park. Accessed October 25, 2012.

Town of Exeter. 2012b. Founders Park. [Online] URL: http://www.town exeter.nh.us/recreation/founders-park. Accessed October 25, 2012.

Trowbridge, Phil and Dr. Stephen Jones. 2005. Summary Report: National Coastal Assessment Monitoring Program; 2000-2001. A Final Report to US EPA, Office of Research and Development. Atlantic Ecology Division.

US Interagency Advisory Committee on Water Data. 1982. Guidelines for determining flood flow frequency, Bulletin 17-B of the Hydrology Subcommittee: U.S. Geological Survey, Office of Water Data Coordination: Reston, Virginia.

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

US Environmental Protection Agency (USEPA). 2000. National Sediment Quality Survey, 2nd Edition (USEPA EPA-823-R-01-01, 2000a) and its Appendix (USEPA EPA-823-R-00-002, 2000b).

US Environmental Protection Agency Region III (USEPA Region III). 2006. Freshwater Sediment Screening Benchmarks for Volatile, Semi-volatile, PAH's and other Organic Compounds. http://www.epa.gov/ reg3hwmd/risk/eco/btag/sbv/fwsed/screenbench.htm

Weston & Sampson, Inc. 2010a. Technical Report entitled Town of Exeter, New Hampshire, Hydroelectric Review Assessment, issued March 2, 2010.

Weston & Sampson, Inc. 2010b. Technical Report entitled Water Supply Alternatives Study- Final Report, issued January 2010.

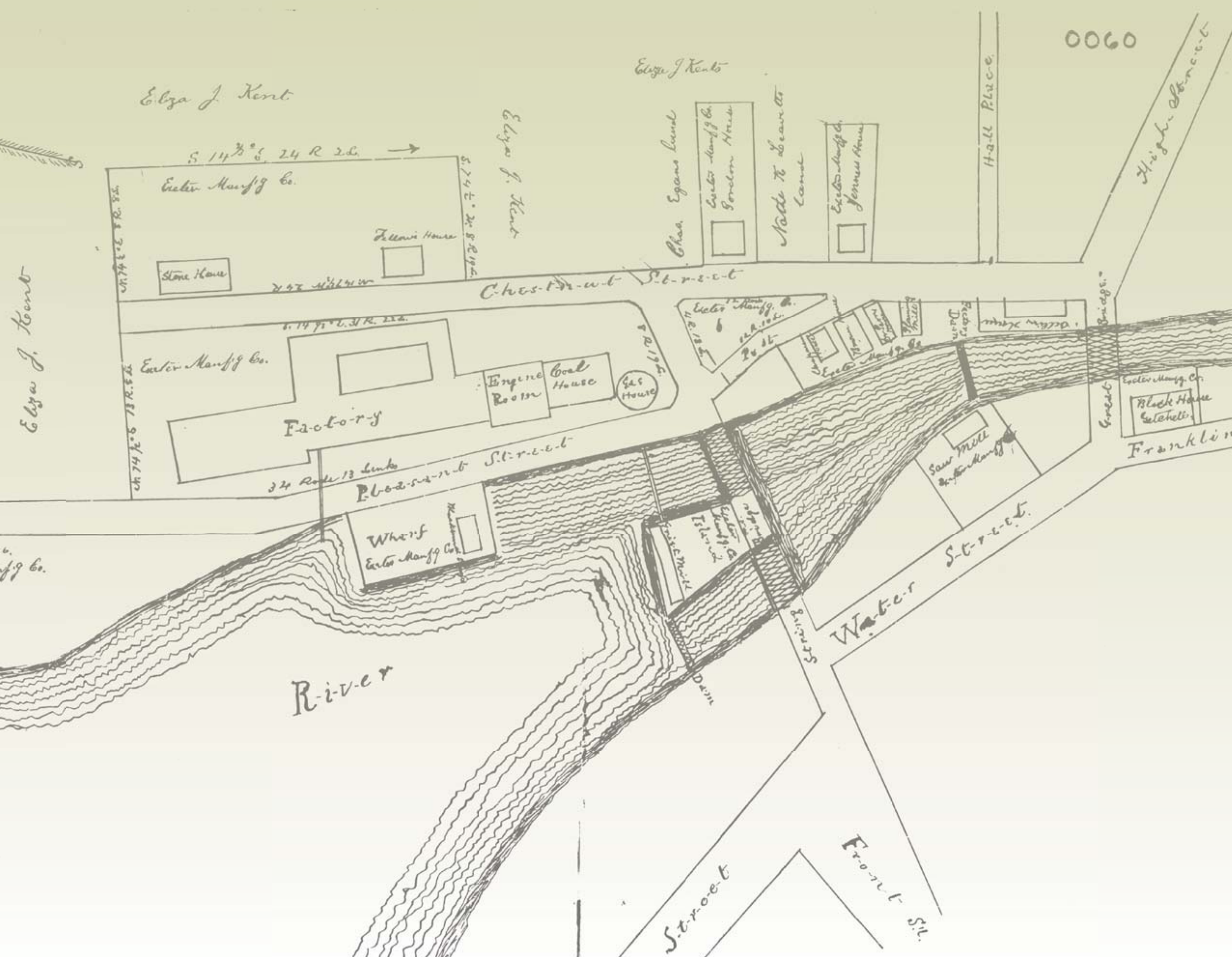
Weston & Sampson, Inc. 2010c. Technical Memorandum entitled Exeter River Drawdown Observations, issued March 2, 2010.

Weston & Sampson, Inc. 2012. Technical Memorandum entitled Exeter River Design Flows, by K. Mackinnon and A. Walker dated January 4, 2012.

Wright-Pierce, Inc. 2007. Exeter River Study Phase I Final Report, Unpublished Technical Report to the Town of Exeter, March 2007.

Wright-Pierce, Inc. 2008. Riverbank Scour Analysis and Discharge Gate Design Impacts to Water Quality, Unpublished Technical Report to the Town of Exeter, April 2008.

Yang, C.T. 1996. Sediment Transport: Theory and Practice. McGraw-Hill Companies Inc.


0060
Eliza J. Kent
Eliza J. Kent
Eliza J. Kent
Eliza J. Kent
Exeter Manf'g Co.
Stone House
Chestnut Street
Exeter Manf'g Co.
Factory
Engine Room
Coal House
Gas House
Pleasant Street
Wharf
Exeter Manf'g Co.
River
Hall Place
High Street
Great Bridge
Exeter Manf'g Co.
Block House
Franklin
Saw Mill
Water Street
Dam
Street
Front St.

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