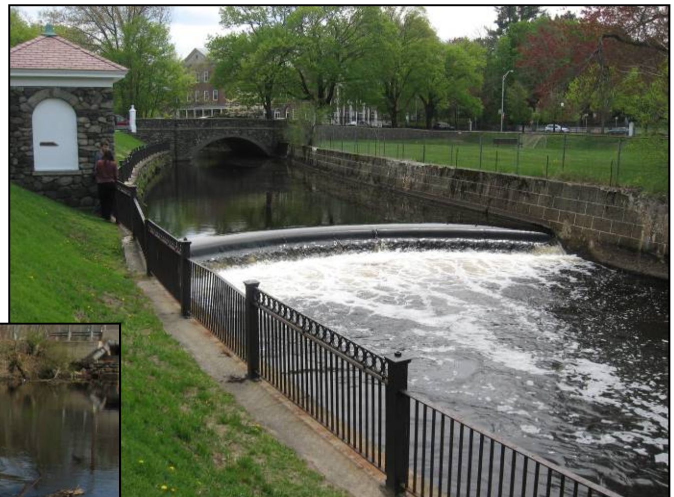
Shawsheen River Restoration
Interim Feasibility Report (30% Design)

October 14, 2009



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1. Executive Summary

The Shawsheen River is one of the largest tributaries of the lower Merrimack River, flowing south to north along a 25 mile course through Northeastern Massachusetts. The Shawsheen flows into the Merrimack about 30 miles from the Atlantic, just downstream of Essex Dam, which is the first (farthest downstream) dam on the Merrimack. The Shawsheen River therefore offers an outstanding opportunity to restore native migratory fish to Massachusetts and the Gulf of Maine, since there are no barriers on the mainstem Merrimack which would obstruct their passage to the sea.

Historically, the Shawsheen supported annual spawning runs of several important sea-run species, particularly Atlantic salmon, American shad, and river herring (blueback and alewives). These species are said to be diadromous, meaning that their lifecycle depends on their ability to move between fresh and salt water—these particular species require fresh water for spawning, but live as adults in salt water. All of these species are present today in the lower Shawsheen but are prevented from using most of the habitat in the river by the presence of three obsolete dams in Andover, Mass. Restoration of fish passage on the Shawsheen River would provide significant benefits to the ecosystems of the Shawsheen River, Merrimack River and Gulf of Maine. Herring and shad are important forage species during all life stages for fresh and salt water fish and wildlife, from ospreys, herons, otters and large-mouth bass in the watershed, to striped bass and bluefish in salt water. These species have been successfully restored on similar rivers throughout the Northeastern U.S. and elsewhere in Massachusetts.

The Balmoral Dam, Marland Place Dam and Ballardvale Dams in Andover present significant barriers to fish migrating in the Shawsheen River. Inter-Fluve was retained to examine the technical feasibility of various fish passage and river restoration options for these dams (for location see Appendix A). Inter-Fluve examined sediment volume and character in each impoundment, topography and bathymetry, potential structural issues surrounding dam removal, watershed characteristics and stakeholder concerns. In this interim report, we detail the methods used and results obtained to date. The Executive Summary below outlines briefly the results of the feasibility study. In the body of the report we explain fully the concept level designs generated for recommended alternatives at the Balmoral, Marland Place and Ballardvale Dams. We conclude that fish passage and river restoration are feasible at all of the dams. Photoshop visualizations of removals can be found in Appendix B. The report also recommends additional river restoration opportunities identified during the course of the study, such as removal of remnant dams at Redmond Card Clothing Co. and an unnamed dam remnant downstream of Balmoral Dam.

1.1. Dams, failure and flooding

Through project partner meetings and public forums, Inter-Fluve has had the opportunity to gauge public opinion regarding restoration of the Shawsheen River. Foremost among the concerns of residents who live on or near the Shawsheen River are concerns over flooding. Dam owners are principally concerned with the liability of ownership. Before proceeding with the report, we feel it is important for every reader to fully understand the issues surrounding dam ownership, liability and flood risk and how they are related. We present here a brief summary of key points.

Dam structural integrity and failure - The large majority of dams in the United States were constructed sometime in the past 150 years. This is true of the current Shawsheen River dams. Although there have been earlier iterations of dams on the Shawsheen, the current dams date no further back than the mid 1800s. All engineered structures have what is called a *design life*. For example, a typical corrugated metal culvert pipe has a design life of 30-40 years. Concrete and stone dams degrade over time and have a design life of generally 50-75 years. Dams older than this were not always engineered and there was likely no consideration of design life at the time of their construction. Dams impound water and thus their failure can have catastrophic results. Federal and State governments recognize this and dam owners are required to inspect dams on a regular basis. Eventually, dams degrade to the point where they are ordered to be replaced, dewatered or removed. In other cases, dams either inspected or not, fail during flood events, regardless of their apparent structural integrity. In some cases, even the threat of failure can cause major financial loss. In 2005, the threat of failure of the Whittenton Mills Dam in Taunton, MA caused evacuation of the town and financial losses in the millions of dollars.

Each dam registered under the National Inventory of Dams has a hazard rating. This rating reflects the potential hazard to the downstream area resulting from failure or mis-operation of the dam or facilities. These ratings are not dependent of the size of the dam, and do not consider the structural integrity of the dam. Hazard ratings are defined under the NID as follows:

- A HIGH hazard dam includes any dam whose failure or mis-operation will probably cause loss of human life.
- A SIGNIFICANT hazard rating applies to any dam whose failure or mis-operation results in no probable loss of human life but can cause economic loss, environmental damage, disruption of lifeline facilities, or impact other concerns. These dams are often located in predominantly rural or agricultural areas but could be located in areas with population and significant infrastructure.

- A LOW hazard rating applies to any dam whose failure or mis-operation results in no probable loss of human life and low risk of economic and/or environmental loss. Losses are principally limited to the owner's property.

Again, the hazard rating says nothing about the current state of the dam and does not excuse owners from liability should the dam fail and unexpected consequences result. The Shawsheen River Dams are privately owned. This means that the dam owners are potentially liable should someone drown at their dam. They are also liable for property damage, injury or loss of life that might occur should their dam fail and an ensuing flood wave move downstream.

Massachusetts dam safety regulations have recently changed, and dam owners are now responsible for registering, inspecting, reporting inspection results to the Office of Dam Safety and maintaining their dams in good operating condition. In 2002 the Massachusetts legislature enacted revisions of the Dam Safety Statute, MGL Chapter 253:44-50, which significantly change the responsibilities of dam owners to register, inspect and maintain dams in *good operating condition*. Owners of dams are required by 302 CMR 10.07 to hire a qualified engineer to inspect and report results every 2 years for High Hazard Potential dams, every 5 years for Significant Hazard Potential dams and every 10 years for Low Hazard Potential dams. The new rules became effective in 2005. The Ballardvale Dam is the only dam on the Shawsheen River with a recent dam inspection (2007).

Flooding – We discussed above the first type of flood issue associated with dams. This includes primarily severe and acute downstream flooding associated with failure of the structure. More frequent, however, is flooding associated with rising river levels. Some dams have an effect on these water levels, while others do not. We present here a cursory overview of dam impacts to flooding. In the next phase of the project, more extensive computer modeling will be undertaken to better demonstrate dam effects or the effect of removal on flooding.

The Shawsheen River dams are “run of river” dams which have no additional storage capacity, and therefore do nothing to mitigate or reduce flooding in the river. Under low-flow conditions, dams such as these raise water levels upstream, but have no effect downstream. During high water events such those seen during a 100-year storm, the Shawsheen River dams are completely under water and have no effect on local flooding. The dam structure is simply too small relative to the cross section of the flooded river to have an impact. Removal of these dams may reduce flood levels immediately upstream of the dam during smaller more frequent storms. Further analysis of flood impacts associated with removal is planned for the next phase of the project.

Consider flooding at Balmoral Dam, shown on the cover of this report (top right). On the upper left of the photo, a small marker is visible on the boarded window of the gate house. This marks the water level during the 2006 spring flood. The 2006 flood was over 7 feet above the crest of the dam, completely drowning out the dam. In this case the dam was not contributing to the flooding problem. The larger the flood, the more water levels are controlled by downstream road crossings, constrictions downstream, and the level of the Merrimack River. Generally speaking, residing in a floodplain or near a river means living with a certain constant level of risk. Flood insurance and estimates of flood frequency can help to manage that risk, but there is always the possibility that flooding will occur, with or without dams.

In steeper reaches of the Shawsheen, such as near Marland Place, removal of the dam would have a more dramatic effect on flood levels upstream. Water levels downstream, however, would remain unchanged. The Shawsheen Dams are like full bathtubs. The amount of water going in must equal the amount of water going out. When considering the removal of dams on the Shawsheen River, the most important message is this: Removal of these particular dams *will not increase* water levels upstream or downstream of the dams during large floods. In some areas, flood water levels will decrease compared to the existing condition.

1.2. Balmoral Dam

The Balmoral Dam is a solid concrete dam with a spillway height of 6.8 ft spanning 50 feet between confining concrete walls. The spillway is a stepped profile with seven (7) drops of 1-ft each spaced 18 inches apart (1.5H : 1.0V). The impoundment contains a maximum of 2,000 cubic yards of deposited sediment consisting primarily of sand. The dam is run of river, with no active control structures, and thus provides no flood control downstream. The dam does contribute to increased water levels upstream of the dam during frequent, smaller storm events (up to the 50-year flood), but those events do not frequently overtop the confined channel boundaries. Basic hydraulic analysis suggests that during high flow events, the effect of the dam is drowned out and any increase in flood elevation caused by the dam is insignificant. Low-head dams such as Balmoral present significant hazards for recreational boaters, as they appear to be benign but in fact have a powerful and dangerous hydraulic roller that can trap and drown boaters.

1.2.1. No Action Alternative (Balmoral)

No action at the Balmoral Dam would result in continued riverine habitat degradation through sediment deposition upstream of and within the impoundment (particularly at Ballardvale), continued raised flood profiles during smaller storm events, thermal pollution, and concentration of nutrients and pollutants. Fish and wildlife passage would remain blocked, a problem compounded by the walled banks near the dam. The negative effects of dams are well documented in numerous studies (Baxter

1977, Dauta et al. 1999, Petts 1984, Poole and Berman 2001, Schuman 1995, Stanley et al. 2002, Ward and Stanford 1979, 1987).

No action will require continued dam inspection, maintenance and eventual repair or replacement to keep the dam in compliance with Massachusetts Department of Dam Safety standards... The cost of these activities is typically borne by the dam owner. All of the Shawsheen River dams including the Balmoral Dam will continue to degrade, and without regular maintenance and repair, the risk of flooding due to dam failure increases. Dam owners are often liable for damages if their dams fail or if life or property is lost as a result of the dam's current state. No action results in continued liability risk to the dam owner and continued risk to public safety (Graber et al. 2001). No action thus does not fulfill the goals of the project and is not recommended.

1.2.2. Dam Removal Alternative - Balmoral (Recommended)

Removal of the Balmoral Dam is feasible and would restore fish passage up to the Marland Place Dam. Inter-Fluve recommends this alternative from a cost (relatively low) versus benefit (ecological, aesthetic) perspective. Removal would result in passage for diadromous fish (alewife, blueback herring, rainbow smelt, American eel) and other species (eg. striped bass, aquatic mammals, amphibians), free flowing conditions, restored riparian and in-stream habitat, lower water temperatures, and increased dissolved oxygen concentrations. These are typical benefits to small dam removal and are reviewed extensively in the literature (Bednarek, A. 2001, Maclin and Sicchio 1999). Dam removal would also reconnect the nutrient flow of upstream and downstream reaches, allowing nutrients to flow through the system without concentrating in large pulses. Migrating and resident fish would be able to move daily as well as seasonally through the reach to ensure access to optimal feeding and spawning habitat. Removal of the Balmoral Dam would also remove dam owner liability and public safety concerns by reducing or eliminating drowning hazards and completely removing the liability for flooding due to dam failure.

Removal of the Balmoral Dam could be completed within the constraints of the concrete walls. Access under the proposed scenario would be from the south side of the Bowling Green. Equipment could access the dam by partially removing a section of concrete wall, building a temporary construction pad and dismantling the structure. The extreme ends of the dam could be left in place to prevent structural impacts to the concrete wall. All disturbed areas would be restored to their pre-construction condition or better.

Stone wall removal - Regardless of which plan is implemented, the stone walls bounding the channel banks on both sides of the stream could be removed. It may be possible to remove the left bank (west) stone wall without impacting the bowling green area. The walls could be replaced by a floodplain bench and bioengineering banks with native vegetation. This would improve safety in the reach, and would aid in wildlife passage through this section. Currently, there is no conduit for wildlife passage via the banks.

1.2.3. Fish Passage Alternatives (Balmoral)

Inter-Fluve examined partial removal and installation of a rock ramp at the Balmoral site, and also examined natural bypass and fish ladder alternatives. A rock ramp was deemed infeasible due to the dam's proximity to the downstream bridge crossing (Haverhill Street). A rock ramp would need to extend past the bridge and would thus decrease the hydraulic capacity of the structure, thereby increasing flooding upstream. A natural bypass channel was ruled out due to the space constraints. Such a bypass channel would require excavation of a significant volume of material from either the left or right banks. The required significant impacts to the historic bowling green or to the condominium property were deemed not acceptable.

A fish ladder is structurally feasible at the site, and could be installed along either the left or right wall. However, the hydraulic impact of a fish ladder could be significant given the confined channel geometry and it's proximity to the downstream bridge crossing. Because removal of the Balmoral Dam will restore the geomorphology of the upstream reach and provide multiple species passage for relatively low cost, the feasibility of a fish ladder was not investigated further.

1.3. Marland Place

The Marland Place Dam (known also as the Shawsheen River Dam or Stevens Mill Dam) is 80 feet long with a historic structural height of 16 feet and a current hydraulic head of 9.5 feet. The active impoundment channel contains approximately 8,500 CY of sand, with as much as 35,000 cubic yards of fine sediment deposited on the floodplain and channel margins. The hydraulic constriction of Stevens Street just upstream provides continual scour of the channel near the right bank. This area remains void of impounded sediment. Impounded sediment is concentrated near the left side of the dam downstream of Stevens Street, and along the left bank upstream of Stevens Street.

The dam provides no flood control, but analysis of FEMA flood profiles and HEC-RAS generated flood profiles suggests that the Marland Place Dam does contribute significantly to increased flood water levels upstream to Essex Street. This effect is visible for both small and large events up to at least the 500-year flood.

A detailed structural inspection (Weston & Sampson 1998) indicated that although the abutments were in good condition, the dam was in fair to poor condition at the time of survey. A structural inspection completed by Fay (2007) lists the spillway in fair condition and in need of a stable spillway cap. Loss of stones and movement of stones was noted, but no bowing or deformation of the dam was observed. Our most recent structural review does not dispute this result, and no repairs have been made to the dam since the prior inspections.

1.3.1. No Action Alternative (Marland)

No action is not recommended at the Marland Place Dam site. No action at Marland Place will maintain the existing condition of the impoundment, and the river conditions will remain relatively static. The ecological effects of no action will be the same as those detailed for the Balmoral Dam above. The dam will continue to block fish passage and will continue to present a maintenance cost and liability due to the risk of flooding from dam failure. The dam will continue to degrade over time, increasing the risk of failure. Structural repairs will eventually be needed to maintain the dam.

1.3.2. Dam Removal Alternative – Marland (Recommended)

Removal of the Marland Place Dam would result in free flowing conditions, restored riparian and in-stream habitat, increased dissolved oxygen concentrations and reestablishment of normal sediment transport function in this segment of river. The reach upstream is currently a deep, trapezoidal, low gradient wetland channel. Removal of the dam would result in a steeper channel slope and more natural geomorphic function, including sediment movement, bar formation and riffle and pool development. Dam removal will ensure improved passage for various migrating and in-stream fish and wildlife. Removal of the Marland Place dam would remove dam owner liability and public safety concerns by eliminating flooding due to dam failure. Dam removal at Marland Place will probably decrease upstream local flood elevations during a range of flood frequencies. Preliminary hydraulic modeling suggests that water levels during a 10-year flood event will be 3-5 feet lower than current levels for the same flood.

Further feasibility analysis and final design engineering for the removal will include a more detailed analysis of the impacts of removal to the channel bed. Removal could cause additional scour at the Stevens Street bridge due to changes in hydraulics. The dam currently backs up water and effects the movement of sediment through the bridge. Construction of a grade controlling riffle at the dam location could help to prevent upstream grade changes while creating a desirable aesthetic. Residents have voiced concerns over loss of the waterfall aesthetic and the sound of falling water at the dam site. Construction of a riffle would preserve some aspects, such as the sound of flowing water, while still allowing for normal ecological and geomorphic processes to resume. Such a riffle would be constructed such that it appears as a natural part of the river system.

1.3.3. Fish Passage Alternatives (Marland)

Three non-removal fish passage alternatives were initially considered at each dam site including Marland Place; rock ramp, natural bypass channel and fish ladder. A rock ramp was deemed infeasible at Marland Place due to the filling of the channel downstream of the dam and the potential hydraulic impacts to adjacent properties. The water surface elevation during floods would be affected, and increased flooding is not acceptable.

A natural bypass channel was eliminated as an option due to the confined nature of the channel. The channel is bounded on both sides by masonry walls and high density residential buildings. There is simply no floodplain area available for construction of a bypass channel.

An Alaska steep-pass or Denil-type fish ladder is not practical for the Marland Place site. The dam has been assessed as being in poor to fair condition. It does not make financial sense to install a fish ladder on a dam that may need significant structural repair in the near future. In addition, the dam is a dry masonry structure with an irregular spillway. In order for a fish ladder to function properly, significant repairs would need to be made to the spillway. Any fish ladder would require significant concrete and masonry work to repair the dam, stabilize the retaining walls and manipulate spillway flow patterns to ensure attraction.

1.4. Ballardvale Dam

The Ballardvale Dam is a concrete masonry dam 85 feet in length, and 9.5 feet in height, just north (downstream) of the Andover Street in the Ballardvale area south of Andover, MA. Survey and hydraulic modeling shows that the most significant apparent impoundment effects occur within 5,000 feet of the dam. Analysis of aerial photographs and depth of refusal surveying across former channel areas near the railroad berm indicates a large area of former floodplain wetlands. The active channel has been truncated at the railroad berm and the remaining channelized reach may contain 4,000 - 8,000 cubic yards of deposited sediment consisting primarily of sand.

1.4.1. No Action Alternative (Ballardvale)

No action at Ballardvale Dam will maintain the existing condition of the impoundment, and the river conditions will remain relatively static. The ecological effects of no action will be the same as those detailed for the Balmoral Dam. The dam will continue to block fish passage and will continue to present a maintenance cost and liability due to the risk of flooding from dam failure. The dam will continue to degrade over time, increasing the risk of failure. Structural repairs will eventually be needed to maintain the dam.

1.4.2. Dam Removal Alternative - Ballardvale (Recommended)

Inter-Fluve recommends the removal of the Ballardvale Dam as a technically feasible alternative with a high cost versus benefit ratio. The dam site has good construction access both upstream and downstream from both banks. Because the dam spans a longer cross-section than the typical bankfull width of the channel, removal can be accomplished while leaving the abutments intact intact, minimizing structural impacts to the adjacent buildings. Historic data suggests that the wetlands upstream will change, but will remain as regularly inundated riparian wetlands and floodplain forest. The dam has no flood control benefit.

Inter-Fluve understands that dam removal will cause a drop in normal pool elevation and thus upstream property owners will see in increase in land surface and a retreat of the shoreline. Of the alternatives examined, full dam removal obviously impacts upstream landowners the most. Although our analysis focuses on the technical feasibility of alternatives, we recognize how the technical aspects of any proposed project can have social impacts. Dam removal fulfills nearly all of the performance criteria as outlined by the project partners in the early stages of the study, principle among these are restoration of fish passage and restoration of river function.

As described in the Balmoral and Marland Place segments above, dam removal would result in passage, free flowing conditions, restored stream habitat, canoe and kayak passage, lower water temperatures, and increased dissolved oxygen concentrations. Significant riparian restoration and in-stream habitat could also be achieved upstream of the Ballardvale Dam. Removal of the Ballardvale dam would also remove dam owner liability and public safety concerns by minimizing the risk of injury and eliminating the risk of flooding due to dam failure.

Recreational boating and fishing - Currently, the impoundment water level is both a result of partial drawdown (top layer of boards removed) and precipitation. Of concern among residents is the depth of water available for boating and fishing activities. If full removal were to occur, the resulting river channel would have a width and depth similar to those reaches downstream of Ballardvale Dam and also upstream of the railroad crossing at the upper end of the impoundment. Channel restoration could include the construction of riffle and pool sequences, channel bars and other features common to rivers. During wet periods following snowmelt, rainstorms and wet weather, the channel will have more water in it and canoe and kayak passage will be unhindered. During dryer periods, such as midsummer, the channel water levels will be lower, and it may be necessary to drag or lift small boats over riffles. Partial dam removal with a grade control on the downstream end could result in a narrower channel than existing, but would still have a long backwater pool. Hydraulic modeling can estimate low flow depths, but river water levels fluctuate widely and depend on the amount of snow and rain in the watershed.

Clearly with removal, the Ballardvale impoundment will change from a lake environment (small boats) to a riverine environment favoring kayak and canoe use. In the same way, the fishing opportunities will change from lake species and fishing style to river species and fishing style. Riverine fishing involves more canoe based casting, flycasting and more bank based fishing opportunities. Dam removal typically results in lower river water temperatures which can favor cool water species over those found in warmer, lentic ponds. In addition, migratory runs of alewife, herring and shad will provide additional fishing opportunities that do not now exist.

Natural aesthetics – Dam removals can create dry land where there was none in recent memory. With many dam removals, impoundment owners are concerned about the appearance of this new land, and worry that their backyard will become a giant, smelly mudflat. Nothing could be farther from the truth. If removal takes place, the former impoundment bed typically dries and revegetates on its own within a few weeks. This phenomenon can be seen along the edges of the former Ballardvale impoundment, which was once larger than the current impoundment. However, it has been shown that if drained impoundment surfaces are left to revegetate on their own, invasive species such as reed canarygrass and Japanese knotweed can take over quickly. These species are aggressive and crowd out native vegetation. With a well planned dam removal, a planting plan is included that assures seeding and planting of desirable native vegetation. In Ballardvale, options for revegetation could include floodplain forest, grassy meadows, forested wetlands or native wildflower, sedge marsh areas or some combination of these options. Many communities and private landowners have incorporated trails, park space, ball fields and other recreation areas into former impoundment area. There are many possibilities for alternative uses of this new land surface.

Information regarding dam removal projects already completed around the country can be found at the American Rivers website www.americanrivers.org/ at the Mass Riverways website www.mass.gov/dfwele/river/ and at the NOAA Restoration Center website:

www.nmfs.noaa.gov/habitat/restoration/projects_programs/crp/partners_funding/noaadamremoval.htm

1.4.3. Fish Passage Alternatives (Ballardvale)

A downstream rock riffle/ramp or a ramp combined with partial removal is not feasible due to the low bank profile on the left bank. Raising the channel bed for a rock ramp could cause increased flooding in the building complexes adjacent to the dam. However, Inter-Fluve did also examine removal of the dam and replacement with a long cascading rock ramp segment that crests farther upstream. Unlike a traditional rock ramp used on other dam projects, this rock ramp approach involves reconstructing the subsurface geology of the reach, creating a permanent soil base and building a new channel on top of that base. This rock ramp would consist of a boulder dominated step-pool channel and would allow for fish passage. The height of the rock ramp crest can be varied depending on project goals, but it may still be considered a jurisdictional dam.

As with Marland Place, given the nearby floodplain infrastructure, a natural bypass channel is also not feasible. A Denil fish ladder could be constructed on either embankment. Considering cost as a factor, we believe that dam removal or fish ladder installation are the only practical fish passage alternatives at the Ballardvale site. Affordable Denil and prefabricated Alaska steep pass fish ladders have been shown to be successful in facilitating the migration of diadromous migratory alosid species (eg. alewife, American eel, blueback herring, American shad) in the northeast (Haro et al. 1999, Quinn 1994). This approach does not remove the dam owner's liability, and does not improve the degraded condition of the upstream channel.

Repair of dams for fish passage installation - A fish ladder would also require considerable dam repair or even full dam replacement prior to installation. The costs of repair include stabilizing the dam structure, concrete repair work on the adjacent abutments, stone masonry repair and possible modification to bring the dam under compliance with Mass Dam Safety regulations under 302 CMR 10.00.

1.5. Remnant Dams

There are two dam remnants under consideration for removal. The first is the Red Card Clothing Company (Red Rocks) dam just upstream of Essex Avenue. Approximately 75% of the spillway and berm have been removed, but a small portion remains and there persists a steep boulder cascade that prevents the channel from cutting down further. This dam presents a hazard to recreational boaters and could be easily modified to direct flow through the reach rather than against the adjacent building on the right bank. The rock cascade could be reconfigured using heavy equipment, and 5-10 feet of the remaining spillway could also be removed, thus widening the breach. A floodplain bench could be excavated in the upstream impoundment to allow for overbank flooding, and native vegetation could be planted to combat invasive species establishment.

The second remnant is 200 feet downstream of the Haverhill Street crossing, and is simply three steel posts and some remnant boards. These could be easily removed by hand with little disturbance to the channel bed.

1.6. Alternatives tables

Restoration options were found to be technically feasible at each of the three study dams, with a range of associated feasibility level cost estimates. The following tables show the alternatives considered at the three dams as well as the two dam remnants. *This information should be viewed as preliminary and conceptual only*. More detailed analysis and cost estimates will be a product of partner review, concept design review meetings and subsequent design phases. Cost estimates are +/- 50-100%

depending heavily on input in the next stages of partner input, public input and design. Estimates include engineering, construction, oversight and permitting.

Table 1-1. Balmoral Dam – fish passage alternatives

*Estimated costs**	*Advantages*	*Disadvantages*
Full Dam Removal *RECOMMENDED* *$217,000 – assuming no special handling of sediments*	• Improved fish passage • Restored natural river processes • Reduced contaminants • Improved in-stream habitat • Reduced public safety risk • Funding available for removal and sediment management	• Short term construction disturbance • Cost of contaminated sediment may require additional grant funding effort • Removal of sediment may add substantial cost, particularly if special handling is required

Table 1-2. Marland Place Dam – fish passage alternatives

*Estimated costs**	*Advantages*	*Disadvantages*
Full Dam Removal *RECOMMENDED* *$374,000 – assuming no special handling*	• Improved fish passage • Restored natural river processes • Reduced or stabilized contaminants • Restored floodplain wetlands • Improved water quality • Increased property value • Reduced public safety risk • Funding available for removal and sediment management • Improved park land opportunity	• May involve significant structural engineering stabilization of abutments • Short term construction disturbance • Cost of contaminated sediment may require additional grant funding effort • Removal of sediment may add substantial cost, particularly if special handling is required

Table 1-3. Ballardvale Dam – fish passage alternatives

*Estimated costs**	*Advantages*	*Disadvantages*
Full Dam Removal *RECOMMENDED* *$460,000 – assuming no special handling and minimal impoundment restoration* *$749,000 – assuming removal of contaminated sediment (assumes 2,000 CY of material removed)*	• Improved fish passage • Restored natural river processes • Reduced or stabilized contaminants • Restored floodplain wetlands • Improved water quality • Increased property value • Reduced public safety risk • Funding available for removal and sediment management • Improved park land opportunity	• Short term construction disturbance • Cost of contaminated sediment may require additional grant funding effort • Removal of sediment may add substantial cost, particularly if special handling is required
Rock ramp *$559,000 – assuming no special handling of sediment*	• Improved fish passage • Maintained impoundment water levels • Reduced public safety risk	• Cost may be prohibitive • Degraded habitat • Water quality impacts - thermal pollution, dissolved oxygen • Slow release of contaminants

		• Sediment accumulation upstream

Fish Ladder (Ballardvale) *$806,000* *Includes approximately $400,000 for dam repair and adjacent structural repairs*	• Improved passage for select organisms • Maintain impoundment water levels	• Degraded pond conditions and liability concerns remain • Sediment accumulation persists • Constant maintenance required

Table 1-4. Red Rocks Dam remnant – restoration alternatives

*Estimated costs**	*Advantages*	*Disadvantages*
Removal of remnants, reconstruction of riffle and bank stabilization *RECOMMENDED* *$50,000-$70,000*	• Improved safety for canoeists and kayakers • Improved fish passage at low flow • Restored natural river processes • Reduced sediment loading Restored floodplain wetlands	• Short term construction disturbance

Table 1-5. Unnamed Dam remnant (downstream of Haverhill Street) – restoration alternatives

*Estimated costs**	*Advantages*	*Disadvantages*
Removal of remnants *RECOMMENDED* *$5,000 – manual labor*	• Inexpensive • Restored natural river processes • Improved habitat	• none

2. Introduction

2.1. Project Origins

In summer of 2007, Fay Engineering was hired by Atria Senior Living to assess dam repair/removal options at Marland Place. Fay Engineering then contacted the USFWS and MA DFW to let them know that their report recommended removing the dam. The USFWS then contacted American Rivers, Massachusetts Riverways and the National Oceanic and Atmospheric Administration (NOAA) to inform them, and all parties then met with Atria staff in October 2007 to discuss the project and potential funding options. Interest then grew to include the only other two dams on the mainstem: Balmoral and Ballardvale, and other stakeholders were brought into the project. The proponents of the project engaged other federal, state and local agencies, dam owners, non-profits and stakeholders to undertake a restoration feasibility study. The first phase of the restoration was funded primarily by Mass. Riverways, NOAA through American Rivers, and U.S. Fish & Wildlife Service. Center for Ecosystem Restoration serves as project manager.

2.2. Project overview

The Shawsheen River Restoration Project is intended to restore fish passage at the Balmoral, Marland Place and Ballardvale Dams on the Shawsheen River in Andover, Massachusetts. The project also addresses fish passage concerns at two breached dam locations, the Red Rocks Dam and an unnamed dam downstream of the Balmoral Street crossing. The recommendations in this report consider and integrate the opinions and concerns voiced by project partners in various site visits and project meetings. This report includes a discussion of concepts, and presents the existing conditions survey information (mapping, sediment quality and due diligence review) and concepts for restoration.

The project team includes the project partners, the design team, and stakeholders. The design team is comprised of Inter-Fluve Inc., and Weston and Sampson Engineers. Project partners include the Massachusetts Riverways Program, the Town of Andover, American Rivers, U.S. Fish and Wildlife Service, NOAA Restoration Center, Mass. Dept. of Fish & Game (Division of Fish and Wildlife and Division of Marine Fisheries), and the Center for Ecosystem Restoration, Inc.. Other partners include the Shawsheen River Watershed Association, Balmoral Condominium Trust (owner of Balmoral Dam), Atria Senior Living Group (owner of Marland Place Dam), Shawsheen Coating & Converting (50% owner of Ballardvale Dam), and Shawsheen River Realty LLC (50% owner of Ballardvale Dam).

2.3. Performance criteria

A project kickoff meeting was held on May 8th, 2008 in Andover. Project funding partners met with Interfluve team staff to review and clarify the goals for the concept design project and to examine ways to integrate public comment. Regarding the technical aspects of final project outcomes, the following performance criteria were developed as being overwhelmingly important:

- Fish passage restoration for a variety of species
- Natural in-stream, riparian and wetland habitat enhancement
- Community involvement, outreach and stewardship
- Flood risk reduction and improvement of public safety
- Improved canoe passage

Under the umbrella criteria of public outreach and community revitalization, the following concerns and performance criteria for the Feasibility Study were commonly cited:

- Develop effective public outreach
- Engage the citizens of the watershed in river restoration
- Reconnect the community to the Shawsheen River
- Integrate the project into other revitalization efforts
- Create environmental education opportunities

As the design progresses, the project partners will solicit public opinion and further define project performance criteria specific to each location. Eventually, these will be translated into actual design components. For example, if canoe passage continues to be a strong issue, canoe landings might become a design component of the restoration.

2.4. Work completed to date

The public was notified of the upcoming study, and a public meeting was held on December 11th, 2008 to inform residents of the methods used and the status of the study. Residents' concerns were solicited and recorded. Surveying and mapping was completed in 2008. Concept Photoshop renderings of proposed alternatives were generated in a Technical Memorandum to the project partners dated December 2008. Concept drawings were generated for the recommended alternatives and submitted in July 2009. Advanced feasibility studies are planned for fall of 2009 and will include investigation into historic resources, further hydraulic modeling and public interaction. This report is an interim report designed to describe the concept designs.

3. Methods

3.1. Review of existing data

Inter-Fluve and Weston & Sampson Engineers conducted a review of pertinent existing information. The following lists the documents reviewed in preparation for the study:

- Andover maps (1692, 1795, 1830, 1872, 1884, 2000 – various sources)
- Aerial photography data (Mass GIS, USGS Eros Data Center)
- As-built and proposed dam and bridge plans
- Various historical documents
- NRCS Soil Surveys
- Stevens Street Bridge Hydraulics and Scour Analysis (Earth Tech 2008)
- Marland Place Dam Safety Inspection/Evaluation Report (Weston & Sampson 1998)
- Fay Engineering Reports (2007)
- Hydraulics Reports for FEMA (URS)
- Flood Insurance Studies
- Merrimack River Watershed Council, Water Flow Analysis Studies
- Shawsheen Watershed Study (EOEA)

Although we were able to locate construction documents for the Balmoral Dam, we were unable to find either design plans or as-built drawings for the Marland Place or Ballardvale dams.

3.2. Survey

Following the project kickoff meeting, Interfluve engineers and fluvial geomorphologists conducted a site reconnaissance of the three Shawsheen River dams and appurtenances in May 2008. Interfluve conducted geomorphic review of the river and watershed during this same visit. In June 2008, Interfluve completed topographic and bathymetric surveying, which included topographic cross sections, local bench marks, channel bottom elevations, sediment depths and sediment character.

Topographic surveying included detailed survey shots in and around the dams sufficient to create a 1-ft contour basemap. Bathymetric survey data and depth of refusal survey points were taken via watercraft and land based total station. Inter-Fluve collected approximately 60 hydraulic cross sections over five miles of the Shawsheen River, from approximately 7000 feet upstream of the Ballardvale Dam to 1000 feet downstream of the Balmoral Dam. Cross-section locations pertaining to topographic and bathymetric data are shown in the Concept Plans.

3.2.1. Hydrology

Extensive hydrologic analysis has recently been completed for the Shawsheen River (URS 2007, URS 2008) and for previous FIS studies (FEMA 1989, FEMA 1993). This work is supported by two stream flow gauges on the river. Inter-Fluve used existing data to set return interval flows for the hydraulic model. The following table lists flood flows for various return intervals at approximately the Marland Place/Balmoral area.

Frequency	Flow (cfs)
10 – yr	2,008
50 – yr	2,834
100 – yr	3,350
Drainage Area	71 square miles

3.2.2. Hydraulics

Existing and collected cross-section geometry data were combined to produce a detailed HEC-RAS model for the dam sites. HEC-RAS is a computer model that takes flow data and cross-section data for a channel and allows the user to determine water surface elevations for those given flows. The model can also help determine erosive forces and model proposed changes to the channel. HEC-RAS Version 3.1.3 was used for this modeling exercise. Ground photographs taken during the field survey were used to estimate Manning's coefficients for the channel and floodplain. Manning's coefficient refers primarily to the amount of roughness found in the channel bed and banks. Roughness comes from vegetation and substrate primarily (eg. Boulders have more roughness than gravel) and influences hydraulic parameters. For the main channel, the Manning's n values ranged from 0.03 to 0.05, and for overbanks, the values ranged from 0.03 to 0.1. The hydraulic model was used to estimate shear stress and average velocity for existing (dam in) versus proposed (dam out) conditions.

3.3. Structural Engineering Review

Following the project kickoff meeting, structural and geotechnical engineers from Weston & Sampson Engineers conducted a site reconnaissance of the three dams and appurtenances in May 2008 and again in May 2009 (Appendix C). Inter-Fluve and Weston & Sampson reviewed existing documents including structural analysis at Marland Place (Weston & Sampson 1998, EarthTech 2008, Fay 2007a, b, c) and as built or proposed drawings. The project sites were reviewed to examine potential impacts of dam removal on walls, streets, utilities, buildings and other structures.

3.4. Sediment Management

3.4.1. Sediment Quantity

Impoundment sediment volume was estimated by analysis of depth of refusal survey data. Up to three types of flexible and non-flexible rod material were used to penetrate fine grained sediment and sand accumulated in the channel. Depth of refusal surveying roughly correlated with bathymetric and topographic cross-sections. AutoCAD 2009 was used to generate volume estimates.

3.4.2. Due diligence review of possible contaminant sources

Interfluve conducted a due diligence review of the Shawsheen River project area. The purpose of this work is to determine, in a preliminary manner, possible river contaminant sources and to support decision making for future sampling and laboratory analysis of impoundment sediments. Due diligence review in this case included review of industrial uses, Superfund or other designated contaminated sites within the watershed, landfills, underground storage tanks, gas stations, chemical storage and general landuse. Due diligence in this case supports the analysis used.

Between 1996 and 2008, there were 9 documented chemical spills that required a professional clean-up in the Shawsheen River watershed in Andover. The more than 25 chemicals spilled included arsenic, lead, fuel oil, diesel fuel, gasoline, chromium, hydrofluoric acid, acetic acid, benzene, potassium cyanide, ammonia, mercury, naphthalene, and total petroleum hydrocarbons. There are 13 facilities that have reported the use of toxic chemicals in Andover. These chemicals include lead, freon, zinc, sodium hydroxide, ethyleneglycol, ammonia, methanol, copper, acetone, and acetic, hydrochloric, nitric, phosphoric, and sulfuric acid.

There are no Superfund sites in the Shawsheen River watershed, as the former Andover town landfill is in the Merrimack River watershed. According to the Andover department of health, phenolic resins were dumped directly into the Shawsheen River at the Lowell Junction Road. This would likely have ended up in the reservoir behind Ballardvale Dam. The City of Andover has identified 61 sites that contain a total of 172 underground storage tanks. Of these, 126 have been removed and most of those that are in use have monitors and detectors to detect leaks in the tanks or pipes. Most of these tanks are used for gasoline or diesel storage.

Due diligence results support testing sediment for priority pollutant metals, PAHs, mercury, and PCBs. Testing for organochlorine pesticides and herbicides was not suggested by landuse or review of watershed contaminant sources. For future phases, a draft sediment management plan will be submitted to Mass DEP for comment. Sampling and testing plans will be pre-approved and completed in full coordination with Mass DEP regulatory staff.

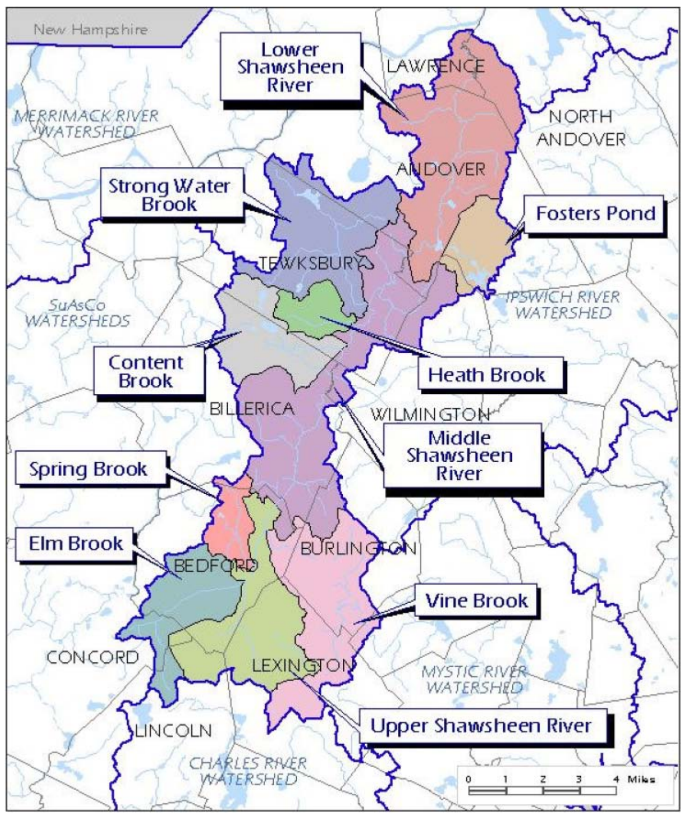
3.4.3. Sediment Quality

Screening level sediment sampling was conducted in October 2008 and samples were tested at Geolabs (Braintree, MA). Samples were taken via small boat with a Wildco manual corer and followed Interfluve internal protocol for dam sediment sampling. One screening level sample was taken in stream sediments downstream of the Balmoral dam, and one within the Balmoral impoundment. Two screening samples were taken in the Marland Place impoundment, one near the dam and another in the upper impoundment. Results of the screening sampling are given in the Geolabs report (see attached Appendix) and detailed in the sections that follow.

4. Background Information

4.1. Natural History

The Shawsheen River flows 25 miles from Bedford, MA to the Merrimack River in Lawrence, MA. The Shawsheen watershed is 78 square miles, one of the smaller watersheds in Massachusetts (See map below – Mass DFW) . The watershed has 60 miles of streams as well as 18 lakes and ponds. The upper Shawsheen River has a low gradient, and flows through wetlands and a wide floodplain.



Four to five percent of the watershed is covered by wetland or open water, and the two largest wetlands are in Tewksbury. The forest along the bank of the river is dominated by red maple (*Acer rubrum*) with white pine (*Pinus strobus*) and red oak (*Quercus rubra*) (Lyon and Gross 2005). Overall, 23 tree species and 30 shrub species can be found along the banks of the river (Lyons and Gross 2005). In the early 1800s, the banks of the Shawsheen River were primarily wooded with white pine, though oaks often succeeded the pines. Native populations frequently used fire as a tool to clear the understory for hunting and additional areas for agriculture. These fires allowed early successional and shade intolerant trees to regenerate in the area. European settlement led to fewer fires and fire suppression, and fire intolerant but shade tolerant red maples have now joined the pines and oaks on the banks of the river (Lyons and Gross 2005). The riparian zone has been diminished as the watershed has been developed, and non-native species have also been introduced into the forest and wetland areas. Most notably, purple loosestrife is very prevalent in the wetlands (Lyons and Gross 2005). Lyons and Gross studied three tributaries of the Merrimack River in northern

Massachusetts and southern New Hampshire and found that the riparian zone of the Shawsheen River was the least species rich. Historically, the Shawsheen River was an important fishery for anadromous fish such as alewife, Atlantic salmon, and shad. The Shawsheen is currently a warm water fishery and supports several native species (Herzfelder 2003).

4.1.1. Fisheries History

When European settlers arrived in Andover, Native Americans of the Pennacook Confederacy were living in the area. They occupied seasonal camps and caught salmon and alewives from the Shawsheen River along with growing corn and tobacco (Andover League of Woman Voters 1994). Early settlers also recognized the importance of fish passage, but dams made fish migration up the lower Merrimac and Shawsheen impossible by the mid-19th century. Not only did these dams impede flows, but they also caused water temperatures to rise. There is an undocumented report of the last Atlantic salmon being caught in the Shawsheen River in 1945 or 1947, but Bill Estes of the MA Department of Fish and Wildlife believes that the Atlantic salmon were absent from the river by 1850. Dating back to 1969, a MA Division of Fish and Wildlife report stated that the Shawsheen was one of only two tributaries in Massachusetts that had potential to provide nursery habitat for Atlantic salmon and American shad (Herzfelder 2003).

The Shawsheen River now supports a self-sustaining warm water fishery. Downstream of the three dams in Andover, surveys have found American eel (*Anguilla rostrata)*, bluegill (*Lepomis macrochirus macrochirus)*, sea lamprey, (*Petromyzon marinus*),, largemouth bass (*Micropterus salmoides salmoides)*, yellow bullhead (*Ameiurus natalis)*, white sucker (*Catostomus commersonii)*, redfin pickerel (*Esox americanus americanus)*, chain pickerel (*Esox niger)*, fallfish (*Semotilus corporalis)*, redbreast sunfish (*Lepomis auritus)*, and pumpkinseed sunfish (*Lepomis gibbosus)*. Most of these species were also found upstream of the dams, though generally in lower numbers. Creek chub (*Semotilus atromaculatus)* and creek chubsucker (*Erimyzon oblongus oblongus)* were also found upstream. The Shawsheen River is also stocked with brown, brook, and rainbow trout, but these species usually die by August due to high water temperatures (Herzfelder 2003).

4.1.2. Cultural Resources

Prior to European settlement, native peoples inhabited the area around the Shawsheen River in Andover. Those that the Europeans encountered were probably of the Pennacook Confederacy, and they are thought to have been greatly reduced in number by disease in the early 17th century, just prior to European settlement. The first permanent European settlement was established in Andover in 1641, and the town was incorporated in 1646.

Many mills were built along Andover's rivers and streams. The earliest mills were sawmills followed by grist mills. Textile mills prospered from the late 1700s to the mid 1900s (Andover League of Woman Voters 1994). The first mill on record in Andover was present in 1661, though it was probably built earlier (Bailey 1888). In 1665, permission for a mill on the Cochichawick River was granted with the condition that it did not stop the passage of alewives (Bailey 1888). As more mills and dams were built, however, this condition was not upheld. Despite the decline of the textile industry, the population of the Shawsheen River Watershed more than doubled between 1950 and 1990. In 1960, 25% of the watershed was developed, and this number rose to 50% by 1971. There has not been much increase since the 1970s (Herzfelder 2003). Three dams currently exist on the Shawsheen River in Andover. These are:

Balmoral Dam – The Balmoral dam was built in the early 1920s as part of Shawsheen Village. William M. Wood, President and CEO of the American Woolen Company, built a mill community in Frye Village, which he renamed Shawsheen Village (Andover League of Woman Voters 1994, Andover Historical Society). The mills began operation in 1922. The more than 200 residences in the village were first rented by mill employees, but by the 1940s, almost all of the houses and administration buildings were in private hands. The American Woolen Company closed in 1953 (Andover League of Woman Voters 1994).

The executive administration building of Shawsheen Village, the Balmoral, housed a private parochial school from 1945 to 1975. The building was converted into apartments in 1975 and condominiums in 1981 (Andover Historical Society). The Balmoral Condominium Trust currently owns the Balmoral Dam.

Marland Place (Stevens Street, Stevens Mill) Dam – Abraham Marland began manufacturing woolen cloth in 1810 at Abbott Village. In 1821 he made an agreement with the site manager to build a woolen-mill. The mill and boarding house buildings were built between 1821-1823 and are the oldest buildings currently remaining on the site. Mr. Marland bought the site in 1828. In 1834, the Marland Manufacturing Company was incorporated. In 1879, 30 years after Abraham Marland's death, the mills, machinery, and property were sold to Moses T. Stevens, who continued to operate the mill (Bailey 1880). The former mill building is now a senior living center, which once used the dam for power. Currently, the dam is not used.

Ballardvale Dam – In 1794, Timothy Ballard first owned a mill privilege at this site and used it for "water improvement" (Bailey 1880). Mr. Ballard later operated a grist and saw mill at the site, and, in 1835, built a 200-foot long dam (Memorial Hall Library 2009). In 1836, John and William S. Marland bought the property from Mr. Ballard and established the Ballardvale Manufacturing Company, named after Mr. Ballard (Bailey 1880). Ballardvale mills produced worsted goods, flannels, and delaines, and even experimented with silk manufacturing through the 19th and early 20th centuries (Memorial Hall Library 2009). Ballardvale was also Andover's first planned mill community and was home to many other manufacturing companies.

It should be noted that any project proposed at the Shawsheen River dams will need to include cultural resources review under Section 106 of the National Historic Preservation Act. The Section 106 review process involves coordination by a lead federal agency, and review of project plans by Mass Historic. Often, this process includes site investigation by a certified professional archeologist.

4.2. Geologic History

The Shawsheen River was formed during the advance and retreat of the last two continental ice sheets that covered New England toward the end of the Pleistocene. The current river channel has a total length of 25 miles with its headwaters at Hanscom Air Force Base in Bedford. From here, the river is joined by Elm Brook and Spring Brook, flowing then into the Pomps Pond is connected in parallel with the river in the Ballardvale area. Finally, the Shawsheen then passes over Marland Place Dam and Balmoral Dam, finally flowing into the Merrimack River.

Surficial geology – Throughout the entire 78 square miles (202 km^2) watershed of the Shawsheen, the surficial sediments consist of thick till and coarse stratified deposits primarily from the last late Wisconsinan Glaciation. As the Laurentide ice sheet retreated between 15,000 and 17,000 years ago, glacial sediments were deposited. Glacial lakes also formed as the ice sheet retreated, and glacial lake Merrimack was one of the larger lakes in the region, with smaller lakes forming in other river valleys. Though the Shawsheen River is south of the extent of glacial lake Merrimack, its bed and floodplain do have the interspersed fine and coarse grain sediment that is typical of large glacial lake deposits (Flanagan 1999). These deposits are generally less that 100 feet thick. Stratified till deposits are also found in Andover along with kames (Flanagan 1999). Underlying the surficial sediment is a more limited distribution of deposits from the Illinoisan Glaciation a thick till composed of non-sorted, non-stratified sand. The coarse, stratified deposits vary throughout, but are generally associated with grain sizes of fine sand or larger (Stone and Stone, 2006).

Soils - The banks of the river are comprised of rich sandy loam (Abbot 1829). Generalized soil surveys have found the soils in the area to have moderate to slow infiltration rates with moderately fine to moderately coarse textures (Flanagan 1999). More specifically, the NRCS describes the sediment around the Ballardvale Dam as coarser material, representative of glacial deposits in the watershed. Hinckley loamy sand, Deerfield loamy fine sand, and Hinckley and Windsor sands are the predominant soil types in this area, and are each comprised of around 78% sand in the grain size distribution. In addition to these deposits, the area bordering the downstream end of the dam consists of gravels and sands introduced as fill for development. Peat bogs and ponds drained into the Shawsheen River in Andover (Abbot 1829, Bailey 1880). These were at least partially drained for development or agriculture (Bailey 1880).

4.3. Existing landuse

Development has been a crucial component in watershed changes that have taken place in the watershed during the last half century. Since 1950, the population of the watershed has tripled, increasing to around 250,000 people (Shawsheen River Watershed Assessment Report, 2003). Increased impervious surface cover (roads, rooftops, driveways, parking lots) has altered the watershed hydrology. Prior to development, rainfall and snowmelt percolated into the ground and reached the Shawsheen River system slowly as cool groundwater flow (groundwater has a temperature of 45-50˚F). As impervious cover increases, more and more water is routed over hard surfaces, into drains, through storm sewers and directly into the river. This water is typically much warmer than groundwater, and reaches the river much more quickly than as groundwater. To demonstrate the significance this has played over time, compare the current baseflow (groundwater) contribution to the total annual stream flow (57%) to the pre-development contribution of 70%. Impervious effects cause more "flashy" flows and increased flooding, decrease the amount of water available between rainfall events. Recent surveys have found that the Shawsheen is significantly lacking in baseflow (Saravanapavan et al. 2000). Nineteen percent of the watershed is under impervious cover, which increases the rate and volume of runoff to the river and increases the severity of flooding (Herzfelder 2003).

The results of this phenomenon become apparent during large storms or during dry years such as the summers of 1995, 1999 and 2001 when the flows in the Shawsheen were extremely low. Although the Shawsheen is not considered a flashy river, the effect of impervious cover is most dramatic near the headwaters near Hanscom Air Force Base. In the 1940s when the base was first constructed, the Shawsheen was moved to an entirely different location on the base and channelized. Furthermore, the base significantly increased the impervious areas and changed the hydrologic balance of the area (Shawsheen River Watershed Assessment Report, 2003).

4.4. Existing Geomorphology

The three major dams on the Shawsheen River, the Balmoral, Marland Place and Ballardvale, are some of the most significant factors influencing the current geomorphic state of the river. In the Ballardvale Area, the Shawsheen River maintains a slope of less than 0.2%, but had a slope less than 0.001% prior to railroad berm construction. The river passes through a large, low gradient wetland complex upstream of Marland Place Dam between Andover Street and Central Street. From the upstream end of the Red Rocks Dam impoundment to the Main Street Bridge, the Shawsheen has a steeper slope of around 0.5% typical of gravel riffle and pool channels. From Main Street to approximately 1 mile downstream of Balmoral, the channel slope is less than .001%, typical of deep, steep banked wetland or tidal rivers. Historically, this channel would have been a groundwater dominated, cool-coldwater stream with a wide, regularly inundated floodplain forest. Such a system has a characteristically deep channel with steep banks and high sinuosity. Remnants of this type of channel are still present where floodplain filling has not occurred (Figure 1)

Figure 1. Remnant meander bends on the Shawsheen River

As the Marland Place and Ballardvale Dams degraded over time, regular maintenance schedules relaxed, and spillways were modified, their impoundment levels dropped. Changes in normal pool elevation can be observed by comparing historic maps and aerial photographs (for Marland Place see Figure 2 and for Ballardvale see Figure 3).

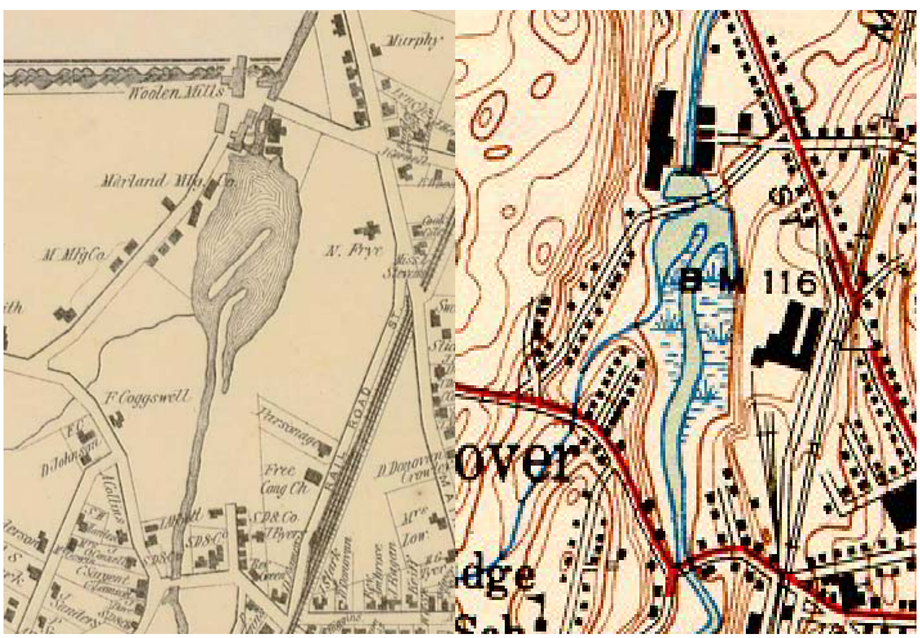


Figure 2. Comparison of Marland Place impoundment depicted in maps from 1872 (left)

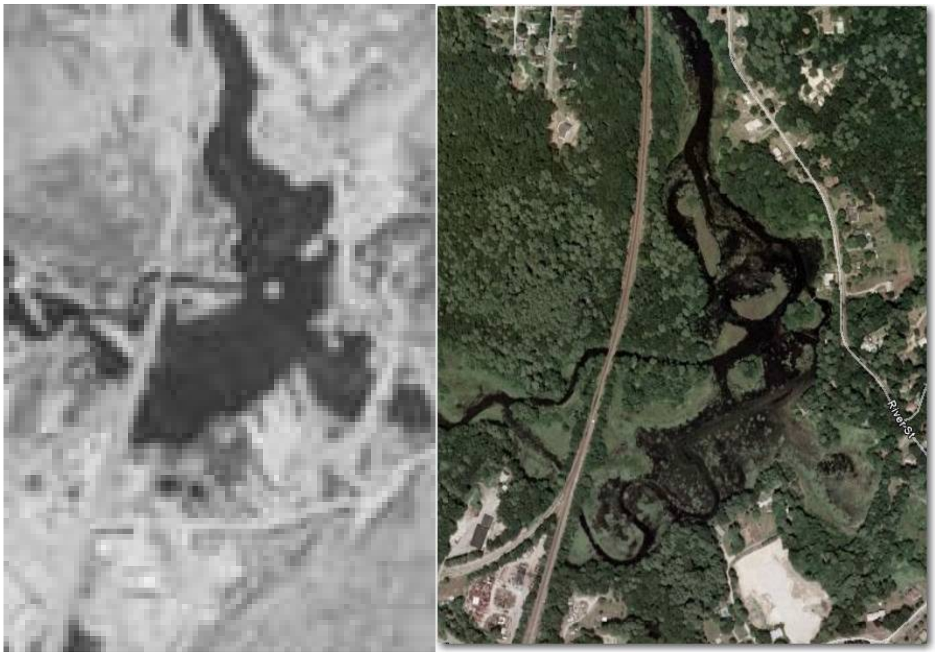


Figure 3. Comparison of Ballardvale impoundment water levels depicted in aerial photos from 1978 (left) and 2009 (right)

The construction and subsequent modification of the Boston and Maine railroad line truncated two significant meander bends and rerouted the river course upstream of Ballardvale Dam. The historic channel profile can still be seen by examining historic and recent aerial photographs (Figure 3). Sediment has accumulated on the upper end of the Ballardvale Reservoir, primarily beyond a point 3000 feet upstream of the dam. However, it is difficult to distinguish between historic floodplain sediment and accumulated sediment deposition due to the fact that the channel was dredged. Truncation of the channel following railroad berm construction cut off approximately 3,200 feet of meandering channel, thereby increasing the slope of the channel from approximately 0.009% to 0.2%, a dramatic change for this stream type. Further investigation will be undertaken to ascertain the possible impact of dam removal on the altered slope...

5. <u>Recommended Alternatives</u>

This report examines dam removal at the Balmoral, Marland Place and Ballardvale dams, and alternative fish passage at the Ballardvale dam. Initial results indicate that fish passage and river restoration through dam removal are technically feasible, and we offer a concept level design discussion of the recommended alternatives. The sections below outline the existing conditions (as assessed to date) and conceptual design approaches for each dam.

5.1. Balmoral Dam

5.1.1. Existing Conditions (Balmoral)

Figure 4. Balmoral Dam looking west toward the Bowling Green

The Balmoral Dam is a solid concrete dam with a stepped arch spillway height of 6.8 ft spanning 50 feet between confining concrete walls (Figure 4). The spillway is a stepped profile with seven (7) drops of 1-ft each spaced 18 inches apart (1.5H : 1.0V – See Figure 5). just downstream of Balmoral Street in Andover, MA. Existing Flood Insurance Study (FIS) and project hydraulic modeling information shows that low flow backwater conditions persist to approximately 1500 feet downstream of the Marland Place dam (4300 feet upstream, 4.0 acres). During the 10-year flood, as modeled in the FIS, water backs up to the Marland Place Dam. It is assumed that the dam has some impact on upstream groundwater and wetland conditions up to the Marland Place Dam.

The floodplain near the dam has been filled historically, with the left floodplain occupied by the historic Bowling Green and the right occupied by the Balmoral Condominium building. Two road crossings bound the dam 170 feet upstream (Balmoral Street) and 67 feet downstream (Haverhill Street), and may influence water surface elevations during high flow periods.

Depth of refusal surveying indicates that the impoundment contains a maximum of 2100 cubic yards of deposited sediment consisting primarily of sand.

5.1.2. Dam structure (Balmoral)

The Balmoral Dam is constructed of solid concrete, likely reinforced according to the standards of the time. Construction plans dated June 10, 1920 show a stepped concrete spillway and embedment into the channel bed approximately 1.5 feet. The drawing suggests a stone apron on the downstream toe (Figure 5). The National ID Number for Balmoral Dam is MA00179 and the name assigned to the dam in the Massachusetts Department of Conservation and Recreation (DCR) DamViewer database is *Brothers of the Sacred Heart Dam*. The dam is considered an Intermediate Size, Low Hazard dam.

The dam appears to be in fair to good condition, but no detailed structural probing was completed. Due to the conceptual nature of this project phase, no diving, structural analysis or borings were performed. During ensuing engineering stages, temporary water routing will be installed to allow for dry inspection of the dam surface, and borings will be taken in the dam face and in adjacent soils to verify construction assumptions.

5.1.3. Flooding (Balmoral)

The Balmoral Dam does contribute to increased water levels upstream of the dam during frequent, smaller storm events (up to the 50-year flood). Floods larger than the 50-year event are influenced by backwater from the Merrimack River and also the downstream road crossings. During events larger than the 100-year flood, any hydraulic effect of the Balmoral Dam is completely drowned out by downstream hydraulic controls caused by bridges and the water level of the Merrimack River (Figure 6).

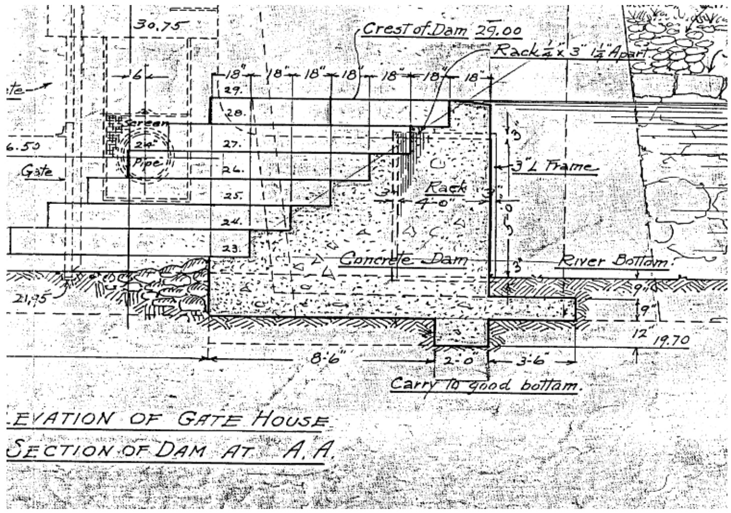


Figure 5. Cross section of the Balmoral Dam proposed design plan (American Woolen Mills Co. 1920)

5.1.4. Recommended Alternative (Dam Removal)

Removal of the Balmoral Dam is a technically feasible alternative for the following reasons:

- Removal will have only a minor affect on depth and will cause only minimal change to the natural aesthetics of the river upstream of the dam
- The site is accessible during construction
- Removal will not have a long term impact on nearby infrastructure (bridges, roads, buildings)
- Removal will likely have only marginal effects on upstream wetlands
- The dam has no flood control benefit

Dam removal would also fulfill the fish and canoe passage performance criteria for the project, and could potentially address many of the public outreach goals. Dam removal would result in passage for diadromous fish (alewife, blueback herring, rainbow smelt, American eel) and other species (eg. amphibians), free flowing conditions, lower water temperatures, and increased dissolved oxygen concentrations (Bednarek, A. 2001, Maclin and Sicchio 1999). The riparian restoration and habitat criteria would not be maximized immediately with simple dam removal, but could be realized with long-term in-stream habitat restoration and riparian management upstream of the Balmoral Street bridge. We have shown a conceptual photo rendering of the removal assuming that the concrete structure could be cut flush with the vertical walls and channel bottom (Appendix B). This would allow

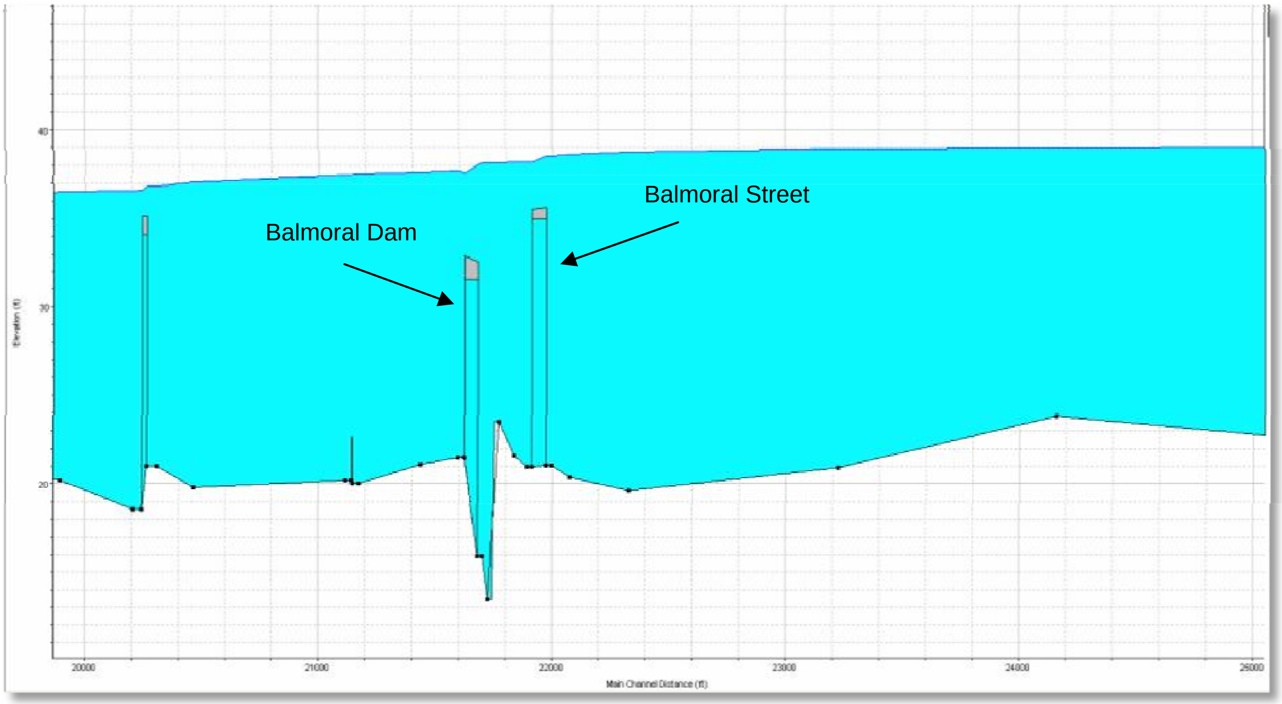


Figure 6 – This hydraulic model output shows the river flowing right to left. The channel bottom is the black line under the blue shaded area. The blue shaded area is the Shawsheen River level during the 100-year flood. The water elevation during this flood is 2-3 feet above Balmoral Street and 5-6 feet above the dam crest. The effect of the Balmoral Dam on large flooding is minimal.

for minimal construction costs while still achieving fish passage objectives. Unless the masonry walls are removed and a more natural riparian area established, habitat restoration options are limited to in-channel riffle and pool construction. Given the location of the historic Bowling Green (left bank) and the building (right bank), we assume that natural bank restoration is not a viable option.

Removal of the Balmoral dam would also remove dam owner liability and public safety concerns by minimizing the risk of injury and eliminating the risk of flooding due to dam failure. Although these were not cited as major performance criteria, they are important for every dam.

Notes on the 30% Plansheets – The 30% plansheets show a simple dam in versus dam out drawing. Site access is good at the Balmoral dam site, although some temporary access ramps may need to be installed to protect historic walls along access points from Main Street or Balmoral Street. Equipment could stage in the Bowling Green area, with any disturbance being restored after completion of the project (Figure 7). This could be an opportunity to both serve the project and provide needed reseeding of the Green. The left bank concrete wall could be cut down 4-5 feet to allow for temporary access. A construction pad of porous cobble or concrete box culverts could be installed to minimize equipment contact with the active channel. The dam would be notched and flow concentrated into a small breach. If the flume along the right bank is operable, this could also be used to help dewater the dam site. Once a breach is complete, the dam/wall interface would be isolated and vertical cuts made in the dam. Dewatering strategies will depend on the method of removal. The methods used in removal (eg. jackhammer, sawcutting, excavation in the channel) will depend in part on materials encountered in the geotechnical borings, noise concerns, bridge loads and other factors determined during final design.

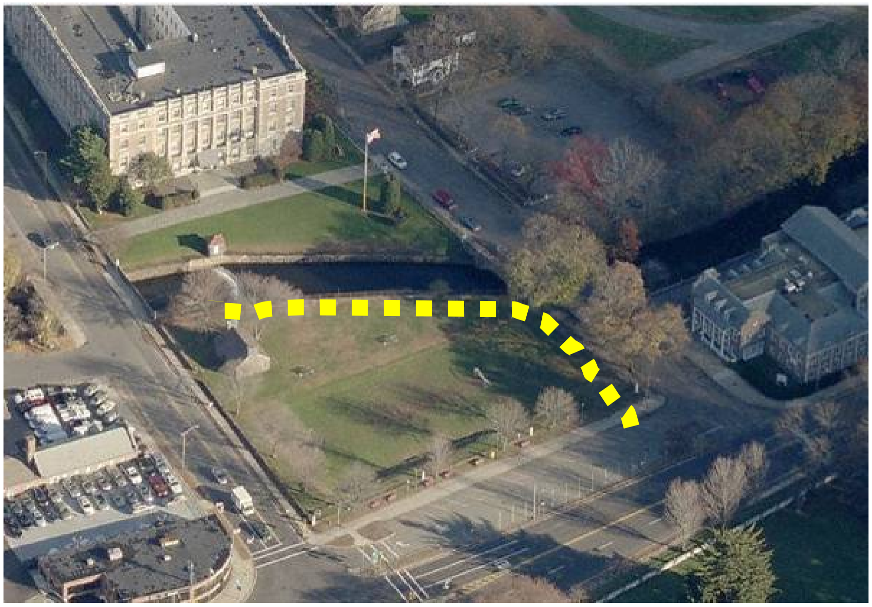


Figure 7. Primary access route proposed for ingress and egress of heavy equipment for the removal of the Balmoral Dam.

The plansheets show a cobble and boulder riffle installed at the dam location. The dam has acted as a grade control for many years, although there appears to be no significant incision occurring at the downstream face. Replacing the dam with a stable riffle will prevent the upstream migration of any incision caused by changes in bed elevation downstream. These changes could be caused by replacement of the Haverhill or Balmoral Street bridges, changes to the railroad berm downstream or other hydraulic controls. It is a prudent measure in a confined channel with concentrated flood flows that could cause post-removal scour. The riffle proposed would only have a crest elevation 1-1.5 feet higher than the existing bed (slope <1.0%), and so would appear to be a submerged riffle passable by canoes and kayaks. The site is currently a popular viewing area for people watching smelt and herring attempt to jump over the dam. An installed riffle will continue to concentrate people and allow them to experience first hand successful fish migration. Interpretive signs could be placed to educate the public about the benefits of dam removal. The installed riffle would have an appearance similar to the riffle shown in Figure 8, installed by Inter-Fluve to control grade and provide habitat in Town Brook, Plymouth, MA.

Cost – We estimate the total cost of removal of the Balmoral Dam to be $217,000 if sediment can be allowed to transport naturally downstream. Detailed cost breakdowns can be found in Appendix C.

5.1.5. Sediment Management

Figure 8. Constructed riffle on Town Brook, Plymouth

Sediment testing data for the Balmoral impoundment screening sample indicates a relatively low concentration (below the Probable Effects Concentration (PEC)) of petroleum hydrocarbons, PCBs (Arochlor 1254 only), barium, copper, lead, zinc and mercury. The PEC is a threshold used by state and federal regulatory agencies to measure probable biological effects. It is one of many such thresholds used and does not necessarily equate to any human effects concentration. The sample was positive for 15 of 17 tested polyaromatic hydrocarbons (PAH), with a total PAH concentration (23.1 mg/Kg) just above the Probable Effects Concentration of 22.8 mg/Kg as posted in Merrill (2003). This summary includes only one sample for 2000 cubic yards of sediment, and should be interpreted accordingly. Further analysis of sediment within the impoundment is planned in the next phase of the project, and will include more extensive sampling to more accurately determine the amount and distribution of contaminants.

Barring major contamination issues, Inter-Fluve recommends that if dam removal is pursued, that the sediment upstream of Balmoral Dam be allowed to transport naturally downstream. The dam is small (7 ft) and extremely large recent floods (eg. 2006) could have transported any impounded sediment downstream. It is possible that the sediments currently found in the impoundment were deposited in 2006 or during other recent floods. Further hydraulic analysis could investigate this likelihood under various flood scenarios.

5.1.6. Fish Passage Alternatives

A rock riffle/ramp is likely not feasible due to the close proximity of the downstream crossing and the possible need for filling within the culvert. Such filling would reduce the hydraulic capacity of the culvert and could worsen local flooding. Partial removal does not make sense because of the dam's small size and low head drop. Any benefit of partial removal would not justify the expense since full removal would be comparable in price. Given the nearby road and floodplain infrastructure, a natural bypass channel is also not feasible. We recommend removal and restoration at the Balmoral site.

5.2. Marland Place Dam

5.2.1. Existing Conditions

The Marland Place Dam is a run of river dam with a currently uncontrolled rock masonry spillway (85 feet in length) spanning concrete and masonry walls just downstream of Stevens Street in Andover, MA. The dam has a vertical drop of approximately 9.5 feet and at low flow, impounds water approximately 2,600 feet upstream (2.38 acres). Existing FIS information shows that low flow backwater conditions persist upstream of Marland Place Dam to the base of the riffle at the former Red Rocks dam site. The 10-year flood, as modeled in the FIS and in HEC-RAS, backs up to approximately 1,500 feet upstream of the Red Rocks Dam. It is assumed that the dam has some impact on upstream groundwater and wetland conditions upstream, but these impacts do not extend upstream of the former Red Rocks Dam site. The floodplain downstream of the Marland Place dam has been filled and buildings encroach to the edge of the walled channel. There is a control structure on the right bank that has not been serviced since 1998, but may still be functional. The left bank powerhouse penstock is no longer functional. Fay (2007) reports that water from the impoundment or in the appurtenant dam structures (penstock, old raceway) is not affecting basement flooding in the Atria facility (left bank).

Depth of refusal surveying indicates that the impoundment contains approximately 8,500 cubic yards of deposited sediment in the active channel (See the concept plans for a map of this sediment extent). This sediment consists primarily of sand and silt. Vegetated bars within 1200 feet upstream of the dam on the left and right banks may contain as much as 35,000 cubic yards of sediment deposited in the impoundment (legacy sediment) that has now become the active floodplain. Further soils investigation (borings) will be required to determine the nature of these sediments and the exact amount of post dam deposition versus historic floodplain. The thalweg of the channel is regularly scoured and hard substrate was observed just upstream of the dam. Just upstream of Stevens Street, deposited sediment has formed an extensive bar along the left bank. Analysis of historic aerial photos and maps suggest that the vegetated island upstream of Stevens has been in place for at least 150 years. It may be a post-dam construction artifact caused by deposition from an extremely large flood event, or it could be a glacial feature that was present prior to any dam construction. Additional borings in this area will be required to determine the depth of impounded sediment versus historic floodplain elevations.

5.2.2. Dam structure (Marland)

The Weston and Sampson report (2009) and the Fay Engineering report (2007) provide a good description of the Marland Place Dam spillway and abutments. The dam is composed of left and right concrete and dry masonry abutments, an uncapped spillway with a 1:1 rock face. The dam spillway is a rock-filled timber crib with a bottom width of 25 feet and a top width of 18 feet. The right abutment has a timber lift gate 65.5 inches wide by 90 inches deep, with an invert approximately 5.5 feet below the dam crest.

Former supporting piers in the fore-bay area are still visible upstream of the dam on the left bank and an abandoned penstock structure occupies the left bank just downstream of the dam. Any former penstock routes through the building or raceway returns to the river have been blocked (Fay 2007b). As mentioned in the Fay report, the small control structure (gate operator) on the right abutment diverted water to power generating stations inside the former mill buildings on the right bank. This structure may be operational, but hasn't been used in several years.

The National ID Number for Marland Place Dam is MA01215 and the name assigned to the dam in the DCR DamViewer database is Shawsheen River Dam. The dam is considered a Large Size, Significant Hazard dam.

Our study did not specifically address the structural integrity of the dam (Appendix A - Weston & Sampson Technical Memorandum). The Weston & Sampson Inspection/Evaluation Report (1998) lists the dam as being in poor to fair condition, although the spillway under water was not closely examined and the rating is admittedly conservative. Fay (2007) noted that the dam was in "fair condition with the general concern/observations including overgrowth of vegetation on both abutments and the necessity for repairs to the top of the spillway crest". Fay estimated the cost of repairing the spillway, developing an emergency action plan, and managing vegetation at the site to cost $131,000 including engineering fees.

5.2.3. Flooding (Marland)

The water level in the Marland Place Dam has no flood control benefit. Analysis of FEMA flood profiles (FEMA 1993, URS 2008) and HEC-RAS generated flood profiles suggests that the Marland Place Dam does contribute significantly to increased water levels upstream to Essex Street. This effect is visible for both small and large events up to at least the 500-year flood (Figure 9).

5.2.4. Recommended Alternative – Marland (Removal)

Removal of the Marland Place Dam is technically feasible for the following reasons:

- Removal will have only a minor affect on depth and will cause only minimal change to the natural character of the river upstream of the dam
- The site has reasonable construction access
- Removal will have little or no impact to adjacent building foundations.
- Removal may require only minor shoring of the Steven Street and Essex Street bridge crossings.
- Removal will likely have only marginal effects on upstream wetlands, resulting in a change in wetland type along the riparian corridor.

- The dam has no flood control benefit.

Removal of the Marland Place Dam will also fulfill the fish and canoe passage performance criteria for the project and can serve as a focal point for community environmental education. As described in the Balmoral segment above, dam removal would result in passage, free flowing conditions, restored stream habitat, lower water temperatures, and increased dissolved oxygen concentrations. Some riparian restoration and in-stream habitat could also be achieved upstream of the Marland Place dam. We have shown a conceptual photo rendering of the removal assuming that the concrete structure could be removed and the adjacent supporting walls left in place. (Appendix B). Because the dam is integrated into the adjacent buildings and walls, removal at this site should involve leaving the dam abutments fully in place and removal of the spillway to grade. If proper shoring of the bridge abutments is completed, removal of the Marland Place Dam should have no impact on the stability of the Stevens Street Bridge, as the channel is currently scoured to the original channel bottom at this location. Initial hydraulic modeling suggests that the water surface slope (energy gradeline) at Essex Street will increase following removal of the Marland Place Dam. Final design may include additional shoring (riprap or other method) of the Essex Street crossing. Further investigation in Phase 2 will confirm assumptions about the bridges, and Inter-Fluve will work with the Town of Andover to develop an acceptable stabilization plan that protects the bridges from undermining.

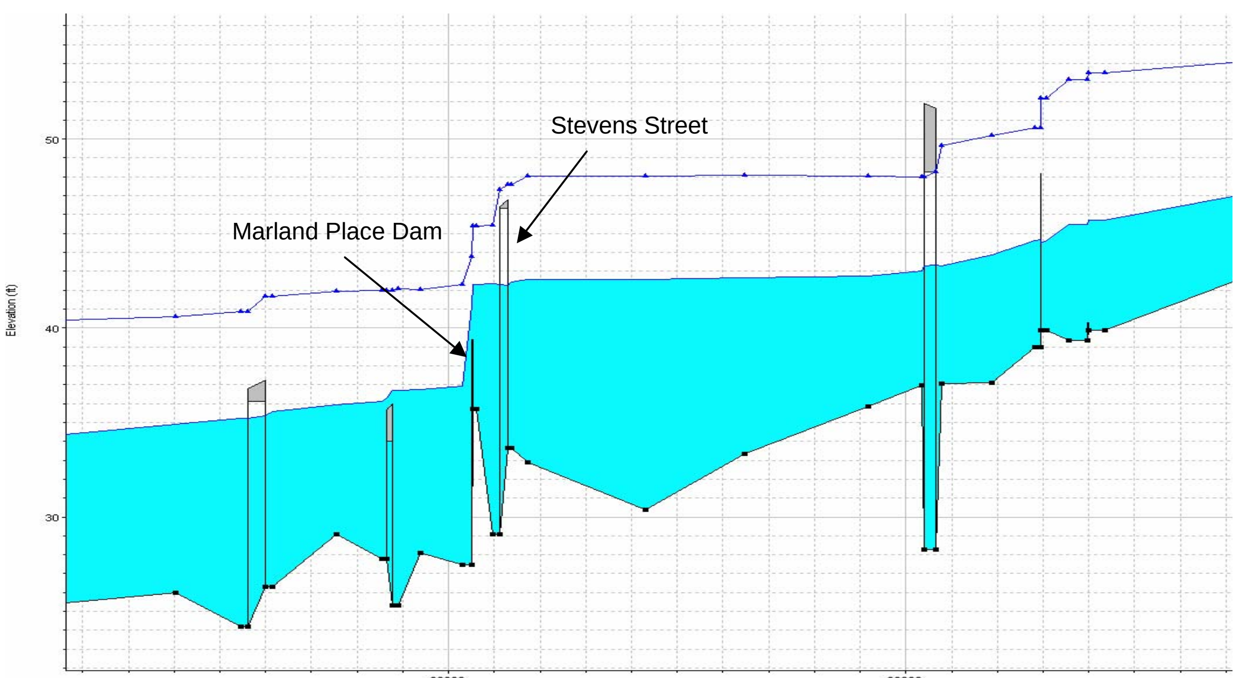


Figure 9 – This hydraulic model output shows the river flowing right to left. The channel bottom is the black line under the blue shaded area. The blue shaded area is the Shawsheen River level during the 2-year flood. The blue line above is the 500-year flood elevation. These preliminary results show that the Marland Place Dam does cause a 5 ft rise in upstream flood elevations for the 2-year flood, and a 2-3 foot rise in the 500-year flood. Removal in this case would help to decrease upstream flood levels.

Unless the masonry walls downstream are removed and a more natural riparian area established, habitat restoration options are limited to in-channel riffle and pool construction. Natural bank restoration is possible at this site, but would involve cooperation with landowners on both banks. We have not depicted any downstream riparian improvements beyond the immediate damsite.

Removal of the Marland Place dam would also remove dam owner liability and public safety concerns by minimizing the risk of injury, and eliminating the risk of flooding due to dam failure. Although these were not cited as major performance criteria, they are important for each of the Shawsheen River Dams.

Notes on the 30% Plansheets – The most practical access to the Marland Place Dam is from the asphalt walk path on the right bank just downstream of the structure (Figure 10). Alternate access could be gained from the parking lot area on the left bank, but this would require heavy equipment crossing the concrete bridge. Any access and staging areas would be repaired to their original pre-construction condition. A construction access pad would need to be constructed along either bank leading up to the structure. The access pad may not need to be extensive, as the channel has a gravel and cobble bed that is currently armored and stable. The control gate on the right side of the dam could be used to partially dewater the structure and allow for full breaching. We recommend staged drawdown of the impoundment to minimize sediment transport downstream. The rock and timber crib structure would then be disassembled and loaded onto trucks. If deemed suitable (eg., native, partially rounded stone of sufficient size), rocks from the dam face could also be incorporated into post-removal in-stream habitat.

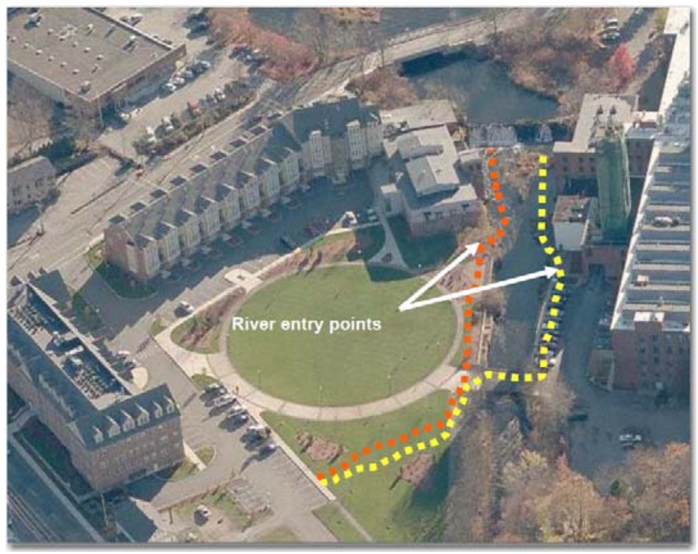


Figure 10. Potential primary (orange) and secondary (yellow) access for the Marland Place Dam removal. White arrows indicate river entry areas requiring temporary access ramp construction.

Given that the dam span is considerably wider than the active channel in adjacent river segments, it is recommended that the dam abutments be left in place to provide long-term structural stability. Our concept plans show construction of streambanks with armored toe protection to prevent substantial channel migration. Adjacent wetland areas could be slightly modified to capture site stormwater as shown, thereby keeping them wet for longer periods and providing some infiltration (and subsequent cooling) of rain water during summer storms. Traditional design would render these areas as upland features. These rain garden or infiltration wetland designs demonstrate how additional ecological benefits beyond dam removal can be gained by simple incorporation of green design elements.

Our concept design plan suggests the construction of a grade controlling riffle structure. This riffle would appear similar to that shown in Figure 8. The dam has acted as a grade control and has created hydraulic backwater through the Stevens Street crossing for many years, limiting scour. Replacing the dam with a stable riffle will prevent the upstream migration of any incision caused by changes in bed elevation downstream. Riffle construction and other habitat construction is often part of post-removal, and in this case will not impound sediment. These changes could be caused by replacement of the Main Street bridge, removal of the Balmoral Dam (changing hydraulics), or other hydraulic controls. It is a prudent measure to prevent excessive scour or bed degradation in an area with a high density of infrastructure, upstream bridges and confined flood flows. The riffle proposed would only have a crest elevation 1-1.5 feet higher than the existing bed (slope <1.0%), and so would appear as a submerged riffle. The riffle will be passable by canoes and kayaks.

The riffle would also provide a falling water aesthetic important to local residents, and would be an excellent location for watching migrating fish. Such focal points are opportunities to concentrate people and educate them regarding the local and historic importance of migratory fish passage.

Cost – We estimate the total cost of removal of the Marland Place Dam to be $374,000 if sediment can be allowed to transport naturally downstream. Detailed cost breakdowns can be found in Appendix C.

5.2.5. Sediment Management

Sediment Quality - Sediment testing data for the Marland Place impoundment screening samples indicates a relatively low concentration (below the Probable Effects Concentration) of petroleum hydrocarbons, phenols, barium, copper, lead, and zinc. The lower impoundment sample was positive for all 17 tested polyaromatic hydrocarbons (PAH), with a total PAH concentration (9.85 mg/Kg) well below the Probable Effects Concentration of 22.8 mg/Kg as posted in Merrill (2003). PAHs are common in impoundment sediments and can come from a variety of sources including atmospheric deposition, industrial effluent and road runoff. Some of the individual PAH compounds have values of concern above published thresholds (Merrill 2003) and justify further testing. PCBs or mercury, which often trigger more stringent disposal or treatment regulations, were not detected in either the upper or lower impoundment samples. Further analysis of these data and additional sampling is planned in the next phase of the project.

Given the screening sample results and the small volume of impounded sediment upstream, we recommend that the dam be removed and the sediment be allowed to transport naturally downstream. Further refinement of sediment volume, transport fates and contaminant levels is recommended in the next phase of the project.

5.2.6. Fish Passage Alternatives

A rock riffle/ramp is not technically feasible due to the encroached floodplain and masonry walls downstream. There would be increased risk of flooding in the immediate area if a rock ramp was installed. Partial removal is not recommended due to the high preparation and mobilization costs required to access the site. Given the adjacent structures, a natural bypass channel is also not feasible.

A fish ladder could provide some passage, but there is a greater cost versus benefit ratio for removal in this case. A fish ladder would require significant costly improvements to the structure. Fay (2007) estimates construction of a spillway cap alone to cost well over $100,000.

Removal would ensure passage of a wide variety of species, including elvers (juvenile eels), and would restore passage to over two miles of free flowing river. We recommend removal at the Marland Place site.

5.3. Ballardvale Dam

5.3.1. Existing Conditions (Ballardvale)

The Ballardvale Dam is a run of river dam with a concrete masonry spillway (85 feet in length) spanning concrete masonry walls just downstream of Andover Street in the Ballardvale area south of Andover, MA. Interfluve survey data suggests that the dam has a vertical drop of approximately 9.5 feet. FIS data shows a practical dam height of 13 feet over an assumed pre-dam channel bottom. This discrepancy could be due to the removal of flash boards between surveys. In this model, the dam impounds water approximately 15,000 feet upstream at low flow. Under current conditions, the most significant apparent impoundment effects occur within 4,000 - 5,000 feet of the dam, and floods periodically backwater approximately 60 acres of active channel, floodplain wetlands and abandoned channel segments. The floodplain near the dam structure has been filled historically, with the left floodplain occupied by the mill building complex and parking lot and the right occupied by the Shawsheen Coating and Converting building.

With flashboards formerly in place, the Ballardvale impoundment was significantly larger than the downstream impoundments. Depth of refusal surveying in the abandoned channel area indicates that the former impoundment contained as much as 120,000 cubic yards of deposited sediment consisting primarily of sand. Depth of refusal data however, does not distinguish between historic floodplain and wetland soils, and historic channel. Much of the depth of refusal area examined is off-line from the current channel location and would not be mobilized in a removal scenario. There is approximately 4,000 – 8,000 cubic yards of sand potentially mobile in the active channel. In future phases of the project, the impact of letting sediments migrate downstream will be examined, and weighed against mechanical removal of sediment or management in some alternative way.

5.3.2. Dam Removal Alternative (Ballardvale)

Removal of the Ballardvale Dam is technically feasible for the following reasons:

- The dam is partially drawn down
- The site has reasonable construction access
- Removal will need have no impact to adjacent building foundations
- Removal will not have a long term impact on nearby infrastructure (bridges, roads)
- Removal will likely have only marginal effects on upstream wetlands, resulting in a change in wetland type along the riparian corridor
- The dam has no flood control benefit

Removal will also fulfill the fish and canoe passage performance criteria for the project, and could potentially address many of the public outreach goals. As described in the Balmoral and Marland Place segments above, dam removal would result in passage, free flowing conditions, restored stream habitat, lower water temperatures, and increased dissolved oxygen concentrations. Significant riparian restoration and in-stream habitat could also be achieved upstream of the Ballardvale Dam . We have shown a conceptual photo rendering of the removal assuming that the concrete structure could be cut flush with the vertical walls and channel bottom (Figure 3). This would allow for minimal construction costs while still achieving fish passage objectives. Unless the masonry walls downstream are removed and a more natural riparian area established, habitat restoration options downstream of the dam are limited to in-channel riffle and pool construction. Given the location of

Figure 11. Wetland area formerly pond area along the tributary leading from Fosters Pond to the Ballardvale impoundment (2009).

the parking lot and building (left bank) and the right bank structures, we assume that natural bank restoration is not a viable option for this area.

Removal of the Ballardvale dam would also remove dam owner liability and public safety concerns by minimizing the risk of injury, and eliminating the risk of flooding due to dam failure. Although these were not cited as major performance criteria, they are important for every dam.

As mentioned in the geomorphology section, railroad berm construction altered the planform of the river and routed the main flow through a single arch bridge upstream of Ballardvale Dam. One concern is that a drop in channel bottom elevation caused by dam removal will now translate through a much shorter distance than if the original channel was still active. Following removal, fine sand in the channel will erode downstream and the active channel would continue to flow through the arch bridge. Unless the river was modified to re-occupy the old meander bends, they would become off-channel oxbow wetlands, subject to regular inundation during floods. Post-removal conversion of pond to seasonally inundated floodplain is shown by examining other segments of the upper Ballardvale Pond that have changed following removal of flashboards. Many of these former pond areas are now seasonal wetlands (Figure 11). It is clear that residents along Lowell Junction Road and on River Road south of Hillcrest Avenue have seen the shoreline change in recent years, limiting their access to the active channel. Dam removal will not significantly alter the channel planform more than what is shown in Figure 3 (current scenario), but water levels will decrease slightly over current. However, this is a low gradient wetland stream channel, and the resulting channel should have a narrow and deep cross-section, and thus an adequate depth for canoeing and kayaking except during unusually dry periods. It would be possible to construct a railroad crossing and reconnect the main channel with the abandoned segments. The current railroad crossing could then serve as a floodplain culvert and secondary channel only.

Notes on the 30% Plansheets – The most practical access to the Ballardvale Dam is from the rear of the right bank buildings (Shawsheen Coating and Converting). Adequate staging area can be found along the road behind the buildings. Additional alternative access could be gained from the right bank

Figure 12. Primary (orange) and secondary (yellow) access routes for construction at the Ballardvale Dam site

upstream of the dam, and from the parking lot on the left bank downstream of the dam (Figure 12). Any access and staging areas would be repaired to their original pre-construction condition. A construction access pad would need to be constructed along either bank leading up to the structure.

We recommend staged drawdown of the impoundment to minimize sediment transport downstream. The dam structure would then be disassembled and material loaded on to trucks. If suitable, rocks from the dam face could also be incorporated into post-removal in-stream habitat. Given that the dam span is considerably wider than the active channel in adjacent river segments, full removal of the abutments is not necessary. It is recommended that the dam abutments be left in place to provide long-term structural stability. Our concept plans show construction of streambanks with armored toe protection to prevent substantial channel migration. Adjacent wetland areas could be slightly modified to capture site stormwater as shown, thereby keeping them wet for longer periods and providing some infiltration (and subsequent cooling) of rain water during summer storms. Traditional design would render these areas as upland features. As with the Marland Dam site, these rain garden or infiltration wetland designs demonstrate how additional ecological benefits beyond dam removal can be gained by incorporation of green design elements.

Our concept design plan suggests the construction of a grade controlling riffle structure. This riffle would appear similar to that shown in Figure 8. The dam acts as a grade control and has created hydraulic backwater through the Andover Street crossing, limiting scour. Replacing the dam with a stable riffle will prevent the upstream migration of any incision caused by changes in bed elevation downstream. It is a prudent measure in an area with adjacent buildings, parking lots and a major road crossing. The riffle proposed would only have a crest elevation 1-1.5 feet higher than the existing bed (slope <1.0%). The riffle will be passable as a Class I rapid by canoes and kayaks except during low flows. We believe that this riffle would be a natural feature and a welcome change from the existing aesthetic, particularly during low flow (see Figure 13).

Figure 13. Angular boulders and loose stones visible during lowflow at the Ballardvale Dam site (looking east)

Cost – We estimate the total cost of

removal of the Ballardvale Dam to be $399,000 if sediment can be allowed to transport naturally downstream. Detailed cost breakdowns can be found in Appendix C.

5.3.3. Sediment Management (Ballardvale)

Screening level contaminant sampling was conducted in the Ballardvale impoundment in 2005. Four core samples were tested for priority pollutant metals, and hydrocarbons. No pollutants were found in excess of thresholds that would indicate special handling of sediments is needed. The next phase of the project will include more extensive sampling of the Ballardvale impoundment. The impoundment sediments encountered in the active channel are primarily sand and the likelihood of significant contamination is thus lower than for finer sediments.

The exact nature of sediment management will depend on the proposed project and the predicted final channel configuration. If dam removal is implemented the current active channel planform is used, sediment movement following dam removal would be minimal (4,000 – 8,000 CY) relative to the size of the impoundment. Under this scenario, Inter-Fluve would recommend allowing the impounded sediment to move naturally through the system.

5.3.4. Fish Passage Alternatives (Ballardvale)

A rock riffle/ramp or a ramp combined with partial removal is likely not feasible due to the low bank profile on the left bank. Further hydraulic analysis is required to test this hypothesis. Given the nearby floodplain infrastructure, a natural bypass channel is also not feasible.

Inter-Fluve examined removal of the dam and replacement with a long cascading channel segment (See 30% Plans). This is similar to a rock ramp concept, but involves reconstructing the subsurface geology of the reach, creating a permanent base and building a new channel on top of that base. This channel would be a boulder dominated step-pool channel and would allow for fish passage.

A Denil fish ladder could be constructed on the right embankment. Fish passage funding for any ladder scenario would probably require first repair or replacement of the dam structure. Fish passage funding sources do not typically fund dam repair or replacement. Because of the high cost of repair associated with a fish ladder, we believe that dam removal is the only practical

Figure 14. Former impoundment sediment exposed after failure and partial removal of the Redman Cloth Dam on the Shawsheen River (photo 2008)

feasible restoration alternative at the Ballardvale site.

5.4. Redman Card Clothing Company (Red Rocks) Dam Remnant

Interviews with watershed residents and the current occupants of the Redman Card Clothing Company (Red Rocks) Dam suggest that the dam was breached sometime around 1973, and the structure was further eroded following the 2006 flood (URS 2008). A rock riffle remnant of the dam still remains, and impounds water a few hundred feet upstream. Exposed banks in legacy sediments upstream clearly show the sedimentation patterns and erosion typical of a rapid drawdown removal (Figure 14). A significant amount of the Marland Place dam sediment may have come from this removal. The floodplain upstream also demonstrates the slow recovery of floodplain conditions in legacy sediments. Reed canarygrass dominates the floodplain and is preventing woody species from colonizing the area.

The current rock riffle is steep and presents a navigation hazard to boaters (Figure 15). According to local recreationists, the rock riffle is a safety hazard for two reasons; segments of the dam are blocking the channel, and the hydraulics tend to guide boats toward an old powerhouse sluiceway under the right bank building. We recommend blockage of the sluiceway, removal of an additional 8-15 feet of remnant dam and reconstruction of the riffle remnant to improve fish passage and canoe conditions. Riffle reconfiguration could be accomplished with a medium-sized excavator (eg. CAT 315) equipped with a hydraulic thumb. Individual stones could be moved and placed to direct water into a more gradual slope. Riffle reconfiguration would likely require importing 25-50 cubic yards of boulders and cobbles. Additional riparian restoration could include grading of impoundment area bank slopes, peeling of reed canarygrass dominated soils, placement of topsoil and planting with native riparian tree species. Restoration and replanting

Figure 15. Remnant of the Red Rocks Dam

Figure 16. Remnant of the Unnamed Dam downstream of Haverhill Street (photo 2008).

of the riparian zone can cool the stream through shading, reduce sediment inputs by minimizing bank erosion, provide habitat and improve water quality by filtering nutrients.

Costs – We estimate the cost of riffle reconstruction to be approximately $50,000-70,000. Grading of soils to stabilize banks and control exotic vegetation could vary in cost from $4 to $8 per cubic yard depending on how much soil is removed and where it was disposed.

5.5. Unnamed Dam Remnant

The unnamed dam is 613 feet downstream of the Balmoral dam. All that remains of this dam are 1-2 feet of boards held in place by rebar rods (Figure 16). There is no significant sediment deposit upstream of this dam. The dam remnant is a hazard to paddlers and may pose an obstruction to migratory fish under low flow conditions. We recommend removal of the boards and rebar using manual labor. No other work is necessary at this site.

6. Next Steps

6.1. Advanced feasibility

The next phase of the project will include the following aspects:

- **Hydrology and Hydraulics**
    - Verification of model data
    - Detailed hydraulic modeling of proposed scenarios
    - Analysis of pre- and post- removal flood impacts
    - Investigate sediment transport conditions under the current dam profile

- **Sediment management**
    - Sediment Sampling Plan (SSP) development
    - Additional sampling and testing
    - Sediment Management Plan (SMP) development

- **Cultural Resources**
    - Historical and archeological permitting initiation (Section 106)

- **Structural Engineering**
    - Detailed structural inspections
    - Soil and structural borings
    - Review of bridge inspections

- **Geomorphology**
    - Detailed investigation of upstream wetland impacts
    - Investigation of slope changes due to railroad berm construction

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