Mine Closure 2023 - Behrooz Abbasi, Jeff Parshley, Andy Fourie & Mark Tibbett (eds)

doi:10.36487/ACG_repo/2315_037

Clinton creek abandoned mine/interim spillway reclamation project—status of the channel restoration effort

K Myers *The MINES Group/Geo-Logic Associates, USA*

M Nahir *Parsons, Inc., Canada*

C Gillis *Yukon Government, Canada*

J Shah *Parsons, Inc., USA*

The Clinton Creek Interim Spillway Reclamation Project is located at the site of the former Clinton Creek Asbestos Mine, about 100 kilometres northwest of Dawson City, Yukon Territory, Canada and about 9 kilometres upstream of the confluence of Clinton Creek and the Forty Mile River. The mine was operated from 1968 through 1978 and extracted approximately 12 million Tonnes of serpentine ore from three open pits. Two waste rock dumps were placed along the south side of Clinton Creek. In 1974 the Clinton Creek Waste Rock Dump experienced a mass failure (a lateral spread) resulting in the blockage of the Clinton Creek channel over a reach length of approximately 700 metres, forming a landslide dam and initiating the formation of a new impoundment named Hudgeon Lake. Upon first filling of the new reservoir, the water discharging from Hudgeon Lake began flowing across the surface of the waste rock dam at the interface between the waste rock and the existing colluvial soil and bedrock of the valley slope to the north. The flow began to incise into the soil and waste rock forming the new alignment of Clinton Creek now displaced hundreds of metres to the north and perched some 25 metres above the former Clinton Creek channel and floodplain. The new channel has gradients ranging from about 3% to 6% and averages about 3.6%. This compares to the channel's original in regime gradient of 0.075%.

Erosion of the new channel at the lake outlet prompted concerns about a breach of the landslide dam and efforts to control erosion of the channel using riprap armor and a rock weir, were began in 1981 However, multiple failures during high flow events resulted in damage and the rebuilding of the erosion protection features over the years. In the spring of 2003, an interim spillway structure to arrest the downcutting in Clinton Creek began construction. The design involved a simple trapezoidal channel with a series of drops constructed using rock filled PVC coated galvanized wire gabion baskets. The upper reaches of this spillway structure have held up reasonably well, but the lower reach below what is referred to as Drop Structure No. 4 has experienced multiple severe erosion/headcutting events over time. Subsequent efforts to arrest erosion and stabilize the channel including an articulated concrete block chute structure have also resulted in failure.

This paper will describe current, on-going efforts to provide a stable, functioning interim channel that will provide at least a 50-yr facility life and, in the process, address desired improvements in fish habitat and fish migration issues until a final, permanent solution can be funded, designed, and constructed.

1 Introduction

The Clinton Creek Mine Site (Site) is an abandoned asbestos mine located in the Yukon Territory in northern Canada, as shown in Figure 1. The Site is approximately 100 kilometres northwest of the nearest community of Dawson City (population under 2000), and 20 kilometres from the Alaska/USA border. It is situated in a very remote area within the traditional territory of the Tr'ondëk Hwëch'in First Nation, with only seasonal (May-October) road access and a subarctic climate. Historically, the area was used for travel, trade, and harvesting fish, berries, plants, furbearers, and caribou. However, following the discovery of gold in 1887, these activities became largely impacted by mining activities when placer gold mining commenced near the Fortymile River and Clinton Creek confluence about 9 kilometres downstream. Later, in 1957 asbestos was discovered at the Site and mining operations took place from 1968 to 1978 under Cassiar Asbestos Corporation. Though select remedial activities were carried out by Cassiar Asbestos Corp., full Site remediation and closure has yet to be completed, and the Site has long since been considered abandoned, currently under the care and control of the Government of Yukon (the Owner). Physical stability and flooding are the greatest concerns on the Site, and the reason the Site is closed to the public to mitigate negative effects on human health and safety. The interim design for the drop structures on site is the subject of this work and an ongoing effort to improve physical stability and risk of flooding.

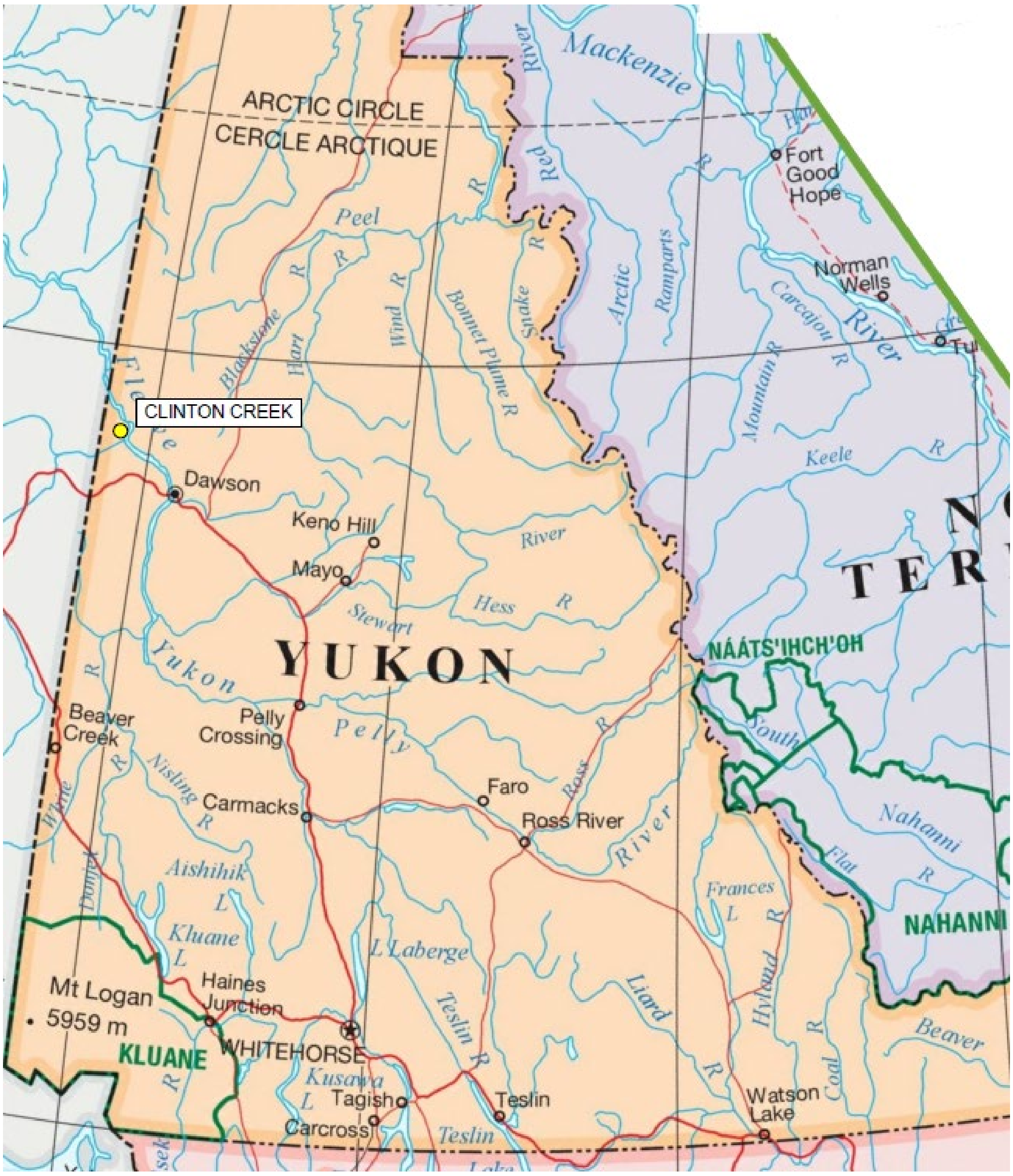

Figure 1 **Clinton Creek mine site location**

The Site is divided into two main sides, based on the area's watershed of either Clinton Creek or Wolverine Creek. During mining, ore was transported from the Clinton Creek side to the mill on the Wolverine Creek side of the Site via an aerial tramway. The ore was then processed in the mill, and the tailings (approximately 12 million tonnes) were deposited along the steep slope of the Wolverine Creek valley in two large piles. Remaining waste rock, from mining the three pits on the Clinton Creek side of the Site, was largely deposited along the south slope of the Clinton Creek valley, among other areas on the Clinton Creek side. The waste rock failed in 1974, blocking the Clinton Creek channel and forming a landslide dam and Hudgeon Lake. Remedial efforts to re-establish and protect the channel were carried out over the years to no success and currently a series of four drop structures, constructed in the early 2000s, act as an interim spillway to prevent further erosion of the waste rock. Site features are shown in Figure 2.

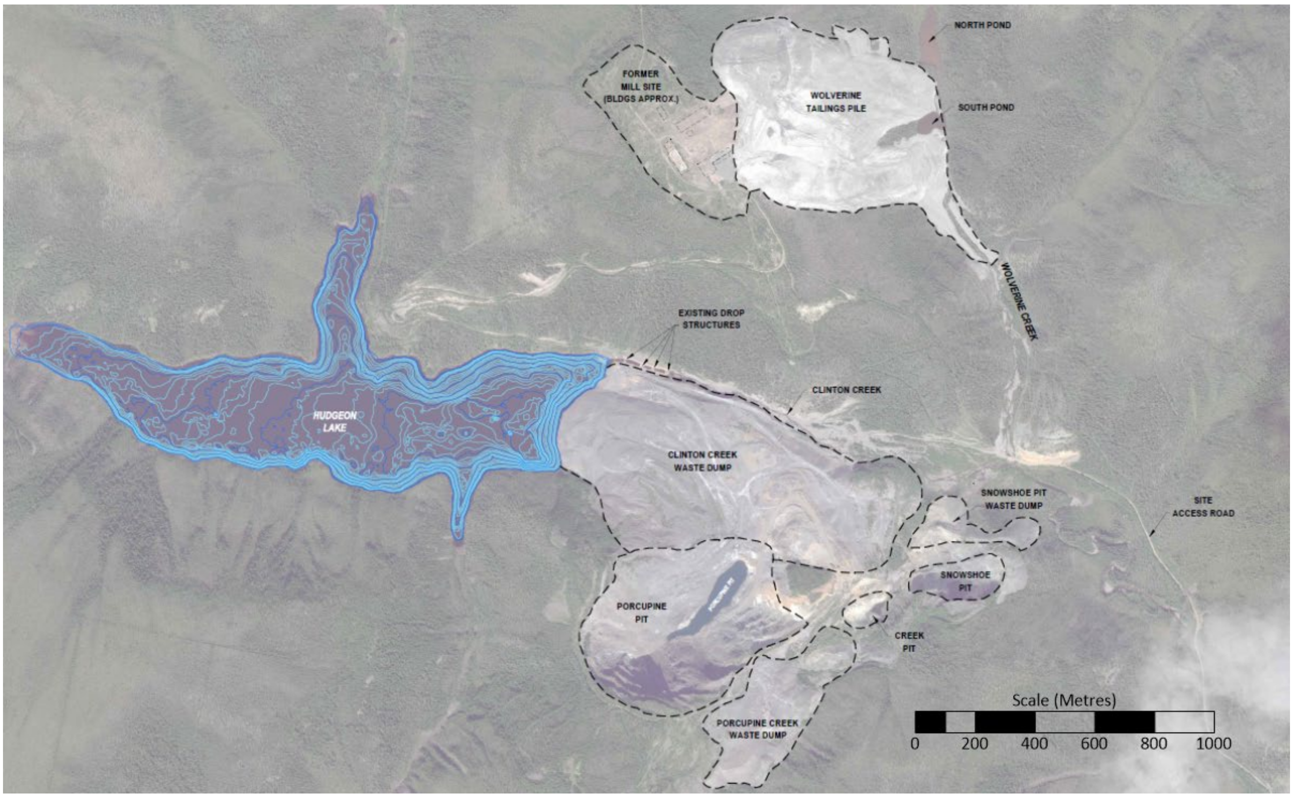

Figure 2 Clinton Creek mine site layout

The fourth and last drop structure #4 or “DS4” has experienced stability challenges, with a few instances of failure with high freshet flows in recent years. Due to stability and capacity concerns, the drop structures are monitored on a daily basis through a remote camera by the Government of Yukon. The waste rock and tailings piles are also continuously deforming and moving and are monitored by the Government of Yukon’s geotechnical engineering consultant, who uses a combination of visual inspection, InSAR (Interferometric Synthetic-Aperture Radar), GPS survey, and instrumentation data collected 3 times per year (slope indicators/inclinometers, ground temperature cables, vibrating wire piezometers) to provide observations and recommendations related to site stability. When recommendations are received, a care and maintenance contractor is contracted to execute construction activities to address shorter-term recommendations to maintain the site until remediation. The Government of Yukon also contracts an environmental monitoring consultant to conduct quarterly surface water quality and hydrology monitoring. Unlike other sites in the region, acid rock drainage is not a concern. There is a meteorological station on site for weather data, but there is limited data for flow rate monitoring. To address some of the stability concerns associated with the Clinton Creek side of the property, prior to remediation, the Government of Yukon has contracted Parsons Inc. to develop a design to improve the stability of drop structure #4 and the unstable, over-steepened channel downstream.

2 History

In 1974 the Clinton Creek Waste Rock Dump experienced a mass failure resulting in the blockage of the Clinton Creek channel over a reach length of approximately 700 metres (m), forming a landslide dam approximately 200 m wide and initiating the formation of a new impoundment named Hudgeon Lake. The failure mechanism has been described as a lateral spread. Upon first filling of the new reservoir, the water discharging from Hudgeon Lake began flowing across the surface of the waste rock dam at the interface between the waste rock and the existing colluvial soil and bedrock of the valley slope to the north. The flow began to incise into the soil and waste rock forming the new alignment of Clinton Creek now displaced hundreds of metres to the north and perched some 25 m above the former Clinton Creek channel and floodplain. The new channel has gradients ranging from about 3% to 6% and averaging about 3.6%. This compares to the channel's original in regime gradient of about 0.075%.

Erosion of the new channel at the lake outlet prompted concerns about a breach of the landslide dam and efforts to control erosion of the channel using riprap were began in 1981. The erosion control features included riprap armor and a rock weir. However, multiple failures during high flow events resulted in damage and the rebuilding of the erosion protection features over the years. Continued lateral movement of the landside debris was monitored and was found to decline over time going from 1.2 m/yr in 1977/1978 to 0.3 m/yr in 1986. As of 1999 up to two (2) to three (3) meters of incision had occurred immediately below the Hudgeon Creek outlet with the amount of incision decreasing further downstream. This kind of behaviour implies that the channel has the ability to self-armor using the particle sizes present in the waste rock and colluvial soil/bedrock in the valley wall, but that the armor has a threshold flow level at which the armor layer is breached allowing rapid incision/head-cutting to begin.

In the spring of 2000, an assessment of the condition of the Clinton Creek channel and an associated risk analysis and dam breach model were prepared. These studies eventually led to the design of an interim spillway structure to arrest the downcutting in Clinton Creek and reduce the risk of a catastrophic breach of the landslide dam (UMA, 2003 to 2005). The design involved a simple trapezoidal channel with a base width of 5 m to 7 m, 3 horizontal to 1 vertical side slopes, and a series of drops constructed using rock filled PVC coated galvanized wire gabion baskets. Spillway construction began in the summer/fall of 2002 and was completed in the summer/fall of 2004. The term 'drop structure' is a bit of a misnomer as the sequence of gabion baskets in the drops falling by 0.5 m every 2 m would be more properly described as a 'step spillway' section. However, in this paper we shall ignore the semantics and continue to refer to the features as drop structures. A long-term closure treatment will be eventually implemented to stabilize Clinton Creek (Wood, 2019), but that work will not occur prior to final closure which is likely to be delayed by a significant period of time.

In August of 2010 an extreme storm event occurred in the headwaters of Clinton Creek, estimated to have a recurrence interval (RI) of between 100 and 200 years. The resulting flows down the spillway channel caused severe damage to the lower steps of DS4 and initiated head cutting in the channel downstream of DS4 that resulted in additional channel incision on the order of 4 m, undermining and destroying the spillway structure from its terminus back to approximately half the distance up DS4 (see Figure 3). The erosion and undercutting along the south bank triggered numerous additional failures in the waste rock pile (see Figure 4).

Figure 3 The failed drop structure 4 (DS4) following the August 2010 storm (Wingrove, 2011)

Figue 4 Additional failures in the waste rock slopes downstream of DS4 (Wingrove, 2011)

Due to access and safety issues, repairs were not completed until September of 2015. The measure consisted of backfilling the head scarp below DS4 (see Figure 5), and forming a channel chute armored by articulating concrete block (ACB) mats. By the spring of 2016 the ACB Chute was already showing signs of deformation that signalled the onset of potential failure mechanisms that would eventually result in unacceptable displacements of blocks/mats (see Figure 6).

Figure 5 The failed surface of DS4 (ADVISIAN, 2015)

Figure 6 Displacements observed in the chute channel in 2016 (BGC, 2016)

By the spring of 2018, peak flows during the 2018 freshet resulted in the near catastrophic failure of the ACB mats and caused sections of the north bank slope to fail, with the channel eroding severely (see Figure 7).

Figure 7 Failed configuration of the ACB mat chute structure in the spring/summer of 2018

Figure 8 shows the current configuration of DS4 as of a site inspection conducted by Parsons and MINES Group/GLA personnel in September of 2021, which visually showed minimal changes in the condition of DS4 and the channel reach immediately downstream since the emergency field fit repairs compieted by Tetra Tech in 2018. The failure surface in the lower portion of DS4 has been armored with very large boulders of durable rock. The current project intends to provide a formal design for the repair of the damage from the 2018 failure of the DS4 drop structure and the ACB Mat lined chute that will provide the needed interim protection of the Clinton Creek landslide dam and spillway structure until such time as the final spillway facility can be designed, funded, and implemented at the site. The design should be capable of passing the largest practical peak design flood flow that can be accomodated within the existing canyon floor and regrading the waste rock slopes above the canyon floor to a stable configuration.

Figure 8 View of the current configuration of the Clinton Creek channel below DS4

3 Options for repair/replacement

The bedrock unit exposed in the Clinton Creek channel is an argillite unit (Pza) described mainly as a fragile carbonaceous argillite with well-defined cleavage. However, the unit exhibits multiple facies including limy argillite, limestone, and limy sandstone (see Figure 9). The limestone and sandstone facies, although sufficiently durable to inhibit erosion, are still subject to hydraulic plucking and transport during extreme events due to the thin bedded, and platy nature of the structure (see Figure 10).

Figure 9 Exposure of the limestone facies of the argillite unit

Figure 10 Chaotic piles of platy bedmaterial deposited on flat shelves of intact rock

3.1 Option 1 – Drop structures with fill

The concept of Option 1 is to construct a series of additional drops, similar to those used in drop structures 1 through 3, to safely deliver the flow to the current elevation of the Clinton Creek channel bed (Jacobs,2019, see Figure 11). Based on a review of the performance of the original drop structure configuration during the 2010 flood event and the more recent failure of the ACB mat and plunge pool structure, it was recommended that the design of the repair of the reach below DS4 consider the following general principles:

1. Limit the hydraulic head drop at each of the drop structures (based on the performance of DS1, DS2, and DS3 a maximum drop of 2.5 m was recommended).
2. Provide a horizontal apron of sufficient length to dissipate the energy of the drop (again, based on the performance of DS1, DS2, and DS3 a minimum length on the order of 30 m was recommended).
3. Extend the profile of the hydraulic drop to meet the downstream slope.

This approach relies heavily on consistency with the generally successful performance of the existing structures upstream (DS1, DS2, and DS3). It requires the filling of the existing channel bed scoured by the head cutting event of 2010 to pick up the remnants of DS4 forming the first in a series of smaller drops and extends the sequence of new drop structures downstream until the final plunge pool and apron can deliver subcritical flow into the current Clinton Creek channel bed. This option is believed to provide the highest degree of reliability and lowest risk of failure among all of the considered options for the interim spillway.

Once repaired, the final spillway structure is expected to have a total length of approximately 270 m. The existing width of the canyon places practical limitations on the magnitude of the peak design flow that can be carried by any of the interim options. While the final closure solution must meet Canadian Dam Association (CDA) design criteria which will have to carry some fraction of the Probable Maximum Flood

(PMF), the interim solution will be designed to carry at least the 50-year RI flood and potentially as much as the 200-year RI flood.

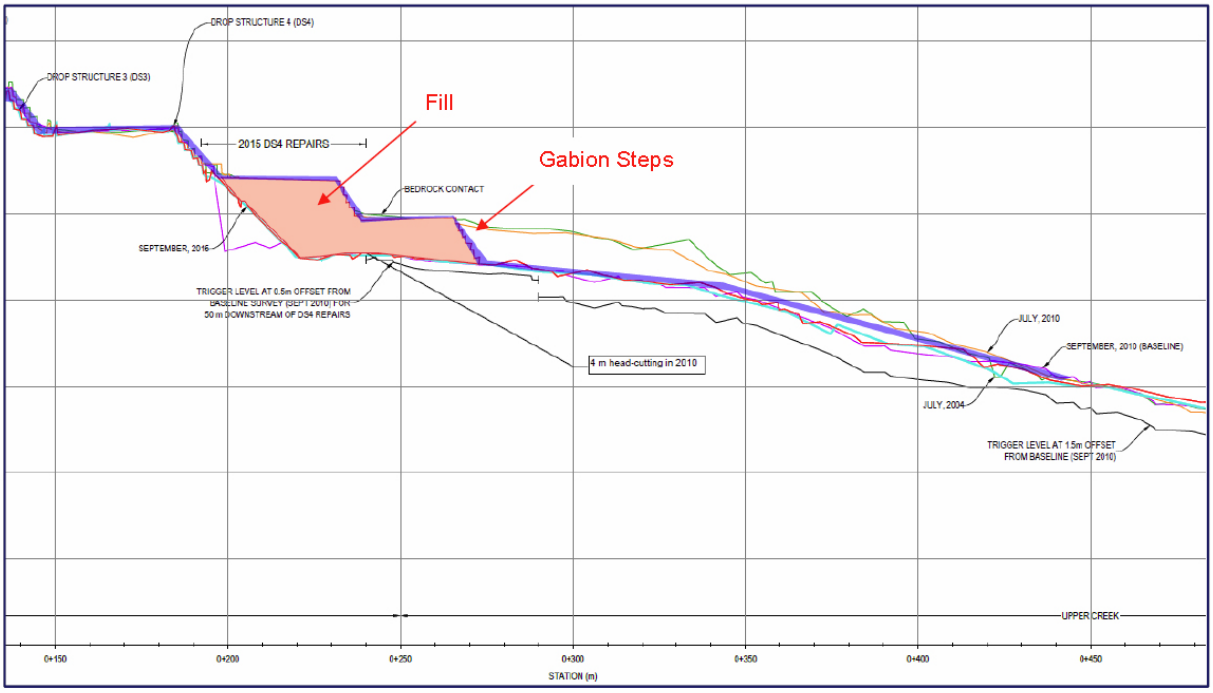

Figure 11 Schematic representation of option 1, drop structures with fill (JACOBS, 2019)

3.2 Option 2 – Drop structures with no fill

This option is similar to Option 1, except that the drop sections consist of a standalone rock weir with no fill material in between (Jacobs, 2019, see Figure 12). Regardless of the seepage capacity of the embankments, during high flows the small reservoirs will be full and the dams will be experiencing an overtopping flow during the design flow event. Therefore, the downstream face of the dams must be designed to safely accommodate this overtopping (which would strongly favor the use of gabions over rockfill). Rock chutes and riprap lined surfaces will often fail first not in a hydraulic transport mechanism but in a mass wasting type of failure or slide (usually a thin, uniform thickness referred to as an 'infinite slope' failure). This represents a significant risk for this option, even for a downstream slope that mimics the slope of the gabion drops (25% or 14°). An estimate of the Factor of Safety against an infinite slope type of mass failure during the passage of the design discharge event is 0.80 (assuming a layer thickness of 1.4 m, a flow depth of 0.7 m, seepage parallel to the slope, and an effective stress friction angle equal to the angle of repose estimated to be 42°). For all the above-described reasons, it is believed that the risks associated with this option are considerably higher than those associated with Option 1.

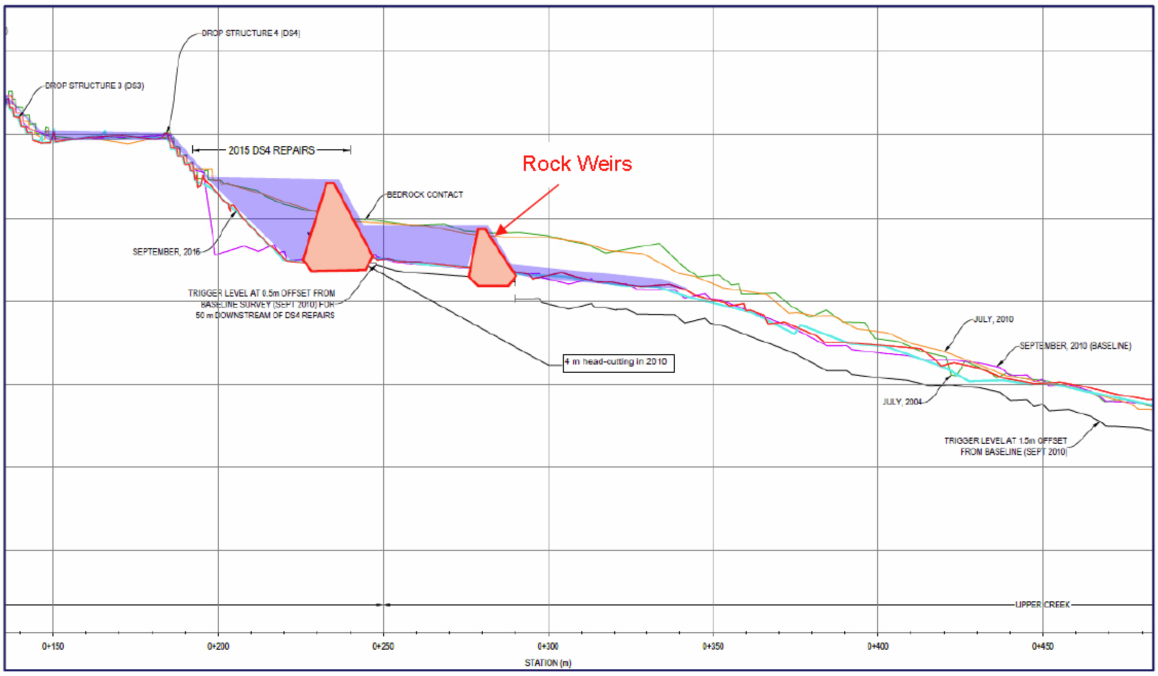

Figure 12 Schematic representation of option 2, drop structures with no fill (JACOBS, 2019)

3.3 Option 3 – Large rock chute

Unlike the failed ACB mat 'chute' structure that suffered from construction flaws and imperfections, an excessive drop length, and an inadequate plunge pool depth and length for energy dissipation, the large rock chute described in the report would rely on a surface of large, immobile, protruding rock (Jacobs, 2019) creating the rough equivalent of a baffled spillway where energy is dissipated in a network of impacts and directional changes, opposing currents, etc. and would still require space at the bottom for an adequate plunge pool and apron for the transition to subcritical flow prior to release into the Clinton Creek channel. The success of this approach relies heavily on the ability to create and maintain a highly controlled, rigid and immobile surface which is probably not very compatible with a site still experiencing lateral movements from landslide creep, and vertical settlement from melting permafrost layers. The risk of experiencing the potential progressive 'unravelling' of the structure in response to small changes is simply too high.

3.4 Option 4 – Development of a step-pool channel profile

The creation of a more natural step-pool channel profile in Clinton Creek (see Figure 13) and an associated 'in regime' channel approaching a condition of dynamic equilibrium is an excellent alternative that would provide any number of benefits in addition to merely providing energy dissipation and improving erosional stability. One of the benefits to this type of geomorphic design and channel restoration is that the channel is no longer a single purpose feature (i.e., not just a ditch to pass water). It is now a self-sustaining and self-maintaining stream with aquatic habitat consistent with unimpacted natural channels. One can even incorporate features like riffles for the production of invertebrate communities (fish food). Vegetation can often be used to create self-sustaining erosion protection and to create riparian habitat that will allow the stream corridor to function near its peak potential. Water quality can be improved by minimizing bed and bank erosion. Often a temporary diversion channel designed for operations will require further modification prior to final reclamation and abandonment. The restored channel system will already be adapted to the watershed and the natural channel systems, will be revegetated, and will have natural function and habitat values restored. It will often require no further modification prior to closure and abandonment and thus will eliminate those costs at the time of final reclamation.

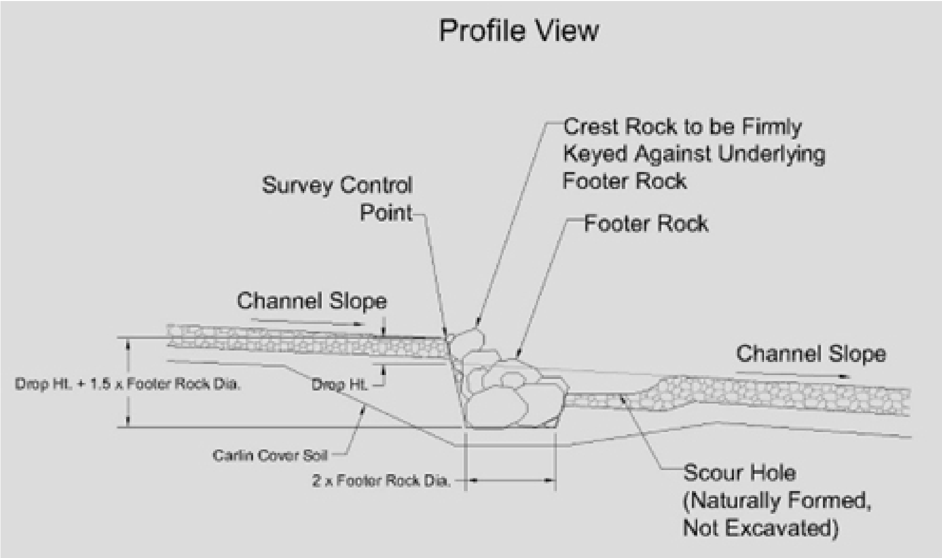

Figure 13 Rock vortex weir grade control structure creating steps in the step-pool channel (Parsons,2021)

However, there are also problems associated with this approach and its application in Clinton Creek with the most significant being that it would require a great deal of large, durable rock, something not readily available at the Clinton Creek site. Potential sources of large, durable rock consist of two existing quarry sites, the closest being about 40 kilometres from the site and the next closest about 60 kilometres away. Particularly in smaller streams, the frequency and spacing of the step-pool elements can make the construction of each individual weir impractical and cost prohibitive. Therefore, rock vortex weirs are often used as grade control structures that periodically anchor the channel gradient, particularly at key locations where there are changes in gradient, bedmaterial, channel dimensions, flow regime, etc. In between the weirs a basic channel cross section is provided along with an adequate type and volume of bedmaterial that will allow the stream to create its own step-pool profile naturally over time.

In natural systems the step-pool channels usually form in weathered and dislocated material derived from the bedrock source that lies immediately below them. Natural step-pool channels 'blowout' periodically during extreme events. But when they do, they do not just disappear. The materials are merely displaced some distance downstream and rearranged. Over time the step-pool configuration can reform from the same materials. When a step-pool channel system is artificially formed above a weak, erodible foundation, it is subject to a significantly different risk during extreme events. Should the flow depth during an event reach the upper edge of the channel system, the channel is at risk of being 'outflanked' meaning that the flow will quickly begin eroding the weak foundation and undermine the channel resulting in an 'avulsion' in which most or all of the flow is redirected into a new channel/flow path from which the step-pool profile is very unlikely to be able to recover over time. This risk makes it difficult to justify the use of such an approach for temporary or interim channel system designs where the design flow has a low recurrence interval (RI). Therefore, despite its many benefits, construction of a natural step-pool channel system is better suited to the final, permanent channel configuration with design flows approaching the Probable Maximum Flood (PMF) and may not be appropriate for interim solutions with a design RI of 25 years or less. The Step-Pool Channel Profile Option could be made viable if:

1. Design discharge criteria are increased with respect to the maximum capacity of the channel to minimize the outflanking/avulsion risk,
2. The thickness of the bedmaterials placed between rock vortex weir grade control structures is sufficient to accommodate the bedforms involved in the formation of the step-pool configuration over time without scouring down to the underlying erodible soils/waste rock, (which could initiate the unraveling of the channel), and

3. The investment in the securing of the very large volume of durable rock/riprap can be justified.

3.5 Option 5 – Maintenance of the existing 2018 emergency repair configuration

The emergency repairs put in place in 2019 (Tetra Tech, 2019) appear to have performed reasonably well over the last several years in preventing severe erosion and maintaining the integrity of the remnants of DS4 during the passage of routine snowmelt base flow and freshet events or routine precipitation sequences. However, the steep, angle of repose wall of large rock that armors the over-steepened headwall from the 2010 headcut is unlikely to be able to withstand the next truly extreme storm event or unusually large freshet, and the loss of that armor will immediately present a risk of the initiation of new head cutting that could undermine more segments of the spillway channel or even result in the catastrophic loss of the entire spillway leading to the risk of breach of the landslide dam. Monitoring and maintenance of these emergency measures is absolutely necessary until final spillway repairs can be implemented. However, this activity does not represent an appropriate solution for the management of breach risk until a permanent solution is in place.

4 Selected options

Based on the above-described evaluation of potential options, two (2) options were selected to proceed forward into conceptual level design. These were Option 1 (drop structures with fill), and Option 4 (development of a step-pool channel profile. Option 5 (continued maintenance) along with monitoring was also retained as a necessary interim measure.

5 Subsequent studies

Additional information would be required to progress to the next level which would include conceptual layout and design, HEC-RAS modelling, a cost sensitivity analysis, and an NCSP risk analysis (Failure Modes and Effects Analysis). The additional studies would include the following:

1. Development of a Design Flood Flow Manual
2. A study of the fluvial geomorphology of the Clinton Creek watershed

Upon completion of the next level design studies, a single preferred design option would be identified to proceed to final, construction ready design.

Although some daily flow observation data was available for Clinton Creek, the data was inconsistent with respect to timing, location, and method of collection (no rating curves available) with significant gaps in coverage (some gaps known to be the years that corresponded to extreme storm events). Therefore, it was decided that the design flows would come from a unit discharge vs drainage area analysis of select, multiple, hydrometric stations serving as surrogates for the Clinton Creek basin.

For the purpose of describing the fluvial geomorphology of the Clinton Creek channel, we divided the channel into seven (7) reaches with distinctly different characteristics (see Figure 14). The transect locations were chosen based on the following criteria:

1. Location(s) upstream from Hudgeon Lake where the waste rock failure has not influenced the creek
2. Location(s) within the waste rock influenced portion of the creek
3. Location(s) downstream from waste rock where the failure has not influenced the creek
4. Location(s) in a surrogate creek that has a climate, geology, and topography similar to Clinton Creek with no waste rock failure influence

The classification system used was the Rosgen Classification of Natural Rivers. Stream characteristics collected at each transect site included bank full width and depth, entrenchment ratio, sinuosity, and channel gradient. A particle size distribution was used to characterize the channel bed material using the Wolman pebble count procedure.

At this point a discussion of how the observed stream types relate to the behavior and history of the Clinton Creek channel would seem appropriate. After the initial filling of Hudgeon Lake, water begins to flow across the area where the slide debris contacts the mountainside to the north which is now displaced far to the north and perched about 25 m above the original valley floor. Both the argillite exposed on the mountainside and the waste rock /slide debris are readily erodible. So, significant flows of sediment starved water results in numerous, repeated erosional events at the junction of the slide debris and the natural ground. The ultimate result is a shallow bench on the argillite forming a low flow channel with a highly erodible bank of waste rock on the south.

Small flows are passed with little erosion on the low flow channel in the argillite/limestone, but large flows reach the easily eroded waste rock at the toe of the south bank and start cutting out the toe. This initiates a common cycle of channel type transition. A Type G channel (erosion gulley) forms at the toe of the waste rock pile. This type of channel is narrow and deep with maximum stream power and sediment transport capacity and quickly cuts below the existing channel bed diverting most or all of the flow into the formation of a headcut. Once the headcutting reaches its limit (peak flow subsides, caving of the bank inhibits further down cutting, etc.) a new base level is formed, and the channel begins adjusting to the new condition. Now the channel transitions from a Type G channel to a Type F channel which is focused not on deepening the channel, but on widening the channel in an attempt to reform a floodplain. Eventually, if the cycle were allowed to progress to completion, a new active floodplain would be formed, and a Type B or Type C meandering channel would be formed within the limits of the floodplain restoring the channel to an in-regime condition and long-term dynamic equilibrium/stability. However, the Clinton Creek channel has not been able to complete the cycle before yet another headcutting erosional event restarts the cycle. This accounts for the presence of the Type F channels in the Canyon Reach with abnormally high gradients, and in the upper portion of the Waste Rock Delta Reach and is consistent with the history of multiple destructive headcutting events in the channel.

Figure 14 The seven stream reaches of Clinton Creek

Yet another issue that needs to be addressed are the over-steepened waste rock slopes along the south side of the channel. Slopes are currently standing at angles at or above the angle of repose for the waste rock with many slopes in the range of 48°to 55°. These slopes must be regraded to satisfy both static and seismic design criteria and minimize the risk of another large mass failure and potential channel blockage.

6 Conclusions

Significant progress is being made in addressing the risk associated with the potential for breaching of the 1974 landslide dam formed in the Clinton Creek Valley of Canada's Yukon Territory. Although final closure design is certainly years and, more likely decades away, the design of a reasonable and practical interim solution is now in progress and is expected to help mitigate those risks until such time as the final spillway facility can be designed, funded, and implemented at the site.

References

Advisian (Subsidiary of Worley Parsons Group), 2015, *Clinton Creek Drop Structure No. 4 Repair*, December 2015.

BGC Engineering, Inc., 2016, *Government of Yukon, Clinton Creek, Independent Engineer's Channel Assessment*, October 31, 2016.

Chilkoot Geological Engineers LTD, 2015, *Borrow Source Assessment*, 2015.

Jacobs Engineering Group Inc., 2019, *Memorandum Report, Clinton Creek Mine, Review of Drop Structure #4 Failure*, April 5, 2019.

Jacobs Engineering Group Inc., 2019, *Memorandum Report, Clinton Creek Mine, DS4 Interim Improvement Options*, April 5, 2019.

Myers, K. L., 2015, 'Stream Relocation and Geomorphic Design to Improve Sustainability', *Proceedings of Mine Water Solutions in Extreme Environments*, April 12-15, 2015, Vancouver, Canada.

Parsons, Inc., *Clinton Creek Mine Site, Drop Structure 4 Options Assessment and Detailed Engineering, Design Options Evaluation Report*. October 25, 2021.

Parsons, Inc., *Design Flow Manual, Clinton Creek Mine Site, Drop Structure 4 Repair Project*, April 16, 2023.

Parsons, Inc., *Technical Memorandum, Field Investigation Results*, February 15, 2023.

Rosgen, David, *Applied River Morphology*, Wildland Hydrology, 1996.

Tetra Tech Canada Inc., 2019, *Field Inspection Memo, DS4 Emergency Repairs Followup Inspection, Long-Term Performance Monitoring Program – Clinton Creek Mine, Yukon,* October 15, 2019.

UMA Engineering Ltd., *Abandoned Clinton Creek Asbestos Mine, Condition Assessment Report*, April 2000.

UMA Engineering Ltd., 2000, *Abandoned Clinton Creek Asbestos Mine, Risk Assessment Report*, April 2000.

UMA Engineering Ltd., 2003, *Clinton Creek Channel Stabilization (Stage 1) Construction Report*, April 2003.

UMA Engineering Ltd., 2003, *Clinton Creek Channel Stabilization (Stage 2) Construction Report*, December 2003.

UMA Engineering Ltd., 2005, *Clinton Creek Channel Stabilization (Stage 3) Construction Report*, February 2005.

Wingrove, T. R. et. al., 2011, 'Former Clinton Creek asbestos mine', *Mine Closure 2011*, Alberta, Canada, pg 489 – 500.

Wolman, M. G., 'A method of sampling coarse river bed material', *Transactions of American Geophysical Union* 35, pg 951 – 956, December 1954.

Wood Canada Ltd., 2019, *Clinton Creek Remediation Project, Dam Breach Assessment*, November 15, 2019.

Wood Canada Ltd., 2019, *Geotechnical Summary*, December 2019.

Worley Parsons Canada, 2015, *Clinton Creek Engineering Review and Assessment. Part 1*, March 31, 2015.