Landslide Dams and Creek Stabilization at the Former Clinton Creek Asbestos Mine

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1.0 Abstract

Risk assessment techniques were used to identify the risk associated with a breach of a landslide dam in the Clinton Creek valley at the former Clinton Creek Asbestos Mine, which is located about 100 km northwest of Dawson City, Yukon. Since closure of the mine in 1978, concerns have been raised with respect to the physical condition of the site, in particular downstream hazards associated with breaching of the landslide dam forming the Hudgeon Lake outlet.

The risk was mitigated by designing a stable channel over the landslide dam, also known as the Clinton Creek waste rock dump, of which the most important design component is the gabion drop structures. The gabion drop structures act as grade control points which are connected by a nearly flat graded channel to prevent erosion of the channel fill materials. Gabions were selected because they are simple to construct yet robust and flexible enough to accommodate some lateral movement of the creeping landslide mass.

The channel stabilization works consist of four gabion drop structures constructed within the first 200 m of the channel downstream of the Hudgeon lake outlet. In the fall of 2002, the first stage of these repairs was undertaken, which included the construction of Drop Structure #1 and re-grading of the Hudgeon Lake outlet. The second drop structure was built in 2003 and the last two drop structures were constructed in 2004.

2.0 Background

The former Clinton Creek Asbestos Mine is located about 100 km northwest of Dawson City, Yukon, 9 km upstream of the confluence of Clinton Creek with the Forty Mile River (Figure 01). The mine site is located within the unglaciated Yukon-Tanana Upland Region. Bedrock in the area consists of black argillite that was exposed to periglacial weathering. Near-surface material is heavily fractured and weathered. The serpentinite ore body in the Porcupine Open Pit strikes NE and dips to the NW at approximately 45 degrees. Very little site-specific information exists with respect to permafrost conditions at the mine site. The mean annual temperature is –2.5 degrees C, ranging on average from 15 degrees C in the summer to –32 degrees C during the winter. Previous research indicates the area consists of wide spread permafrost distribution up to 60 m thick and the active layer was reported to be 0.3 to 0.5 m thick.

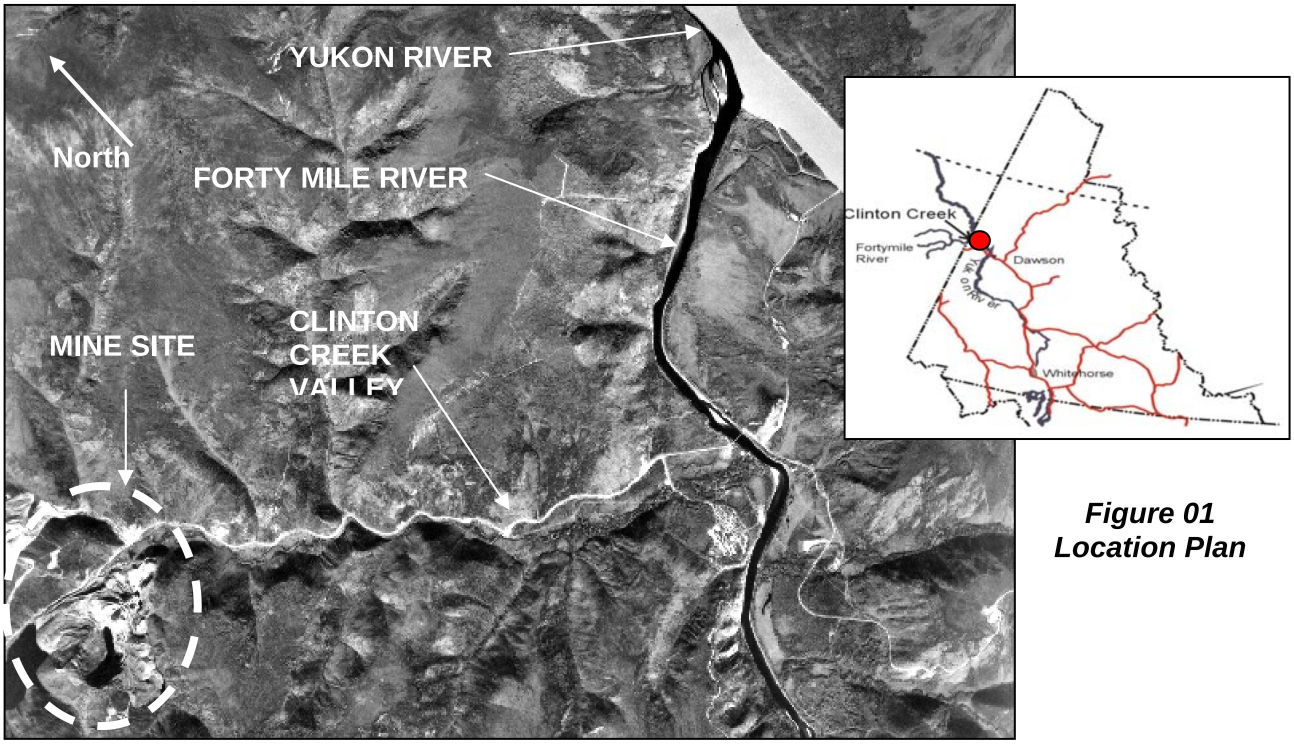


Figure 01
Location Plan

The mine consists of three open pits, two waste rock dumps and a tailings pile (Figure 02). From 1968 until depletion of economic reserves in 1978, the Cassiar Mining Corporation extracted approximately 12 million tonnes of serpentine ore from the bedrock. Over 60 million tonnes of waste rock from the open pits was deposited in the waste rock dumps. The ore was transported by an aerial tramway to the mill site located on a ridge along the west side of Wolverine Creek. Over the same period of time, about 10 million tonnes of asbestos tailings from the milling operation were deposited over the west slope of the Wolverine Creek valley.

Since closure of the asbestos mine, concerns have been raised with respect to the physical condition of the site, in particular downstream hazards associated with channel blockages resulting from landslides of the Clinton Creek waste rock dump. The main concern is the deteriorating condition of the main landslide dam which forms the Hudgeon Lake outlet. In areas with significant relief such as the Clinton Creek Mine Site, flooding from failures of channel blockages can be especially dangerous and their occurrence can be unrelated to normal precipitation events that would be expected to produce flooding conditions.

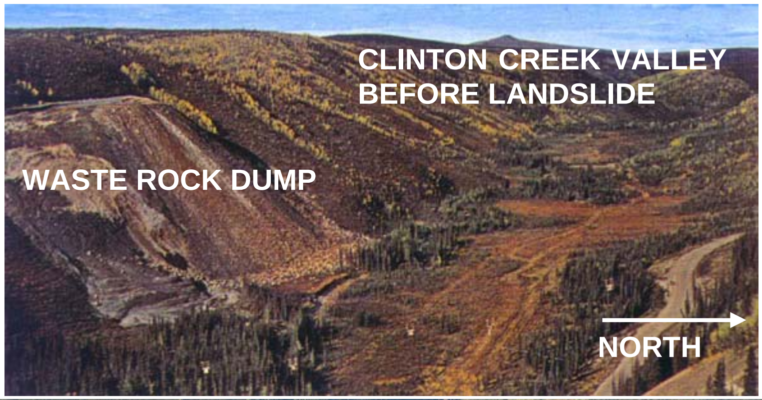
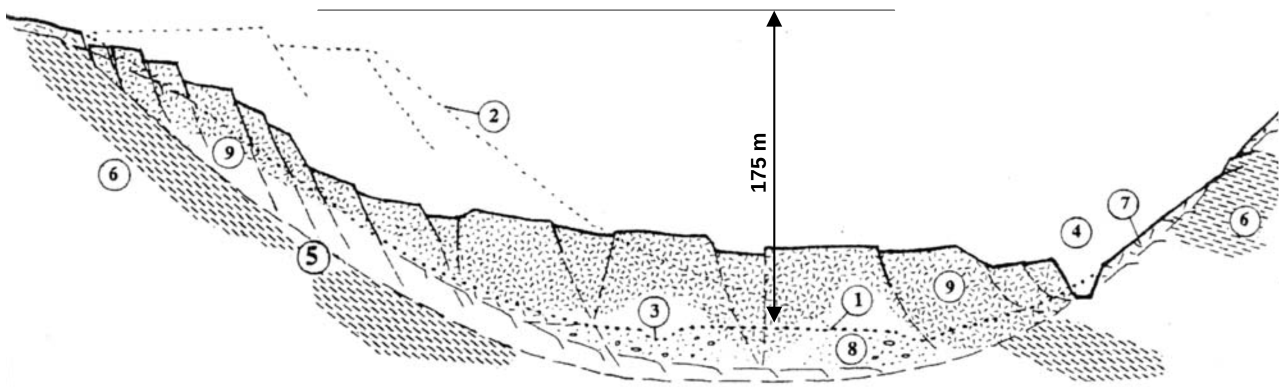


Figure 02
Mine Site Plan (1976)

3.0 Clinton Creek Waste Rock Dump

A significant slope failure of the waste rock dump into the Clinton Creek valley occurred in 1974 (Figure 03). The resulting landslide dam blocked natural drainage through the valley creating a 74 ha lake (Hudgeon Lake) as shown in Figures 02 and 04. Figure 02 also shows the valley before the landslide. Stability analysis indicates a weak foundation material is contributing to the continued horizontal displacements following the initial failure of the waste rock dump. The loss of strength may be related to a number of geological conditions unique to the site including ice content, soil type and the relationship between the rate of thawing and dissipation of excess pore-water pressures. It is likely that disturbance to the thermal regime, in particular thawing of permafrost beneath the dump, has resulted from filling of the upstream reservoir (Hudgeon Lake).



***1**-Original Ground Surface, **2**-Initial Waste Rock Configuration, **3**-Original Creek Channel, **4**-Present Creek*

Figure 03
Channel Cross Section After Waste Rock Slide (View Upstream)
(Reference: Stepanek & McAlpine, 1992)

Figure 04 Waste Rock Dump In 1974 (View Downstream)

Figure 05 Clinton Creek Channel

As illustrated in Figure 05, a new creek channel was subsequently formed along the interface between the landslide material and north valley slope, some 25 m above the original valley bottom at the Hudgeon Lake outlet. Within the area now occupied by the waste rock dump, the creek channel is approximately 700 m long with a gradient ranging from about 3 to 6 percent compared to its natural gradient of approximately 0.08 percent.

The original channel erosion protection measures constructed just downstream of the Hudgeon Lake outlet in 1981 included a series of small rock weirs, which were by-passed in the spring of 1982 (Figure 06). The erosion control works, which were constructed using large boulders recovered from the open pits, have proven to be largely unsuccessful and by 1984 had been re-constructed twice. The erosion control works re-constructed in 1984 (Figure 07) were by-passed in a significant flood event in the spring of 1997 (Figure 08). Based on the creek profiles shown in Figure 09, approximately 3 m of channel erosion or head-cutting occurred immediately downstream of the outlet between 1986 and 1999. Farther downstream, less down-cutting was evident, likely because the creek channel has cut into the bedrock.

Figure 06
Hudgeon Lake Outlet (1982)

Figure 07
Hudgeon Lake Outlet (1984)

Figure 08
Hudgeon Lake Outlet (1997)

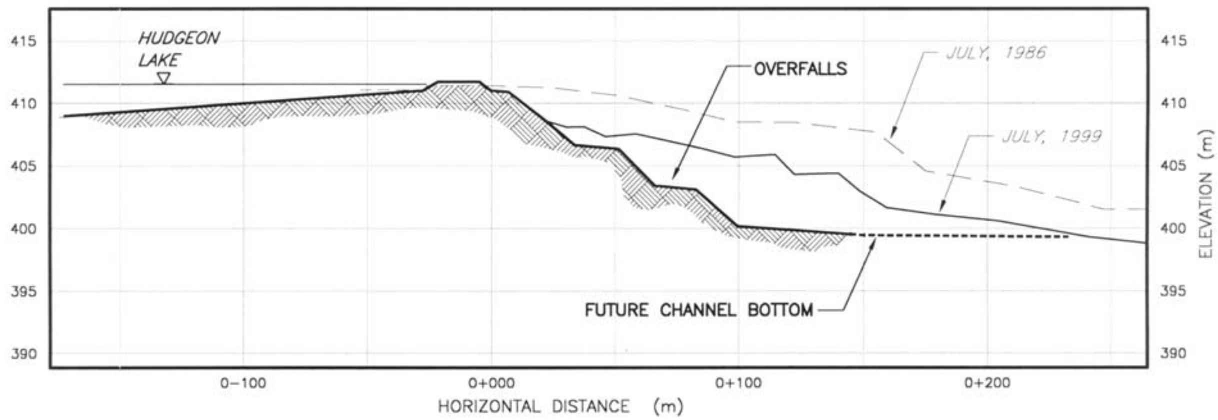


Figure 09
Channel Erosion at Hudgeon Lake Outlet

4.0 Breach Potential of the Hudgeon Lake Outlet

Progressive head-cutting or incising of the Clinton Creek channel immediately downstream of and towards the Hudgeon Lake outlet has increased the likelihood of the development of a full breach of the landslide dam (Figure 09). Following the spring 1997 flood event when the erosion control works were effectively destroyed, a full breach at the lake outlet could have been triggered at any time and was not considered susceptible to any particular precipitation event i.e. a relatively minor inflow could trigger the failure mechanism necessary to initiate a breach.
A full breach of the waste rock blockage at the Hudgeon Lake outlet would result in a peak discharge of approximately 500 m^3/s and a maximum flow velocity of about 4 m/s. The flood peak quickly attenuates however, reaching a base flow level at the valley constriction downstream of Wolverine Creek.

5.0 Risk Assessment and Downstream Hazards

Before the creek channel stabilization repairs were completed, the conditions at the former mine site potentially exposed individuals, property and the environment to some degree of risk mainly associated with flooding. Using available information, a qualitative assessment of risk scenarios and human and ecological exposure levels associated with a breach of the lake outlet was possible. A quantitative estimate of risk was not considered appropriate given the considerable uncertainty in parameters necessary to arrive at precise predictions of risk under various scenarios and circumstances. There was however, sufficient reliability in the results to determine the acceptability of potentially hazardous activities and develop guidelines for appropriate risk management strategies. In this regard, the level of risk downstream of the mine site was categorized as high, medium or low based on the severity of flooding within each zone. The inherent risk to human health and potential loss-of-life is dependent upon the potential for human exposure within these zones. These risks can be broadly placed into public safety and ecological and health risk categories as follows:

Public Safety

In terms of public safety, the level of risk downstream of the mine site was categorized as high, medium or low based on the severity of flooding in each zone (Figure 10). The inherent risk to humans and the potential for loss-of-life is dependent upon the likelihood of exposure (occupancy) within these zones. The potential for loss-of-life is greatest immediately downstream of the mine site in the area potentially inundated by a breach of the Hudgeon Lake outlet. Farther downstream along Clinton Creek, the risks are reduced, as the high water levels will be confined to the creek valley below the road where human exposure is less likely. The risk is considered low at the next most likely downstream area of occupancy in the vicinity of the former Clinton Creek Town-site where the valley widens considerably.

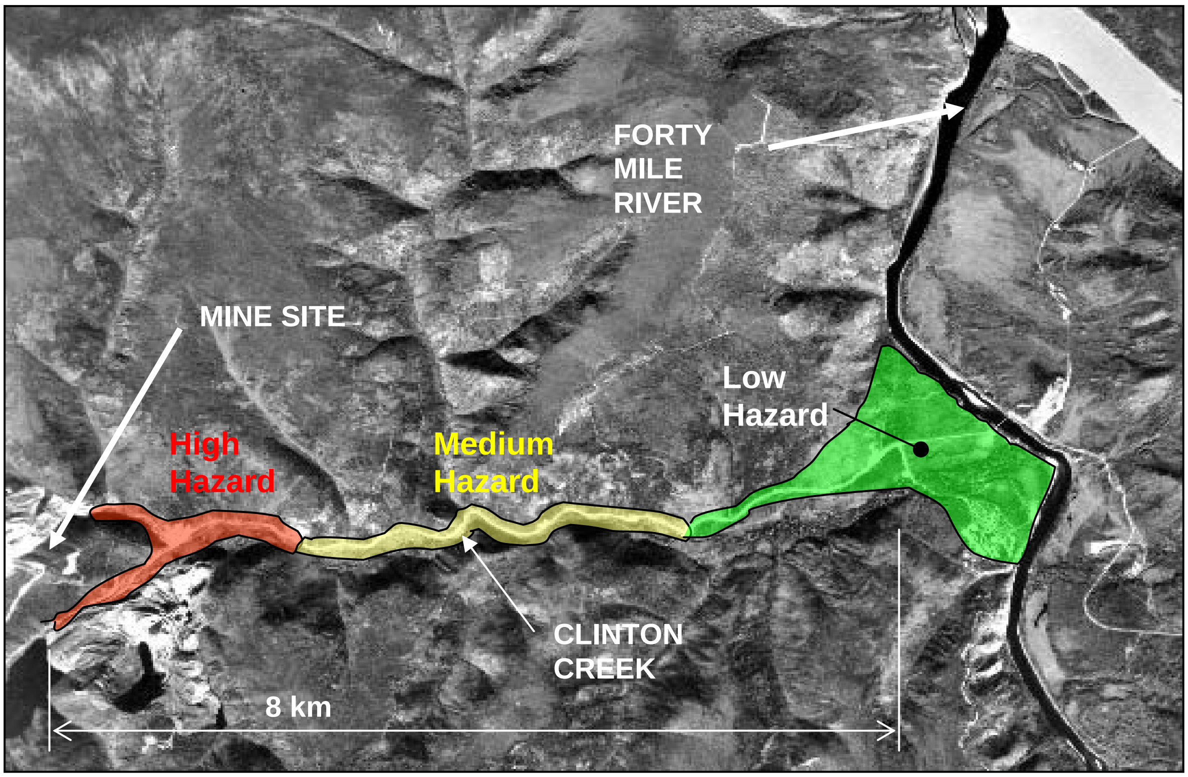


Figure 10
Downstream Hazard Mapping

Ecological and Health Risks

Aquatic life and mammals downstream of the mine site are potentially at risk from the redistribution of eroded waste rock. The largest risk is believed to be from a sudden breach of the waste rock dump (i.e. Hudgeon Lake outlet) resulting in fisheries habitat loss through downstream smothering and flooding.

For each of the ecological or human health risks identified, it was important to determine what level of risk should prompt a risk management or remedial strategy. In the interim between completing the risk assessment and completing the creek stabilization repairs an FM broadcast station was established and warning signs posted to warn remote area travellers of the possibility of flash flooding.

6.0 Creek Stabilization Measures

Based on evidence of on-going deterioration of the Hudgeon Lake outlet (Figure 09), the implementation of remedial measures (i.e. creek stabilization) was considered necessary. Because the waste rock is still undergoing creep movements, and may do so for many more years, the channel stabilization measures had to be able to accommodate some movements of the waste rock pile and remain functional. This design requirement was met through the use of gabion drop structures that serve as grade control points connecting nearly flat channel sections. The waste rock movements are being monitored along with the measurements of the gabion drop structures to determine if the channel stabilization works are being impacted.

In 1999, the movement monitoring program for the Clinton Creek waste rock dump was re-established and the results confirmed observations made shortly after mine closure that the movement rates of the waste rock dump were decreasing over time. Subsequent monitoring events reveal that the waste rock is creeping in a northward direction at rates of about 5 to 7 cm per year.

A number of constraints were considered in the selection and design of channel stabilization measures. These include:

- Continued creep movements of the waste rock may distort or shift any structures constructed in the creek channel;
- Remoteness of the mine site with respect to availability and delivery of construction materials and equipment;
- Rapid and straightforward construction.

Gabion drop structures (i.e. grade control structures) were selected over rigid structures (e.g. concrete) because they are flexible enough to allow some deformation while remaining structurally sound and fully functional, an important consideration given the observed creep movements of the waste rock. In addition, gabions are permeable and don't have the potential uplift problems associated with rigid structures. Gabion structures are also robust and simple to construct using granular fill material available at the mine site and conventional construction equipment. The only materials that had to be transported over a long distance were the gabion baskets and geotextile.

The potential for erosion of the creek channel between the gabion drop structures was minimized by lowering the velocity of the water such that it can no longer scour or erode the bed of the creek channel. This was achieved using a minimal channel grade and designing the channel cross-section to the required width and depth to pass the design creek flows. Channel erosion will continue downstream of the stabilized portion of the channel, possibly at a greater rate due to the reduced sediment load from the stabilized portion of the channel.

The flow from Hudgeon Lake is recognized as being highly variable and sensitive to precipitation events within the drainage basin. Flows measured in Clinton Creek between 2000 and 2004 at a location 5 km downstream of Hudgeon lake have ranged from lows of 0.2 m^3/s to highs of 7 to 10.5 m^3/s. The estimated 25-year flood (Q=28.9 m^3/s) was used for the design of the channel stabilization works. However, the discharge of a 25-year flood at the Hudgeon Lake outlet will be smaller due to the flood attenuation caused by Hudgeon Lake, resulting in a higher level of protection than indicated by the 25-year return period. Based on the design discharge of 28.9 m^3/s, 3H:1V channel side slopes and a grade (between drop structures) of 0.1%, the new channel geometry requires a bed width of 7m and a flow depth of 2m. With the dimensions of the individual gabion baskets used for the drop structures (3.0m long, 1.0m wide, 0.5m high), the freeboard at the control structures is approximately 0.5m which is sufficient to confine the 50-year flood within the new channel cross-section.

As illustrated on Figure 11, the gabion drop structures or grade control points are essentially a set of 0.5m high steps, which provide energy dissipation between each step as the water travels through and over the structure. A draw-down reduction weir at the top of each structure creates a constriction that reduces the water surface draw-down immediately upstream of the structure to control the flow velocity in the channel upstream of each drop structure. An end sill at the bottom level of the structure prevents a floor jet from extending downstream of the structure during high discharges. A separating layer of non-woven geotextile was used between the foundation material and the gabions to prevent migration or loss of fines due to seepage or erosion. The geotextile is anchored below the structure at the upstream and downstream ends to further confine the foundation material below the gabions. A 0.5m thick layer of riprap was placed 3m upstream and downstream of the drop structures for channel revetment. The gabion baskets chosen for the work were constructed of galvanized wire and coated with PVC for added durability during construction and also a longer design life.

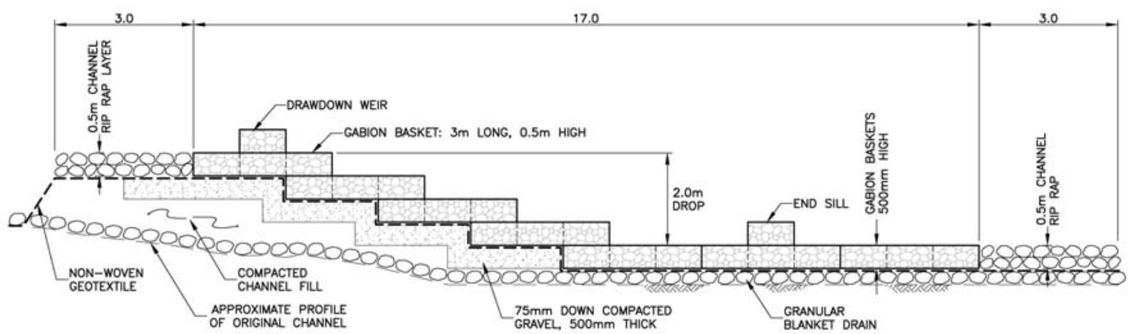


Figure 11 Gabion Drop Structure – Centerline Profile

Additional gabion baskets were added to the downstream end of the last drop structure because channel degradation of the non-stabilized portion of the channel can be expected to continue. The additional gabions should provide adequate protection to the constructed works. If the creek bed starts to undercut the baskets at this location the baskets will start to settle down onto the eroded creek bed and minimize damage to the drop structure until some maintenance work can be completed.

The creek stabilization repairs were constructed in three stages. The intent of the first stage, which was constructed in the fall of 2002, was to address the potential for a catastrophic breach of the Hudgeon lake outlet, i.e. to reduce the possibility of conditions worsening at the outlet before the rest of the gabion drop structures could be constructed. The configuration of the drop structures constructed downstream of the lake outlet is illustrated on Figure 12.

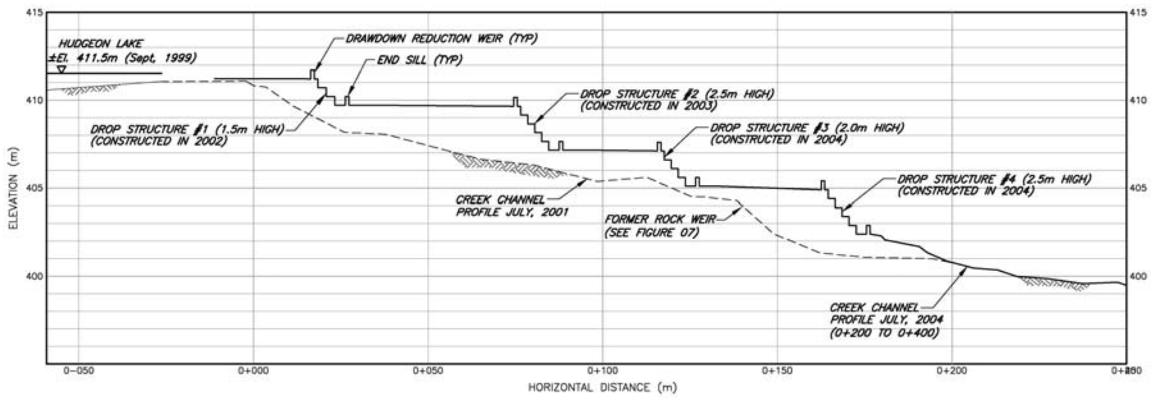


Figure 12 Clinton Creek Profile (2004)

Dewatering of the channel was required to facilitate construction. During the first stage of construction a base flow in the channel downstream of the work area was maintained for fish habitat. This was accomplished by diverting some flow from Hudgeon lake around the work area using a series of steel culverts coupled together. This was not possible during the construction of the remaining structures due to work space limitations. During the last two construction stages, the flow from Hudgeon lake was completely blocked and a fish salvage operation between Hudgeon Lake and the first downstream tributary stream (Wolverine Creek) was completed. Following construction of the cofferdam, fish salvage operations were undertaken to recover fish trapped in Clinton Creek between the cofferdam and Wolverine Creek. Up to 1,000 fish (mainly Arctic Grayling and Slimy Sculpins) were salvaged during the fish salvage operation and returned to Hudgeon Lake or downstream reaches of Clinton Creek.

In general, construction of the channel stabilization works involved building the gabion drop structures and infilling the channel between the structures. Construction of the drop structures is straightforward. The most challenging things to deal with during construction were initial preparation of the creek bed and groundwater seepage. Channel preparation included the removal of many large boulders from the original channel stabilization works and rough cutting the side slopes for the new channel, as illustrated on Figures 13 and 14. Groundwater seepage was controlled during construction through the use of granular blanket drains installed below the drop structures (Figure 15). The granular drain also served as a foundation material in some cases. Once the initial preparation work was completed construction proceeded by constructing one row of gabion baskets at a time. The foundation material for each row of baskets was placed and compacted followed by placement of the baskets on the prepared base. The baskets were stapled together using stainless steel ‘C’ clips. Once assembled, the baskets were filled with granular material ranging in size from 75 mm to 200 mm and the lids of each basket stapled shut. The general construction of the gabion baskets is illustrated on Figures 16 and 17. Construction of a single drop structure, including channel infilling, took about 10 to 14 days depending on the height of the structure. The completed channel stabilization work is illustrated on Figure 18.

Annual inspections of the gabion drop structures and continued monitoring of the waste rock movements will be undertaken to determine if and when maintenance of the gabion drop structures is required.

Figure 13   Channel Bed Preparation

Figure 14   Initial Side Slope Preparation

Figure 15 Granular Blanket Drain

Figure 15 Installing Gabion Baskets

Figure 16 Filling Gabion Baskets

Figure 17   Completed Channel Stabilization Works

7.0 Acknowledgements

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8.0 References

Stepanek, M. and McAlpine, H.F. (1992). "Landslide Dams at Clinton Creek" in Geotechnique and Natural Hazards, BiTech Publishers, Vancouver, B.C., pp 291-298