Ludden's Ford Dam and State Street/ Cross Street Dam Removals Feasibility Study
40% Basis of Design Report

SUBMITTED TO
North and South Rivers Watershed Association in partnership with the Towns of Hanover, Hanson and Pembroke

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1. Introduction

Inter-Fluve, Horsley Witten, the Herring Pond Tribe, and the Public Archaeology Laboratory were contracted by the North and South Rivers Watershed Association in partnership with the Towns of Hanover, Pembroke and Hanson to provide conceptual designs of the removal of the Ludden's Ford (LF) and State Street/Cross Street (SC) Dams on the Indian Head (IH) River in Plymouth County. This project was funded by the Massachusetts Executive Office of Energy and Environmental Affairs Natural Resource Damages Trust as administered by MassDEP to assess the potential for fish habitat and river restoration at these two sites. Ludden's Ford Dam, jointly owned by the Towns of Hanover and Pembroke, is approximately 4,600 feet from the Indian Head River's confluence with the North River, which flows unimpeded to the Massachusetts Bay (the Bay). State Street/Cross Street Dam, owned by the Town of Hanover and Hanson, is located 1.5 miles upstream of Ludden's Ford Dam. Ludden's Ford and State Street/Cross Street Dams are the first and second obstructions, respectively, upstream from tidal water at the Bay (Figure 1). While once significant to the growing industrial movement in the early colonial settlement of eastern Massachusetts, in the present day the dams no longer serve the same purpose. Prior to settlement, the Indian Head River flowed freely and played a critical role in the subsistence economy of the indigenous population. The fragmentation caused by the dams prevents fish and other wildlife from accessing essential habitat, impacts water quality and flow, increases flood risk, impacts natural sediment processes, and harms indigenous peoples' cultural values.

Along with the North and South Rivers Watershed Association, the Towns of Hanover, Pembroke, and Hanson, MassDEP's Natural Resource Damages Program and the Massachusetts Bays National Estuary Partnership have formed the Indian Head (IH) River Steering Committee to collaboratively explore the feasibility of removing Ludden's Ford and State Street/Cross Street Dams. Through the development of this project, the IH Steering Committee has established the following goals:

- Restore natural river processes.
- Improve flood and community resilience.
- Restore habitat connectivity and ecosystem health.
- Reduce infrastructure management needs.
- Eliminate public safety hazards.
- Enrich community values and experiences with the river.

In response to these goals, specific objectives for this project include the following:

- Restore safe, timely, and effective passage potential for native sea-run and resident fish.
- Enhance resilience to climate change by eliminating unused structures from the river corridor to maximize space for future floods and natural stormwater buffering.
- Reduce the towns' resources required to maintain and repair aging infrastructure and manage risk.
- Avoid or mitigate impacts to infrastructure that will remain along the river corridor.
- Enhance the community knowledge and use of the river through research, interpretation and dissemination of knowledge.

Building on the conceptual designs (Stantec 2021a and Stantec 2021b), the IH River Steering Committee progressed the dam removal options for the Ludden's Ford and State Street/Cross Street Dams to 40% complete designs. This report summarizes the results of the feasibility study and the 40% designs for the two sites. The work was completed by Inter-Fluve (IF), Horsley Witten (HW), Herring Pond Tribe (HPT), and the Public Archaeology Laboratory (PAL). The project was supported through a financial grant from the Natural Resources Damages Trust Fund.

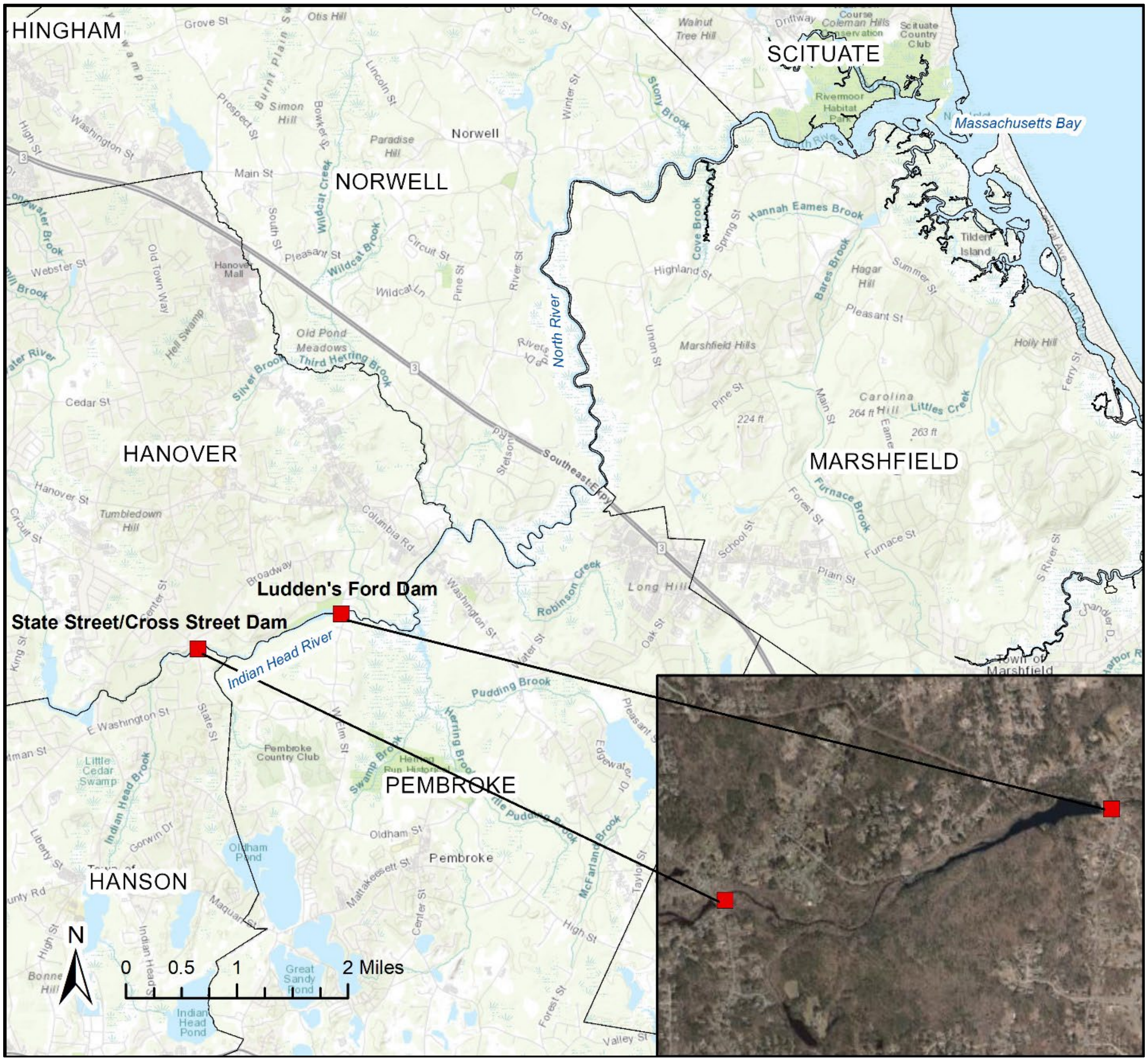


Figure 1: Map of the Indian Head River in eastern Massachusetts. The flow direction of the river runs from the west of the map up to the east.

2. Site History

PAL conducted Cultural Resources Assessment to identify known and potential historic and archaeological resources and baseline existing conditions at the two dam sites and their environs. In a technical memorandum, which can be found in Appendix F, PAL documents the results from their review and research of background materials as well as their site visit in April 2023. The HPT also visited the two dam sites and researched the historical use of the area pre-European colonization (Appendix G). This section provides an overview of the history of the two dam sites based on PAL's and HPT's findings. More detailed information can be found in the listed appendices.

Prior to European settlement, diadromous fish runs in the IH River were staples of the Native American subsistence way of life. The river was not only a place to fish, but also a corridor for trade and transportation. The surrounding forests and wetlands were also vital to indigenous life, providing food and materials for shelter and crafting. The South Shore section of Massachusetts Bay, particularly along the North River drainage, is rich in pre-contact Native American archaeological sites. A few locations of these pre-contact cultural materials were discovered around the LF site as a part of the North River Archaeological Project conducted in the late 1980s and early 1990s. Based on the findings, the principal archaeologist, Dr. Curtiss Hoffman deduced that the field on the Hanover side of the LF park was the site of a large fall-line campsite dating to the Late Archaic -Transitional Period (5000-2000 BP). The tools, including Squinocket Triangle projectile points, stem bases, flint knives, and multi-purpose scrapers, illuminate the resourcefulness that sustained and shaped traditions of the indigenous culture bond to the Land. These instruments were more than mere implements; they embodied survival and self-sufficiency. Vital for hunting, food preparation, and crafting essential items, they exemplified native people's profound connection to the gifts of the Earth. The presence of graphite and hematite paintstone adds another layer of significance, suggesting artistic expression and the preservation of traditions. Moreover, the abundance of flakes signifies an active hub for tool production, reflecting a thriving community coexisting in harmony with the gifts of the Earth. The indigenous people who called this place home understood that the land's resources were never commodities but sacred elements of existence.

European settlers arrived in the area in the late sixteenth century and shortly thereafter began to harness the IH River by constructing a series of dams that powered mills along its banks. The settlers in the region followed native trails that were improved into regional highways, including the Plymouth Path, which connected Plymouth to Boston. The Elm Street Bridge, a bridge on the Bay Path just downstream of the LF dam, was a major crossing on the IH River during this time.

LF dam, initially established in 1693, saw several changes in ownership and usage over the years, including the manufacturing anchors, iron, and other heavy items. George Curtis, who acquired the property in 1791, moved a carding mill to the Pembroke side of the river in the early 1830s.

As the demand for larger ships increased in the mid-nineteenth century, shipbuilding on the North River declined, and the supporting industries, including anchor forges and furnaces, shifted to other types of iron manufacture, such as tack machines, cotton gins, and iron ploughs.

In 1873, Eugene H. Clapp and Frederick W. Clapp, who were in the business of grinding rubber and reclaiming it for reuse in the manufacture of new goods, renovated the old anchor works buildings to accommodate their machinery, introduced steam power, and expanded their operations. They rebuilt the dam in its current location in 1908 to replace an earlier dam. In 1934, financial difficulties led to the auction of their properties. Following the auction, the factory buildings were abandoned and later removed by the State and the towns. In the mid-1950s, the dam was significantly modified including the construction of the fishway. The dam was improved again in 1970 as part of the development of the recreational areas in Hanover and Pembroke.

The history of the SC Dam is also intricately tied to the industrial evolution of the region. In 1720, a forge and dam were constructed. The forge was built on the north side of the river in Hanover, and ownership and operations shifted over time. The forge changed ownership and purposes over the years, eventually specializing in tack production. The tack and nail factory expanded significantly, employing a substantial workforce and utilizing advanced machinery, including a steam engine. By the early twentieth century, the factory was powered by electricity but was vacant by the 1930s. Most of the buildings were removed by the 1960s, with some foundation remains still visible today on both sides of the river channel upstream and downstream of the dam.

3. Site Conditions

Following a review of available background information, IF, HW, and the HPT conducted a series of site investigations from April through May of 2023. The investigations included a topographic and bathymetric survey of the river channel and adjacent infrastructure; geomorphic and habitat assessment of the river channel in the study reach; depth of refusal survey of the impoundments; and sampling of accumulated sediment in the impoundments. This section provides an overview of the existing conditions throughout the project area.

3.1 SITE CONTEXT

The IH River runs 3.8 miles from Factory Pond to where it meets Herring Brook to form the North River (Figure 1). The river is a single-thread channel buffered by wooded deciduous swamps along the flood prone areas of the banks upstream of LF dam and vegetated wetlands and shallow marshes downstream to the North River confluence. There are various upstream tributaries such as the Indian Head Brook, Drinkwater River, French Stream, Cushing Brook, Ben Mann Brook, Shinglemill Brook, and Longwater Brook. The watershed area draining to the LF Dam is approximately 30 square miles and includes the communities of Hanover, Pembroke, Hanson, Whitman, Rockland, Abington, Weymouth, Hingham, and Norwell (Figure 2). The watershed receives 46.9 inches of precipitation annually, on average (USGS 2019). Approximately half of the land use of the watershed area consists of densely developed residential and commercial areas. The remaining area is made up of forests (~27%) and wetlands (~20%). Less than 3% of the watershed is covered by open water bodies. Approximately 18% of the watershed area is impervious.

The reach of the IH River downstream of SC dam is a recognized coastal fish run and serves as crucial spawning habitat. The river supports at least six species of diadromous fish, including alewife (*Alosa pseudoharengus*), blueback herring (*Alosa aestivalis*), American eel (*Anguilla rostrata*), sea lamprey (*Petromyzon marinus*), and American shad (*Alosa sapidissima*). The anticipated upstream migration timing of diadromous fish species is from March to July. In addition to sea-run fish, resident fish occupy the watershed, such as brook trout. The species designated in this list have shown a marked decline in abundance throughout the Atlantic region. This decline is attributed in large part to loss of habitat, especially relating to dam installation (Limburg and Waldman 2009).

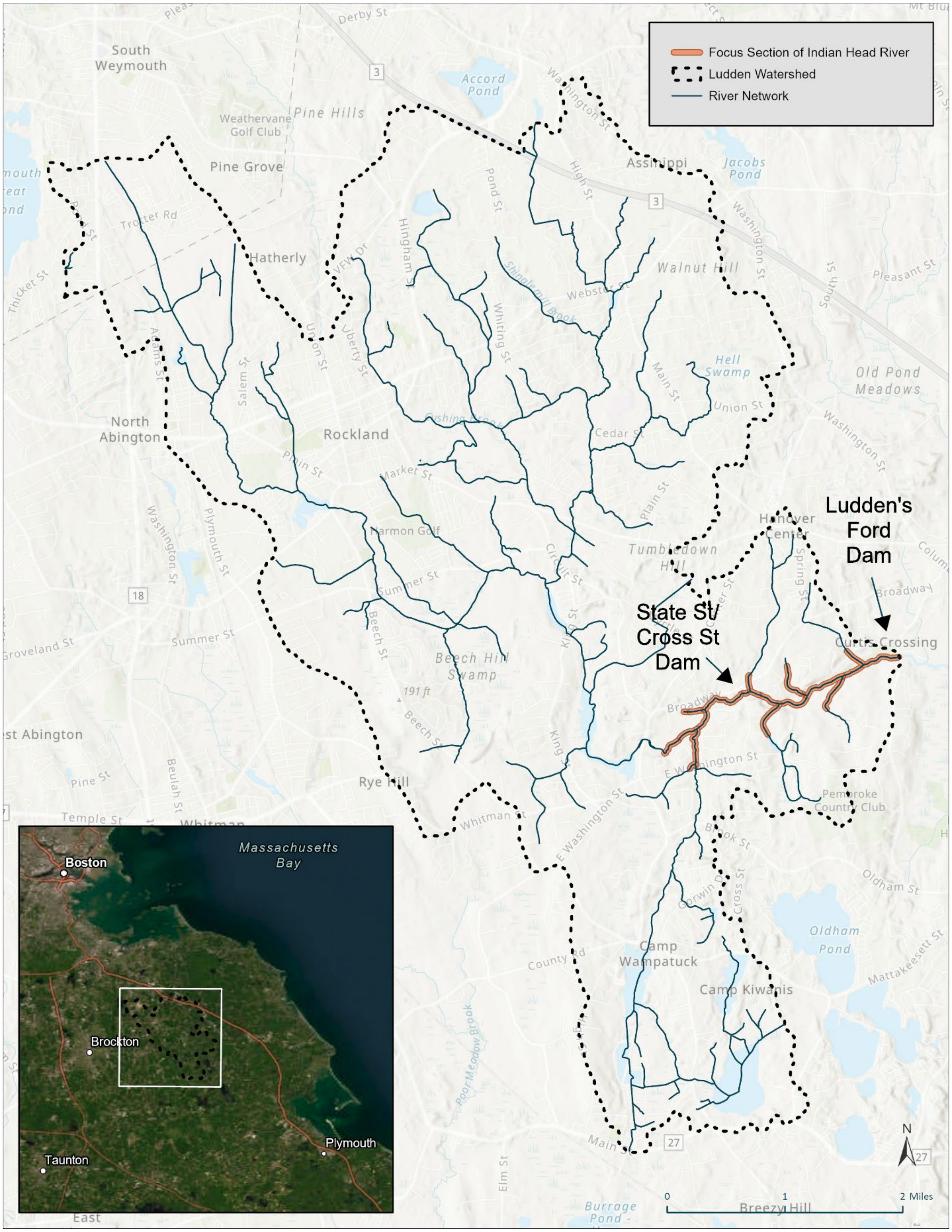


Figure 2: Drainage area to Ludden's Ford Dam.

The IH River has been shaped by the geologic events of the past 20,000 years as well as human interventions since the arrival of Euro-American colonists in the 17th and 18th centuries. During the last glacial maximum in the Pleistocene epoch (~21,000 years ago), the Laurentide ice sheet, over a mile thick, extended over New England and as far south as Long Island. The ice sheet scoured the surface of the earth and in the process generated a massive volume of sediment that was deposited both during ice sheet advance and as the ice sheet retreated (retreated to north of the Site vicinity by ~15,000 years ago). Sediments deposited directly beneath the ice manifest as a dense, poorly sorted mix of soil and rocks, known as till. Sediments deposited in front of the retreating ice by meltwater streams tend to form as less dense, well-sorted alluvial deposits, known as stratified drift or outwash deposits (Figure 3). Till is far less permeable than outwash deposits and, therefore, from a hydrology standpoint, areas covered by till tend to generate more runoff during storm events and contribute less to aquifer recharge and storage. These two primary types of geologic deposits are evident in the project area, and along with bedrock outcrops influence the geomorphology of the Indian Head River. Riffles and steeper reaches along the channel coincide with coarser deposits of cobbles and boulders that exceed the stream's transport capacity. The finer deposits of silt, sand, and gravel make up the alluvium that the IH River has transported and deposited along its banks since the retreat of the ice sheet.

When human settlers set about damming the river to harness its power, they typically exploited steeper reaches where stream power was higher, and dams could be spaced closely together. This is the case in the IH River from the LF dam up to the SC Dam, which is likely why at least three dams were constructed along the reach (Figure 4). This reach is relatively steep within the IH Watershed, flowing through a regional valley constriction that likely forms from a concentration of coarse glacial deposits narrowly situated between surrounding bedrock highlands.

Figure 3. Glacial till exposed by a root throw along the edge of Ludden's Ford Dam Impoundment. The diagnostic range of grain size from silt to large, rounded cobbles is evident.

Figure 4. The site of the former tack factory, the Waterman Dam, sits on a riffle at a local valley constriction. Bedrock outcrops are visible on the hillslope.

The dams have had a profound impact on the ecology and geomorphology of the watershed. The dams block passage for migratory fish species, including river herring, Atlantic shad, native brook trout and American eel, who have historically utilized the watershed for spawning. In addition to blocking fish passage, the dams form impoundments that extend upstream and create ponded conditions where sediment is deposited, and water quality diminishes due to increased temperatures and reduced dissolved oxygen and hyporheic exchange. This disrupts the natural sediment transport regime, depriving downstream reaches of needed sediment, and degrades the quality of water downstream from the dam. The impoundments also exhibit reduced geomorphic complexity compared to the free-flowing reaches in the project area.

Unimpounded sections within this reach provide a good example of how the channel may look and function in a future dam removal scenario. Like most upland channels formed across the glaciated landscape of New England, the channel exhibits pool-riffle morphology through these free-flowing reaches (Figure 5). The spacing of these pool-riffle couplets is generally about 5-7 channel widths, or about every 200-300 feet. The planform is relatively straight due to the gradient and confined nature of the valley. This is manifested in the narrow impoundments formed upstream of the dams.

Figure 5. A riffle downstream of the State Street/Cross Street Dam.

These steeper pool-riffle sequences stand in contrast to the geomorphic conditions downstream of the project area. Downstream of LF dam the stream begins to approach the North River and, ultimately, the tidal zone along the coastal plain. The stream gradient decreases, the planform becomes more sinuous, and large wetlands flank the channel. In this context, the project area represents potentially valuable freshwater habitat for coldwater species like herring, shad and lamprey.

3.2 LUDDEN'S FORD DAM

The LF Dam (aka the Luddam's Ford Dam, Curtis Crossing Dam or the Elm Street Dam), located just west of Elm Street in the village of Curtis Crossing, Hanover, is a run-of-river dam. A run-of-river dam uses the natural flow of a river to capture energy. It does not provide flood control and stores relatively little water. The LF Dam is classified as an Intermediate sized, Class III (Low) hazard dam and, as reported in the Phase 1 Inspection/Evaluation Report (2016), is presently in poor condition. The dam is an approximately 240-foot-long earthen embankment and concrete/stone masonry dam. The structural height of the dam has been reported as 12 feet (Figure 6). Its normal pool height is approximately 9.5 feet. The dam consists of a 90-foot-long gravity overflow primary spillway made of concrete and stone masonry, along with a concrete and earthen non-overflow section.

The primary spillway is divided into eight bays by stepped concrete abutments, and the downstream side of the spillway is constructed with concrete mortared boulders. A stilling basin on the downstream side is created by a concrete weir spanning the river channel width. According to the Phase 1 Dam Inspection report for the LF Dam, the spillway design flood capacity is unknown, which suggests that the spillway was not built to adhere to the Department of Conservation & Recreation (DCR) Office of Dam Safety's spillway capacity requirements. For an intermediate dam, the required spillway design flood is the 50-year design storm for existing dams and the 100-year design storm for new dams.

Figure 6. Ludden's Ford Dam, constructed in 1908 with a Denil-type fishway built in 1956.

Additionally, there is a Denil-type fishway constructed on the dam by the Massachusetts Division of Marine Fisheries (DMF) in 1956 under an agreement where costs were shared by the DMF and the Towns of Pembroke and Hanover. This fishway is approximately 35 inches wide and 110 feet long, situated in the middle of the primary spillway, spanning the length of the spillway and downstream stilling basin (Figure 7). It features a gradually sloping floor from the stilling basin grade to the spillway crest grade, supported on concrete piers and elevated above the discharge channel for most of its length. Large wood and debris often rack against the dam and clog the fishway. Because the fishway is in the middle of the spillway, maintaining the fishway boards, clearing the debris, and monitoring fish runs are challenging. Access is particularly dangerous during high flows, which often occur in the spring during fish migration. From 2021 to 2023, the DMF fishway crew removed woody debris, replaced the wood Denil baffles, replaced the water control boards, and repaired cracks throughout the concrete.

Figure 7. Denil-type fishway in the middle of Ludden's Ford Dam.

The dam to the right of the primary spillway is a concrete wall with a maximum exposed height of about 4 feet. The right abutment is lower than the concrete wall, which allows higher flows to circumvent the concrete wall. The concrete wall has visible cracks and signs of aging.

The left abutment of the dam has an earth slope and masonry walls. The upstream slope is steep with some signs of erosion. An old intake structure near the left abutment has been filled in and decommissioned.

There's a concrete stilling basin weir downstream of the dam spillway, with three stop-log controlled channels.

Figure 8. Concrete stilling basin weir on Ludden's Ford Dam.

On the left and right embankments, there are remains of former industrial buildings. The foundation remains have been mostly filled in. The LF dam is tied into a building foundation along the left bank of the river.

3.3 DOWNSTREAM OF LUDDEN'S FORD DAM

Between the stilling basin and the Elm Street Bridge, the downstream river channel has a concrete retaining wall with riprap on the left side and an unprotected vegetated bank on the right side. The river left concrete wall is skewed off perpendicular from the bridge, confining the channel and potentially increasing the scour potential at the bridge. This section of channel is also the upstream extent of the tidal influence. While the river is impacted by tidal oscillations, it remains a freshwater ecosystem.

The Elm Street Bridge, built in 1894, is approximately 250 feet downstream of the dam. It is a 32.5-foot long by 35-foot-wide single-span elliptical stone arch bridge (Figure 9). The bridge has a plaque that commemorates the crossing of the historic Bay Path at Ludden's Ford. The bridge is listed in the Inventory of Hanover Historical Resources and is included as a historic resource in the Massachusetts Cultural Resource Information System.

The channel below the Elm Street Bridge steepens and is characterized by a gravel/cobble bed with a series of riffles and pools. Forested wetlands line both sides of the river downstream of the bridge.

Figure 9. Elm Street Bridge, standing on river left looking downstream.

3.4 LUDDEN’S FORD IMPOUNDMENT

The impoundment behind the LF dam is approximately 3,400 long and is filled with sediment that has deposited over the years since the dam was in place (Figure 10). The 2016 Phase I Report lists the normal pool as 13.6 acres with a normal-pool impoundment volume of 46 acre-feet. IF conducted a depth of refusal survey, which entailed surveying and probing the surface of the impounded sediment. The sediment, mostly sand and organic matter, varies in depth throughout the impoundment with the deepest deposits close to the spillway. Depths of sediment range from 1 to 5 feet. The lowest points in the impoundment were located on northern side of the impoundment approximately 500 feet upstream from the dam. Typically, the pre-dam river channel can be located based on the low spots determined by the depth-of-refusal survey. The alignment of the low spots corresponds to the valley shape as the north side of the impoundment curves. Further upstream, the valley narrows and steepens, and the accumulated sediment becomes less detectable. The upstream end of the impoundment is at the site of the former Waterman Dam in Hanover. The remnants of the dam are still visible, but the dam was breached and is no longer a barrier for fish passage.

Figure 10. Impoundment upstream of the LF dam. Standing on river left looking upstream.

While the dam no longer serves its original purpose, the impoundment is used by the public for fishing and boating. There are recreation trails that follow the impoundment from the dam upstream to the State Street/Cross Street Bridge.

3.5 STATE STREET/CROSS STREET DAM

The SC dam is located approximately 7,850 feet upstream of the LF dam, on the east side of the State Street Bridge (Figure 11). The dam has a 49-foot breached spillway that spans both the towns of Hanover and Hanson. Originally, the dam was a run-of-river structure consisting of an earthen embankment and a stone masonry spillway with stone masonry foundation walls related to former mill buildings. In 1973, the spillway suffered substantial breaches, leaving only 4 to 5-foot-high remnants. The original spillway weir was 7 to 8 feet tall with a caplog weir over a stone masonry foundation. Flow cascades over the spillway into a steep section of channel with large cobbles and boulders. A small forebay area with large stone material is above the spillway between the State Street/Cross Street Bridge and the former stone masonry bridge abutments. Stone masonry bridge abutments are still present on both sides of the spillway downstream of the current bridge, and there's a small forebay area between the bridge and these abutments.

Figure 11. State Street/Cross Street dam pictured to the right of the concrete bridge. This dam was breached in 1973 and only remanent portions incapable of impoundment remain.

On the north side of the river channel, a mill raceway can be found, with another filled raceway channel in between, both following the east-west orientation of the river channel and passing through former mill buildings. The north raceway channel is approximately 150 feet north of the former dam's spillway center and passes under the road through a 6-foot reinforced concrete pipe culvert.

Figure 12. Six-foot culvert under Cross Street to the northeast of Cross Street/State Street Bridge.

3.6 DOWNSTREAM OF THE STATE STREET/CROSS STREET DAM

The downstream river channel is partially lined with large angular granite blocks on the north side, possibly added after the dam breach to prevent erosion. The channel bed contains cobbles and large gravel, some of which have washed downstream from the breached dam. The adjacent upland terrace downstream does not show evidence of the south raceway channel. The east shoreline of the low-lying terrace contains slag chunks and historical remnants like nail blanks and finished nails. Remnants of brick and cut granite tack factory foundation walls are present on the south side of the river channel. The park area below the road on the downstream side of the dam features walking paths, benches, and interpretive signage.

3.7 STATE STREET/CROSS STREET IMPOUNDMENT

Because of the breach, the dam has a relatively small impoundment above it. The estimated impoundment area is about 7 to 8 acres, extending roughly 4,800 feet upstream of the dam spillway (Figure 13). There is some fine sediment accumulated behind the dam but most of the fines are transported downstream to the LF impoundment. Coarser sediment deposits were found through probing above the dam. The impoundment is surrounded by a wooded swamp buffer. The impoundment narrows approximately 600 feet upstream of the dam. At the upper end of the impoundment, the river blends into vegetated wetland area.

Figure 13. Impoundment upstream of the State Street/Cross Street dam.

The State Street Bridge also known as the Robert S. Hammond Bridge, rehabilitated in 1995, is about 20 feet upstream of the breached dam structure. According to the Massachusetts Department of Transportation Highway Division Bridge Inspection Management System database, the bridge is made of prestressed concrete. The bridge opening spans 49 feet, and its low chord is about 5 feet above the normal water level. The State Street Bridge as-built drawings do not provide specific information about the depth of the abutment footings' bottoms, except for a detail suggesting that concrete was to be poured to an estimated elevation of around 30.5 feet (NGVD29), with exact elevations to be determined onsite during excavation. From this information, it can be inferred that the abutments might be about 3 feet below the spillway weir of the SC Dam; however, the actual elevation is still unknown. The boring log data presented on Sheet 2 of 12 of the Drawings suggest that the bridge footings may be founded on medium dense fine sand and coarse gravel.

Figure 14. State Street/Cross Street Bridge. Standing on river right looking upstream.

3.8 NATURAL RESOURCES

The area around the two dams hosts significant wetland habitats. These wetlands offer diverse ecosystems, transitioning from shallow marsh meadows and shrub swamps downstream to wooded deciduous swamps and mixed wood swamps further upstream. While the dams and their impoundments have a wide variety of native flora, there was a significant invasive population of Japanese knotweed located along the upper sections of the riverbank on the southern side of the river, between LF dam and Elm Street. There is also a smaller population of Japanese knotweed present along the edge of the forest at the western side of the southern Ludden's Ford Park area.

While there is no mapped priority habitat within the two dam sites and their impoundments, there is priority habitat (PH 892) designated by the Natural Heritage Endangered Species Program located where the IH River meets the North River. This area aligns with the portion of the IH River that experiences heightened tidal influence and encompasses extensive shallow marshes and shrub swamps.

On April 17th, 2023, HW conducted field delineation of wetlands resources in the immediate vicinity of anticipated construction disturbances at the two dam sites. The following resource areas were delineated:

- Bank (the portion of land surface which normally abuts and confines a water body);
- Land Under Water Bodies and Waterways;
- Riverfront Area;
- Bordering Land Subject to Flooding; and
- 100-foot Buffer Zone associated with the Bank.

Prior to conducting field delineations, HW reviewed existing source data, including USGS Geological Survey 7.5 minute topographic maps, Massachusetts Department of Environmental Protection (MassDEP) wetlands source data available through the Massachusetts Geographic Information System (MassGIS), USDA Natural Resources Conservation Service soils survey, U.S. Fish and Wildlife Service National Wetland Inventory maps, and other source data to identify the presence of jurisdictional wetlands and waters of the United States within the Site. This information was used to compile base mapping to assist in the understanding of the hydrologic variables, soils conditions, and vegetation communities (where applicable).

HW followed wetland resource area identification and on-site delineation procedure guidelines described in the MassDEP handbook, entitled *Massachusetts Handbook for Delineation of Bordering Vegetated Wetlands* (September, 2022), the Massachusetts *Wetlands Protection Act* (M.G.L. Ch. 131 § 40), and its implementing Regulations (310 CMR 10.00), as well as relevant local wetlands bylaws and associated regulations. Delineated resource areas are shown on the existing conditions site plans for the project (Appendix A).

3.9 IMPOUNDED SEDIMENT

3.9.1 Due Diligence

HW completed a limited due diligence review to evaluate potential historical threats to sediment quality and to inform sediment sampling to be conducted as part of our preliminary restoration design project for LF dam and the SC dam (the "Subject Properties"). The report titled *Due Diligence Review & Sediment Sampling Plan* was submitted to MassDEP in May 2023 and is attached as Appendix D.

The limited due diligence review consisted of the following:

- An evaluation of online records available from the Massachusetts Department of Environmental Protection (MassDEP) Waste Site and Reportable Releases Database (the "Database");
- A review of historical topographical maps, Sanborn Fire Insurance maps, and historical aerial photographs available online from the EDR™ Report, published by Environmental Data Resources Inc. ("EDR");
- A screening of regulatory records for environmental conditions at and abutting the Subject Properties from the EDR Radius Map™ Report, published by EDR; and
- A visual field assessment of the Subject Properties for evidence of a release of oil and/or hazardous materials (OHM).

Based on the above-discussed due diligence review, the IH River project area, including the SC dam and LF dam, has a long history of industrial land use for manufacturing. Former factories and sites include the National Fireworks site, located two miles upstream of the Subject Properties; a former tack factory which utilized the SC dam; a second tack factory immediately downstream of Cross Street; and a former rubber factory located at Ludden's Ford. A former railroad line also traversed the left bank of the river across the project area. The known contaminant source at the National Fireworks Site upstream and the other historic mills and industrial land use more closely surrounding the Subject Properties suggested the potential for polychlorinated biphenyls (PCBs), metals, semi-volatile organic compounds (SVOCs), and volatile organic compounds (VOCs) to impact sediment quality. Additionally, the former railroad line along the river's left bank suggested the potential for pesticides, herbicides, creosote, and metal contributions to sediments.

Based upon the above-discussed due diligence review, and in consideration of the 401 Water Quality Certification requirements (314 CMR 9.00), a sediment sampling plan was discussed with and approved by the NSRWA and the IH River Steering Committee that included all the standard 401 WQC parameters, plus additional parameters for MCP-14 metals, SVOCs, and herbicides. The following section discusses HW's executed sampling plan.

3.9.2 Sediment Assessment

HW conducted sediment sampling on June 20 and August 1, 2023, as part of the preliminary restoration design project for the Subject Properties. Sediment sampling was completed following the MassDEP-approved Sediment Sampling Plan (Appendix D), which itself was informed by a Due Diligence Review of potential contamination sources (Appendix D). The Sediment Sampling Plan defined which chemical parameters to test for, where samples would be collected, sampling procedures, and how individual sediment sample locations would be composited for laboratory analysis.

Sediment sampling locations included the following:

- Three composite samples from each impoundment (six total), each to be constituted from three locations.
- One composite sample constituted from three locations below LF dam, used to characterize baseline sediment quality downstream of the impounded sediment.

Included in the attached Appendix D, Figures 8A and 8B depict the discrete sampling points and the groupings for each composite sample.

Field Sampling

Based upon the due diligence review, and in consideration of the 401 Water Quality Certification (WQC) requirements (314 CMR 9.00)[1], a sediment sampling plan was discussed with and approved by the NSRWA and IH River Steering Committee that included all the standard 401 WQC

[1] 401 Water Quality Certification is the primary permit regulating sediment management for dam removal projects in Massachusetts. 401 Water Quality Certification requirements (314 CMR 9.00) apply to the discharge of dredged or fill material, dredging, and dredged material disposal activities in waters of the United States within the Commonwealth.

parameters, plus adding additional parameters for Massachusetts Contingency Plan (MCP)-14 metals, SVOCs, and herbicides, as follows:

- Metals;
    - 401 WQC Metals (arsenic, cadmium, chromium, copper, lead, mercury, nickel, and zinc);
    - MCP 14 Metals (antimony, arsenic, barium, beryllium, cadmium, chromium, lead, mercury, nickel, selenium, silver, thallium, vanadium, and zinc);
- Extractable Petroleum Hydrocarbons (EPH);
- Volatile Organic Compounds (VOCs);
- Polycyclic Aromatic Hydrocarbons (PAHs);
- Polychlorinated Biphenyls (PCBs) with congeners;
- Total Organic Carbon;
- Percent water;
- Grain Size Distribution – wet sieve (ASTM D422);
- Semi-Volatile Organic Compounds (SVOCs);
- Organochlorine Pesticides and Herbicides;
- Volatile Petroleum Hydrocarbons (VPH); and,
- Total Petroleum Hydrocarbons (TPH).

The MassDEP MCP is the primary regulatory guidance for oil and hazardous materials in the state. MCP guidance and sampling methods are typically used for any property that has had a release, or for which there is a threat of release of oil and/or hazardous materials. MCP methodologies were followed here for this project because of the due diligence historical research of identified industrial uses within the area, as well as to inform potential sediment management options if impounded sediment needs to be dredged and disposed of at an on-site or off-site upland location.

MCP Toxicity Characteristics Leaching Procedure (TCLP) analyses were run for those parameters that are detected above the TCLP 20X rule relative to the standards from 40 CFR 261.24. TCLP analyses were run for lead and mercury for samples IHR-LLB, IHR-LCL, and IHR-LD, and TCLP analyses were run for lead for IHR-LDS.

Samples were collected according to the Sediment Sampling Plan on June 20, 2023.

State Street/Cross Street Dam

Three composite samples, each composed of three grabs from 0 to 1 foot deep at the sediment surface, were collected upstream of SC dam and included the following:

- IHR-SCD immediately upstream of SC dam;
- IHR-SCCL along the centerline of SC dam; and
- IHR-SCV further upstream of SC dam.

Ludden's Ford Dam

Three composite samples, each composed of three grabs from 0 to 1 foot deep at the sediment surface, were collected upstream of LF dam and included the following:

- IHR-LLB along the left bank upstream of LF dam;

- IHR-LCL along the centerline of IH River; and
- IHR-LD immediately upstream of LF dam.

One composite sample (IHR-LDS), composed of three grabs from 0 to 1 foot, was collected downstream of LF dam.

All samples were collected in appropriate, laboratory-delivered containers, stored on ice, and picked up by ESS Laboratories from Cranston, Rhode Island. During field sampling, visual and olfactory observations were made for evidence of release of oil and hazardous materials (OHM). Soil samples were field screened for Total Organic Vapors (TOV) with a photoionization detector (PID) using the jar headspace method. TOV PID values ranged from less than the detection limit of the equipment (<0.1 ppmv or parts per million (106) by volume) to a maximum of 0.4 ppmv. According to MassDEP's *Implementation of the MADEP VPH/EPH Approach*, TOV PID values below 100 ppmv are considered de minimis.

Sediment samples were submitted under two chains of custody to ESS for two separate sets of analyses; one to meet analytical methods and reporting limits for WQC and the other for MassDEP MCP disposal requirements. Appropriate laboratory procedures were followed for the two separate chains of custody. As noted above, management alternatives for the subject sediment (defined in Massachusetts 314 CMR 9.00: 401 WQC as any matter below mean high water) are regulated by the 401 WQC regulations. Note that there are no MassDEP standards for disposal of sediment. The MassDEP MCP regulations come into play for soil, which is material located above mean high water. Analyses for selected MCP compounds were conducted here, in addition to the standard WQC compounds, due to the industrial history of the Sites. In addition, if impounded sediment were to be dredged from the Sites and moved to any on-site or off-site location above mean high water it would become classified as soil from a MassDEP regulatory standpoint and subject to the MCP for assessing disposal requirements. Therefore, HW utilized both 401 WQC laboratory methodologies and Mass Contingency Plan (MCP) soil disposal methodologies. Analytical laboratory data are attached as Appendix E.

Results

Sediment Quality Assessment for 401 Water Quality Certification Reporting

Laboratory sediment quality results were entered into the standard Mass Division of Ecological Restoration (DER) sediment quality spreadsheet for comparison to MCP standards for human health as well as the key ecological thresholds, Threshold Effects Concentrations (TEC)[2] and Probable Effects Concentrations (PEC)[3], for freshwater. The analytical results are included in the attached Table 1 in Appendix E, a sediment quality spreadsheet formatted by DER. A statistical summary of the upstream (US) sampling locations within the river is shown at the right edge of the spreadsheet, including minimum, maximum, and mean values. No statistics are shown for the downstream (IHR-

[2] TEC: The concentration of a hazardous substance in sediment below which adverse effects on sediment-dwelling organisms are unlikely to occur.

[3] PEC: The concentration of a hazardous substance in sediment above which adverse effects on sediment-dwelling organisms are likely occur.

DS/IS) location as only one sample was taken from this area. The full laboratory results are included here as Appendix E.

Key observations from the sediment sampling results using the 401 WQC requirements are as follows:

<u>401 WQC Metals</u>

- Metals (401 WQC Metals, i.e, arsenic, cadmium, chromium, copper, lead, mercury, nickel, and zinc) were detected above laboratory reporting limits.
- Lead was detected in four samples (IHR-LLB, IHR-LD, IHR-SCD, and IHR-LDS) at concentrations greater than the MassDEP Method 1 S-1/GW-1 standards and Natural Soil Background values. Lead was detected in the remaining samples; however, the detected concentrations were below their respective S-1/GW-1 standard.
    - Lead was also detected in these samples at concentrations greater than the sediment Threshold Effects Concentrations (TEC), Probable Effects Concentrations (PEC) for freshwater, and Natural Soil Background values.
    - In sample IHR-LCL, concentrations of lead exceeded TEC.
- Mercury was detected in five samples (IHR-LLB, IHR-LD, IHR-SCD, IHR-SCV, and IHR-LDS) at concentrations greater than the sediment TEC for freshwater and in three samples (IHR-LLB, IHR-LD, and IHR-SCD) concentrations exceeded PEC.
    - Via WQC analytical processes, no other parameters were in excess of S-1/GW-Standards. Note that the laboratory oven dried the sediment samples prior to laboratory analysis, and mercury is known to volatilize. (See Disposal Results in Table 2A and 2B in Appendix C attached)
    - Per MassDEP 401 WQC Unit, the additional characterization for methyl mercury and total cyanide was not required for sediment related to this proposed SC dam and LF dam project.
- Cadmium was detected in two samples (IHR-LLB and IHR-LD) at concentrations greater than TEC and in sample IHR-LLB greater than Natural Soil Background Levels.
- Copper was detected in two samples (IHR-LLB and IHR-LDS) at concentrations greater than TEC and Natural Soil Background values. Copper in IHR-LDS was also greater than PEC.
    - There is no MassDEP Method 1 S-1/GW-1 standard for copper.
- Zinc was detected in three samples (IHR-LLB, IHR-LD, and IHR-LDS) at concentrations greater than TEC and Natural Soil Background values and in sample IHR-LDS greater than PEC.

<u>Polycyclic aromatic hydrocarbons (PAHs)</u>

- While PAHs were detected above laboratory limits, no PAHs were in excess of S-1/GW-1 standards. In samples IHR-LLB and IHR-LDS, various PAHs were detected above TEC.

<u>Polychlorinated Biphenyls (PCBs)</u>

- While PCBs were detected above laboratory limits, no PCBs were in excess of S-1/GW-1 standards.

<u>Pesticides</u>

- Pesticides (4-4' DDD and 4-4' DDE) were detected in samples IHR-LLB PCBs above laboratory reporting limits but did not exceed S-1/GW-1 standards. No additional pesticides were detected above laboratory reporting limits.

<u>Total Petroleum Hydrocarbons (TPH) and Extractable Petroleum Hydrocarbons (EPH)</u>

- TPH was detected above laboratory reporting limits in five samples (IHR-LLB, IHR-LCL, IHR-LD, IHR-SCD, and IHR-LDS) but did not exceed S-1/GW-1 standards. TPH was not detected above laboratory reporting limits in the remaining samples.
- No EPH values were detected above laboratory reporting limits.

Results shown in green font on the DER spreadsheet (Table 1, attached in Appendix C) had values less than or equal to half of the laboratory reporting limit.

Sediments were predominantly silty sand or poorly graded sand, except for IHR-LDS (located downstream) which consisted of poorly graded sand and gravel.

Sediment Quality Assessment for MassDEP Disposal Purposes

As mentioned above, sediment samples were submitted under two chains of custody for different laboratory methodologies to meet both 401 WQC requirements as well as MCP soil disposal requirements should the excavated sediment be disposed of off-site. As such, laboratory sediment quality results, under MCP methodologies, were tabulated and compared to MassDEP reportable concentrations (RCS-1 and RCS-2), CCOMM-94 Limits for reuse of sediments, and MassDEP Sediment Screening Values. The analytical results are included in Tables 2A and 2B, attached in Appendix C.

Key observations from sediment sampling results using the MCP requirements are as follows:

<u>MCP 14 Metals</u>

- Select MCP 14 metals were detected in all seven sediment samples above the laboratory reporting limit.
    - Lead was detected above RCS-1 in samples IHR-LLB, IHR-LD, and IHR-LDS but below COMM-94 reuse levels. RCS-1 levels are 200 mg/kg and detections were 453 mg/kg and 380 mg/kg. MassDEP Sediment screening values were exceeded for lead in samples IHR-LLB and IHR-LD.
    - Mercury was detected above RCS-1 in samples IHR-LLB**.** RCS-1 levels are 20 mg/kg and IHR-LLB was detected at 46 mg/kg. Mercury also exceeded COMM-94 reuse levels for IHR-LLB and IHR-LD. Reuse levels are 10 mg/kg, and concentrations were 46 and 19.5 mg/kg, respectively. MassDEP Sediment screening values were exceeded for mercury in samples IHR-LLB, IHR-CLC, IHR-LD, IHR-LDS, IHR-SCD, and IHR-SCV.
    - Toxicity Characteristics Leaching Procedure (TCLP) analyses were run for lead and mercury for samples IHR-LLB, IHR-LCL, and IHR-LD, and TCLP analyses were run

for lead for IHR-LDS. These concentrations were either non-detect or did not exceed the Theoretical TCLP Value (20X Rule) determining that the sediment does not exhibit the characteristic of toxicity.

Semi-Volatile Organic Compounds (SVOCs)

- While some SVOCs were detected above reporting limits (i.e., Fluoranthene, Phenanthrene, and Pyrene), no parameters were in excess of RCS-1. Pyrene was detected above the MassDEP Sediment Screening values in IHR-LDS (downstream) at a concentration of 0.626 mg/kg whereas the screening value is 0.2 mg/kg. No other SVOCs exceeded standards.

Volatile Petroleum Hydrocarbons (VPH)

- VPH was not detected above the laboratory reporting limit in any of the sediment samples submitted for laboratory analysis.

Pesticides and Herbicides

- Select Pesticides were detected above laboratory reporting limits (4,4'-DDD and 4,4'-DDE) in sample IHR-LLB but were below RCS-1. Concentrations were above MassDEP Sediment Screening values. Detected concentrations were 0.0195 and 0.0153 mg/kg respectively, and screening values are 0.0049 and 0.0032, respectively.
- No Herbicides were detected above laboratory reporting limits.

Polychlorinated Biphenyls (PCBs)

- Select PCBs were detected above laboratory reporting limits, but the calculated total PCBs were below RCS-1, reuse levels, and MassDEP Sediment Screening Values.

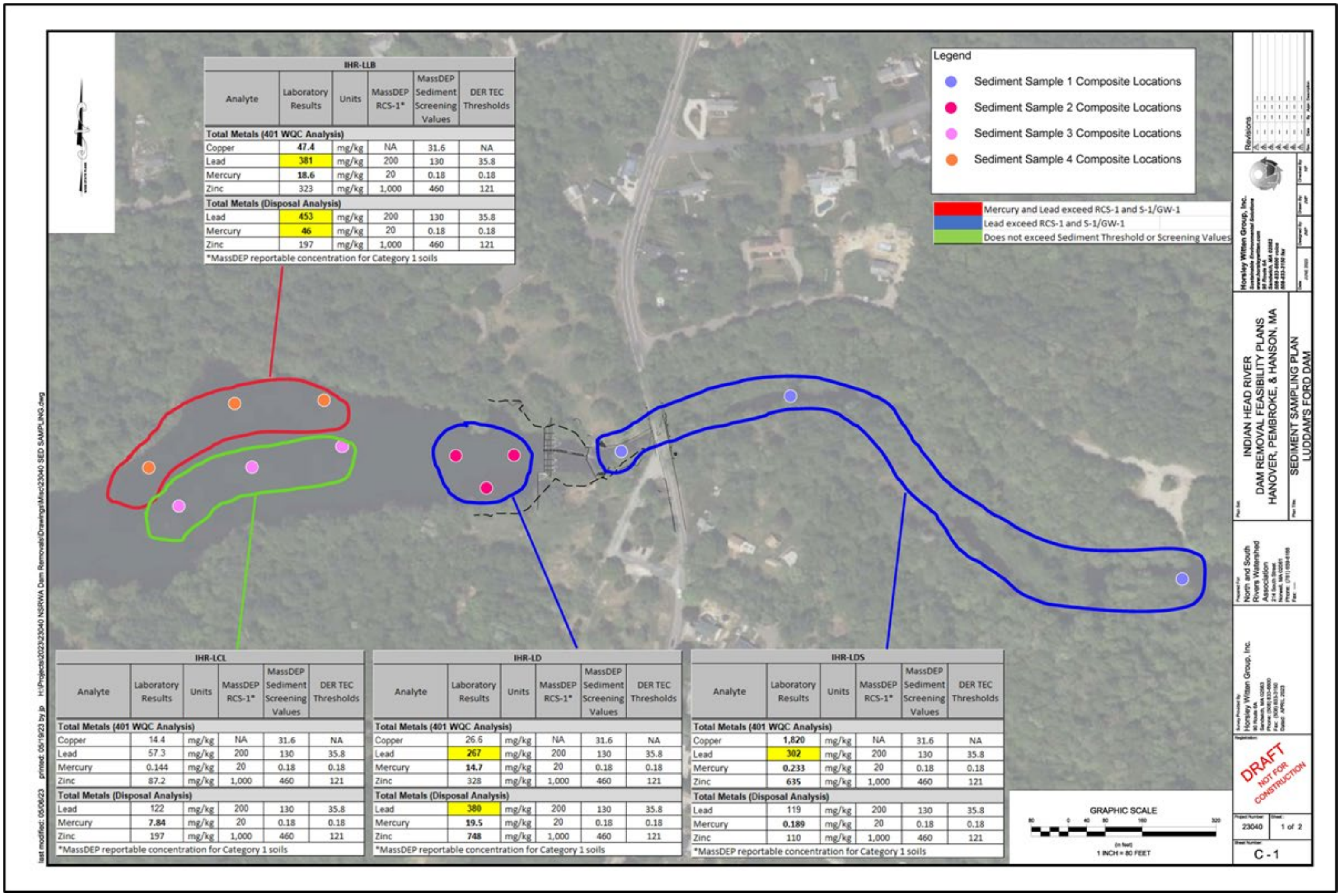
Total Petroleum Hydrocarbons (TPH)

- TPH was detected above laboratory reporting limits; however, concentrations were below RCA-1 and reuse levels.

Volatile Organic Compounds (VOCs)

- Select VOCs were detected above laboratory reporting limits but were below RCS-1 standards. Acetone was one analyte detected and is a typical laboratory contaminant.

Tabulated sediment analytical data is included in Appendix E. Figure 15 and Figure 16, below, depict the sediment sampling locations, as well as information regarding metal detections. Note that results tabulated on the following figures are the highest detected laboratory results during sampling (i.e., 401 WQC parameters and laboratory methods or MCP disposal parameters and laboratory methods).



IHR-LLB

Analyte	Laboratory Results	Units	MassDEP RCS-1*	MassDEP Sediment Screening Values	DER TEC Thresholds
Total Metals (401 WQC Analysis)					
Copper	**47.4**	mg/kg	NA	31.6	NA
Lead	**381**	mg/kg	200	130	35.8
Mercury	**18.6**	mg/kg	20	0.18	0.18
Zinc	323	mg/kg	1,000	460	121
Total Metals (Disposal Analysis)					
Lead	**453**	mg/kg	200	130	35.8
Mercury	**46**	mg/kg	20	0.18	0.18
Zinc	197	mg/kg	1,000	460	121
*MassDEP reportable concentration for Category 1 soils					

IHR-LCL

Analyte	Laboratory Results	Units	MassDEP RCS-1*	MassDEP Sediment Screening Values	DER TEC Thresholds
Total Metals (401 WQC Analysis)					
Copper	14.4	mg/kg	NA	31.6	NA
Lead	57.3	mg/kg	200	130	35.8
Mercury	0.144	mg/kg	20	0.18	0.18
Zinc	87.2	mg/kg	1,000	460	121
Total Metals (Disposal Analysis)					
Lead	122	mg/kg	200	130	35.8
Mercury	**7.84**	mg/kg	20	0.18	0.18
Zinc	197	mg/kg	1,000	460	121
*MassDEP reportable concentration for Category 1 soils					

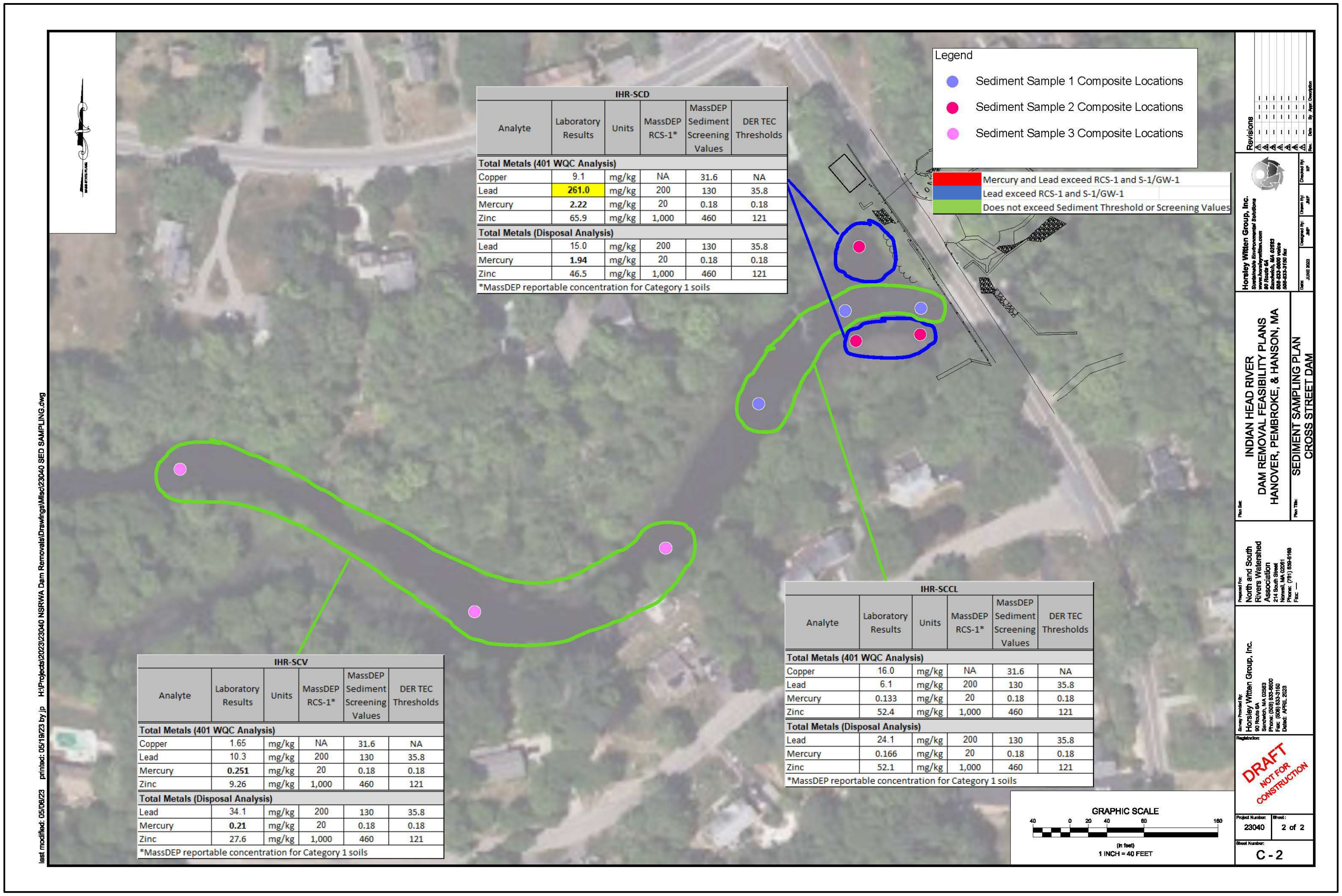
IHR-LD

Analyte	Laboratory Results	Units	MassDEP RCS-1*	MassDEP Sediment Screening Values	DER TEC Thresholds
Total Metals (401 WQC Analysis)					
Copper	26.6	mg/kg	NA	31.6	NA
Lead	**267**	mg/kg	200	130	35.8
Mercury	**14.7**	mg/kg	20	0.18	0.18
Zinc	328	mg/kg	1,000	460	121
Total Metals (Disposal Analysis)					
Lead	**380**	mg/kg	200	130	35.8
Mercury	**19.5**	mg/kg	20	0.18	0.18
Zinc	**748**	mg/kg	1,000	460	121
*MassDEP reportable concentration for Category 1 soils					

IHR-LDS

Analyte	Laboratory Results	Units	MassDEP RCS-1*	MassDEP Sediment Screening Values	DER TEC Thresholds
Total Metals (401 WQC Analysis)					
Copper	**1,820**	mg/kg	NA	31.6	NA
Lead	**302**	mg/kg	200	130	35.8
Mercury	**0.233**	mg/kg	20	0.18	0.18
Zinc	**635**	mg/kg	1,000	460	121
Total Metals (Disposal Analysis)					
Lead	119	mg/kg	200	130	35.8
Mercury	**0.189**	mg/kg	20	0.18	0.18
Zinc	110	mg/kg	1,000	460	121
*MassDEP reportable concentration for Category 1 soils					

Figure 15. Sediment sampling results for metals collected near the Ludden's Ford Dam (See Appendix E for larger version).



IHR-SCD					
Analyte	Laboratory Results	Units	MassDEP RCS-1*	MassDEP Sediment Screening Values	DER TEC Thresholds
Total Metals (401 WQC Analysis)					
Copper	9.1	mg/kg	NA	31.6	NA
Lead	**261.0**	mg/kg	200	130	35.8
Mercury	**2.22**	mg/kg	20	0.18	0.18
Zinc	65.9	mg/kg	1,000	460	121
Total Metals (Disposal Analysis)					
Lead	15.0	mg/kg	200	130	35.8
Mercury	**1.94**	mg/kg	20	0.18	0.18
Zinc	46.5	mg/kg	1,000	460	121
*MassDEP reportable concentration for Category 1 soils					

IHR-SCCL					
Analyte	Laboratory Results	Units	MassDEP RCS-1*	MassDEP Sediment Screening Values	DER TEC Thresholds
Total Metals (401 WQC Analysis)					
Copper	16.0	mg/kg	NA	31.6	NA
Lead	6.1	mg/kg	200	130	35.8
Mercury	0.133	mg/kg	20	0.18	0.18
Zinc	52.4	mg/kg	1,000	460	121
Total Metals (Disposal Analysis)					
Lead	24.1	mg/kg	200	130	35.8
Mercury	0.166	mg/kg	20	0.18	0.18
Zinc	52.1	mg/kg	1,000	460	121
*MassDEP reportable concentration for Category 1 soils					

IHR-SCV					
Analyte	Laboratory Results	Units	MassDEP RCS-1*	MassDEP Sediment Screening Values	DER TEC Thresholds
Total Metals (401 WQC Analysis)					
Copper	1.65	mg/kg	NA	31.6	NA
Lead	10.3	mg/kg	200	130	35.8
Mercury	**0.251**	mg/kg	20	0.18	0.18
Zinc	9.26	mg/kg	1,000	460	121
Total Metals (Disposal Analysis)					
Lead	34.1	mg/kg	200	130	35.8
Mercury	**0.21**	mg/kg	20	0.18	0.18
Zinc	27.6	mg/kg	1,000	460	121
*MassDEP reportable concentration for Category 1 soils					

Figure 16. Sediment sampling results for metals collected near the State Street/Cross Street Dam(See Appendix E for larger version).

3.9.3 Sediment Volume

The total sediment volume impounded by the LF and SC dams was estimated based on the results of the bathymetric survey and sediment probing conducted by IF between April 10 and April 13, 2023. The total volumes of sediment impounded by each dam are shown below in Table 1.

Table 1. Sediment volumes impounded by Ludden's Ford and State Street/Cross Street Dams

Dam	Volume of Coarse Material (CY)	Volume of Fine Material (CY)	Total Volume (CY)
Ludden's Ford	4,000	31,000	**35,000**
State Street/Cross Street	1,600	3,600	**5,200**

The sediment management plan for the material impounded by both dams has not yet been determined, and potential sediment management approaches are discussed at greater length below.

Within the estimated channel alignment, approximately 16,000 CY of sediment at LF and 600 CF at State Street may be mobilized (Table 2). The total quantity of material that will be removed from the impounded area, either through active dredging or passive sediment release will fall between the lower bounds of Table 2 and the upper bounds of Table 1.

Table 2. Potentially Mobile Sediment Volumes within Estimated Channel Alignment

Dam	Sediment Volume (CY)
Ludden's Ford	16,000
State Street/Cross Street	600*

*Comprised of coarse sediment, likely to be redistributed on site

Profile views taken along the thalweg of the IH River are shown below in Figure 16 and Figure 17. Areas of impounded coarse sediment are depicted in dark brown and located immediately upstream of the dams in both locations, while areas of impounded fine sediment are depicted in light brown and were found further upstream in the impoundment. A dashed blue line indicates the approximate natural channel gradient in the Indian Head River based on the bathymetry of the channel underlying impounded sediment.

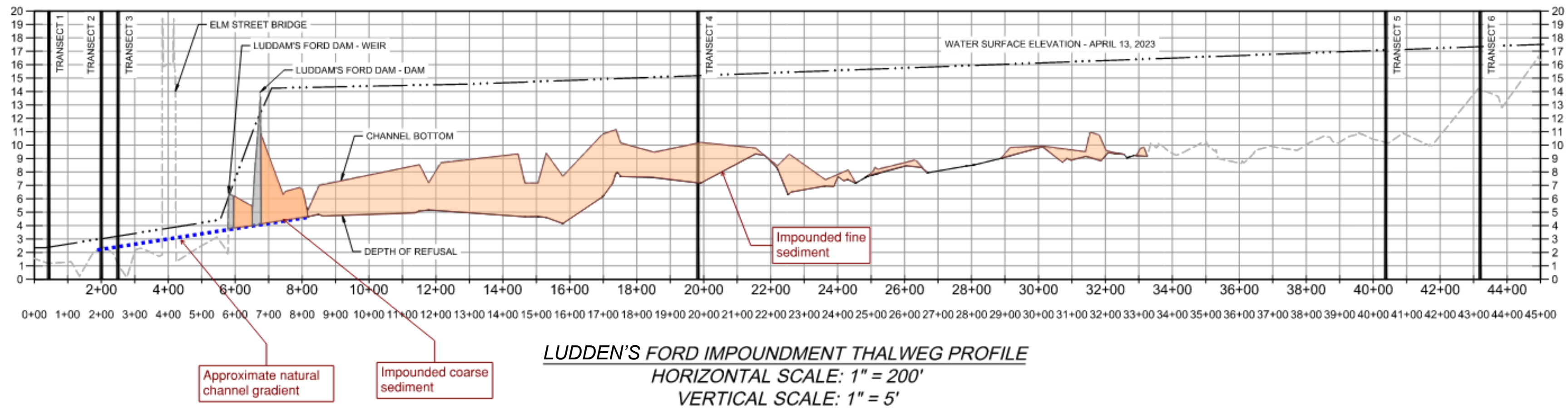


Figure 17. Sediment impounded by the LF dam along the thalweg of the IH River

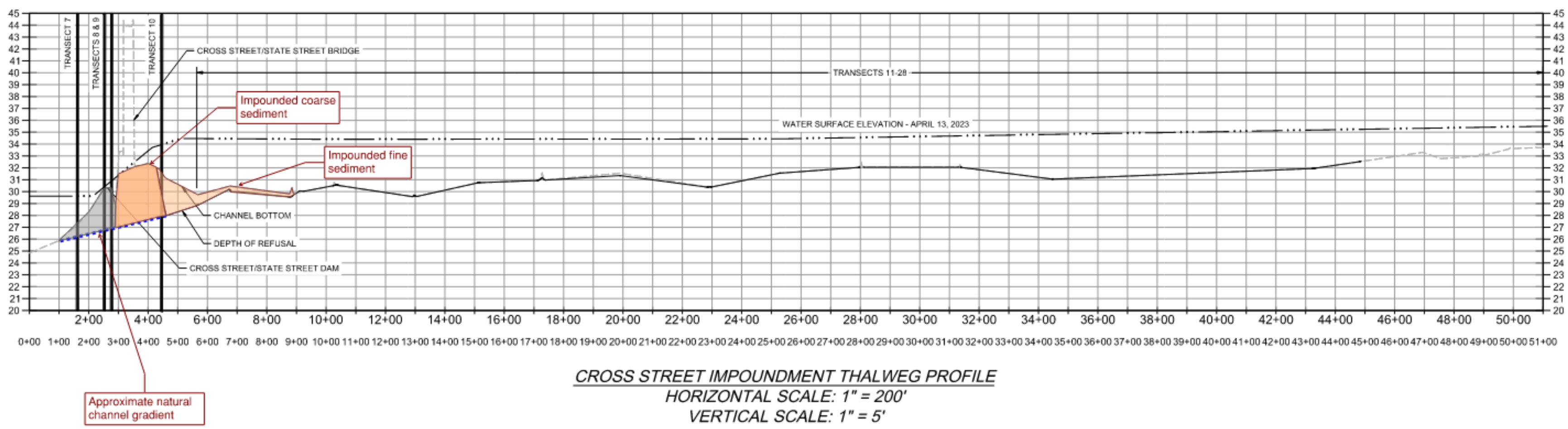


Figure 18. Sediment impounded by the SC Dam along the thalweg of the IH River

3.9.4 Sediment Management Plan

Sediment management will be largely determined by the contaminant characteristics of the mobile sediments impounded by the LF and SC dams, and the potential sediment quantity and quality impacts to downstream resources from release of those sediments.

Physical removal of accumulated sediment as part of a restoration plan would require permitting through the MassDEP and additional sediment testing beyond what has already been completed, in accordance with MassDEP's requirements.

The impounded sediment at SC dam may be suitable for passive release per discussion with MassDEP. While sediment testing results along both banks of the river upstream of the dam do slightly exceed the MCP threshold for lead, sediment from those locations are unlikely to mobilize following dam removal. Further sampling and discussion with MassDEP will be necessary for formal approval of passive release but, based on data to date and preliminary discussions with MassDEP, passive release of the relatively small volume of mobile sediments retained behind the SC dam is the most likely management scenario for the majority of that sediment.

Based on data available to date and preliminary discussions with MassDEP, sediment management for the LF dam is more complicated and less certain. Additional sampling and assessment of sediment management options will certainly be required and some level of sediment remedial action beyond passive release will likely be needed as part of dam removal here. HW developed potential remedial actions to address the elevated concentrations of contaminants observed to date in the sediment behind the LF dam within the context of dam removal. Several sediment management alternatives have been identified and preliminarily discussed with MassDEP, including:

1. **No action**: Allow the dam to remain in place, with no action taken in regard to sediment removal and/or management at this given time.
    - This alternative limits mobilization of sediment, but does not achieve the restoration goals of dam removal.
2. **Full passive release**: If impounded sediment is deemed to be of comparable quality to downstream sediment and pose no significant additional risk for human exposure or degradation of aquatic ecosystem health, passive release would be the most cost-effective method of sediment management that would accompany dam removal. MassDEP approval of this option would likely require some or all of the following additional analyses:
    a. Conduct an exposure point concentration calculation to estimate the average concentrations within mobilization areas, to determine which potentially mobile sediment areas may be appropriate for passive release and which, if any, may need to be physically removed or retained.
    b. Conduct more detailed, discrete, sampling for the priority metals only to identify hotspot areas that would need to be either retained or physically excavated.
3. **Partial dredging, capping, and retention and partial passive release**: This alternative involves targeted dredging and capping onsite of hot spot areas with the remaining lower concentration sediment areas allowed to release passively. The cost for this option would be more than for full passive release but less than for full dredging and removal. Where in the range that costs would fall depends on the proportions of dredge vs passive release. MassDEP approval of this option would likely require the same additional analyses discussed above for exposure point calculations and additional sampling.

4. **Full dredge and cap on site**: Would only be necessary if all or most of the mobile sediment were deemed to be inappropriate for passive release. Based on results received to date for this project, this option seems unlikely. There is insufficient space on site to accept all of the potentially mobile sediment. It would also likely not be feasible due to its high cost.
5. **Full dredge and removal to out of state landfill facility**: This option is even more extreme, unlikely, and costly than the full site dredging and capping option and would only be necessary if all or most of the mobile sediment were deemed so contaminated as to be inappropriate for passive release or onsite capping. Based on results received to date for this project, this extreme option seems unlikely. It would also likely not be feasible due to its high cost.

Any dredged sediment would either be temporarily stockpiled on site and covered with polyethylene sheeting (sheeting must be a minimum thickness of six millimeters) or loaded directly onto trucks for off-Site disposal. Any sediment designated for disposal would be transported under a MassDEP Bill of Lading to a facility permitted to accept the excavated sediments.

Additional sediment sampling will occur in subsequent project phases to better inform the sediment management plan. Several discrete sediment samples will be taken, and samples will be tested for specific contaminants of concern. Based on the results of this sampling, coordination with MassDEP will occur to determine which, if any, methods of sediment management are acceptable.

4. Hydrologic and Hydraulics

4.1 HYDROLOGY

4.1.1 Peak Flow Estimates

The hydrologic inputs along the IH River were evaluated based on the available flow record of United States Geological Survey (USGS) Gage No. 01105730, which is located approximately 200 feet downstream of the LF Dam. The drainage area contributing to the flow at the gage is 30.3 square miles. A total of 55 years of flow measurements were available for analysis, from 1967 to 2021. Annual peak flows over this period are shown below in Figure 19.

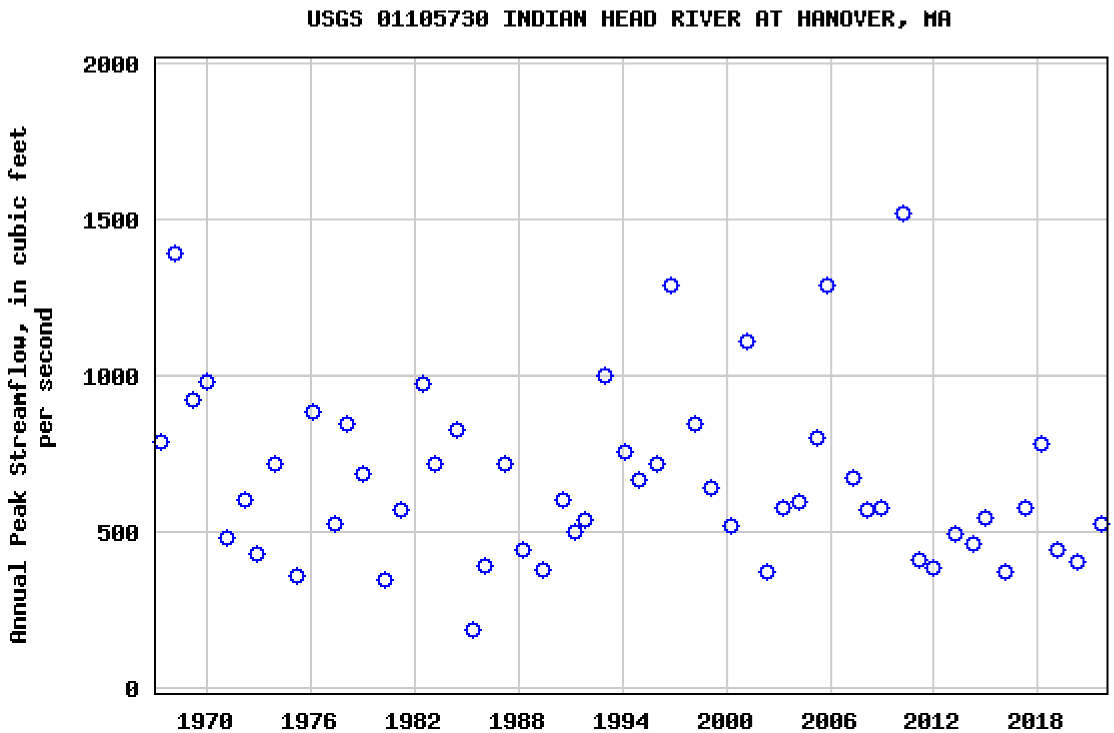


Figure 19. Annual Peak Flows at USGS Gage 01105730

Peak discharge flow events for recurrence intervals ranging from the 1-year to the 100-year flow were developed using the available peak annual flow data, while daily exceedance flow events for the 95%, 50%, and 5% flows were developed using the available mean daily flow data. Peak discharge flows were assumed to follow a log-Pearson Type III probability distribution, the parameters of which were used to generate flow estimates. Daily exceedance flows were calculated as the percentile of the exceedance probability of each daily mean flow (Figure 20).

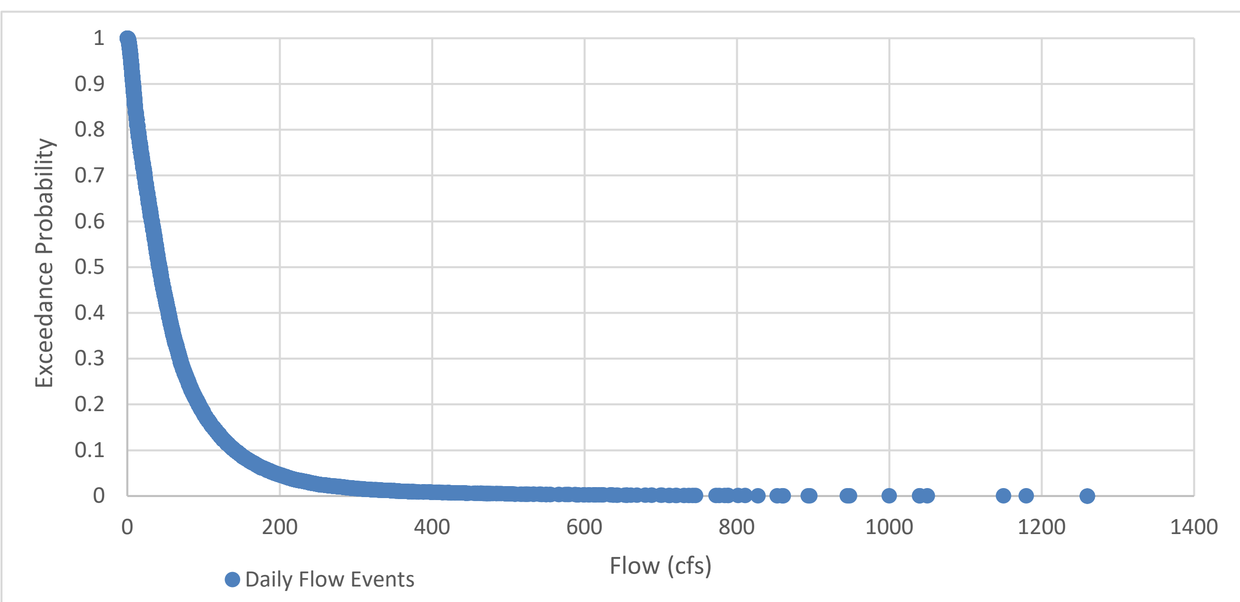


Figure 20. Exceedance Probability Curve of daily flows of the IH River (1967 to 2021)

Discharge estimates for all flow events were also generated at the upstream and downstream points of the LF dam and SC dam project reaches. Discharge values were scaled by the ratio of the contributing drainage area at each point to the drainage area at USGS Gage 01105730. Flow estimates at all upstream and downstream locations are shown below in Table 3.

Table 3. Daily and Peak Flow Estimates at Locations Along Indian Head River (1967-2021)

Recurrence Interval	USGS Gage (Ludden's Ford DS)	Ludden's Ford US	Cross Street DS	Cross Street US
	Drainage Area (square miles)			
	30.3	29.5	28.2	22.7
	Discharge (cfs)			
95% exceedance	5.1	5.0	4.9	4.1
50% exceedance	42	41	39	32
5% exceedance	194	189	181	145
1-year	252	245	235	189
2-year	610	594	568	457
5-year	864	841	804	647
10-year	1041	1014	969	780
25-year	1276	1242	1187	956
50-year	1458	1419	1357	1092
100-year	1646	1603	1532	1234

4.1.2 Climate Change Impacts

It is unclear based on Figure 19 whether the magnitude of annual peak flow events has tended to increase among the more recent years of the flow record. To evaluate potential climate impacts, a log-Pearson Type III flow analysis was conducted using only the data from 1990 to 2021, corresponding to the approximate year in which several of the highest discharge events appear to occur. A comparison of the post-1967 flow statistics and the post-1990 flow statistics is shown below in Table 4. In general, the more common peak flows (the 1-year through the 25-year flows) are estimated to be similar, if slightly lower or higher, when only the post-1990 peak flow record is used as compared to the post-1967 record. For less frequent peak flows (the 50- and 100-year flows), the post-1990 flow record results in flow estimates that are greater than the estimates of flow calculated using the full flow record from 1967 to 2021.

Table 4. Peak Flow Estimates at USGS Gage 01105730 – Period of Record Comparison

Recurrence Interval	Discharge (cfs) 1967-2021	Discharge (cfs) 1990-2021
1-year	252	276
2-year	610	599
5-year	864	839
10-year	1041	1028
25-year	1276	1305
50-year	1458	1541
100-year	1646	1804

A similar, if more moderate, pattern emerges when the post-1990 daily flow record is analyzed. As shown in Table 5, the exceedance flow estimates generated from the post-1990 record are marginally higher than those of the post-1967 record.

Table 5. Daily Exceedance Flow Estimates at USGS Gage 01105730 – Period of Record Comparison

Recurrence Interval	Discharge (cfs) 1967-2021	Discharge (cfs) 1990-2021
95% exceedance	5.1	5.4
50% exceedance	42	44
5% exceedance	194	200

Taken together, these analyses suggest that peak and daily exceedance flow rates are tending toward slightly higher values in more recent years. A full flow distribution among the upstream and downstream locations along the project reach generated from the post-1990 record is shown below in Table 6.

Table 6. Daily and Peak Flow Estimates at Locations Along Indian Head River (based on 1990-2021 flow record)

	USGS Gage (Ludden's Ford DS)	Ludden's Ford US	Cross Street DS	Cross Street US
Recurrence Interval	**Drainage Area (square miles)**			
	30.3	**29.5**	**28.2**	**22.7**
	Discharge (cfs)			
95% exceedance	5.4	5.3	5.0	4.0
50% exceedance	44	43	41	33
5% exceedance	200	195	186	150
1-year	276	269	257	207
2-year	599	583	557	449
5-year	839	817	781	629
10-year	1028	1001	957	770
25-year	1305	1271	1215	978
50-year	1541	1500	1434	1154
100-year	1804	1756	1679	1352

4.2 HYDRAULICS

IF used the USACE Hydraulic Engineering Center-River Analysis System (HEC-RAS) software 6.4.1 to develop a one-dimensional model for each study area to simulate water surface profiles for existing and post-project dam removal conditions for both LF and SC dams. The existing conditions represent the site conditions surveyed in April and May 2023.

4.2.1 Existing Hydraulic Model

The existing conditions models for the LF and SC dams provide a baseline for comparison with the proposed designs. They represent the condition of the Indian Head River at the time the survey was completed.

We developed a georeferenced model geometry using RAS Mapper tools for each dam. The models' geometries are based on a composite digital elevation model of the channel bathymetry and overland topography. The composite digital elevation models include high-resolution data from a site-specific bathymetric and topographic survey, supplemented with high-resolution LiDAR data (OCM Partners 2023).

Ludden's Ford Dam Geometry

The model geometry for the LF dam model extends approximately 650 feet downstream and 3,720 feet upstream of the existing LF dam spillway. Bridge data for the Elm Street bridge was added into the model based on survey data collected by HW. The high chord of the modeled bridge is based on the top of the stone wall located on the upstream side of Elm Street roadway.

The LF dam spillway and downstream control weir were modeled as reach cross sections based on survey data collected by HW and IF.

State Street Dam Geometry

The model geometry for the SC Dam model extends approximately 356 feet downstream and 4,730 feet upstream of the State Street/Cross Street bridge. Bridge data was added into the model based on survey data collected by HW. The high chord of the modeled bridge is based on the roadway elevation. The guardrails on the upstream and downstream side of the bridge are ignored in the model. The bridge and culvert openings were modeled using the multiple opening analysis feature in HEC-RAS.

SC dam is modeled as a reach cross section based on survey data collected by HW and IF.

Boundary conditions

A normal depth boundary condition was applied to the upstream and downstream model boundaries for both the LF dam and SC dam models. The average bed slope in these locations was used to estimate normal depth conditions. The boundaries were located sufficiently far from the area of interest such that the selection of boundary condition does not influence hydraulic model results near the area of interest.

Table 7. Normal depth boundary conditions used in the Ludden's Ford and State Street Dam hydraulic models.

	Upstream Boundary Condition	Downstream Boundary Condition
LF Dam Model	0.02	0.0025
SC Dam Model	0.0016	0.01

Manning's "n" Roughness Coefficients

Manning's "n" values were assigned based on observed channel substrate and floodplain vegetation conditions. We calibrated the Manning's "n" values based on results of the 1D model and observations of water surface elevations collected during IF's survey. Table 8 summarizes the Manning's "n" values used along each reach.

Table 8. Manning's "n" values used in the Ludden's Ford Dam and State Street Dam hydraulic models.

Location	Manning's "n"	Typical Descriptions	Notes
Channel	0.040 - 0.045	Channel with sand/gravel cobble substrates and little woody material.	Used throughout the reach
Channel	0.050 - 0.055	Channel with large gravel/cobble, boulder and bedrock substrate and some woody material.	Used for areas with larger substrate, bedrock, or significant woody material
Overbank	0.060	Maintained grass / lawn, developed vegetation area	Grass type overbank.
Overbank	0.080	Medium to dense brush	Shrub type overbank.
Overbank	0.100	Dense brush	Forest type overbank.

Expansion and Contraction

We assumed expansion and contraction coefficients of 0.1 and 0.3, respectively for standard reach cross sections. These values are typical default values recommended in the HEC-RAS Hydraulic Reference Manual.

For model simulations that include a representation of flow constrictions at stream crossings and dam outlets, at cross sections immediately upstream and downstream of the structure(s), we assumed expansion and contraction coefficients of 0.3 and 0.5, respectively. This is consistent with standard engineering practice.

Ineffective Flows

We applied ineffective flow areas in the vicinity of the bridges in both models in accordance with standard practice. We applied ineffective flow areas to low points in the overbank as appropriate.

4.2.2 Proposed Hydraulic Model

IF developed proposed condition hydraulic models to represent the design conditions shown on the 40% Design Drawings that accompany this report. The hydraulic models were developed from the baseline existing conditions hydraulic models.

Ludden's Ford Dam

For the LF proposed conditions model, IF removed the entirety of the dam and proposed the construction of a channel through the impounded sediment from a point just downstream of the dam to a point approximately 1,800 feet upstream of the existing dam. The proposed channel was graded based on the pre-dam channel elevations and hydraulic control upstream and downstream. The proposed channel has an average slope of 0.2% for the first 900 feet (station 3+50 through station 12+50 on the Drawings). The slope increases to 0.3% to tie into an upstream riffle (station 12+50 to station 22+36 on the Drawings). The channel has a typical top width of 50 feet, a bottom width of 36 feet, and a depth of 3.5 feet. Channel bank slopes are 2H:1V up to 3.5 feet. From there, the banks slope at 5H:1V until reaching the existing impoundment surface.

The channel slope is consistent with reaches observed upstream and downstream of the dam. A proposed conditions surface was created to represent the new channel conditions, which was incorporated into the proposed hydraulic model geometry.

State Street/Cross Street Dam
For the SC proposed conditions model, IF removed the entirety of the dam and incorporated the proposed grading of the channel from a riffle downstream of the dam (station 1+63) to a point just upstream of the bridge (station 2+71). The proposed channel was graded to achieve a slope of 2.2%. The former flume culvert was left in place as an overflow channel. Removing the culvert could potentially increase flood profiles for the proposed condition.

4.2.1 Hydraulic Model Results

Ludden's Ford Dam
Under existing conditions, the water surface profile along the river is controlled by the dam, which reduces the river's slope and velocity within the impoundment. The dam overtops at the 5-year recurrence-interval flood event. Overtopping occurs on river right where the ground elevation to the right of the concrete wall is lower than the wall. The removal of the dam results in increased water surface slope and velocity upstream of the dam, with no downstream changes (Figure 21 and Figure 22). The flood profiles also show a backwater condition above the Elm Street Bridge for existing and proposed conditions, indicating that the bridge is a constriction for floods above the 2-year event. The hydraulic changes associated with dam removal are most notable in the vicinity of the dam and the impoundment. The water surface profiles for the existing and proposed conditions begin to converge at the upstream extent of the impoundment where the channel steepens and bedrock was observed on the bank.

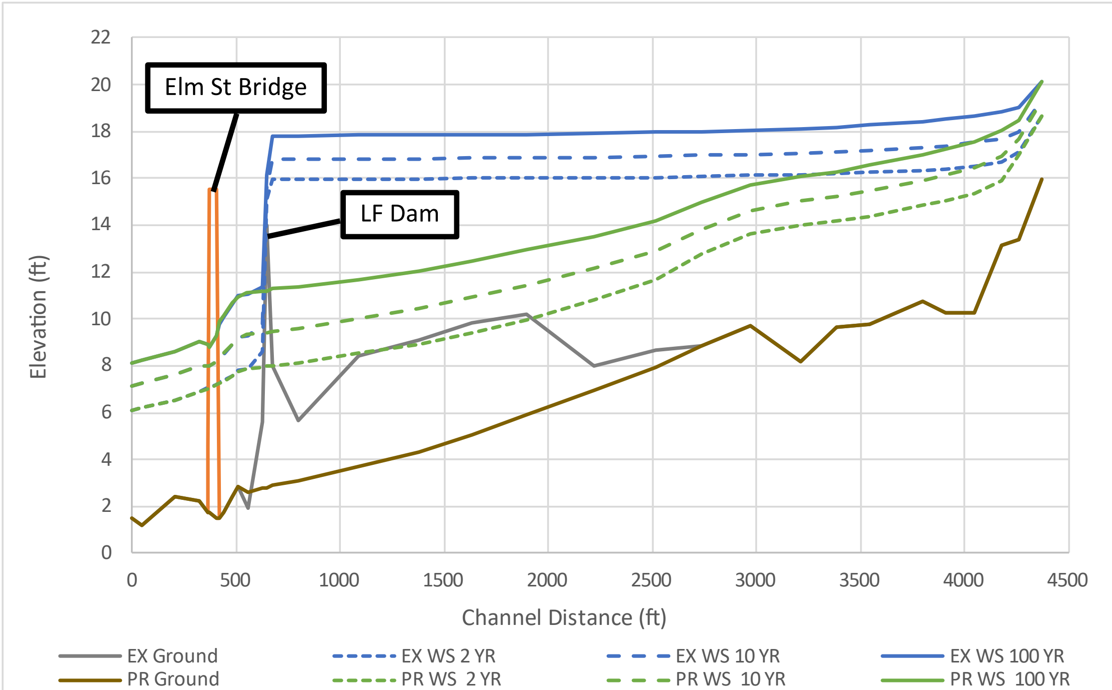


Figure 21. Peak Flood Profile Comparison for Ludden's Ford (2-, 10-, and 100-year events)

The water surface elevations for the proposed condition range from 6 to 8 feet lower than that of the existing condition directly upstream of the dam during the 100-year and 2-year floods, respectively. The water surface elevations for the proposed condition range from 0.5 to 1 foot lower than that of the existing condition near the upstream end of the impoundment during the 100-year and 2-year floods, respectively.

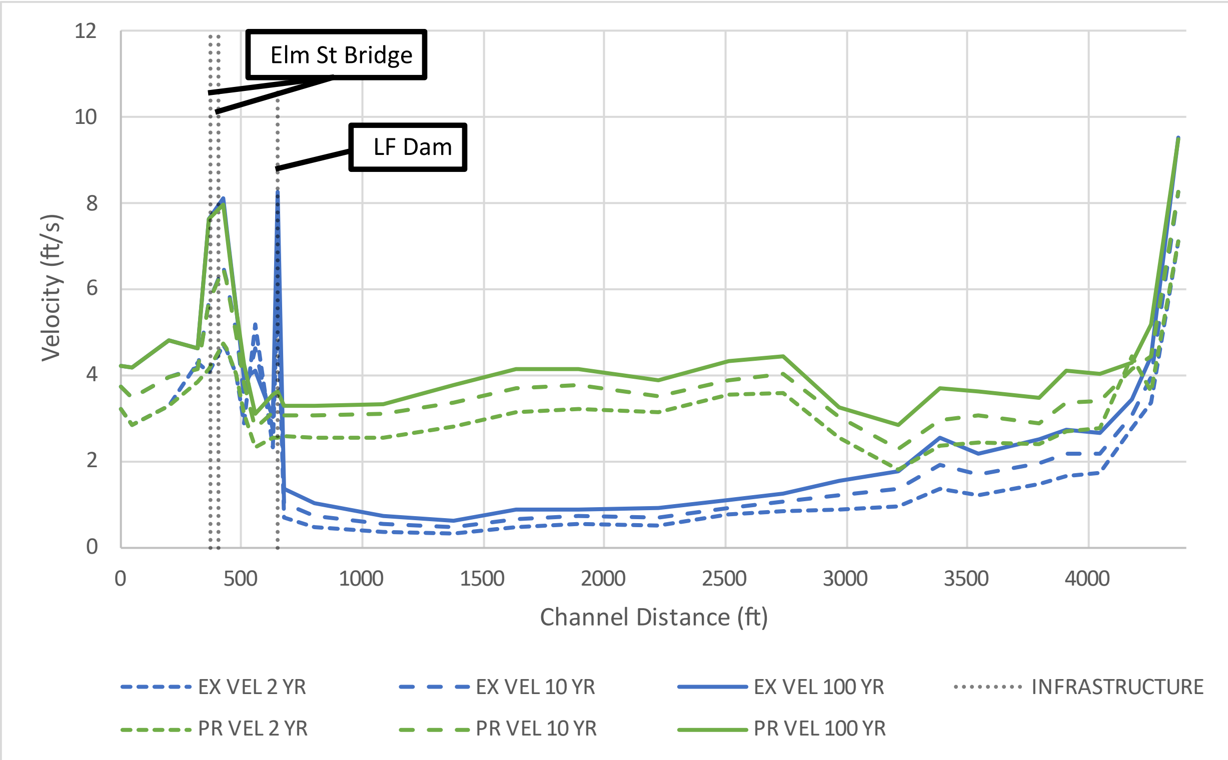


Figure 22. Peak Flood Velocity Comparison for Ludden's Ford (2-, 10-, and 100-year events)

The hydraulic model was also utilized to assess patterns in erosive forces through the project reach. Figure 23 displays a plot of shear stress in the stream channel for selected flows, while Figure 22 displays a plot of average cross-sectional velocity for the same range of flows. Hydraulic data was used to calculate incipient motion of the channel bed material and bank treatments. The shear stresses under proposed conditions remain the same in the channel downstream of the dam. Therefore, it is expected that the dam removal will have no impact on the Elm Street Bridge. In the area of the dam and the weir, the shear stresses decrease under the proposed condition. Upstream of the dam, for the majority of flow events, proposed shear stress values increase to approximately 0.5 lb/sqft.

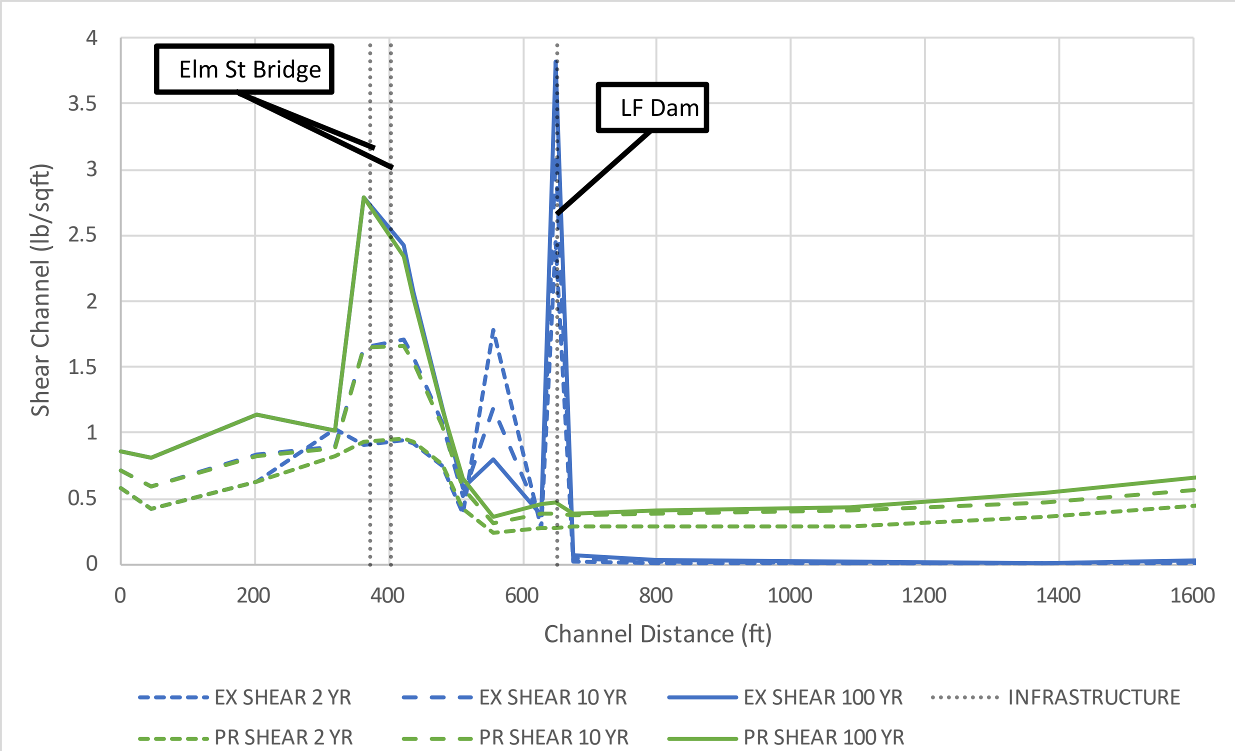


Figure 23. Peak Flood Shear Comparison for Ludden's Ford (2-, 10-, and 100-year events)

State Street/Cross Street Dam

Under existing conditions, the SC dam controls the water surface profile. Currently the flow that goes through the former flume culvert, located to the northeast side of Cross Street, provides attractive flow for fish; however, the culvert is perched and there is no way for them to pass upstream (Figure 12). Removing the dam and creating a slope of 2.2% will not only remove the major barrier for fish passage, but also create more attractive flow through the main channel.

The water surface elevation for the proposed condition is approximately 1.5 feet lower than that of the existing condition for the flood profiles around the dam shown in Figure 24. At the upper end of the impoundment the proposed condition water surface profiles are minimally lower (0.2 to 0.3 feet) than that of the existing condition.

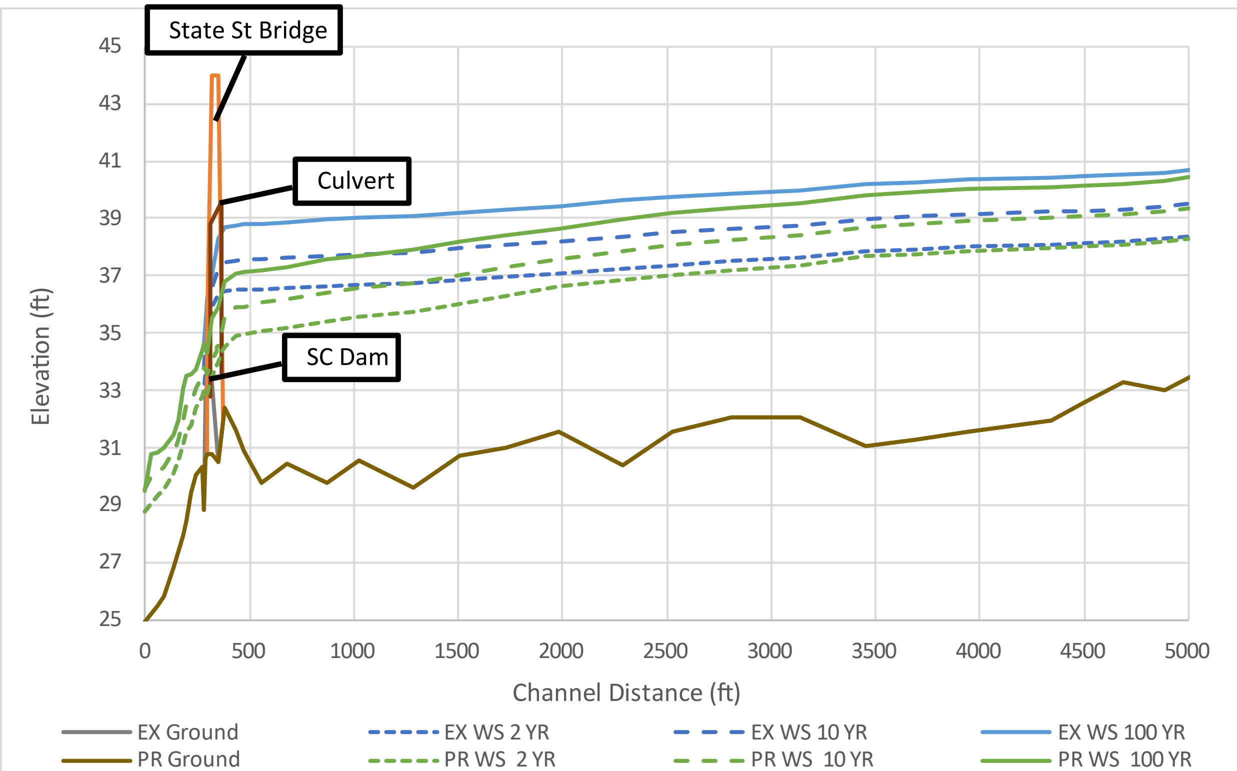


Figure 24. Peak Flood Profile Comparison for State Street/Cross Street (2-, 10-, and 100-year events)

The average channel velocities for the 2-, 10-, and 100-year flow events increase in the proposed condition; however, they do not vary greatly. The maximum difference in velocity around the SC dam location between the existing and proposed condition is 1ft/s.

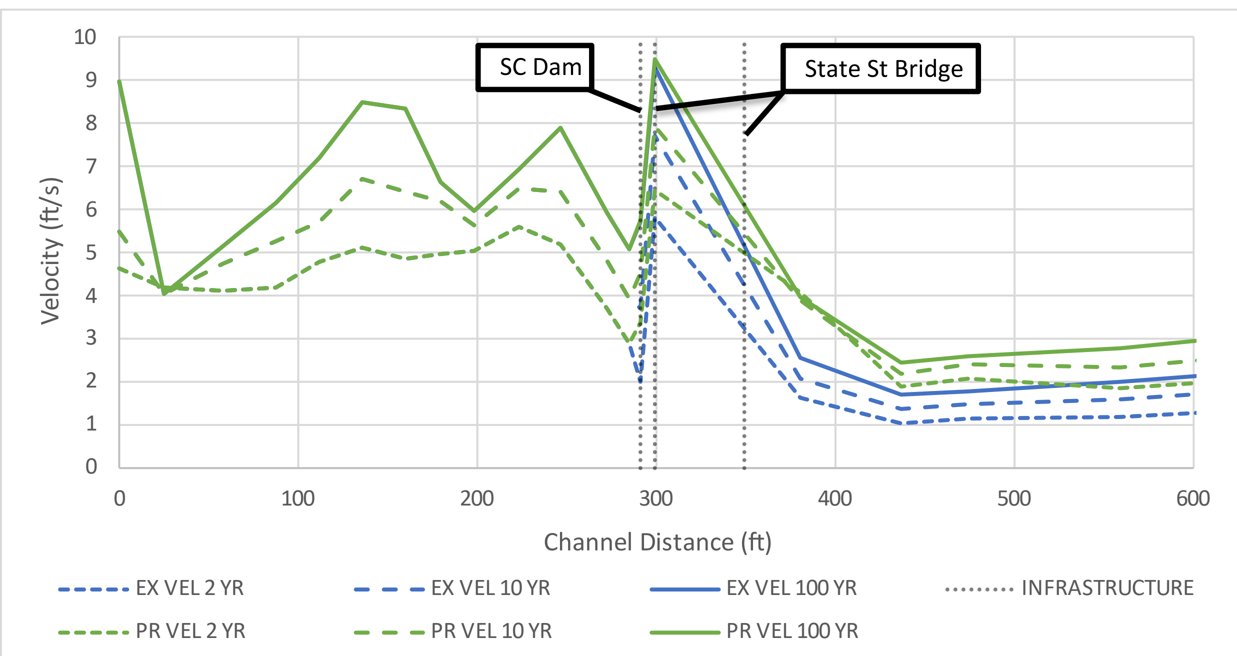


Figure 25. Peak Flood Velocity Comparison for State Street/Cross Street (2-, 10-, and 100-year events)

Figure 26 displays a plot of shear stress in the stream channel for selected flows. Hydraulic data was used to evaluate incipient motion of the channel bed materials and bank treatments. The shear stresses under proposed conditions remain the same in the channel downstream of the dam. In the area of the dam, the shear stresses minimally decrease under the proposed condition. Directly upstream of the dam where the State Street Bridge is located, proposed shear stress values increase by 0.5 pounds per square feet under most flood flow conditions. This change in conditions will require, at a minimum, design of additional scour protection measures at the downstream end of this bridge structure. The design of scour countermeasures will be advanced in the next phase of work. Upstream of the bridge, model results indicate that shear stresses are relatively similar between existing and proposed conditions during flood conditions.

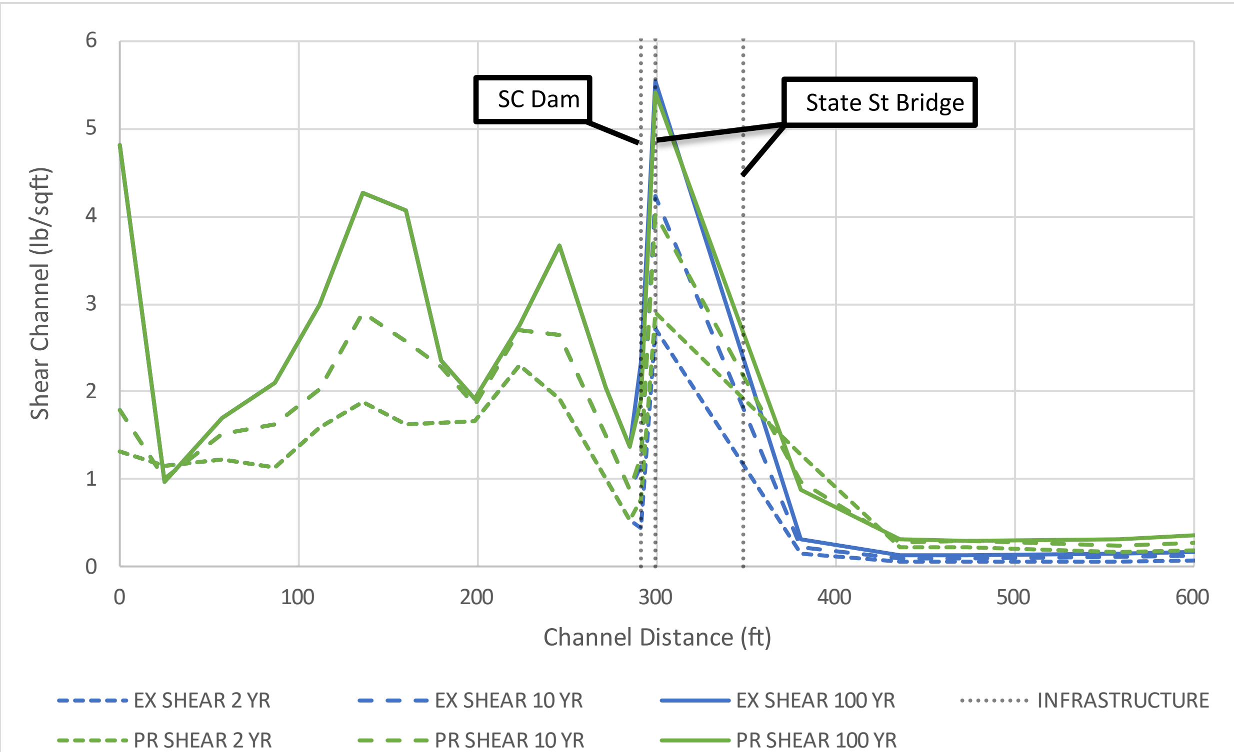


Figure 26. Peak Flood Shear Comparison for State Street/Cross Street (2-, 10-, and 100-year events)

Fish Passage Impacts

The maximum stream velocities under proposed LF dam removal conditions during the upstream migratory period (April to June) range from 2 to 2.8 feet per second (Figure 27), which are within the swimming capabilities of the target fish (American eel passage is less dependent on velocity because of their unique capabilities in ascending streams) listed in Table 9. The maximum stream velocities under proposed SC dam removal conditions during the upstream migratory period range from 2 to 4 feet per second (Figure 28). It should be recognized that the reported velocities are cross-sectional averages, and thus within each cross section, zones of lower and higher velocity will be present. The monthly flows shown below are averaged daily flow values between the 5- and 95-percent exceedance flows.

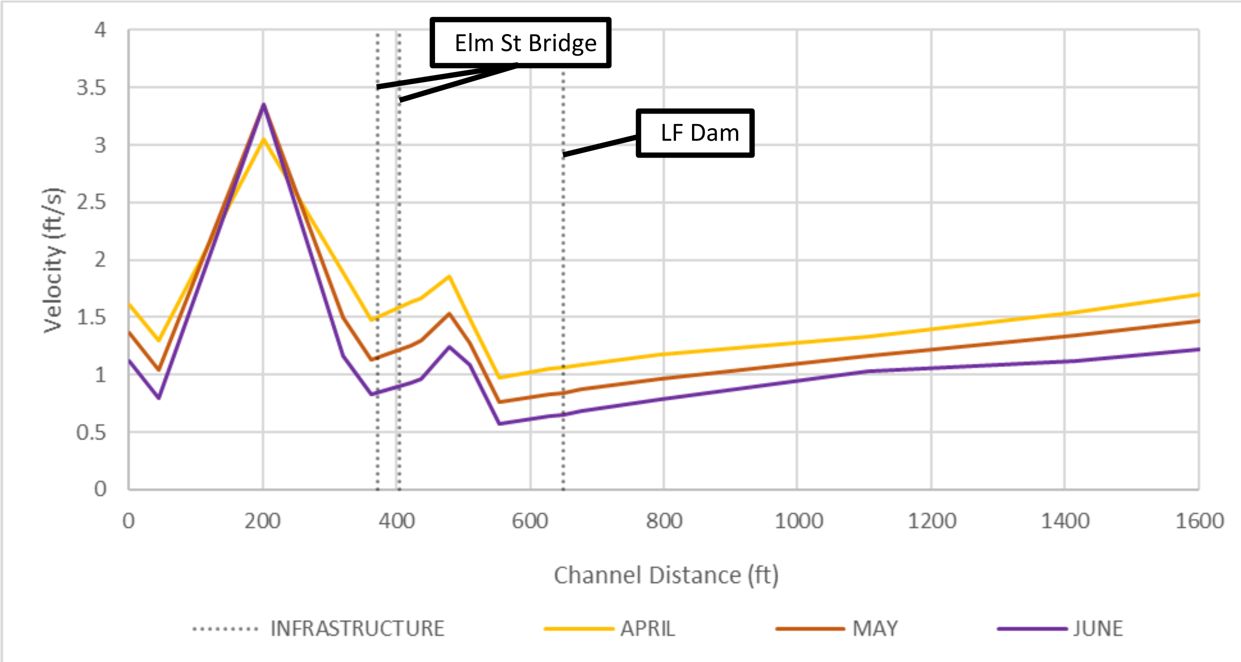


Figure 27. Velocity profile for average April, May, and June flows for the proposed condition Ludden's Ford model.

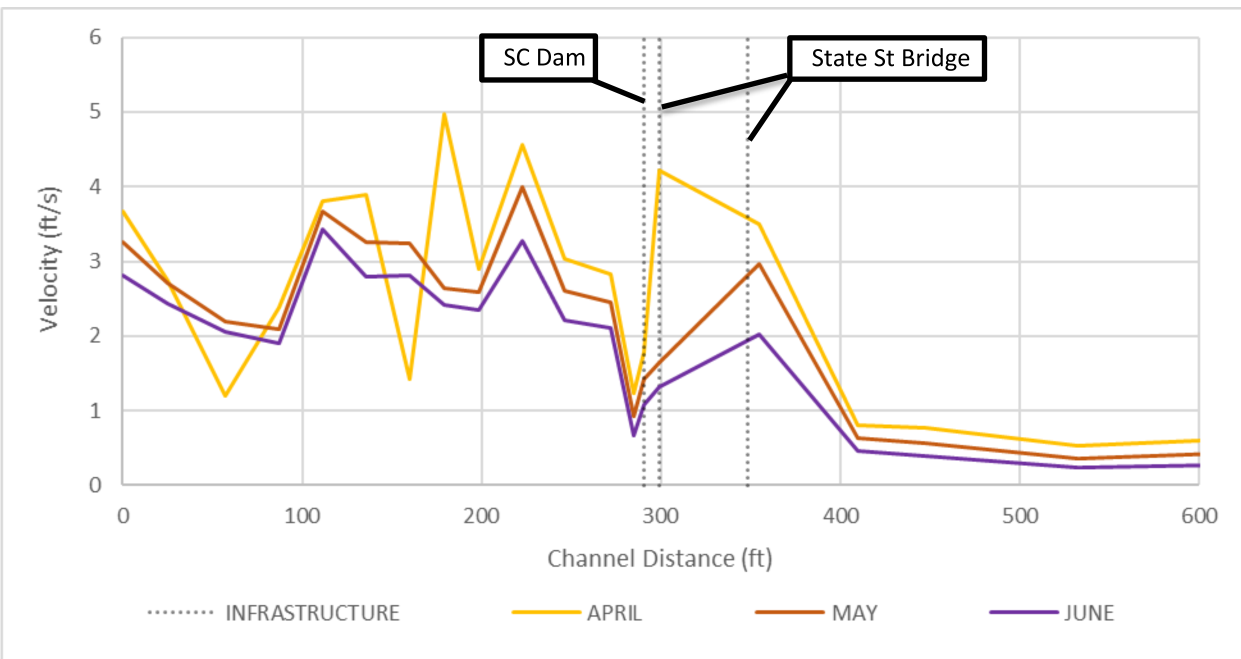


Figure 28. Velocity profile for average April, May, and June flows for the proposed condition State Street/Cross Street model.

The natural channel construction will result in a variety of flow patterns that fish can use opportunistically to migrate through the reach. Channel substrate provides a wide variety of velocity fish have evolved to negotiate. Further, the swim speeds included in Table 9 can be considered conservative because they were determined in a laboratory flume setting in which there was minimal boundary layer flow turbulence that migrating fish would utilize in natural settings. Based on these factors, it is expected that the fish species should be able to move upstream along the IH River during most years.

Table 9. Selected literature values of swimming speeds for a few of the target species at various life stages.

Species	Mode	Life Stage	Speed (BL/s)	Speed (ft/s)	Notes	Citation
Alewife	Critical	Juvenile	6	2-2.5		Terpin et al. (1977)
	Burst	Adult	15-16	11.55-12.48		Dow (1962)
	Sustained	Adult	2.8	2.2		Castro-Santos (2005)
	Burst	Adult (236 - 239 mm FL)	5	3.85-3.9	predicted value	Castro-Santos (2005)
Blueback Herring	Burst	Adult (217 - 225 mm FL)	5	3.55-3.7	predicted value	Castro-Santos (2005)
American Eel	Critical	Elver	35 - 40 cm/sec	1.1-1.3		McCleave (1980)
	Critical	Elver	25 cm/sec	0.8	Elvers rested on bottom at velocities exceeding 25 cm/sec.	Jessop (2000)
Brook Trout	Burst	6.2-40.5 cm	0.59-2.34	1.94-7.68		Peake (1997)
	Prolonged	6.2-40.5 cm	0.43-1.97	1.41-6.47		Peake (1997)
	Sustained	6.2-40.5 cm	0.46-1.77	1.52-5.80		Peake (1997)

Tidal Impacts

With the removal of LF dam, tidal influences could potentially extend upstream. Given the existing tidal fluctuations, it is anticipated that these influences will reach what is currently the lower LF's impoundment area. As seen in the stretch of the IH River downstream of the dam, this newly affected stretch is expected to maintain its freshwater nature, albeit with minor fluctuations in water level resulting from tidal oscillations.

5. Proposed Design

5.1 LUDDEN'S FORD DAM

The LF dam removal design (see Drawings in Appendix A) includes the complete removal of the spillway, fishway, and weir; selected grading of the channel upstream of the dam; habitat enhancements; and revegetation (including invasive species management) of native riparian species.

5.1.1 Dam Removal

Prior to construction, measures such as a buffer area should be in place to protect Elm Street Bridge. For the proposed design, the LF Dam and the right abutment will be removed in their entirety, while minimizing impacts to the surrounding infrastructure. On river left, the building foundation will be detached from the left abutment, and the adjacent foundation structures will remain as shown on the Drawings (Appendix A). Between the Elm Street Bridge and the LF Dam, the concrete retaining walls will be removed in their entirety and the surface will be graded to blend into the existing landscape. Surface fabric will be installed in place of the concrete wall to stabilize the banks. A constructed riffle will be placed in the footprint of the existing dam to provide channel stability.

5.1.2 Channel Restoration

The river channel alignment and profile shown on the 40% Design Drawings were developed using the channel grades estimated through sediment probing upstream and downstream of the project area as an analogue. Channel dimensions were estimated using an analysis of reference reaches and actual physical conditions of the IH River. The design includes 36-foot channel bottom width with 2H:1V bank slopes up until a 3.5-foot bank height. Above 3.5 feet the banks slope at 5H:1V to the existing surface.

Starting downstream of the dam (station 3+50 in the Drawings), the restored channel will be a gravel- and cobble-controlled channel. Above the existing dam, the new channel will be located to the north where the impoundment curves. The new channel position, likely the former thalweg prior to the dam, was indicated by the depth-of-refusal survey data.

At a minimum, the mobile accumulated sediment will be actively removed from the dam through the upstream tie in location, although refinements to the sediment removal strategy will be advanced during subsequent detailed design phases. The refinements will balance the cost of sediment removal with river-floodplain interaction and habitat quality, and potential downstream effects of passive sediment release.

The LF impoundment offers the opportunity to provide a reach of restored habitat quality for migratory and resident fish alike that is novel along the IH River. Therefore, restoration elements including grading of instream habitat (pools and riffles), bank construction using surface fabric with a rock toe, and incorporation of large wood habitat features are all included in the 40% design. The bank construction techniques will also moderate channel movement and sequester sediment that will remain in the overbank areas. The constructed conditions will also provide opportunities for paddlers and other river users.

5.2 STATE STREET/CROSS STREET DAM

The SC dam removal design (see Drawings in Appendix A) includes the complete removal of the spillway, selected grading of the channel upstream of the dam, and revegetation of native riparian species.

5.2.1 Dam Removal

If deemed necessary during subsequent analysis, prior to dam removal, scour countermeasures will be installed at the State Street Bridge. The full vertical extent of the stone masonry SC dam spillway will be removed. On river left, the dam will be removed to the ledge outcrop that it abuts. On river right, the dam will be removed while maintaining the existing masonry wall. Upstream of the dam, including in the channel under the bridge and upstream of the bridge, selected stones will be removed to create free-flowing conditions and provide aquatic organism passage. There is potential to repurpose these granite blocks and boulders in the construction of the riffle at the location of the former dam.

5.2.2 Channel Restoration

The design includes river channel shaping to restore connectivity and facilitate fish passage following dam removal. Approximately 110 feet of channel will be shaped and excavated in the vicinity of and immediately upstream of the dam. The channel will be composed of a mix of cobble and boulders to create a graded channel with 2.2% slope, which matches the reach downstream of the dam. Interactions with the existing rock along with the existing channel formation will facilitate varying and complex flow patterns through the rest of the reach, creating both areas for fish to pass upstream safely and an aesthetically pleasing cascading riverine environment. The former flume culvert and side channel present to the north will stay open to pass excess flow during large storm events. It will not be the active flow path to avoid attractive flow issues with fish. Periodic maintenance will be required to keep the culvert free of debris.

5.3 REVEGETATION PLAN

Management of invasive plant species will be implemented as part of the ecological restoration for the LF dam and SC dam removals. Japanese knotweed is present downstream of LF dam on the southern bank, as shown in the design plan set. Other invasive species present at the project site include oriental bittersweet, common/glossy buckthorn, and multiflora rose. Treatment of invasive species entails a combination of hand removal or mowing and application of approved, aquatic-safe herbicide. Several years of monitoring and treatment is often required to control invasive species.

Selected riparian herbaceous plants, shrubs, and trees will be planted to help establish native vegetation and stabilize constructed banks and former impoundment areas. The suggested plantings are currently present at the project site and/or common to local plant communities. We suggest three planting zones, as shown in the 40% designs (Appendix A). Zone 1 is the wetland zone that includes the streambanks and floodplains adjacent to the channels. A native wetland seed mix will be hand-spread throughout this zone to initiate growth of grasses, sedges, rushes and other herbaceous plants. Fast-growing native species such as willows and dogwoods are recommended along the constructed streambanks in the form of dormant live stakes. These plants will stabilize the banks and provide shade to the channel. Additional container stock will be planted in the other portions of Zone 1, referred to as the floodplain. The container stock will be a mix of trees (3'-4' height) and shrubs (2'-3' height). Trees and shrubs for this zone may include red maple, silver maple, speckled alder, red-osier dogwood, winterberry holly, and American elderberry. Zone 2 is the transitional zone for the slopes extending up from the floodplain to the upland. A native seed mix that is composed of wetland, transitional, and upland species will be seeded throughout this area. Trees and shrubs for this zone may include black birch, tulip tree, black gum, sweet pepperbush, grey dogwood, meadowsweet, and northern arrowwood. The size of these plantings will follow that specified for Zone 1 above. Zone 3 is the upland zone disturbed for staging and access during construction. An upland erosion control seed mix will be seeded throughout this zone. Trees and shrubs for this zone may include red maple, yellow birch, sweet pepperbush, northern bayberry, and northern arrowwood. The size of these plantings will follow that specified for Zones 1 and 2 above. The exact locations of the live stakes, shrubs, and trees will be determined at the time of construction in coordination between IF and the contractor.

Table 10. Revegetation species by wetland zone.

ZONE 1: WETLAND ZONE - STREAMBANK			
BOTANICAL NAME	**COMMON NAME**	**STOCK TYPE**	**STOCK SIZE**
Cornus sericea	Red osier dogwood	live stake	4'; 3/4" dia
Cornus amomum	Silky dogwood	live stake	4'; 3/4" dia
Salix discolor	Pussy willow	live stake	4'; 3/4" dia
Salix sericea	Silky willow	live stake	4'; 3/4" dia

ZONE 1: WETLAND ZONE - FLOODPLAIN			
BOTANICAL NAME	**COMMON NAME**	**STOCK TYPE**	**STOCK SIZE**
Acer rubrum	Red maple	container	3'-4' height
Acer saccharinum	Silver maple	container	3'-4' height
Alnus incana	Speckled alder	container	2'-3' height
Cornus sericea	Red osier dogwood	container	2'-3' height
Ilex verticillata	Winterberry holly	container	2'-3' height
Sambucus canadensis	American black elderberry	container	2'-3' height

ZONE 2: TRANSITIONAL ZONE			
BOTANICAL NAME	**COMMON NAME**	**STOCK TYPE**	**STOCK SIZE**
Betula lenta	Black birch	container	3'-4' height
Liriodendron tulipifera	Tulip tree	container	3'-4' height
Nyssa sylvatica	Black gum	container	3'-4' height
Clethra alnifolia	Sweet pepperbush	container	2'-3' height
Cornus racemosa	Grey dogwood	container	2'-3' height
Spiraea latifolia	Meadowsweet	container	2'-3' height
Viburnum dentatum	Northern arrowwood	container	2'-3' height

ZONE 3: UPLAND ZONE			
BOTANICAL NAME	**COMMON NAME**	**STOCK TYPE**	**STOCK SIZE**
Acer rubrum	Red maple	container	3'-4' height

Betula alleghaniensis	Yellow birch	container	3'-4' height
Clethra alnifolia	Sweet pepperbush	container	2'-3' height
Myrica pensylvanica	Northern bayberry	container	2'-3' height
Viburnum dentatum	Northern arrowwood	container	2'-3' height

The incorporation of culturally significant plants is proposed in addition to the above table. Some of these plants include cattails (Typha spp.), Parker's pipewort (Eriocaulon parkeri), arrowhead (Sagittaria spp.), goldenrod (Solidago spp.), and white turtlehead (Chelone glabra). The importance of these plants is described in HPT's memo (Appendix G).

5.4 RESOURCE IMPACTS

Dam removal projects result in short-term impacts and long-term benefits to regulated resources areas. To remove a dam and convert the impoundment to a free-flowing stream, state and federal resource boundaries such as wetlands, river bank, land under water, ordinary high water, land subject to flooding, the 100-yr flood line, and riverfront area are almost always altered. In many cases, the resource areas are swapped, such as the conversion of land under water to wetland. The resource area impacts for the two dam removals can be found in the Drawings (Appendix A).

5.5 TIDAL INFLUENCE AND CLIMATE CHANGE CONSIDERATIONS

In future climate conditions, Massachusetts's coastal ecosystems, including the IH River, are expected to change significantly. The IH River displays modest seasonal variation of flow in a typical year with the highest magnitude flows occurring in the spring following snowmelt, and the lowest flows occurring in late summer. Climate change effects are leading to shifts in timing, magnitude, and frequency of streamflow in coastal Massachusetts. Researchers have observed increasing March flows and decreasing May flows in New England in general. Sea level rise could lead to higher saltwater intrusion and greater tidal fluctuations further upstream on the IH River. These changes could include shifts in species composition, alterations in food webs, and changes in the physical characteristics of the habitat.

Removal of the dams will provide greater resilience to hydrologic intensification that is resulting from climate change. First, the removal of aging dam structures eliminates the risk of structural failure of each dam, while maintenance and operation costs of the dams are similarly eliminated. Second, dam removal reduces the elevation of flood water surface profiles, reducing potential flood impacts upstream of each dam. Third, dam removal increases floodplain storage in formerly impounded areas, reducing flood elevations, slowing flow in overbank areas, and creating ecologically important lateral connections between the channel and floodplain areas. Lastly, dam removal provides a substantial buffer against the uncertainty in future flow conditions, by providing the maximum amount of flow capacity along the river.

Restoring natural river processes offers additional buffering capacity and resiliency in response to future climate conditions. The restoration of sediment transport to the coastal zone can counteract sediment deficits and facilitate land accretion, enhancing the resilience of coastlines against the impacts of sea level rise. Moreover, dam removal plays a crucial role in mitigating elevated water temperatures, which are particularly important under future climate conditions. As global temperatures rise, maintaining cooler river environments becomes essential for preserving aquatic ecosystems and biodiversity.

5.6 INTERACTIONS WITH INFRASTRUCTURE AND PROPERTY

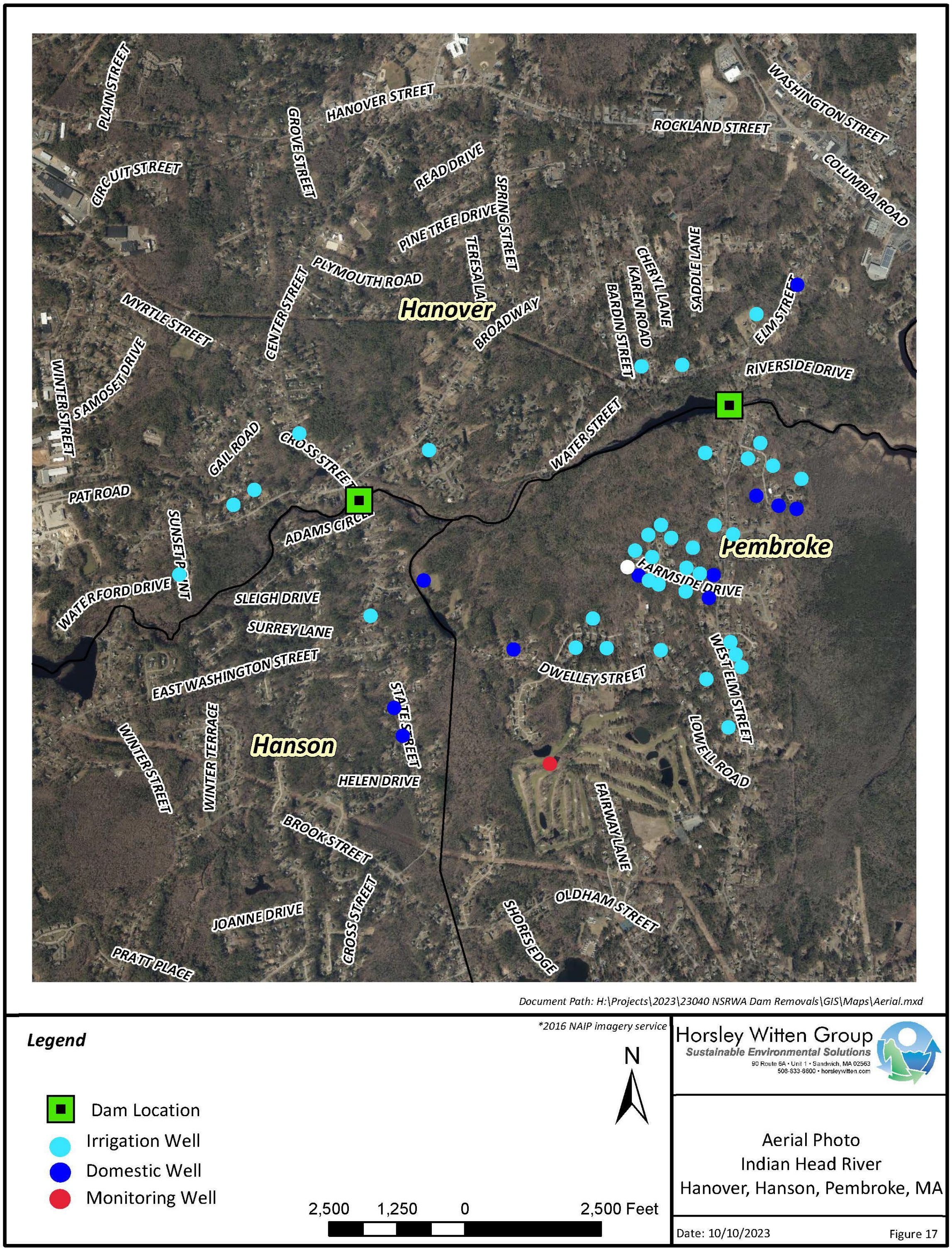
The proposed dam removals are anticipated to be significant hydraulic changes that may impact both surface and ground water levels for the project area. HW estimated changes in groundwater elevation likely to occur because of the proposed dam removals. Changes in groundwater elevations in areas near the LF and SC impoundments were estimated based on the modeled reduction in water surface elevations in both impoundments during median daily flow conditions (41-42 cfs for the LF impoundment, 32-39 cfs in the SC impoundment).

5.6.1 Estimated Change in Average Groundwater Elevation Post Dam Removal

In typical New England hydrogeologic conditions, groundwater elevations surrounding rivers occur at levels close to, but slightly higher than adjacent river water surface elevations. This slight gradient is what allows groundwater to flow into the river. Along dam-impounded stretches of river, that gradient is frequently inverted when the impounded river levels are high enough to create a localized reversed gradient from the river to adjacent groundwater. Downstream of dams, the naturalized gradient from groundwater to the river generally resumes. Groundwater fluctuations caused by changes in river levels are also generally most significant in immediate proximity to rivers and become progressively muted with increased distance from the river.

In order to evaluate the potential for impact to private drinking water wells from dam removal at both subject sites, HW first evaluated the likely potential for the presence of private drinking water wells in near vicinity to the two subject impoundments, and then evaluated how far away from the two impoundments significant groundwater level declines would be likely to occur relative to the distance of residences with the potential to be served by private drinking water wells.

According to the available records from the respective town water departments and visual observations of street hydrants, it appears that town water is available along the nearest streets to the subject impoundments in all three towns (Hanover, Hanson, and Pembroke). Based on the MassDEP Wells Database, it also appears unlikely that there are private drinking water wells within the immediate 500 feet radius of the impoundments. Figure 20, below, includes various wells within the vicinity of the impoundments.



**Bureau of Geographic Information (MassGIS), Commonwealth of Massachusetts, Executive Office of Technology and Security Services*

Figure 29. Approximate Nearby Well Locations from MassDEP Well Database

HW calculated the distance-variable change in average groundwater elevation estimated to occur because of the proposed dam removals. To do this, HW utilized standard pumping test evaluation techniques - specifically the Theis distance drawdown method. This approach requires first conceptualizing the anticipated river level declines at each impoundment because of dam removal as if those river level declines were caused by a conceptual pumping well located adjacent to each impoundment and using the Theis method to calculate the conceptual pumping rate necessary to produce the anticipated river level declines (conceptual drawdown). Next, that conceptual pumping rate is incorporated into the same Theis method equations to solve for the groundwater drawdown that would occur in the aquifer at specified distances from the impoundments under the conceptualized pumping withdrawal conditions.

To estimate the conceptual groundwater drawdown associated with the water level reduction in the post-dam removal impoundments, HW used an online calculator version of the Theis methodology (New Mexico Office of the State Engineer, 2017. https://www.ose.state.nm.us/Hydrology/Theis/index.html). Input factors for the Theis method estimation are as follows:

- Hydraulic conductivity (or "K") is a factor that defines the ability of the aquifer materials to transmit water. It is generally associated with permeability but is presented in units of velocity (e.g., feet per day), even though it technically does not define the groundwater velocity of any given location. Higher values of K indicate higher capacity to transmit water. K values were estimated for both sand and gravel and for till which predominantly make up the surficial geology that exists around the Indian Head River. These values were estimated based on local data obtained from the USGS publication *Simulated Ground-Water Flow for a Pond-Dominated Aquifer System near Great Sandy Bottom Pond, Pembroke, Massachusetts* by Carl S. Carlson and Forest P. Lyford (USGS Scientific Investigations Report 2004-5269) and surficial geologic mapping obtained from MassGIS.
- Aquifer Thickness ("b") was estimated based on the USGS publication and the MassDEP well database of groundwater wells nearby.
- Transmissivity ("T") is the product of K and b.
- Storage Coefficient ("S") represents the percentage of unit aquifer volume that is open pore spaces between aquifer sediment grains available to store and transmit water.
- Pumping Rate in gallons per minute (gpm).
- Distance in feet from the river to nearby residences and potential wells for which drawdown is to be calculated.
- The modeled average drawdown behind each dam site post dam removal as predicted by the IF HEC-RAS model.

Table 11,Table 12, and Table 15 list the range of input factor values utilized in our assessments. These calculations were conducted for both dams.

Ludden's Ford Dam

Based on the IF hydraulic model results, an average water level reduction of 8.8 feet was predicted to occur in the impoundment immediately upstream of LF dam during median flow conditions post-dam removal. This value was used as the simulated drawdown for the conceptual groundwater well withdrawal rate assessment.

Based on MassGIS mapping, surficial geology north of the IH River at LF dam consists mainly of sand and gravel while south of the river is mainly till. The two types of glacial aquifer materials have different hydraulic properties, with sand and gravel generally being significantly more conductive to groundwater flow than till. Therefore, for a given pumping rate, more drawdown will be experienced in a till aquifer than in a sand and gravel aquifer. Using the range of likely input factors for the Theis method and drawdown estimation (Table 11), HW calculated two hypothetical groundwater pumping rates necessary to create the 8.8 feet of "conceptual drawdown": one representative of sand and gravel aquifer conditions and the other for glacial till. Estimated aquifer groundwater level drawdowns were then calculated at variable distances from the river based on that "conceptual pumping rate".

Sand and gravel aquifer materials are mapped to exist for most of the area north of the river. Glacial till is mapped to exist approximately 500 feet and beyond southeast of the river. For sand and gravel aquifer conditions, a hypothetical groundwater pumping rate of approximately 74 gallons per minute (gpm) is estimated to be necessary to produce the 8.8 feet of simulated groundwater drawdown adjacent to a simulated withdrawal point in the impoundment (Table 11). For glacial till aquifer conditions, the hypothetical pumping rate necessary to produce that same drawdown is approximately 19 gpm (Table 12).

Using the range of calculated conceptual pumping rate and the other Table 11 and Table 12 input values, HW used the same Theis method calculator in reverse (solve for drawdown at variable distance based on the previously estimated pumping rate) to estimate the potential groundwater drawdown at 100 feet, 500 feet, and 1,000 feet away from the impoundment. Those evaluation distances were selected to bracket the distances to the closest residences (estimated to be approximately 400 feet from the dam site, based on MassGIS mapping).

Table 11. Input Factors for Theis Drawdown Calculations for Ludden's Ford Dam (Sand and Gravel)

Factor	**Min.**	**Likely**	**Max.**	**Comments**
K *Sand and Gravel*	25 ft/day	45 ft/day	80 ft/day	From USGS model
b	15 ft	35 ft	60 ft	From USGS model and well database
T *Sand and Gravel*	375 ft^2/day	1,575 ft^2/day	4,800 ft^2/day	= K * b
S aquifer	0.1	0.2	0.25	Estimate for Unconfined Aquifer
S river	0.99	0.99	0.99	Open water high S
Time	30 days	60 days	120 days	For avg. steady state
Distance	100 feet	500 feet	1,000 feet	Residence effect nearby

Table 12. Input Factors for Theis Drawdown Calculations for Ludden's Ford Dam (Till)

Factor	Min.	Likely	Max.	Comments
K Till	1 ft/day	10 ft/day	20 ft/day	From USGS model
b	15 ft	35 ft	60 ft	From USGS model and well database
T Till	25 ft2/day	350 ft2/day	1,200 ft2/day	= K * b
S aquifer	0.1	0.2	0.25	Estimate for Unconfined Aquifer
S river	0.99	0.99	0.99	Open water high S
Time	30 days	60 days	120 days	For avg. steady state
Distance	100 feet	500 feet	1,000 feet	Residence effect nearby

Note that some combinations of factors that produce a high simulated pumping rate requirement (i.e., high T and low time to steady state) are inverted from those to produce maximum drawdown at distance (i.e., low T and longer pumping duration). Therefore, the maximum and minimum factor combinations are not the absolute maximums and minimums of each factor, but the maximum and minimum combinations of factors that might reasonably occur.

Based on MassGIS mapping, the nearest residences on either side of LF dam are located approximately 400 feet northeast and 400 feet southeast of the dam. As shown in both Table 13 and Table 14 the potential groundwater drawdown that may occur because of removal of the LF dam at the nearest residences is approximately 1-2 feet and, therefore, is unlikely to impact the actual performance of private wells, were any such wells in use at those nearest residences. As discussed above, Town water is available along those nearest streets and, therefore, the presence of private drinking water wells here is also unlikely. Potential drawdown impacts become progressively smaller farther away from the dam location.

Table 13. Results for Theis Drawdown Calculations for Ludden's Ford Dam (Sand and Gravel)

	Min. Combo of Factors	Likely Combo of Factors	Max. Combo of Factors
Conceptual Pumping Rate to Produce Dam-Out River Drawdown	19.87 gpm	73.70 gpm	195.77 gpm
Avg. Groundwater Decline at Nearest Residences Estimated for Dam-Out River Drawdown	1.04 feet	1.39 feet	2.18 feet

Table 14. Results for Theis Drawdown Calculations for Ludden's Ford Dam (Till)

	Min. Combo of Factors	Likely Combo of Factors	Max. Combo of Factors
Conceptual Pumping Rate to Produce Dam-Out River Drawdown	1.93 gpm	18.66 gpm	54.29 gpm
Avg. Groundwater Decline Residences Simulated Dam-Out River Drawdown	0.0 feet	0.60 feet	1.5 feet

According to MassDEP's Well Database, the closest known existing private well to the LF dam impoundment is an irrigation well located at 34 Old West Elm Street, Pembroke, approximately 600 feet south and upstream of LF dam. Based upon the publicly available well completion report, the well was completed at 145 feet below grade in bedrock with bedrock located approximately 20 feet below grade. With over a hundred feet of saturated material (combined both fractured bedrock and overburden materials), the small groundwater level declines estimated to occur at this location because of the proposed dam removal are highly unlikely to impact this private irrigation well.

State Street/Cross Street Dam

To calculate the estimated change in average groundwater elevation at the SC dam site on the IH River from the proposed dam removal, the same methodology described above for the LF dam was utilized again.

Based on the IF hydraulic model results, an average water level reduction of 2.1 feet was predicted to occur in the impoundment immediately upstream of SC dam during medium flow conditions post-dam removal. This value was used as the simulated drawdown depth for the conceptual groundwater well withdrawal rate assessment.

Based on MassGIS mapping, surficial geology surrounding the SC impoundment consists mainly of sand and gravel. Therefore, in this situation, only sand and gravel aquifer properties were used in the Theis method conceptual drawdown calculations (Table 15). The hypothetical groundwater pumping rate necessary to create the 2.1 feet of "conceptual drawdown" in this impoundment is approximately 18 gpm (Table 16).

Based upon those pumping rates and the other Table 15 input values, HW used the same Theis method calculator in reverse (solve for drawdown at variable distance based on the previously estimated pumping rate) to estimate the potential groundwater drawdown at 100 feet, 500 feet, and 1,000 feet away from the impoundment. Those evaluation distances were selected to bracket the distances to the closest residences (estimated to be approximately 200 feet from the dam site, based on MassGIS mapping).

Table 15. Input Factors for Theis Drawdown Calculations for State Street/Cross Street Dam (Sand and Gravel)

Factor	Min.	Likely	Max.	Comments
K *Sand and Gravel*	25 ft/day	45 ft/day	80 ft/day	From USGS model
b	15 ft	35 ft	60 ft	From USGS model and well database
T *Sand and Gravel*	375 ft^2/day	1,575 ft^2/day	4,800 ft^2/day	= K * b
S aquifer	0.1	0.2	0.25	Estimate for Unconfined Aquifer
S river	0.99	0.99	0.99	Open water high S
Time	30 days	60 days	120 days	For avg. steady state
Distance	100 feet	500 feet	1,000 feet	Residence effect nearby

As shown in Table 16, the potential groundwater drawdown that may occur at the nearest residence following dam removal is approximately 0.5-1 feet and, therefore, is unlikely to impact the actual performance of any private wells, if any exist in this near proximity.

Table 16. Results for Theis Drawdown Calculations for State Street/Cross Street Dam

	Min. Combo of Factors	Likely Combo of Factors	Max. Combo of Factors
Conceptual Pumping Rate to Produce Dam-Out River Drawdown	5.07 gpm	17.59 gpm	46.72 gpm
Avg. Groundwater Decline Residences Simulated Dam-Out River Drawdown	0.40 feet	0.56 feet	0.73 feet

Note that some combinations of factors that produce a high simulated pumping rate requirement (i.e., high T and low time to steady state) are inverted from those to produce maximum drawdown at distance (i.e., low T and longer pumping duration). Therefore, the maximum and minimum factor combinations are not the absolute maximums and minimums, but the maximum and minimum combinations of factors that might reasonably occur.

According to MassDEP's Well Database, a known existing well located nearby the SC dam impoundment is an irrigation well located at 1269 Broadway, Hanover, approximately 1,500 feet northwest and upstream of SC dam. Based upon the publicly available well completion report, the well was completed 185 feet below grade with bedrock located approximately 50 feet below grade.

With over 150 feet of saturated material (combined both fractured bedrock and overburden materials), the small groundwater level declines estimated to occur at this location because of the proposed dam removal are highly unlikely to impact this private irrigation well.

Please note that the groundwater impact evaluations discussed above are likely conservative overestimates of the potential groundwater level declines surrounding the LF and SC dam sites resulting from estimated post-dam removal river level changes. While the approach of simulating the potential water surface elevation changes as a well withdrawal allows for the use of pumping test analytical equations to estimate drawdown, it is an oversimplification of actual site conditions.

Natural climatic and hydrologic variations currently occur for river level and groundwater level conditions at the site and would continue to occur under potential dam-out conditions. Therefore, the post-dam removal river levels are unlikely to remain 8.8 feet and 2.1 feet lower, respectively for the LF and SC dam sites, than current impoundment water levels for the multiple months' time period simulated in the steady state analysis described above. Altogether, the analysis described above provides a reasonable maximum range of potential groundwater level changes adjacent to the two subject dam sites on the Indian Head River.

6. Further Analysis

As the design process moves forward, there are several items that require additional detailed evaluation or exploration. For the LF dam, additional evaluation of sediment depth-of-refusal probing in the impoundment is needed to better refine the channel bed profile and historic thalweg location, which has a direct interplay with required sediment excavation volume and influences the estimated project cost. A deeper look into the impacts of tidal influence and sea level rise at the Ludden's Ford site would provide more information on future climate conditions. There could be hydrodynamic modeling to forecast changes in water levels due to tidal oscillations after dam removal, while also simulating various sea level rise scenarios. Concurrently, using the results of that modeling to predict changes in habitats, particularly for species sensitive to salinity and water levels. In addition, to facilitate project permitting and project review under the beneficial sediment reuse program for both the LF and SC sites, supplemental sediment testing will be required to meet the required density of testing based on the impounded sediment volume and will better inform sediment management options. Lastly, additional review and investigation of the State Street Bridge is necessary to understand any potential impacts for the bridge associated with dam removal. While our model results indicate there are minimal impacts to the erosive forces on the bridge with the dam removed, it is recommended to have structural/geotechnical engineer to confirm the depth and type of abutment footings.

7. Conceptual Renderings

HW developed two graphical representations for each of the LF and SC sites for use by project partners to convey what the site may look like following the LF and SC dam removals (Appendix C). For each site, there is a plan view, colored version of the planting plan sheet from the 40% design plans and an artistic rendering of anticipated conditions post dam removal. These graphical products can be useful in discussions of the project with adjacent landowners, leadership from the towns, the Conservation Commissions, and other regulators. While they do not provide the technical detail of the engineering designs, they provide a depiction of the anticipated post dam removal conditions (based off the design elements) at the 50% exceedance flow. In the plan view colored depictions for each site, the proposed treatment and planting areas are shown. The perspective renderings include paired "before" photos and "after" renderings as oblique view images of each project site without the dam. The "after" rendering for the LF dam site is a view perspective from just downstream of the dam looking upstream at the impoundment, with a riffle/run in place of the dam area in the foreground. The floodplains and slopes are vegetated in the condition of approximately 5 years after the removal of the dam. The "after" rendering for the SC dam site is a view from just upstream of the dam looking downstream. The floodplains and slopes are vegetated in the condition of approximately 5 years after the removal of the dam.

8. Opinions of Probable Costs

Opinions of probable cost were developed for each site and are included in Appendix B. According to the definitions developed by the American Association of Cost Engineering (AACE 2016), the goal for the cost analysis fits in the range of Class 3 estimates. The cost analysis includes project delivery and construction costs.

The cost opinions have been developed based on review of construction costs for similar items in past projects and applicable reference cost data. Refinement of quantities and unit prices will occur in future more detailed design phases.

The actual costs of implementation of the project may vary from the cost opinions due to heavy construction market fluctuations and other unforeseen factors, detailed design development and possible optimization, and other factors. Recent bid results from the last few years have seen substantial escalation and volatility in bid pricing. Conversations with construction contractors suggest costs may also escalate with increased stimulus and infrastructure spending currently being discussed nationally. To account for potential variation, a 30% construction cost contingency has been included in the cost opinions, consistent with a Class 3 estimate.

Several assumptions were required to facilitate preparation of the cost analysis, discussed below. A primary assumption is related to sediment management associated with dam removal. For the SC dam, it is assumed that the mobile sediment accumulated in the impoundment will be allowed to transport naturally downstream. It was assumed in the cost opinion that sediment in this impoundment would not be excavated.

A major uncertainty in the LF dam removal is how the excavated sediment will be managed. Because of the substantial volume of accumulated sediment, sediment management is the primary cost factor at this site. To be conservative, the cost opinion for the LF dam assumes all the sediment will need to be excavated and removed offsite. Supplemental sediment probing and testing at the site in the next design phase will allow the sediment management options, and therefore costs, to be refined and optimized.

A no action cost opinion was prepared for LF dam and can be found in Appendix B. For SC dam, because the dam has already been breached, a no action cost opinion was not considered appropriate.

9. References

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Appendix A – 40% Detailed Design Plan

Appendix B – Opinion of Probable Costs

Appendix C – Photo Renderings (HW)

Appendix D – Due Diligence Report (HW)

Appendix E – Sediment Sampling Results (HW)

Appendix F – Cultural Resources Assessment (PAL)

Appendix G – Indigenous Memo (HPT)

Appendix A – 40% Detailed Design Plan

Appendix B – Opinion of Probable Costs

Appendix C – Photo Renderings

Appendix D – Due Diligence Report

Appendix E – Sediment Sampling Results

Appendix F – Cultural Resources Assessment

Appendix G – Indigenous Perspective Memo