Water Treatment Intake and Fish Barrier Design in Mountainous Streams

Avneet Button, Wood Environment and Infrastructure Solutions, Canada
Daniel Mackle, Wood Environment and Infrastructure Solutions, Canada
Matthew Graham, Wood Environment and Infrastructure Solutions, Canada
Hooman Mahjoobi, Wood Environment and Infrastructure Solutions, Canada

Abstract

As part of a new mine water treatment project in the Elk Valley, British Columbia, Wood is designing an intake structure and fish barrier in a steep, mountainous creek (herein referred to as the creek). The purpose of the intake is to draw mine-affected water and replace it with treated water, prior to discharging to the environment. A multi-criteria options analysis was conducted to assist with selection of a design option that is easily constructible, offers ease of operations, is economical and facilitates environmental enhancement. An options analysis for a fish barrier design was also conducted considering ecologically sensitive fish species, including Westslope Cutthroat Trout (WSCT).

Five different intake options were investigated including infiltration gallery, precast concrete pump well, self-priming pumps, floating barge pump and new intake downstream of the pond. The treated water is returned immediately downstream of the intake location. An options analysis matrix was compiled to assess each intake / outfall option based on the project criteria. The mining company is in the process of reviewing the options analysis with project stakeholders.

A desktop literature review was completed to understand the mobility of WSCT in order to guide the design of the fish barrier. The following considerations were investigated for fish barrier design: leaping ability; burst speed; minimum water depth requirements; and water turbulence. Due to the remote nature of the site, the following low-maintenance physical fish barriers were considered: drop structure; chute; and pipe. The fish barrier will be constructed downstream of the selected intake location.

This paper will highlight the key considerations for the intake / outfall and fish barrier options appraisal and design. In addition, this paper will discuss key design constraints related to construction and operation in remote settings surrounded by environmentally sensitive habitat. Furthermore, the paper will provide a summary of sustainability measures including indigenous engagement and practices to limit impacts to the environment during the execution of the works.

Introduction

There are several steelmaking coal mines in southeastern BC, Canada that have been in operation since the 1960's (Ministry of Energy and Mines, 2015). To access the coal, large quantities of rock are mined and placed in piles. Precipitation and surface water runoff transport selenium and other substances from the waste rock piles into the local watershed. This transport mechanism is expected to continue for many more decades (Teck, 2014). There is strong evidence to suggest that dissolved selenium emissions originating from waste rock piles is deleterious to resident fish populations, particularly the WSCT (Lemly, 2014). Mining activities in this area must adhere to the Elk Valley Water Quality Plan, submitted to the BC Minister of Environment in 2014 which outlines water quality targets including selenium concentrations within the watershed (Teck, 2014). To achieve the targets set out in the Elk Valley Water Quality Plan, the mining company commissioned the Saturated Rock Fill (SRF) facility for removal of selenium and nitrate from mine-affected water prior to discharge to the environment. An SRF is a mined-out open pit backfilled with waste rock and partially water saturated, which can support a microbial community that is conducive to microbial reduction of selenium and nitrate (Teck, 2018). As part of the next phase of SRF expansion, the mining company is planning to intake mine-affected water from the creek and to re-supply the creek with treated water from the SRF.

The creek is a braided and steep mountain stream which collects drainage from 8.6 km^2 of mined and natural forested lands. The mining company is planning to expand its mine rock storage facility in the creek's catchment area as the mining operations continue. The braided channels of the creek collect into a sediment pond (herein referred to as the pond) and discharge through a 10 m wide overflow spillway. Figure 1 shows the site location plan including the creek and the pond. There is accumulation of calcite at the pond overflow spillway, a by-product of mine-affected water which can be detrimental to fish habitats (Teck, 2014). Figure 2 shows the pond and its spillway. The creek has been identified as a fish bearing stream through fisheries surveys.

The purpose of the current project is to increase treatment rate of the SRF. Key components of the project include construction of an intake to draw mine-affected water from the creek and pump it to treatment facilities (as part of the SRF program) and an outfall structure to return treated water into the creek. A fish barrier will be constructed at the intake / outfall location to inhibit migration of fish species into the intake structure location. Wood has developed several conceptual options for intake / outfall and fish barrier. The project is currently at the options analysis phase. This paper describes the aforementioned design options and presents the benefits and drawbacks of each option with regards to environmental effects, cost, operability and constructability.

Figure 1: Site location plan

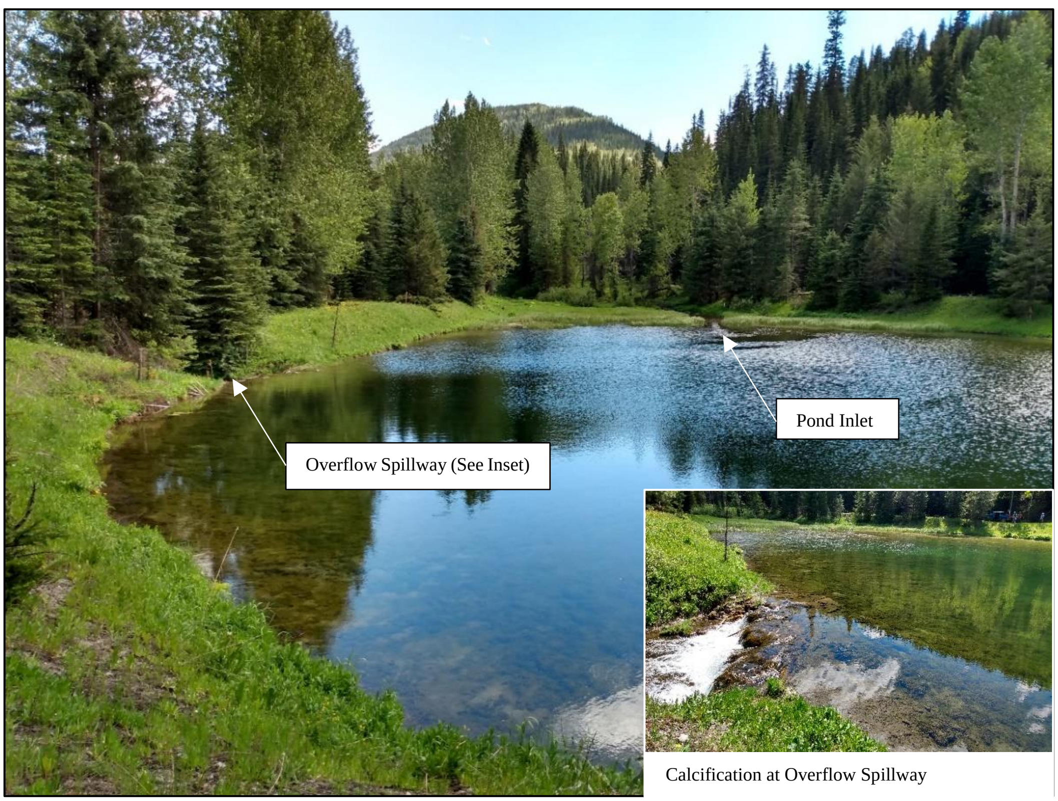

Figure 2: Sediment Pond

Intake / Outfall Options Analysis

The intake treatment design maximum flow rate is 1,500 m^3/day, with planned future expansion to 7,500 m^3/day. Through several stakeholder consultations, Wood analysed five intake / outfall options at the creek. The first four options draw mine-affected water from the pond, whereas Option 5 is proposed downstream of the pond spillway. In all five options, the treated water pipeline will outlet into the creek downstream of the pond. Riprap armouring will be placed at the outfall location for erosion protection. The five intake / outfall options are as follows:

- Option 1: Infiltration gallery at pond overflow spillway (see Figure 3) – perforated HDPE pipes connected to a pump well to draw mine-affected water from the pond, prior to discharging through overflow spillway. This option will require re-construction of the existing overflow spillway, which will simultaneously address the existing calcification issue (refer to Figure 2).

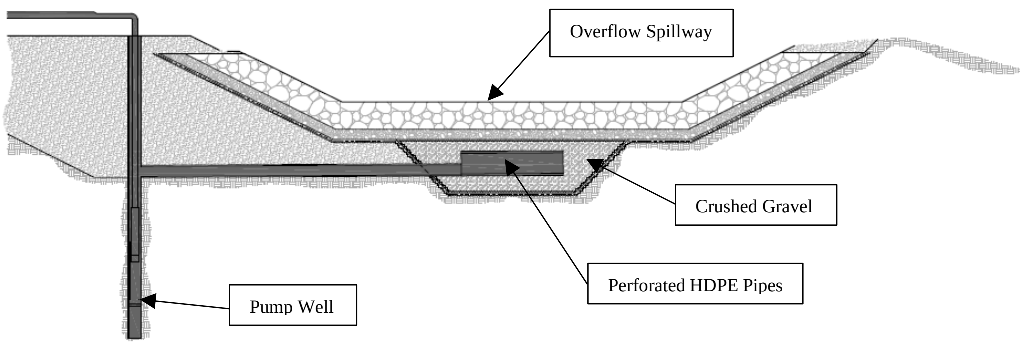

Figure 3: Infiltration gallery at pond overflow spillway

- Option 2: Intake pump well within pond (see Figure 4) – precast concrete pump well constructed adjacent to the pond spillway. The inlet pipe elevation will be designed below the anticipated maximum ice thickness (0.5 m lower than permanent water level). Provided that a section of the pond berm will be excavated for installation of pump well, Wood proposed that the overflow spillway be reconstructed using concrete lock blocks to address calcification at the pond spillway. The lock block spillway will also offer the flexibility to raise the pond weir, if needed for future expansion.

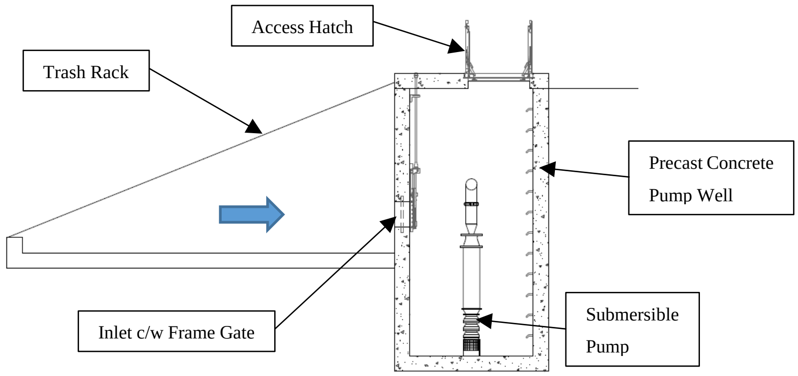

Figure 4: Intake pump well within pond

- Option 3: Self-priming pumps (see Figure 5) – self-priming, end suction pumps will be located on the pond berm with suction hoses extending to center of pond. A back-up pump will also be installed for redundancy. Strict monitoring and maintenance of pumps will be required to ensure continual operation. No earthworks are required in the pond to install the self-priming pumps.

Figure 5: Self-priming pumps

- Option 4: Floating barge pump (see Figure 6) – a self-contained unit will be equipped with two pumps (for redundancy) and connected directly to HDPE intake pipeline. A walkway will also be installed for easy access from the pond berm to the barge for maintenance / operations. No earthworks are required in the pond to install the floating barge.

Figure 6: Floating barge pump

- Option 5: Intake downstream of pond spillway (see Figure 7) – a concrete lock block weir wall will be constructed to create a small ponding area. Water from the ponded area will be pumped via a precast concrete pump well intake structure (similar to Option 2). Cut-off walls upstream and downstream of the ponded area may be required to prevent seepage of mine-affected water. This option will be constructed completely outside of the existing pond area.

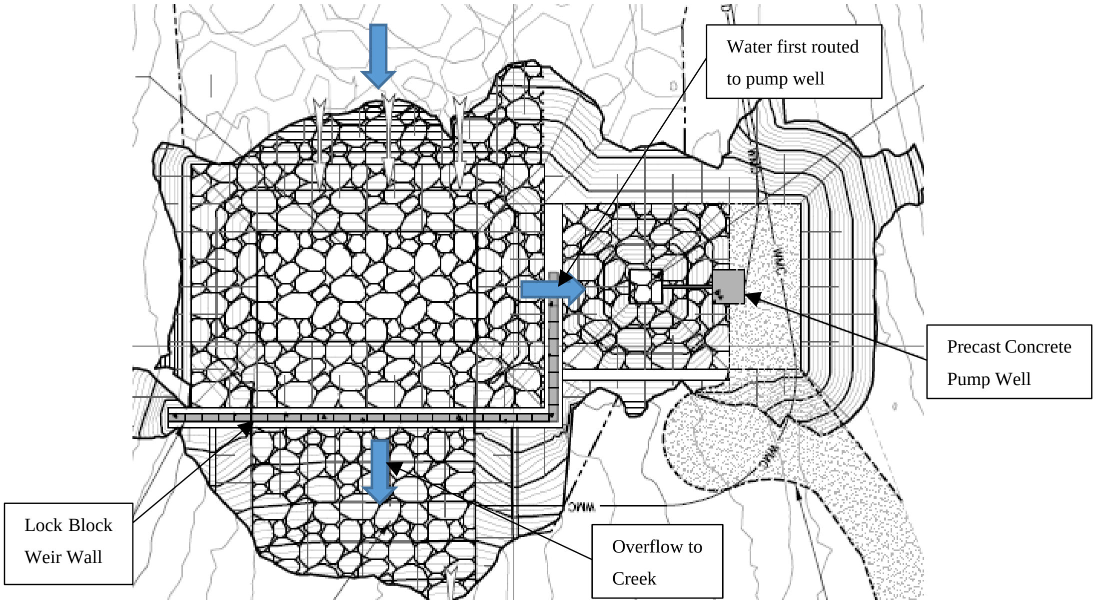

Figure 7: New dam and intake downstream of pond

The five intake / outfall options were evaluated based on key project criteria agreed upon by Wood and project stakeholders. The following list summarizes the project criteria and its key considerations:

- Environmental: impacts to the air, land, vegetation, water, fish and wildlife directly resulting from implementation of the selected option.
- Constructability: specialized construction equipment, rugged terrain, suitability of underlying soils and materials sourcing.
- Operation / Maintenance: ease of access, ease of equipment replacement, design life and reliability.
- Economic: construction, operational and replacement parts cost.

Table 1 shows the key summary of the options analysis for the intake / outfall options.

Table 1: Intake / outfall options analysis

	Option 1	Option 2	Option 3	Option 4	Option 5
Environmental	+removes calcification at existing spillway - Creek upstream of the pond overflow spillway will lose fish habitat	+removes calcification at existing spillway - Creek upstream of the pond overflow spillway will lose fish habitat			-potential for reduction in fish habitat
Constructability	-disturbance to existing pond berm	+opportunity to raise spillway weir for future pond expansion -disturbance to existing pond berm	+no pond earthworks required +quick installation	+no pond earthworks required +equipment will be shop fabricated and assembled on site	+no construction near existing pond -new intake location has potential issues including channel erosion and seepage of mine-affected water
Operation / Maintenance	-potential calcification of perforated pipes -difficult to replace buried perforated pipes	+easy pump replacement -requires consistent trash rack maintenance	-requires strict monitoring -potential freezing of intake pipes -potential risk of leaks	-potential to draw sediments from pond bottom -potential downtime / repairs in case of ice build up	+easy pump replacement
Economic	-high construction cost -high replacement cost	-high construction cost	+low construction cost -highest maintenance / operations cost	+low construction cost	-high construction cost

Note 1: Benefits of each option are labeled as "+", whereas drawbacks of each option are labeled as "-".

The project site is located in a relatively remote area of the overall mine and vehicular access to the pond is difficult. Therefore, a new access road and pipeline corridor will be built from the intake / outfall location to the SRF. The new access road will allow heavy equipment to be transported to the project site and facilitate hauling operations. Furthermore, the creek will be temporarily diverted around the proposed intake / outfall location to allow for construction in a dry environment. The construction of the access road, any of the above intake / outfall options and flow diversion will have potentially negative impacts to the environment. Therefore, a strict environmental policy (including erosion and sediment control and care of water plan) will be planned, implemented and enforced during construction. The erosion control plan will specify use of best management practices (BMPs) such as silt fencing, fibre roll logs and soil stockpile stabilization to either immobilize sediment or contain site sediment runoff on site. Flow monitoring will also be conducted in downstream watercourses to check for elevated turbidity, which will indicate that additional erosion control measures are required.

Fish Barrier Selection and Design

WSCT is listed as a species of Special Concern in British Columbia due to the ‘anthropogenic manipulation and degradation of the environment in which it lives’ (COSEWIC, 2006). Because of the sensitivities around this species, its habitat, and the management implications for industry, the use of fish barriers can be a powerful tool to maintain regulatory compliance and limit operational risks. There are several types of fish barriers in use around the world, including electrical, hydraulic, and physical barriers. A physical barrier provides a low-cost, low-maintenance solution and this approach has been proposed for these reasons. To ensure success, an effective physical fish barrier needs to address one or more of the following considerations - in comparison to the capabilities of the target species:

- Leaping ability – how high can the fish jump?
- Burst speed – what is the maximum swimming speed of the fish?
- Minimum water depth requirements – is the water deep enough to prevent effective swimming?
- Water turbulence – is the water turbulent enough within the barrier to reduce density and therefore prevent effective swimming?

As with all salmonid species, cutthroat trout are powerful swimmers, with documented burst speeds between 3.55 m/s (Blank MD, 2020) and 4.11 m/s (NRCS, 2007). The mountain rivers and streams they inhabit also require commensurate leaping abilities to traverse natural impediments as they move throughout their habitat. This is demonstrated by the large home ranges for WSCT in the Elk River watershed, reaching a maximum of 23 km in its upper reaches (COSEWIC, 2006), where gradients increase, and the habitat becomes more susceptible to naturally occurring barriers due to limited water depths and channel widths. Adult cutthroat trout have had successful leaps recorded at maximum height of 0.9 m (NRCS, 2007); however, anecdotal reports from fisheries biologists working in nearby areas have reported successful leaps of ~3.0 m in height by WSCT into hanging culverts. In this instance, it was reported that an area of relatively deep water existed beneath the culvert outfall – providing sufficient ‘runway’ for the fish to initiate a leap.

The natural habitat of WSCT often provides refuge opportunities (e.g., boulders, woody debris, eddies etc.) amongst obstacles where fish can rest and recover in an area of reduced water velocity before continuing their movements. In certain instances, waterfalls can create plunge pools to facilitate leaping and cascade features can present regularly spaced ‘staging areas’ where fish can recover their energy between leaps, as they ascend. Therefore, our approach in the proposed designs for this installation was to use a combination of considerations to increase barrier efficacy – including limiting water depths and increasing water velocity (to prevent effective swimming) and eliminating the presence of a plunge pool (to limit leaping ability).

Due to the remote site location, a low-maintenance fish barrier is preferred. The fish barrier needs to be functional for a wide range of flow conditions, from minimal winter flows to extreme flood events (such as the 1:200-year storm runoff). Therefore, the following three physical barriers were considered for this site:

- Option 1: Drop structure (see Figure 8) – a 2 m high drop structure will prevent fish from leaping into the creek upstream of the fish barrier. The drop structure will be mostly precast concrete with a cast in place concrete slab. If regular flow monitoring is required at this location, a steel plated weir and flow measurement level meter can be installed immediately upstream of the drop structure. Considering that the creek is relatively steep, a 2 m high barrier can be constructed without the need for extensive earthworks.

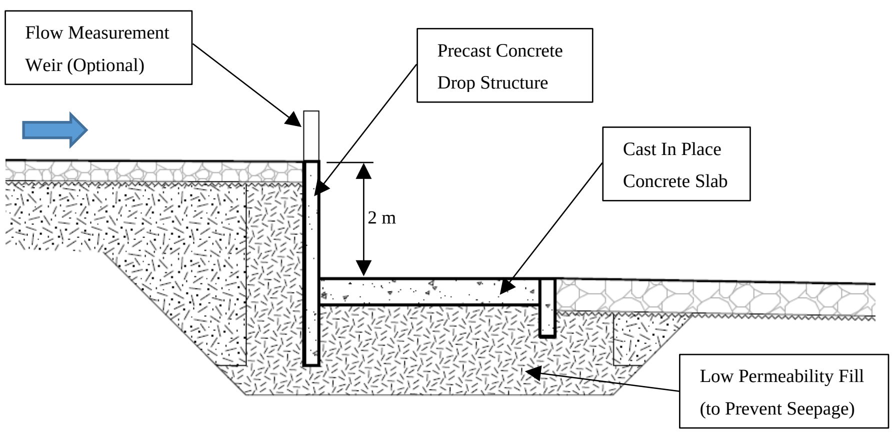

Figure 8: Drop structure fish barrier

- Option 2: Chute (see Figure 9) – Fish barrier will be a cast in place concrete chute at minimum 7H:1V slope. Flow of water over the chute will be fast and shallow, inhibiting fish from migrating upstream of the fish barrier. Concrete blocks can also be placed to reduce flow area and further increase flow velocity.
- Option 3: Pipe – The creek will be conveyed through a 20 m long smooth-wall pipe at 5% slope. According to BC culvert assessment standards, a 20 m pipe alone would only present a moderate risk to fish passage but when coupled with the 5% slope, it presents a high risk to fish passage. With the added consideration of smooth walls and lack of internal baffles, this option can be considered as a fish barrier. Designing the pipe with a stream width ratio greater than 1.3 (where

the stream width is ≥1.3x culvert width) would also provide an additive barrier effect due to increased water velocity within the pipe.

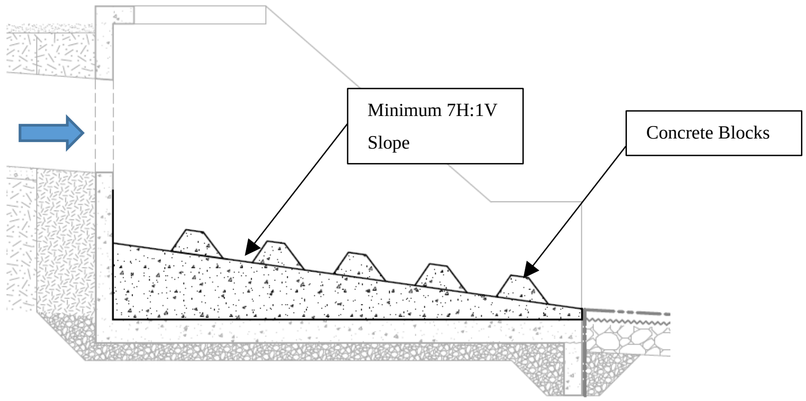

Figure 9: Chute fish barrier

Table 2 summarizes the advantages and disadvantages of each fish barrier option:

Table 2: Fish barrier options advantages and disadvantages

Fish Barrier Option	Advantages	Disadvantages
Drop Structure	- Allows for easy and reliable flow monitoring, if needed - Ease of maintenance	- Although a 2m drop should provide an effective barrier to passage, anecdotal reports from nearby areas indicate that WSCT can successfully leap heights ~3.0m - During periods of increased flow, the drop height may be reduced and the risk of fish migration above the structure increased if the flow rate is less than the burst speed of WSCT and sufficient water depths are present.
Chute	- Ease of maintenance - Outfall drop and slope present an effective barrier to fish passage under normal flow conditions	- Increased potential for erosion downstream of the chute due to high velocity flow - Flow velocities and/or limited water depths must be maintained to ensure efficacy of fish barrier - During periods of increased flow, the drop height may be reduced and the risk of fish migration above the structure increased if the flow rate is less than the burst speed of WSCT and sufficient water depths are present.
Pipe	- The proposed slope and lack of baffles within the pipe present an effective barrier to fish passage at any flow rate - Water velocity within the pipe will increase significantly during periods of increased flows, providing an effective barrier to fish passage	- A large pipe diameter is required to convey the full creek design flow - Potential for seepage around the pipe, eventually undermining structural stability - Potential for blockage with debris resulting in more challenging maintenance than with open structures

Conclusions and Recommendations

All intake / outfall options analysed will ultimately serve the purpose of capturing and reducing selenium and nitrate concentrations in downstream receivers and improve water quality for WSCT. The physical fish barrier will be installed downstream of the intake location to keep fish outside of the intake location as well as the pre-treated water. The mining company is in the process of reviewing the options analysis with key stakeholders, Indigenous communities and regulatory bodies. Construction is expected to be completed by October 2023. This project will also be integrated within the mine closure and reclamation plans in which a multitude of values (set by communities of interest, local Indigenous groups and regulators) will be incorporated, in addition to ecological conditions.

Wood will carry forward with detail design of the selected intake / outfall and fish barrier options. The following construction and monitoring recommendations are proposed regardless of the selected options:

- An environmental protection work plan will be established and implemented for the duration of construction. The environmental protection work plan should identify critical areas, potentially harmful activities and the steps taken to mitigate negative effects to the environment.
- Erosion and sediment control measures will be checked and if needed, repaired or upgraded, on a frequent basis. Regular flow monitoring in downstream water bodies is required to ensure that there is no unintentional sediment laden runoff from the construction area.
- A strict environmental reporting system should be in place any of the following are encountered: spills; invasive plant species; bird nests while clearing; bear dens; badger burrows and fish mortalities.
- Construction activities should be completed in dry conditions, to the extent possible. This may involve diversion of the creek around the work area. In-stream work must be completed within the least-risk fish window.

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