Clinton Creek Site:

Fish Utilization and Passage

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Cover: Clinton Creek waste rock, channel and Hudgeon Lake: July 15, 2008.

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Clinton Creek Site: Fish Utilization and Passage

Introduction

Planning is underway to abandon the Clinton Creek Asbestos Mine Site. Clinton Creek flows through the mine site and was impacted by mine works and consequences thereof. Wolverine Creek, a tributary of Clinton Creek, was impacted by tailings from milling operations.

A number of Options for the design, monitoring and maintenance of channels to convey the flow of Clinton Creek through the mine site and Wolverine Creek over the tailings deposits were developed and presented in WorleyParsons (2014). A short-list of Options was chosen. In December 2015 the author was contracted to assist Yukon Government Assessment and Abandoned Mines and other parties through a review of the short-listed Options and existing aquatic information. The specific tasks were:

- Provide a summary of pre-mining aquatic baseline conditions;
- Update the information provided in the *"Distribution and Habitat Utilization of Clinton Creek by Fish: State of Knowledge to March, 2012"* ;
- Provide an understanding of the effect that Hudgeon Lake has on downstream resources in Clinton Creek, including known risks to aquatic life;
- Prepare a description of the long-term utilization by fish of each Clinton Creek Option; and
- Determine the upstream limit of fish migration in Wolverine Creek following the removal of the current culvert.

Each task was completed and Summaries of the results follow. Detailed information, including rationales and references addressing each task is presented in Appendices A to E following.

Summary of material presented in Appendices.

Pre-existing aquatic baseline conditions – Appendix A

The Clinton Creek mine was developed prior to regulatory requirements to collect aquatic baseline information. No written reports or imagery specific to the channels of Clinton or Wolverine Creek was found. Photographs of the general mine area exist but are of limited use. Air photos were the best information source found for pre-mine conditions. They show that Clinton Creek was typical of watercourses of its size in the non-glaciated portion of the Yukon River watershed. The creek had a relatively low and constant gradient with no waterfalls. Stands of mature spruce along the channel imply winter flows below the creek bottom. There were no active or abandoned beaver dams or ponds. Wolverine Creek had a low gradient near the mouth and then ascended more quickly to the upper watershed.

The same fish species use Clinton Creek today as would have used Clinton and Wolverine Creeks prior to mine development, and in much the same manner. The limit of upstream migration by fish in the main creek and tributaries would have varied annually and would have been related to environmental factors such as streamflow and gradient.

The lack of Slimy Sculpin in Hudgeon Lake may be attributed to the seasonal lack of dissolved oxygen in the Lake. Sampling conducted to date has not resulted in the capture of Slimy Sculpin in upper Clinton Creek or any other tributary entering the lake. This implies that there was little or no overwintering habitat upstream of the high water mark of the current lake at the time the lake was created.

Update of "Distribution and Habitat Utilization of Clinton Creek by Fish – State of Knowledge to March, 2012" - Appendix B

Information gathered since the publication of the *"Distribution and Habitat Utilisation of Clinton Creek by Fish: State of Knowledge to March, 2012"* added to the previous information and knowledge base. The Dawson District Renewable Resource Council (DDRRC) conducted their annual stream stewardship program between 2013 and 2015. They captured juvenile Chinook Salmon near the mouth of Clinton Creek and restored them to productive habitats near the mouth of Wolverine Creek. This enabled growth monitoring, overwintering investigations and the harvest of tissue for genetic stock identification.

Growth monitoring confirmed high rates of growth of juvenile Chinook Salmon near the mine-site. Overwintered juvenile Chinook Salmon were captured in 2014 and 2015. Tissue samples were collected in 2012 and 2013 from juvenile Chinook Salmon for DNA analysis. The leading edge of the anal fin was clipped from each Chinook as the sample. Five new stocks-of-origin were added to the 6 previously documented. Samples harvested by the DDRRC in 2014 and 2015 have not been analysed. Recapture of clipped Chinook in subsequent autumn or spring sampling provided insight into survival and rates of growth.

A study into the effects of asbestos exposure on Slimy Sculpin in Clinton Creek by Fisheries and Oceans Canada (DFO), Environment Canada (EC) and the British Columbia Animal Health Center was completed in 2013. Slimy Sculpin were chosen as they are the only year round resident fish in Clinton Creek. Their health was found to be comparable to other populations in the Yukon.

Slimy Sculpin were captured below Drop Structure #4 during late summer 2015 salvage activities. This was the first capture in this location since the catastrophic flood of August 2010, and indicated re-colonization of this area by Sculpin.

Effects of, and risks posed by, Hudgeon Lake on downstream aquatic life – Appendix C

Effects of Hudgeon Lake on downstream aquatic life

Hudgeon Lake appears to have reached its current size in the mid- to late 1970s as a result of a waste rock landslide across the Clinton Creek valley. During the last ~40 years it has developed relatively stable shorelines and limnologic characteristics. These include development of a seasonally aerated epilimnion, or top most water layer and an underlying, permanently anoxic hypolimnion or bottom water layer. Sulphides form in the hypolimnion and result in anoxic conditions extending upward through the epilimnion to the bottom of the ice during some or most winters. Fish have survived in aerated refuge areas in the past, but Hudgeon Lake and its tributaries are now considered to be barren of fish.

Aerated water enters the lake from tributaries in the spring and vertical mixing of the epilimnion starts at ice off. Limited sampling to date indicates rapid aeration- and warming of the top 2 meters of the epilimnion. Oxygen levels are depressed but capable of sustaining life and temperatures are low at 5 meters.

The lake modifies water quality, temperature and flow in Clinton Creek downstream of its outlet. These in turn are considered to have effects on algae, invertebrates and fish. As a general statement, algae feeds invertebrates and invertebrates feed fish. Most invertebrates cannot survive freezing. Those that can tend to be the favored food of smaller fish, such as juvenile Arctic Grayling, Chinook Salmon and Slimy Sculpin.

The primary effect of the lake on water quality in downstream waters has been to increase nutrients in surface outflowd and the seeps that result at least in part from lake water entering the waste rock and discharging downstream. The source of the nutrients is the decomposing organic matter in the lake. Invertebrate abundance downstream is high, and supports large numbers of fish.

Hudgeon Lake captures significant thermal energy, which is subsequently exported to Clinton Creek downstream from the lake outlet. This, in concert with the large crop of algae produced, increases the growth rates of invertebrates. Fish are able to use the thermal heterogeneity of the waters to maximize their feeding behaviour.

Risks posed by Hudgeon Lake on downstream aquatic life

The lake also poses risks to downstream aquatic life. Risks can be divided into existing- and possible risks. Existing risks include those that can be expected as a result of annual or multi-year variation in flow or temperature. Possible risks are those that may occur in exceptional circumstances or are not directly related to seasonal or annual variations in climatic or hydrologic conditions.

Existing risks include Hudgeon Lake buffering flows in Clinton Creek downstream of the mine, which has enabled beaver to colonize the creek and impact upstream migration by fish. Freezing of the outlet of Hudgeon Lake may result in the lake rising until the ice surface is overtopped, followed by a rapid discharge of the surcharged lake. Long term seepage from the lake may reduce surface outflows during summer low flow periods.

The greatest potential risk posed by Hudgeon Lake to downstream aquatic resources is the catastrophic release of water resulting from a breach of the waste rock deposits. The primary effects to, and response by fish in the mine site area would be related to the rapidly rising flows and sediment levels. Most fish in the creek would be displaced downstream to the Fortymile River. Effects would persist for years and perhaps decades until the creek had regained a state of equilibrium. A secondary effect would be the release of sulphide rich, saline water from the below the thermocline. This would probably result in the death of any fish or invertebrate remaining in Clinton Creek near the minesite after the initial outflow of surface water from above the thermocline.

The downstream extent of the effect would depend on the volume, concentration and duration of outflow of the water released. There would be no long-term, persistent effects.

Risk of releases of sulfide laden water from the outlet of Hudgeon Lake at current lake elevations is considered low. If it did occur, rapid aeration of the water as it passed over and through the gabion structure is anticipated.

Extent of long-term utilization by fish for each Clinton Creek Option - Appendix D

Five Options were reviewed. A number of general elements common to most of the Options were identified. They included:

- Effects of North Valley Wall instability. A future rock fall/slide could temporarily reduce the capacity of the channel to convey flows.
- Effects of aufeis. Channel designs appear to assume an unobstructed channel for each Option. Residual aufeis has been documented downstream of Drop Structure 4 after freshet, with clear indications that flows had been over the top of the ice surface rather than below it. Aufeis would reduce the capacity of the channel to convey spring freshet flows.
- Effects of retention of the surface elevation on the existing and future seepage of water from Hudgeon Lake. There is little flow over the lake outlet during summer low flow periods. Seepage from the lake is believed to be a cause, and to be related to the area of the waste dump that water can enter and the effective head (difference in elevation between the lake level and discharge areas downstream).
- Effects of beaver. Beaver are present up- and downstream of the mine area and pose a significant risk to the integrity and capacity of portions of channels for all Options except Option F. Low gradient channels and the outlet of the lake are at highest risk of damming. Beaver dams across the outlet of Hudgeon Lake may result in risk of significant flooding downstream if the dam were to collapse or otherwise rapidly fail.
- Maintenance and rebuilding. Monitoring of the completed channel is proposed for all Options. Maintenance is limited to certain of the Options. The Options that do not include maintenance pose an increased risk that upstream passage will not be achieved in the long term.

With a few design considerations, it is likely that all Options with the exception of I2 will allow the upstream migration of adult and sub-adult Arctic Grayling and juvenile Chinook Salmon to Hudgeon Lake immediately after construction. Many or most Arctic Grayling reaching Hudgeon Lake are expected to enter the lake. Some will remain there throughout the summer in aerated surface waters. Others will cross the lake and then enter and ascend upper Clinton Creek and lower Easter Creek if it is not obstructed. Most juvenile Chinook Salmon will probably remain in the channel, but some are expected to move through the lake to upper Clinton Creek.

Results of the review of the Options

Options C3 and D3 could allow fish access to Hudgeon Lake and tributaries thereof after construction. Long term access is unlikely in the absence of maintenance of the channel.

Option E3 would allow long term fish access to Hudgeon Lake and tributaries thereof at most times under most conditions, and without channel maintenance.

Option F would allow long term fish access throughout the Clinton Creek watershed but would result in a lengthy period of decreased productivity.

Option I2 would not allow fish access to Hudgeon Lake due to the 8% gradient section of channel.

Potential upstream limit of fish migration in Wolverine Creek – Appendix E

Fish cannot enter Wolverine Creek at present but are believed to have done so in the past. Removal of the existing culvert will restore access to the creek.

Wolverine Creek has an acceptable gradient and sufficient flow under most conditions to allow long term seasonal use by Arctic Grayling and juvenile Chinook Salmon as far upstream as the mouth of the first tributary entering from the East. The downstream end of the rock-lined channel in middle Wolverine Creek is immediately upstream of this point. The rock-lined channel has a nominal gradient of 15% and is too steep to allow upstream migration by fish.

The upstream limit of migration by fish in Wolverine Creek is considered to be the mouth of the first tributary entering from the East.

APPENDICES

Appendix A

Pre-mining aquatic baseline conditions.

Summary

The Clinton Creek mine was developed prior to regulatory requirements to collect aquatic baseline information. No written reports or imagery specific to the channels of Clinton or Wolverine Creek was found. Photographs of the general mine area exist but are of limited use. Air photos were the best information source found for pre-mine conditions. They show that Clinton Creek was typical of watercourses of its size in the non-glaciated portion of the Yukon River watershed. The creek had a relatively low and constant gradient with no waterfalls. Stands of mature spruce along the channel imply winter flows existed below the creek bottom. There were no active or abandoned beaver dams or ponds. Wolverine Creek had a low gradient near the mouth and then ascended more quickly to the upper watershed.

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Information sources accessed

Searches for documents or images were conducted at the Yukon Archives, the Energy Mines and Resources Library and the Yukon e-library. No documents were found.

Yukon Government Water Resources had no documents from the mine development- and operation period. The Yukon Water Board had a copy of the last water license issued but no supporting documents.

From 1971 to 1979, what is now Fisheries and Oceans Canada (DFO) and Environment and Climate Change Canada (ECCC) reported to the Minister of the Environment (1971-76) and the Minister of Fisheries and the Environment (1976-79). During this period, the Environmental Protection Service (EPS) was the departmental contact for the Clinton Creek mine. Their files provide a comprehensive record of the initial water licensing process and the public concern regarding the potential effects of asbestos exposure on human health and the environment. However, all their information is from after the mine started production and the waste rock and tailing landslides had been initiated.

Gordon Bradshaw, a past resident of Clinton Creek and an intervenor at the November 28, 1973 Yukon Territory Water Board hearing regarding the mine was approached but could not provide any information.

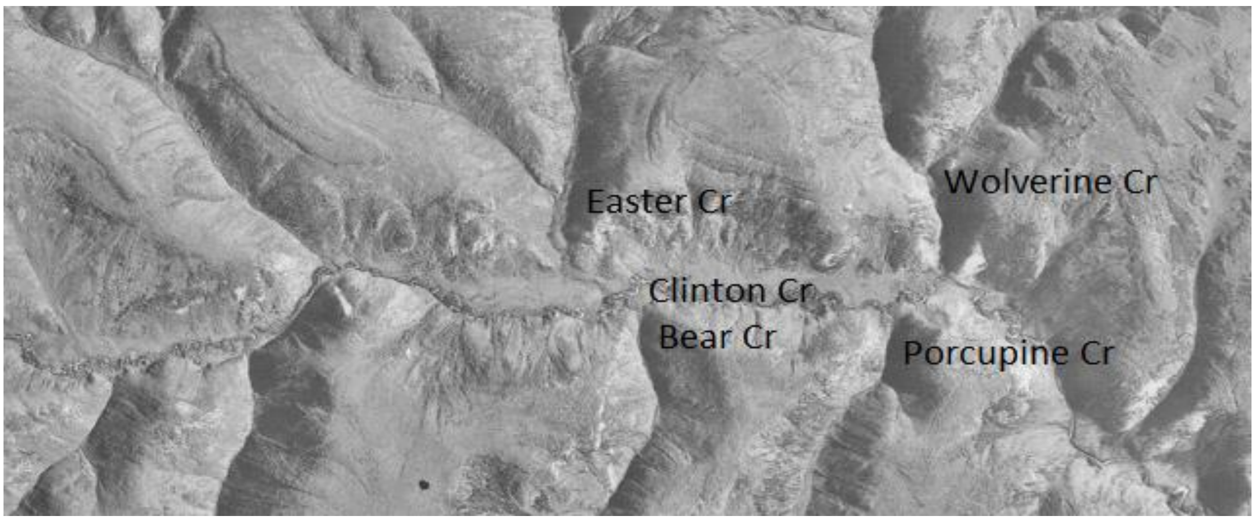
Gerry Whitley and Bud McAlpine, long-time employees of Department of Indian Affairs and Northern Development (DIAND) Water Resources and its successor, the Yukon Government Environment Water Resources, were approached. Gerry's role had been mainly in water management, while Bud was an engineer and focussed on the physical stability of the site. He was a frequent visitor to the mine, co-authored a report on the landslide dam in 1994 (Stepanek and McAlpine, 1994), and commissioned a series of monitoring reports on the site by Geo-Engineering Incorporated. He said that he and his co-author could find very little information on the pre-existing environment or the circumstances leading to the slide.

The Dawson community was not approached for local information. It is likely that members of some of the local First Nation- and other long term families worked at the mine when it was being developed and operated.

Pre-mine aquatic baseline conditions: impacted area of Clinton Creek.

The section of Clinton Creek impacted directly by the mine originally flowed along the southern margin of the valley. The valley is relatively wide. The southern valley wall rises steeply to a plateau surface. To the north, the valley bottom sloped gently away from the channel margin and then rose more steeply to the plateau. In 1951, some or most of the active layer detachments that are still visible above Hudgeon Lake were already present on the south valley wall. Active-layer detachments are defined as slope failures "in which the thawed or thawing portion of the active layer detaches from the underlying frozen material" (van Everdingen, 1998). Pioneering vegetation on the detachments tends to be birch and aspen, in contrast to the dwarf spruce and moss usually found on north-facing slopes.

Wildfire had burned much or most of the Clinton Creek watershed prior to 1951. It burned to the edge of the channel in some areas, while other areas escaped the fire. The unburned areas are those with the dark tone in Photograph A-1, while the burned areas show light tones to the channel edge. An effect of wildfire is an increase in the number of surface layer detachments. Many reach the stream bottom and deposit sediment into the stream flowing through it (Lipovsky et.al., 2005). Sands and silt size particles erode quickly and are soon transported downstream, while gravels, cobbles and larger particles are transported more slowly.



Photograph A-1. 1951 - the Clinton Creek valley prior to mine development.

Clinton Creek had a sinuous- to meandering channel, with a few short, straight sections. Stream side vegetation that escaped the wildfire was dominated by large spruce. Vegetation along the burned area was at an early stage of development. The 1951 aerial photograph was taken in the morning, with the sun in the east. The shadow of the stream bank in the burned area where the channel was aligned north-west is visible as a fine dark line, implying that the bank was high- and steep enough to cast a shadow. This is consistent with the steep, high banks typical of streams in unglaciated areas. The light tone of much of the channel bottom, where visible, is consistent with dry gravel exposed during a summer low flow period. The wetted area at the time of photography would have only taken a small portion of the channel bottom. These characteristics are consistent with streams in unglaciated areas. There were no obstructions to the upstream migration of fish such as water falls or beaver dams. This is also consistent with streams in unglaciated areas.

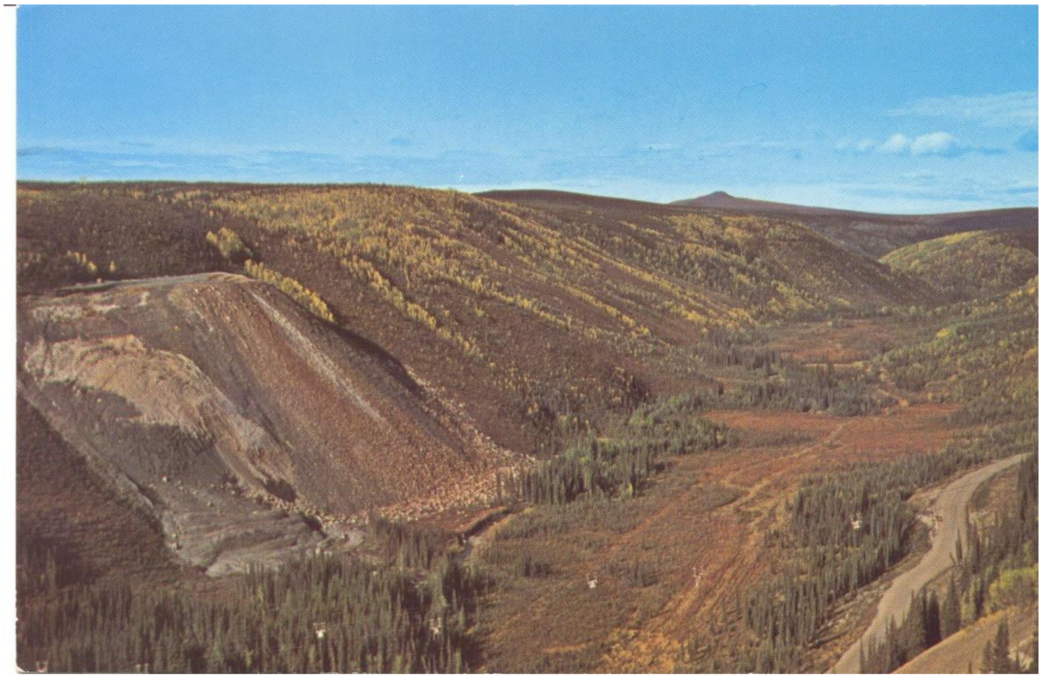
Photograph A-2. 1970. Clinton Creek valley, during early production.

Photograph A-2 shows the valley bottom in 1970, shortly after the mine started production. Easter Creek enters from the top center of the photograph. In the right side of the photograph Clinton Creek flows through the second diversion, as the waste rock has already buried parts of the original creek channel.

The channel upstream of the mouth of Easter Creek was undisrupted in 1970. The channel remained in virtually the same location it had been 19 years before, indicating a high degree of lateral stability. The channel bottom continued to be wide and composed of dry gravels. Stream side vegetation had become well established in the burned areas: the emergent deciduous vegetation has a lighter tone than spruce.

The channel downstream of Easter Creek had been disturbed by various mine-related activities including roads and trails.

Photograph A-3 was probably taken in autumn 1969 and shows the Clinton Creek valley in the area of what would later become Hudgeon Lake. Easter Creek enters from the right at mid photo. A waste rock dump on the south valley wall in the left foreground has already started to fail. A section of the creek has been buried under the advancing toe of the waste rock dump and the creek is flowing through the first diversion. The second diversion will follow the Cat trail extending along the toe of the right valley wall in the foreground. The mature spruce forest in the foreground corresponds to the spruce dominated stream side vegetation to the left of the mouth of Porcupine Creek in Photograph A-1. The emergent deciduous stream side vegetation is visible further along the creek. Past surface layer detachments on the north facing valley wall have been colonized by deciduous trees. Most detachments start near the top of the slope and some extend to the valley bottom.



Photograph A-3 – Clinton Creek valley, possibly early autumn 1969.

Fish species annually using the impacted area and upstream waters of Clinton Creek prior to mine development would have included Arctic Grayling, juvenile Chinook Salmon and Slimy Sculpin. Arctic Grayling would have entered in the spring and left the creek in the autumn. They are likely to have migrated further up the watershed than the other species of fish. Juvenile Chinook Salmon would have entered the creek between late June and September and migrated upstream. Migrations in excess of 20 km are known, so they could have migrated well beyond the current west end of Hudgeon Lake.

The lack of Slimy Sculpin in Hudgeon Lake may now be attributed to the seasonal lack of dissolved oxygen in the Lake. However, sampling conducted to date has not resulted in the capture of Slimy Sculpin in upper Clinton Creek or any other tributary entering the lake. Sculpin populations in these tributaries prior to the flooding of the Clinton Creek valley should have been able to sustain themselves, as the species has very modest habitat requirements. Their apparent absence implies that there was little or no overwintering habitat upstream of the high water mark of the current lake at the time the lake was created.

Pre-mine aquatic baseline conditions – Wolverine Creek

Wolverine Creek has a drainage basin of 28.6 km^2, of which 21 km^2 is above the upstream end of the tailings slide zone (UMA, 2000). The tailings slide extended across

Wolverine Creek and displaced the active stream channel to the northwest. The channel is now perched above the original valley bottom. In 2003 the existing channel bottom was up to 13 meters above the original channel elevation (UMA, 2003). The tailings deposits impound water and interrupt normal sediment transport from the upper watershed. The valley bottom below the downstream end of the tailings deposit is entirely transformed.

Photograph A-4 - Lower Wolverine Creek.

Photograph A-4 was taken in 1970, before substantive disturbance to the watershed occurred. The creek flowed through a "V" shaped valley. The section of the creek downstream of the first tributary entering from the right (east) was not actively incised in bedrock but had developed a narrow, relatively flat valley bottom through which it flowed. Stream side vegetation in this section of the creek appeared to be dominated by spruce near the creek. Access roads are generally located on the side hills beside the valley rather than the valley bottom, implying that soft ground conditions existed along the creek.

The area that would later be buried by tailings is upstream of this section of creek. The creek appeared to be incised through much or most of the upper area and occupy the entire valley bottom. Spruce were present along the creek, as scattered stems or small stands rather than continuous stream side communities such as those along Clinton Creek. The original stream gradient was ~2.5%, and it is likely that the creek tumbled through boulders and over bedrock prior to the failure of the tailings piles and their subsequent deposit in Wolverine Creek.

Fish species using Wolverine Creek prior to the mine development would have included Arctic Grayling, juvenile Chinook Salmon and Slimy Sculpin. Only the lower creek would have been utilized due to the rapid increase in gradient above the mouth of the first tributary entering from the East. The same seasonality of use as Clinton Creek would apply.

References for Appendix A:

Lipovsky, P.S., J. Coates, A.G. Lewkowicz, and E. Trochim. 2005. Active-layer detachments following the summer 2004 forest fires near Dawson City, Yukon. In: Yukon Exploration and Geology 2005, D.S. Emond, G.D. Bradshaw, L.L. Lewis and L.H. Weston (eds.) Yukon Geological Survey, p. 175 – 194.

Stepanek, M. 1986. Cassiar Asbestos Mine Abandonment Plan Review Report. Letter report to J. Nickel, Indian and Northern Affairs Water Resources. 51 p. & Appendices.

Stepanek, M and H.F. McAlpine. 1994. Landslide Dams at Clinton Creek. Water Report #378. 8 p.

UMA. 2000. Indian and Northern Affairs Canada Abandoned Clinton Creek Asbestos Mine Risk Assessment Report. 52 p & appendices

UMA. 2003. Abandoned Clinton Creek Asbestos Mine Environmental Liability Report. 43 p. & Appendices.

van Everdingen, R. (ed.), 1998 (revised January, 2002). Multilanguage glossary of permafrost and related ground-ice terms. International Permafrost Association Terminology Working Group, Boulder, CO: National Snow and Ice Data Centre/World Data Centre for Glaciology, 88 p.

Appendix B

Update of "Distribution and Habitat Utilization of Clinton Creek by Fish – State of Knowledge to March, 2012"

Summary

Information gathered since the publication of the *"Distribution and Habitat Utilisation of Clinton Creek by Fish: State of Knowledge to March, 2012"* adds to the previous information and knowledge base. The Dawson District Renewable Resource Council (DDRRC) conducted their annual stream stewardship program between 2013 and 2015. They captured juvenile Chinook Salmon near the mouth of Clinton Creek and restored them to productive habitats near the mouth of Wolverine Creek. This enabled growth monitoring, overwintering investigations and the harvest of tissue for genetic stock identification.

Growth monitoring confirmed high rates of growth of juvenile Chinook Salmon near the mine-site. Overwintered juvenile Chinook Salmon were captured in 2014 and 2015. Tissue samples harvested from juvenile Chinook Salmon for DNA analysis were collected annually from 2012 to 2015. The leading edge of the anal fin is clipped from each Chinook as the sample. Analysis of the 2012 and 2013 samples allowed five new stocks-of-origin to be added to the 6 previously documented. Samples harvested in 2014 and 2015 have not been analysed. Recapture of clipped Chinook in subsequent autumn- or spring sampling provided insight into survival and rates of growth.

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Slimy Sculpin were captured below Drop Structure #4 during late summer 2015 salvage activities. This was the first capture in this location since the catastrophic flood of August 2010, and indicated re-colonization of this area by Sculpin.

Fish in Clinton Creek

The three fish species most likely to use Clinton Creek at the mine-site include Arctic Grayling, Chinook Salmon and Slimy Sculpin.

Arctic Grayling are distributed through North America and Siberia (Northcote, 2000). Most scientific knowledge on Arctic Grayling should be applied cautiously to Yukon populations as it based on studies conducted elsewhere in the species' range (von Finster and Reid, 2015). Stewart et.al. (2007) summarized available information and characterized the species as having complex seasonal migrations into and between rivers, streams and, where present, lakes. All life stages prefer clear water environments and relatively shallow waters and are generally tolerant of low dissolved oxygen (DO) levels. Young-of-year juveniles were able to survive at DO levels of 1.5 mllligrams/litre (mg/l) at 10^{0}C and 2.0 mg/l at 20^{0}C. Young-of-year and juvenile Arctic Grayling were also tolerant of high temperatures, particularly when acclimatized: lethal temperatures were as high as 29.3^{0}C. Tolerance to turbidity or to levels of suspended sediments was low.

Arctic Grayling enter Clinton Creek from the Fortymile River in the spring. At least some of the adults spawn in the mine site area or immediately downstream of it. Some or most young-of-year juveniles, sub-adults, and adult grayling remain in the creek and feed there for most of the open water period. The great majority of Arctic Grayling migrate downstream to the Fortymile River and beyond in the autumn.

The original range of Chinook Salmon was northward along the Pacific Coast from California to the eastern Siberian coast (Raliegh et.al., 1986). Yukon River Chinook Salmon have a high social and economic value, are intensively managed and have received far more scientific attention than any other fish species in the Yukon. They have the longest upstream migration of any population in the world, with spawning occurring in excess of 3000 km above the river's mouth (Eiler et.al. 2014). Spawning occurs in more than 100 streams and rivers in Canada (Bradford et.al., 2009), of which all but one are upstream of the Fortymile River, into which Clinton Creek flows.

Juvenile Chinook Salmon are the only life stage of the species that utilizes Clinton Creek. They are a portion of the juvenile Yukon River Chinook Salmon population that moves downstream after emergence from their streams of origin and ascends non-natal rivers and streams to rear (Bradford et.al., 2001). The distance between the natal and non-natal streams may be several hundred kilometers or more (Bradford et.al., 2009; Daum and Flannery, 2011). The extent of possible upstream migration in non-natal streams has not been established: however, during placer classification studies in the

Sixtymile and Indian River basins in the 1980s and early 1990s the author repeatedly captured juvenile Chinook Salmon in non-spawning streams more than 20 kilometers upstream of their mouths. During the rearing period Chinook Salmon require temperatures between 4.5^{0}C and 19.1^{0}C to grow, with optimum temperatures around 15^{0}C (McCullough, 1999) and DO levels above 4.5 mg/l (Raleigh, et.al., 1986). Overwintering has been associated with ground discharging into creeks or rivers (Bradford et.al., 2001). Yearling juveniles grow quickly as water temperatures warm in the streams they have overwintered in (Moodie et.al., 2000). Downstream migration of yearling Chinook Salmon past Dawson City generally occurs prior to July 15 (Bradford et.al, 2008).

Young-of-year Chinook Salmon utilizing Clinton Creek first ascend the Fortymile River and then enter the creek in early July (Smart, 2006). Small numbers of young-of-year Chinook that migrated to the mine site unassisted were captured prior to 2005 (Delaney et.al., 1981). Chinook have been captured as far upstream as the lower end of the gabion structures (von Finster, 2007). Overwintered juvenile Chinook Salmon were captured in Clinton Creek near the mouth of Wolverine Creek, establishing the presence of overwintering habitat (Mackenzie-Grieve, 2011).

Slimy Sculpin are small fish, seldom exceeding 100 mm in total length (TL) and are considered to be non-migratory (Morrow, 1980). They have been captured in minnow traps set for juvenile Chinook Salmon during spring, summer and autumn (von Finster, 2005, 2006, 2009). They are year-round residents of Clinton Creek at the mine-site and conduct all live processes there.

Smaller numbers of juvenile Longnose Sucker and adult Lake Chub have also been occasionally captured at or near the mine site (von Finster, 2009).

New information

New information sources include the annual reports from the Dawson District Renewable Resource Council (DDRRC) regarding stewardship-related activities; memoranda reports by DFO on the analysis of genetic samples collected by the DDRRC, a study by DFO, EPS and BC Animal Health Center on the effects of asbestos on Slimy Sculpin, and fish salvage reports from Ecological Logistics and Research Ltd. The knowledge gained is accretionary rather than substantive: it adds to the previous base of knowledge rather than changing it. Updates to the 2012 State of Knowledge include:

1. Restoration of juvenile Chinook Salmon to productive fish habitat in the general vicinity of the mine site has continued. The activity started in 2006 and has taken place every year since. Annual numbers of juvenile salmon restored to the

creek have ranged widely, with a low of 15 in 2011 to a high of 2070 in 2007 (Taylor, 2015) and with a mean annual release of 677 juvenile Chinook. The annual numbers of juvenile Chinook Salmon restored to Clinton Creek near Wolverine Creek during 2012 – 2015 inclusive were within this range, with 702 in 2012; 685 in 2013; 633 in 2014; and 311 in 2015 (Taylor 2015).

2. Chinook captured at the mine site are larger than those captured in the lower section of the creek in autumn. Average fork lengths (distance from end of nose to fork of tail) of juveniles captured at the mine site were 6.8 mm longer in 2012 and 7.6 mm longer in 2014 (Taylor, 2012 & 2014). Autumn sampling was not conducted in 2013 due to high water conditions (Taylor, 2013), and in 2015 due to construction activities on Clinton Creek in September (Taylor, 2015).
3. Juvenile Chinook Salmon overwintered in Clinton Creek during the winters of 2013/14 (Taylor, 2014) and 2014/15 (Taylor, 2015). Eight overwintered juvenile Chinook Salmon were captured in spring of 2014 and 6 in spring of 2015. Sampling occurred after the spring freshet, which would have displaced most Chinook Salmon downstream. Capture of these fish further confirms that Clinton Creek and associated waters provide suitable overwintering habitat for juvenile Chinook Salmon.
4. Tissue samples acquired from juvenile Chinook for DNA analysis in 2012 and 2013 were analysed and reported by Mackenzie-Grieve (2013 & 2014). In 2009, juvenile Chinook Salmon produced by populations described as the Yukon Main (between the mouth of the Pelly and Tatchun Rivers), Little Kalzas, Teslin, Big Salmon, Nordenskiold and Hoole River were identified (Mackenzie-Grieve, 2010). In 2012, juveniles assigned to the Little Salmon, Whitehorse, Klondike and Mayo were identified (Mackenzie-Grieve, 2013) and in 2013 juveniles assigned to the Chandindu population were identified (Mackenzie-Grieve, 2014). Samples acquired in 2014 and 2015 have not yet been analysed.
5. Acquisition of the tissue sample provided a mark to allow re-captures to be identified. The tissue sample was clipped from the leading edge of the anal fin in early August and the juvenile Chinook Salmon restored to Clinton Creek near the mouth of Wolverine Creek. Each Chinook captured in autumn or spring assessment sampling was examined to determine whether the anal fin had been clipped. In autumn of 2014, 4 of 23 juveniles captured had an obvious clip. By spring the fin rays had regrown in some individuals to the extent that it was difficult to determine whether they had been clipped. Other individuals still had obvious clips, as the re-grown fin had a different shape than that of an un-clipped fish. In spring of 2014, a minimum 3 of 8 overwintered juveniles had been clipped, and in 2015 a minimum 1 of 6 juveniles had been clipped. This

information confirmed that those juveniles captured in the autumn and following spring were from among the group restored to the creek.

6. Slimy Sculpin in Clinton Creek showed little medical evidence that they were less healthy than those in other Yukon streams The qualification was due to a liver lesion in one of the fish taken from Clinton Creek that could have been pre-cancerous (Marty et.al, 2013). As Sculpin are considered residents (as opposed to seasonal transients, such as Arctic Grayling and Chinook Salmon) of streams, any effect of asbestos would be most severe on this species. The lack of any obvious effect provides address to the perceived risk to fish from exposure to asbestos.
7. Fish salvage activities conducted immediately below the lowest gabion structure documented the presence of Slimy Sculpin and Longnose Sucker at the site, with 159 salvaged from below the drop structure (ELR, 2015). Sculpin disappeared from the upper canyon after the catastrophic flows of early August 2010 and were not captured during sampling in 2012 or 2013. Longnose sucker have not been reported from this specific area in the recent past.

References for Appendix B

Bradford, M.J., J.A. Grout, and S. Moodie. 2001. Ecology of juvenile chinook salmon in a small non-natal stream of the Yukon River drainage and the role of ice conditions on their distribution and survival. Canadian Journal of Zoology, vol. 79, p 2043-2054

Bradford, M.J., J. Duncan and J.W. Jang. 2008. Downstream Migrations of Juvenile Chinook Salmon and Other Fishes in the Upper Yukon River. Arctic. Vol. 61, No. 3 (September 2008) P. 255 – 264.

Bradford, M.J., A. von Finster, and P.A. Milligan. 2009. Freshwater Life History, Habitat, and the Production of Chinook Salmon from the Upper Yukon Basin. Pages 19 – 39 in Pacific Salmon: Ecology and Management of Western Alaska's Populations. C.C. Krueger and C.E. Zimmerman, editors. American Fisheries Symposium 70, Bethesda, Maryland.

Daum, D.W. and B.G. Flannery. 2011. Canadian-Origin Chinook Salmon Rearing in Non-Natal U.S. Tributary Streams in the Yukon River, Alaska. Transactions of the American Fisheries Society, 140:207 – 220.

Delaney, P.W., R. Stewart, D. Konasewich and G.A. Vigers. 1981. Assessment of the Effectsw of the Clinton Creek Mine Waste Dump and Tailings, Yukon Territory. EVS Consultants. Prepared for Cassiar Resources Ltd. 65 p. & Appendices.

Ecological Logistics & Research Ltd. 2015. Clinton Creek Environmental Monitoring and Fish Salvage. Memoranda report to Assessment and Abandoned Mines. 8 p. & Appendices

Eiler, J. H., M.M. Masuda, T.R. Spencer, R.J. Driscoll, and.C.B Schreck, 2014 Distribution, Stock Composition and Timing, and Tagging Response of Wild Chinook Salmon Returning to a Large, Free-Flowing River Basin. Transactions of the American Fisheries Society, 143(6), 1476-1507.

Mackenzie-Grieve, J. October 26, 2010. Clinton Creek jcs Genetics. Memo to file. DFO OHEB. 18p.

Mackenzie-Grieve, J. 2011. Clinton Creek site visit- May 25-26, 2011. Fisheries & Oceans Canada, Memorandum to file, June 1, 2011. 4 p.

Mackenzie-Grieve, J. June 13, 2013. 2012 Clinton Creek JCS DNA work. Memo to file. DFO FCSAP. 5 p.

Mackenzie-Grieve, J. March 14, 2014. 2013 Clinton Creek JCS DNA work. Memo to file. DFO FCSAP. 10 p.

Marty, G.D., J. Mackenzie-Grieve, J. Miller and M. Guilbeault. 2013. Health Assessment of Slimy Sculpin in Three Yukon Streams. Aquatic Health Centre, Fisheries and Oceans and Environment Canada. 68 p.

McCullough, D.A. 1999. Review and Synthesis of Effects of Alterations to the Water Temperature Regime on Freshwater Life Stages of Salmonids, with Special Reference to Chinook Salmon. Columbia River Inter-Tribal Fish Commission for the US Environmental Protection Agency. 279 p.

Moodie, S., J.A. Grout, and A. von Finster. 2000. Juvenile Chinook Salmon *(Oncorhychus tshawytscha)* utilization of Croucher Creek, a small Non-natal Tributary of the Upper Yukon River during 1993. Canadian Manuscript Report of Fisheries and Aquatic Sciences 2531. 65 p.

Morrow, J.E. 1980. The Freshwater Fishes of Alaska. Alaska Northwest Publishing Company. 248 p.

Northcote, T.G. 2000. An Updated Review of Grayling Biology, Impacts, and Management. PWFWCP Report. 24 p.

Raleigh, R.F., W.J. Miller, and P.C. Nelson. 1986 Habitat Suitability Index Models and Instream Flow Suitability Curves: Chinook Salmon. Fish and Wildlife Service. U.S. Department of the Interior. 64 p.

Smart, C. 2006. Spawning and Rearing Access Restoration. Prepared for the Yukon River Panel by Dawson Renewable Resources Council. 17 p. and Appendices.

Stewart, D.B., N.J. Mochnacz, J.D. Reist, T.J. Carmichael, and C.D. Sawatzky. 2007. Fish life history and habitat use in the Northwest Territories: Arctic Grayling *(Thymallus arcticus)*. Central and Arctic Region Fisheries and Oceans Canada. Canadian Manuscript Report of Fisheries and Aquatic Sciences 2797. 63 p.

Taylor, L. 2013. Yukon River North Mainstem Stewardship. DDRRC. Yukon River R&E Fund. CRE13-06 45 p.

Taylor, L. 2014. Yukon River North Mainstem Stewardship. DDRRC. Yukon River R&E Fund. CRE14-06 45 p.

Taylor, L. 2015. Yukon River North Mainstem Stewardship. DDRRC. Yukon River R&E Fund. CRE15-06 49 p.

von Finster, A. 2005. Clinton Creek, tributary to the Fortymile River, Yukon River North Mainstem sub-basin – Record of 2005 sampling. Memo to Clinton Creek FCSAP file. DFO OHEB. 8 p.

von Finster, A. 2006. Clinton Creek, tributary to the Fortymile River, Yukon River North Mainstem sub-basin – record of 2006 activities. Memo to file. DFO OHEB. 6 p.

von Finster, A. December 23, 2007. Clinton Creek, tributary to the Fortymile River, Yukon River North Mainstem sub-basin – record of 2007 activities. Memo to file. DFO OHEB. 12 p.

von Finster, A. 2009. Clinton Creek, tributary to the Fortymile River, Yukon River North Mainstem sub-basin – record of 2008 activities. Memo to file. DFO OHEB. 12 p.

von Finster, A. and D. Reid. 2015. Potential Impacts and Risks of Proposed Next Generation Hydroelectric Dams on Fish and Fish Habitat in Yukon Waters. Wildlife Conservation Society Canada Conservation Report No. 8. Toronto, Ontario, Canada. 86 p.

Appendix C

Effects of, and risks posed by, Hudgeon Lake on downstream aquatic life.

Summary

Hudgeon Lake appears to have reached its current size in the mid- to late 1970s as a result of a waste rock landslide across the Clinton Creek valley. During the last ~40 years it has developed relatively stable shorelines and limnologic characteristics. These include development of a seasonally aerated epilimnion, or top most water layer and an underlying, permanently anoxic hypolimnion or bottom water layer. Sulphides form in the hypolimnion and result in anoxic conditions extending upward through the epilimnion to the bottom of the ice during some or most winters. Fish have survived in aerated refuge areas in the past, but Hudgeon Lake and its tributaries are now considered to be barren of fish.

Aerated water enters the lake from tributaries in the spring and vertical mixing of the epilimnion starts at ice off. Limited sampling to date indicates rapid aeration- and warming of the top 2 meters of the epilimnion. Oxygen levels are depressed but capable of sustaining life and temperatures are low at 5 meters.

The lake modifies water quality, temperature and flow in Clinton Creek downstream of its outlet. These in turn are considered to have effects on algae, invertebrates and fish. As a general statement, algae feeds invertebrates and invertebrates feed fish. Most invertebrates cannot survive freezing but some can. Those that do are the favored food of smaller fish, such as juvenile Arctic Grayling, Chinook Salmon and Slimy Sculpin.

The primary effect of the lake on water quality in downstream waters has been to increase nutrients in surface outflow and the seeps that result from lake water entering the waste rock and discharging downstream. The source of the nutrients is the decomposing organic matter in the lake. Invertebrate abundance downstream is high, and supports the large numbers of fish.

Hudgeon Lake captures significant thermal energy, which is subsequently exported to Clinton Creek downstream from the lake outlet. This, in concert with the large crop of algae produced, increases the growth rates of invertebrates. Fish are able to use the thermal heterogeneity of the waters to maximize their feeding.

The lake also poses risks to downstream aquatic life. Risks can be divided into existing- and possible risks. Existing risks include those that can be expected as a result of

annual or multi-year variation in flow or temperature. Possible risks are those that may occur in exceptional circumstances or are not directly related to seasonal or annual variations in climatic or hydrologic conditions.

Existing risks include Hudgeon Lake buffering flows in Clinton Creek downstream of the mine, which has enabled beaver to colonize the creek and impact upstream migration by fish. Freezing of the outlet of Hudgeon Lake may result in the lake rising until the ice surface is overtopped, followed by a rapid discharge of the surcharged lake. Long term seepage from the lake may reduce surface outflows during summer low flow periods.

The greatest possible risk posed by Hudgeon Lake to downstream aquatic resources is the catastrophic release of water resulting from a rapidly developing breach of the waste rock deposits. The primary effects to, and response by fish in the mine site area would be related to the rapidly rising flows and sediment levels. Most fish in the creek would be displaced downstream to the Fortymile River. Effects would persist for years and perhaps decades until the creek had regained a state of equilibrium. A secondary effect would be the release of sulphide rich, saline water from below the thermocline. This would probably result in the death of any fish or invertebrate remaining in Clinton Creek near the mine site after the initial outflow of surface water from above the thermocline. The downstream extent of the effect would depend on the volume, concentration and duration of outflow of the water released. There would be no long-term, persistent effects of the discharge on water quality.

Risk of releases of sulfide laden water from the outlet of Hudgeon Lake at current lake elevations is considered low. If it did occur, rapid aeration of the water as it passed over and through the gabion structure is anticipated.

Description of Hudgeon Lake.

Hudgeon Lake formed as a result of a landslide that crossed Clinton Creek. The landslide is composed of waste rock that was end-dumped into the Clinton Creek valley (Stepanek and McAlpine, 1994). The landslide occurred in 1974 (RRU, 1999), and impounded the waters of Clinton Creek. The functional creation of Hudgeon Lake can be considered to be 1975, giving a current age of 41 years.

In 2010 Hudgeon Lake was approximately 2100 meters long, up to 600 meters wide, had a maximum depth of 29 meters, a surface area of 72 hectares and contained about 10 million m^3 of water (AECOM, 2011). The drainage basin upstream of the lake outlet has an area of 111.9 km^2, or 54% of the 203.8 km^2 total drainage basin of Clinton Creek. The primary inflow to the lake is from upper Clinton Creek which enters from the west and has a drainage basin of 63.1 km^2. Easter Creek is the secondary inflow, enters from the north and has a drainage basin of 26.3 km^2 (UMA, 2000).

The lake is ice covered for about 6 months of the year, typically from late October to early May. During some or most winters the waters of the lake are entirely anoxic, and cannot support fish (UMA, 2008). The primary cause of the anoxic conditions is decomposition of organic material on the lake bottom, and a contributing factor is naturally high concentrations of sulphate in waters entering the lake (UMA, 2008; Liebau, 2010). The decomposition also results in the formation of sulfides which tend to be concentrated in the lower levels of the lake. Anoxic surface water conditions are likely partly caused by oxidation of methane, which bubbles up from the lake bottom throughout the year and can be trapped below the ice in the winter.

Aerated refuges composed of water suitable for aquatic life remain during some winters. Evidence for this is a female Arctic Grayling captured in the lake in autumn of 2005 (von Finster, 2005). Assuming it was in the lake at the time of substantive completion of the gabion structures in 2003, it survived two winters in the lake prior to capture. Much more comprehensive sampling of the lake and inlet streams conducted in 2007 did not result in the capture of any fish, establishing that the lake did not support fish (WMEC, 2008). As fish cannot ascend the present gabion structures, Hudgeon Lake is now barren of fish.

Spring break up/ice off conditions have not been investigated. This may not be a bad thing, as considerable annual variation in the timing and duration of these processes is anticipated and a single year of data could provide misleading results. There appears to be little or no surface flow from the lake during the winter. It is likely that the current outlet of the lake freezes to the bottom in some or most years. Outflow under these conditions would be limited to seepage through the bottom of the channel or through the waste rock deposits. Inflows to the lake in the spring resulting from snowmelt are aerated and initially have low levels of dissolved solids. The inflowing melt water is less dense than the lake water and will flow over its surface to the outlet. Limited vertical mixing between the lake and melt water is anticipated under these conditions.

Vertical mixing of lake water commences as soon as the lake becomes ice free. Mixing depends primarily on the action of wind on the lake surface. Wind causes waves, and waves result directly or indirectly in vertical mixing. The direction, velocity and duration of wind and the nature and form of the shoreline are key variables: as a rule, the greater the wind speed, the longer the fetch (distance that the wind can blow unobstructed over the lake surface) and greater the duration, the greater the potential vertical mixing. Recent information (HEI, 2016) indicates that most wind measured above Hudgeon Lake in 2015 was aligned in north/north west or south/south east directions. Wind events can also be derived from water temperatures measured in Hudgeon Lake, or immediately downstream of the outlet. Rapid declines in temperature during times of the day when air temperatures are at or near maximum (such as late afternoon) indicate mixing of colder, deeper water with warmer surface water. The sharp and short drops in August water temperatures presented in Figure 4 on page 23 of HEI (2016) are believed to be examples of wind events, and correspond to similar drops in water temperature recorded within the gabion structures (von Finster, unpublished information).

The annual rate of aeration of Hudgeon Lake has not been investigated. However, by summer the surface waters have sufficient oxygen to be able to support fish and other aquatic life (RRU, 1999). Dissolved oxygen levels are generally highest in the upper 2 meters of the lake and then decline with depth. Levels measured at 5 meters have been depressed but remained sufficient to sustain aquatic life (Liebau, 2010; MacKenzie-Grieve, unpublished data). The chemical characteristics of the water change quickly below 5 meters.

Aquatic life in downstream waters.

The seasonal use of downstream waters by algae, invertebrates and fish are presently affected by Hudgeon Lake. A very brief description of the more important characteristics of each of these groups of organisms follows.

Algae directly or indirectly comprise a substantial portion of the diet of aquatic invertebrates. The most noticeable algae in Clinton Creek is filamentous green algae. It streams from the gabions and is present in, or is associated with, ground water discharges throughout the mine site. This type of algae requires sunlight and grows best in alkaline waters (LaPerriere, 1994). It may not be as noticeable in shaded areas but will develop in unshaded areas downstream.

Aquatic invertebrates comprise a substantial portion of the diet of fish. Most management models of aquatic invertebrate community structure are based on temperate zone environments. They poorly address northern aquatic ecosystems, particularly in small streams subject to freezing to the bottom in some or all years. Irons et.al. (1993) found that most types of invertebrate in shallow streams in interior Alaska were unable to survive freezing temperatures. They have to move into refuge areas with suitable water quality, such as deep pools or saturated subsurface areas. Some Dipterans (true flies) can withstand freezing. They are uniquely well adapted to streams and portions of streams that freeze. They are generally the dominant taxa in areas subject to freezing and without refuge areas. Dipterans tend to have small body sizes and to emerge from their pupae simultaneously in "hatches".

Dipterans are a favored food for the three stream dwelling, sight-feeding fish species most commonly found in Clinton Creek at or near the mine site. These include young-of-year and overwintered juvenile Chinook Salmon (Gutierrez, 2011; Jones-Foster, 2009); younger Arctic Grayling (Jones et.al., 2003); and smaller Slimy Sculpin (Morrow, 1984).

Low numbers of juvenile Longnose Sucker are generally present, and Lake Chub are very occasionally captured. They are a minor component of the aquatic environment. Juvenile burbot are common in Clinton Creek near the mouth.

Effects on aquatic life in downstream waters

Water quality

Photograph C-1. Filamentous algae at the downstream end of Drop Structure 4.

The main effect of the lake on downstream water quality has been an increase in nutrients. Support for this includes the heavy growth of algae in the outlet channel. Seeps entering the channel bed and banks within the gabion structure can be identified by the early growth of algae at the discharge site. Later in the summer, the area covered by algae is greatest when the flows from the lake have been low and relatively constant. Photograph C-1 shows this effect.

A number of seeps or larger ground water discharges occur on the surface of the developing alluvial fan downstream of the canyon, and more along the southern margin of the valley wall (LES, 2011; ELR, 2015). The discharge zones on the surface of the fan have generally been subject to the cycle of deposition and erosion by which the fan is developing. They have appeared and then been buried by subsequent flood events. Photograph C-2 shows a typical seep and the algal response to it surfacing. Of note, the seepage shown was buried by material transported downstream in the August 2010 flood.

Photograph C-2 July 26, 2005. Filamentous green algae in a seep on the developing alluvial fan, indicating the rapid assimilation of available nutrients by algae.

Some seeps persist for an extended period: the discharge site at HEI (2016) Station GWCC-5 not physically changed since 2011 although the volume of flow from the discharge has varied. The source(s) of the ground water discharging on the fan are not apparent.

There are dense populations of dipterans downstream of algae producing areas wherever the stream bottom (or any man-made structure) is stable enough to allow the insects to attach. This includes the gabion structures and areas downstream of the canyon in 2007 and 2009 (WMES, 2008; Minnow, 2010).

Assessment of indirect effects of increased nutrients through increased food for fish downstream of the lake is confounded by the gabion structure, which serves as a barrier to upstream migration. Large numbers of fish tend to be present in the canyon or downstream waters (Roach and Ricks, 2003; Copland, 2004 & 2008; ELR, 2015). The high densities of fish many reflect their inability to move higher into the watershed rather than be a response to the abundant food organisms present.

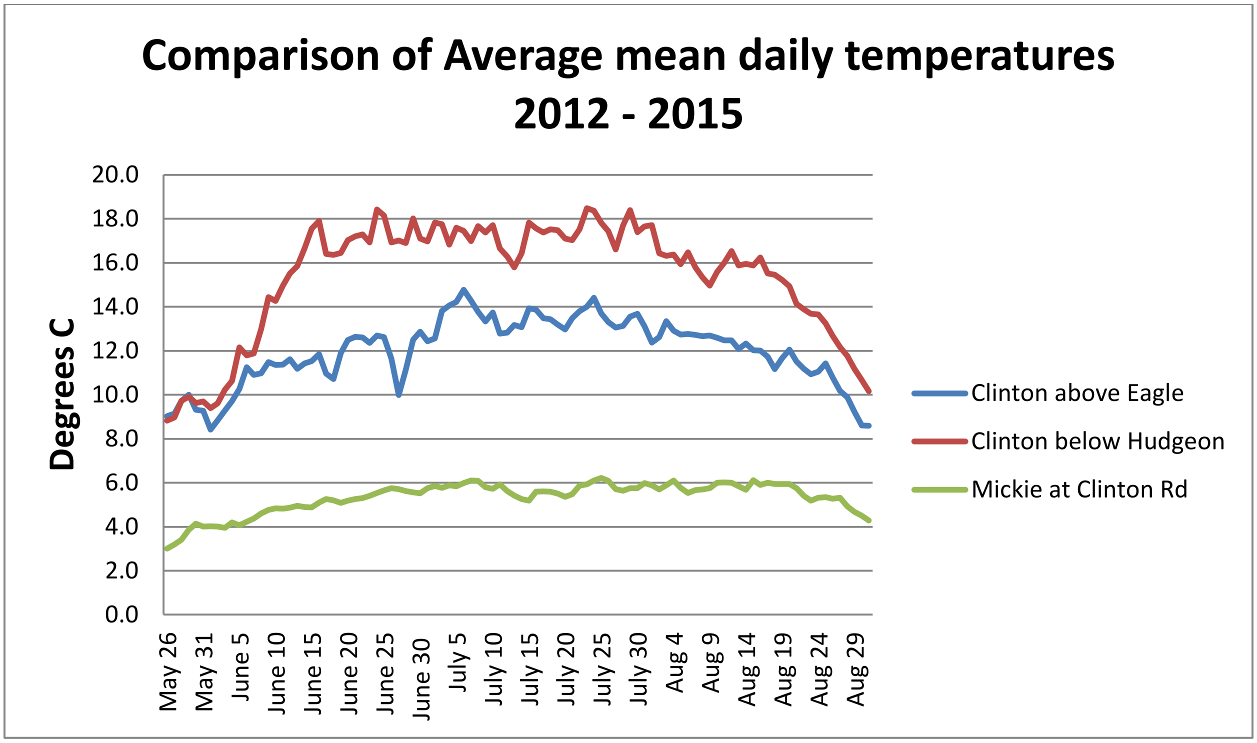
Arctic Grayling were virtually absent from Clinton Creek at the mine site in 2007. Young-of-year Chinook captured at the downstream end of the gabion structures were very large, implying excellent rearing conditions (von Finster, 2007). The lack of competition from the Grayling for food resources could have been a contributing factor for the rapid growth by the Chinook, as the 2007 rate of growth was not exceeded or even approached before or since.

Water temperatures

Aquatic invertebrates and fish are ectotherms, or cold blooded. Assuming sufficient food is available, invertebrates in northern aquatic ecosystems generally grow most rapidly when water temperatures are warm.

Temperatures control or heavily influence all life stages of fish (Caissie, 2006). This includes migration(s), spawning, incubation, rearing and overwintering. A critical concept is that the aquatic thermal environment is not homogenous. Fish can feed in an area with water temperatures above their published tolerance levels and then move to cooler waters, such as downstream of seeps or into deeper water, to digest and recover.

Hudgeon Lake effects downstream temperatures of Clinton Creek. Figure 3-1 demonstrates this effect. Data loggers recorded hourly temperatures in Clinton Creek below Hudgeon Lake, Clinton Creek above Eagle Creek and Mickie Creek at below the Clinton Road crossing. The mean daily temperatures were calculated annually for 2012 – 2015 and then averaged to produce the graph. Summer temperatures at the outlet of Hudgeon Lake were generally 2 – 4^{0}C above those upstream of Eagle Creek and 10 – 12^{0}C above those of Mickie Creek.



Graph C-1. Averages (2012 – 2015) of Mean daily temperatures of Clinton Creek below Hudgeon Lake; above the mouth of Eagle Creek; and in Mickie Creek.

During warm, calm, and sunny conditions surface waters of Hudgeon Lake warm quickly. Temperatures of outflows from the lake may be very high relative to the latitude and altitude of the lake. The maximum water temperature measured to date is 26.85^0 C, and was recorded by a data logger at 2200 hrs on July 7, 2007 (von Finster, 2007). Winds and wave actions carry the thermal energy below the surface, where it is stored and released in the autumn. As a collateral effect wind brings colder water to the surface of the lake, resulting in short term depressions in water temperatures at the lake outlet and in e channel downstream (von Finster, unpublished data). This increases the thermal heterogeneity of the waters of the channel. Regardless of these depressions the outlet of the lake and Clinton Creek downstream remains warm relative to other streams in the area and does so well into the autumn.

Considerable variation in optimum growth temperatures for juvenile Chinook Salmon has been reported: however it may be as high as 19^0 (McCullough, 1999). Juvenile Chinook Salmon are small fish and can take advantage of minor seeps in stream bottoms for thermal refuges during warm water periods. They can therefore feed in warm water and then retreat to cooler water to digest their food and rest.

Arctic grayling spawn in the spring. Eggs develop very quickly when water temperatures are sufficiently warm and may hatch in as little as 9 days. Assuming sufficient food is available, growth can be rapid (Scott and Crossman, 1979). Young-of-year juveniles have been observed feeding in water exceeding 25^0 and then returning to colder waters.

<u>Flow</u>

The effects of Hudgeon Lake on downstream flow is more difficult to determine than that of water quality/nutrients or temperature. The lake is expected to buffer flows into lower Clinton Creek during summer precipitation events, as 54% of the overall watershed is located above the lake outlet (UMA, 2000). The Clinton Creek watershed appears to have been colonized by beaver since 1980: neither Fisheries and Environment Canada (1977) or Delaney et.al. (1981) mention beaver and no sign of beaver cuttings is visible in the photographs in either report. Active or abandoned beaver dams and ponds are not apparent on 1951 or 1970 aerial photographs. Beaver dams across smaller streams in non-glaciated terrain are rare to absent, except where the streams cross flood plains of the rivers to which they drain. Once established in Clinton Creek, beaver moved into Hudgeon Lake and dammed Easter Creek (WMES, 2008). They have also built dams in the reach of reduced stream gradient resulting from the tailings deposit in the Wolverine Creek valley (Minnow Environmental, 2009).

It is possible that Hudgeon Lake increases the severity of the spring freshet in Clinton Creek in some years. This would be due to the freezing of the lake outlet, which may serve to obstruct the outflow until the blockage is breached. Although the outlet of Hudgeon Lake has not been monitored at freshet, lake outlet freezing at Coal Lake in the southern Yukon resulted in an outburst flood (Jassek and Ford, 1998).

The effects of beaver damming or outburst floods on the aquatic life of Clinton Creek will primarily be on the upstream migration of fish. Beaver dams can delay or obstruct these migrations, particularly when a series of dams must be passed over. Arctic Grayling migrate upstream during or immediately after the spring freshet. Many dams across migration routes tend to be in a state of disrepair at this time as they cannot be maintained during the winter. Those that continue to hold back water generally have sufficient flow over or around the dam to allow grayling to crest them. Since aquatic monitoring began in 2005, Arctic Grayling were virtually absent at the mine site in 2007 but were present in all other years between 2006 and 2015. Juvenile Chinook Salmon enter Clinton Creek in July, after active dams have been rebuilt or repaired. Prior to the start of the DDRRC Stream Stewardship project in 2006, only small numbers of Chinook were able to reach the mine site area. This was attributed to the large number of beaver dams built across the creek between the Fortymile River and the mine site (von Finster, 2005). This attribution was supported when 17 beaver dams were counted between the mouth of Clinton Creek and the mine site in 2006 (von Finster, 2006).

Surface flows from Hudgeon Lake may be very low, with the creek flowing through the gabion structures rather than over them. Low flows usually occur in early to mid-summer. A contributing factor may be evaporation from the lake's surface, which would be greatest at that time. However, the transpiration from the terrestrial vegetation in the flooded portion of the valley would have been greatest in early summer. Any comparisons of water lost to the atmosphere before and after the lake creation must be conducted cautiously.

Seepage from the lake either into the waste rock deposit or into a talik under the original stream bed may also contribute to low flows at the lake outlet. Prior to mine development, Clinton Creek flowed along the southern margin of the valley. There was a riparian fringe of large spruce on each side of the channel, implying a saturated talik under the creek. The waste rock dumps covered a section of the active Clinton Creek channel prior to the 1974 failure. It is probable that at least a portion of the original talik remains and may conduct flows from the lake to the downstream discharge points. As noted by HEI (2015) the springs/seeps on the south side of the valley are at the toe of the original waste dump. They are also near the pre-mine channel of Clinton Creek. The methods chosen to analyse the data collected in this monitoring should allow better insight to the source(s) of the ground water discharging.

Risks posed to aquatic life in downstream waters

Catastrophic release of water

The dominant risk to downstream aquatic life is that of a catastrophic release of water from Hudgeon Lake. UMA (2000) described a series of potential failure modes based on the site (as it was then) and provided a qualitative assessment of the risk to human health and infrastructure downstream to the Fortymile River. This was reviewed and updated by AECOM (2009). AECOM's assessment recognized the reduction in risk resulting from the completion of the outlet control structure in 2004. The August 2010 rainstorm and flood subsequently occurred resulting in significant vertical erosion of the channel at the downstream end of the lake outlet structure.

The severity of effects to downstream aquatic life from a sudden release of the contents of Hudgeon Lake would be catastrophic in the short term and severe in the longer term. A sudden release is likely be associated with some form of reduction of the capacity of the channel and resulting flow over the waste rock. This could be associated with ice or aufeis in the spring, debris in the summer or a combination of the two. Beavers dam Clinton Creek downstream of the mine site (von Finster, 2006) and have been active in tributaries to Hudgeon Lake (WMEC, 2008). Damming the lake outlet channel is entirely within their capacity: the damming of outlets of similar or larger lakes by beaver has occurred, including Hutshi Lake (Champagne and Aishihik First Nation, 2003), Fox Lake (Grady, 1997), and Klusha Lake (Jang, 2001). The potential of beaver damming the outlet of the lake must be considered as a potential threat.

UMA (2000) conducted an analysis of the potential breach of the waste rock piles. Recognizing the changes that have occurred, such as the construction of the gabion structures and the subsequent down-cutting of the channel below them, the findings they arrived at remain valid. As a worst-case scenario, the outflow flood would occur in less than an hour, would peak at over 500 cubic meters per second (cms) and have an initial velocity of up to 4 meters per second (mps). The flood peak would attenuate with distance downstream.

UMA do not describe the potential volume of waste rock that could be eroded in the process of breach development or its downstream transport. However, the majority of the waste rock will be carried downstream from the breach and deposited when and where insufficient energy remains in the flood to move it further downstream. Finer material will travel furthest, and much of the sand and smaller particles will probably reach the Fortymile River. Elevated sediment transport down the creek is expected to continue for years and perhaps decades until the mine site stabilized and the creek re-established a state of equilibrium downstream of the mine site.

The immediate effects on aquatic life would be related to the increase in volume of flow and levels of sediment in the water. Most aquatic invertebrates would be destroyed, although many of those living within the hyporheic zone (zone of saturated material lying below the stream bottom) may survive. Many or most juvenile Chinook Salmon would be displaced downstream to the Fortymile as the flood waters rose. This is their response to extreme high water events and associated high sediment levels in non-natal streams (Daum and Flannery, 2011). The behaviour of Arctic Grayling has been less studied, but is expected to be similar to that of juvenile Chinook Salmon as they tend to be absent from streams after extreme high flows have occurred. It is likely that all Slimy Sculpin below the breach and for some distance downstream would be destroyed, as this species does not have the swimming capacity of Grayling or juvenile Chinook Salmon.

An additional effect would be the release of water from below the oxygenated level of Hudgeon Lake at the time of the breach. This water would be a risk only until it becomes aerated. The rate at which this would occur with such a large volume of water, and over such a large area, is unknown. However, since the great majority of aquatic life in Clinton Creek downstream of the breach would have been destroyed or displaced by the outflow flood/torrent, the effect of the sulphides below the lake chemocline is of lesser concern than the flood. If the anoxic or sulfide rich water extends downstream to the Fortymile River, any fish in the river will be able to avoid the plume. Additionally, the release of anoxic or sulfide rich water would be of limited duration.

In the longer term, Clinton Creek would have to continually form new channels either by moving sediment downstream- or out of the existing channel or by eroding new channels around the materials deposited in the existing channel. A long period of instability is probable, accompanied by reductions in algae, invertebrate production, and fish use.

<u>Sulfide in outflows from Hudgeon Lake</u>

Sulfides are common in nature. They form under anaerobic conditions, and may be found in areas underlain by organic materials and flooded or saturated with still water. They have a strong sulfurous odour. This odour has been noted on the delta being formed by upper Clinton Creek as it enters Hudgeon Lake. The delta is composed of deposits of inorganic sediments and organic materials deposited at the lake margin. Sulfurous odours have also been noted in the footprint what was the large beaver pond upstream of the mouth of Wolverine Creek. This pond is now abandoned and has filled with waste rock transported downstream from the waste rock piles.

Risk of releases of sulfide laden water from the outlet of Hudgeon Lake at current lake elevations is considered low. Sulfides were absent from the top 5 meters of the lake in the summer of 2007 (Liebau, 2010) and in early July of 2012 (Mackenzie-Grieve, unpublished data). Winter sampling has only been conducted at depths of 10 meters or more. However, other parameters collected during the winter months imply that the chemocline remained below 5 meters (Liebau, 2010). The distinctive odour of sulfides was not present during spring site visits in 2008 -2010 and 2012 – 2015. No remains of dead fish were observed in Clinton Creek during sampling conducted during these visits. The absence of past releases of anoxic or sulfide rich water at current lake levels is not a perfect predictor of potential future releases, but is a good indicator that there is a low risk this will occur except under exceptional circumstances.

An example of such a circumstance would be during or immediately following a long period of sustained high east- or west winds. Releases of anoxic waters would be most likely in a spring following a winter with a low snow pack. The low snow pack would limit the amount of oxygen rich snow melt run off to the lake. The aerated surface layer would be more shallow as a result, and in concert with high and sustained winds could result in anoxic water mixing with surface water. A mitigating factor would be that the wind would provide a high degree of aeration by increasing the effective surface area of the lake (waves have a higher surface area than does flat water) and continually bringing fresh air to the water/atmosphere interface.

Flows into the lake resulting from major precipitation events would be less dense than the deeper lake waters and would flow over the top of the lake waters.

Fish that had migrated upstream as far as the obstruction to upstream migration existing at the time of discharge would be at most risk. However, aeration of water passing through the gabion structures and the canyon would occur. The dissolved oxygen levels might not be at saturation levels. Aquatic life can survive at levels well below saturation, and it is likely that a short duration depression of dissolved oxygen would not result in serious harm to downstream fish.

Of note, the sole fish kill recorded to date in Clinton Creek was a result of Clinton Creek being completely blocked at the lake in 2003 to allow construction of the gabion structure. All fish could not be salvaged from the canyon section, and a minimum of 130 died (Roach, 2003). Discharge of water into the channel immediately downstream of the work site were required during subsequent construction.

References for Appendix C

AECOM Canada Ltd. 2009. Former Clinton Asbestos Mine Overview Report. Prepared for Government of Yukon. 81 p.

AECOM Canada Ltd. 2011. Clinton Creek Technical Options Assessment. Prepared for Government of Yukon. 60 p. & appendices.

Caissie, D. 2006. The thermal regime of rivers: a review. Freshwater Biology (2006) 51, 1389-1406.

Champagne & Aishihik First Nations. 2003. Upper Nordenskiold River Salmon Restoration – Final Project Report, 2002. Yukon River Panel Restoration and Enhancement project CRE-55-02. 13 p.

Copland, H. Dec 15, 2004. Report on Operations Under License to Collect Fish Number 04-17, Clinton Creek. Government of Yukon Energy, Mines and Resources, Assessment and Abandoned Mines. 2 p.

Copland, H. Jan 8, 2008. Report on Operations Under License to Collect Fish #CL07-19, Clinton Creek. Government of Yukon Energy, Mines and Resources, Assessment and Abandoned Mines. 2 p.

Daum, D.W. and B.G. Flannery. 2011. Canadian-Origin Chinook Salmon Rearing in Non-Natal U.S. Tributary Streams in the Yukon River, Alaska. Transactions of the American Fisheries Society, 140:207 – 220.

Delaney, P.W., R. Stewart, D. Konasewich and G.A. Vigers. 1981. Assessment of the Effects of the Clinton Creek Mine Waste Dump and Tailings, Yukon Territory. EVS Consultants. Prepared for Cassiar Resources Ltd. 65 p. & Appendices.

Ecological Logistics & Research Ltd. 2015. Clinton Creek Environmental Monitoring and Fish Salvage. Memoranda report to Assessment and Abandoned Mines. 8 p. & Appendices

Fisheries and Environment Canada. 1977. An Environmental Assessment of the Effects of Cassiar Asbestos Corporation on Clinton Creek, Yukon Territories. Surveillance Report, EPS 5-PR-77-3. 38 p.

Grady, D.J. 1997. 1997 Summer Field Studies of Fox (Richthofen), Laurier, and Joe Creeks, Tributaries of Lake Lebarge Yukon. Ta'an Kwäch'än Council. Yukon River Panel R&E Project CRE-16-97.

Gutierrez, L. 2011. Terrestrial Invertebrate Prey for Juvenile Chinook Salmon Abundance and Environmental Controls in an Interior Alaska River. MSc. Thesis. University of Alaska, Fairbanks.

Hawkshaw, S.C.F. 2011. Temperature preference and distribution of juvenile Arctic Grayling (Thymallus Arcticus) in the Williston Watershed, British Columbia, Canada. MSc. Thesis, University of British Columbia. 102 p.

Hemmera Envirochem Inc.(HEI). 2016. Fall Clinton Creek Surface Water Quality and Hydrological Monitoring Program. Report Prepared for Government of Yukon Assessment and Abandoned Mines 34 p. & Tables & Appendices.

Irons, J.G. III, L.K. Miller, and M.W. Oswood. 1993. Ecological adaptations of aquatic macroinvetebrates to overwintering in interior Alaska (U.S.A.) streams. Canadian Journal of Zoology, Volume 71, p 98 – 100.

Jang, J.W. 2001. Assessment of the Quantity and Quality of Potential Chinook Spawning Habitat Klusha Creek - Yukon Territory. Prepared for DFO Habitat Restoration and Salmon Enhancement Program. 14 p.

Jasek, M., and G. Ford. 1998. Coal Lake outlet freeze-up, containment of winter inflows and estimates of related outburst flood (abstract only). Proc. Wolf Creek Research Basin Hydrology, Ecology, Environment, Whitehorse, Yukon, Mar. 5-7. p. 89

Jones, N.E., W.M. Tonna and G.J. Scrimgeourb. 2003. Selective feeding of age-0 Arctic grayling in lake-outlet streams of the Northwest Territories, Canada. Environmental Biology of Fishes 67: 169–178.

Jones-Foster, S.K. 2009. Food Habits of Age 0 Juvenile Chinook Salmon, *Oncorhynchus tshawytscha*, from the lower Kenai River, Alaska. Graduate Research Project. University of Nebraska Kearney. 13 p.

Laberge Environmental Services. 2011. Summary of Environmental Monitoring Activities at the abandoned Clinton Creek Asbestos Mine. Prepared for Assessment and Abandoned Mines Energy Mines and Resources Yukon . 27 p. & Appendices.

Laperriere, J. D. 1994. Benthic ecology of a spring-fed river of interior Alaska. Freshwater Biology (1994) 32. 349 – 357.

Liebau, W.H.O. 2010. Hydrogen Sulphide in Hudgeon Lake, Yukon: Evaluation and Remediation Options. MSc. Thesis. 91 p.

Mackenzie-Grieve, J. 2011. Clinton Creek site visit. May 25 – 26, 2011. Fisheries and Oceans Canada Memo to file. DFO OHEB. 4 p.

McCullough, D.A. 1999. Review and Synthesis of Effects of Alterations to the Water Temperature Regime on Freshwater Life Stages of Salmonids, with Special Reference to Chinook Salmon. Columbia River Inter-Tribal Fish Commission for the US Environmental Protection Agency. 279 p.

Minnow Environmental Inc. 2010. Assessment of 2009 Aquatic Data for Clinton Creek Mine, Yukon. Prepared by for Assessment and Abandoned Mines Branch Energy, Mines and Resources Government of Yukon. 15 p. & Appendices.

Morrow, J.E. 1980 The Freshwater Fishes of Alaska. Alaska Northwest Publishing Company, Anchorage, Alaska. 248 p.

Northcote, T.G. 1993. A Review of Management and Enhancement Options for the Arctic Grayling (Thymallus Arcticus) With Special Reference to the Williston Reservoir Watershed In British Columbia. PWFWCP Report No. 78. 69 p.

Roach, P., and R. Ricks. 2003. Abandoned Clinton Creek Asbestos Mine - Fish Salvage July 31-August 02, 2003. License 03-19. Northern Affairs Program. 9 p.

Royal Roads University (RRU). 1999. An Environmental Review of the Clinton Creek Abandoned Asbestos Mine, Yukon, Canada. Applied Research Division. Prepared for Indian and Northern Affairs Canada. 100 p. & Appendices.

Scott, W.B. & E.J. Crossman. 1979. Freshwater Fishes of Canada. Bulletin 184 Fisheries Research Board of Canada. 966 p.

Stepanek, M and H.F. McAlpine. 1994. Landslide Dams at Clinton Creek. Water Report #378. 8 p.

UMA. 2000. Indian and Northern Affairs Canada Abandoned Clinton Creek Asbestos Mine Risk Assessment Report. 52 p & appendices

UMA. 2008. Former Clinton Creek Asbestos Mine Review of Suggested Improvements to Hudgeon Lake. Prepared for Government of Yukon. 21 p. & Appendices

von Finster, A. December 6, 2005. Clinton Creek, tributary to the Fortymile River, Yukon River North Mainstem sub-basin – Record of 2005 sampling. Memo to Clinton Creek FCSAP file. DFO OHEB. 8 p.

von Finster, A. October 31, 2006. Clinton Creek, tributary to the Fortymile River, Yukon River North Mainstem sub-basin – record of 2006 activities. Memo to file. DFO OHEB. 6 p.

von Finster, A. December 23, 2007. Clinton Creek, tributary to the Fortymile River, Yukon River North Mainstem sub-basin – record of 2007 activities. Memo to file. DFO OHEB. 12 p.

White Mountain Environmental Consulting (WMEC). 2008. Clinton Creek Mine Site Fisheries and Benthic Invertebrate Assessment Monitoring 2007. Prepared for: Hugh Copland, YG Assessment and Abandoned Mines. 27 p. & Appendices.

Appendix D

Extent of long-term usage by fish for each Clinton Creek Option

Summary

Five Options were reviewed. A number of general elements common to most of the Options were identified. They included:

- Effects of North Valley Wall instability. A future rock fall/slide could temporarily reduce the capacity of the channel to convey flows.
- Effects of aufeis. Channel designs appear to assume an unobstructed channel for each Option. Residual aufeis has been documented downstream of Drop Structure 4 after freshet, with clear indications that flows had been over the top of the ice surface rather than below it. Aufeis would reduce the capacity of the channel to convey spring freshet flows.
- Effects of retention of the surface elevation on the existing and future seepage of water from Hudgeon Lake. Little water flows over the lake outlet during summer low flow periods. Seepage from the lake is believed to be a cause, and to be related to the area of the waste dump that water can enter and the effective head (difference in elevation between the lake level and discharge areas downstream).
- Effects of beaver. Beaver are present up- and downstream of the mine area and pose a significant risk to the integrity and capacity of portions of channels for all Options except Option F. Low gradient channels and the outlet of the lake are at highest risk of damming. Beaver dams across the outlet of Hudgeon Lake may result in risks of significant flooding downstream if the dam were to collapse or otherwise rapidly fail.
- Maintenance and rebuilding. Monitoring of the completed channel is proposed for all Options. Maintenance is limited to certain of the Options. The Options that do not include maintenance pose an increased risk that upstream passage will not be achieved in the long term.

With a few design considerations, it is likely that all Options with the exception of I2 will allow the upstream migration of adult and sub-adult Arctic Grayling and juvenile ChinChinook Salmon to Hudgeon Lake immediately after construction. Many or most Arctic Grayling reaching Hudgeon Lake are expected to enter the lake. Some will remain there throughout the summer in aerated surface waters. Others will cross the lake and then enter and ascend upper Clinton Creek and lower Easter Creek if it is not obstructed. Most juvenile Chinook Salmon will probably remain in the channel, but some are expected to move through the lake to upper Clinton Creek.

Review of Options

Options C3 and D3 could allow fish access to Hudgeon Lake and tributaries thereof after construction. Long term access is unlikely in the absence of maintenance of the channel.

Option E3 would allow long term fish access to Hudgeon Lake and tributaries thereof at most times under most conditions, and without channel maintenance.

Option F would allow long term fish access throughout the Clinton Creek watershed but would result in a lengthy period of decreased productivity.

Option I2 would not allow fish access to Hudgeon Lake due to the 8% gradient section of channel.

Introduction

All of the Options propose the construction of a channel to replace, in whole or part, the existing channel extending from the lake to the valley floor about 700 meters downstream. A typical standard channel design and cross section is proposed for all channels, with exception of Option F. The standard design is based on a 200 year flood: however, WorleyParsons (2014) recommend that the calculations be revisited.

A series of common elements was identified that were common to most channel designs. These will be described first. The results of the review of each Option will follow. General elements that do, or do not, apply will be identified. Specific comments will be made where applicable.

Effects of common elements

Photograph D-1. 2003. Rockfall in canyon section, showing how the capacity of the channel can be reduced.

Effects of North valley wall instability. The north valley wall is unstable through the length of the canyon section downstream of the existing gabion structure. In the absence of stabilization measures it is likely to remain so. The typical channel design appears to have sufficient capacity to hold most material sliding down or falling from the valley wall and to allow it to be conveyed downstream by the creek over time. Portions of the north valley wall have been subject to rock falls such as that shown in Photograph D-1. Note the column to the left, which will soon fall forward: this is a typical type of failure from the north valley wall in the lower canyon. An assessment of the risk of a rock fall reducing the capacity of the channel is advised for options utilizing the present channel location through the canyon. If considered appropriate, local adjustments to channel design could address this concern.

Effect of aufeis. Significant aufeis build up has occurred in the upper canyon downstream of the present gabion structure in some years. Spring freshet flows, at least initially, have been over the top of the aufeis. Photograph D-2 was taken on May 20, 2010. It shows the aufeis remaining in the channel below Drop Structure 4, a portion of which is visible in the background. Note the recent erosion and high water mark above- and downstream of the surface of the remaining aufeis. Signs of flow were more than 3 meters above the channel bottom. The risk of aufeis formation and build up and the potential effects on the capacity of the downstream channel should be a consideration in channel design. Aufeis accumulation may reduce the channel capacity to such an extent that the spring freshet flows could not be conveyed within the as-built channel.

Photograph D-2. May 20, 2010. Aufeis remaining after spring freshet.

Effects of retention of the surface level of Hudgeon Lake. Hudgeon Lake's present elevation is about 35 meters above that of the valley at the downstream end of the waste rock deposits. The waste rock deposits continue to move and deform. The nature of the foundation below the waste rock is uncertain. The presence, form and stability of permafrost in those materials has been inferred but not confirmed (Stepanek and McAlpine, 1994). The source(s) of the seepage reporting below the waste rock deposits has not been determined. Seepage includes the large and persistent springs above the mouth of Wolverine Creek (LES, 2011; Hemmera, 2016). The source(s) of the ground water discharging at these locations has not been determined. If the source of some of the ground water is Hudgeon Lake, water entering aquifers in the waste rock will not leave the lake as surface flow. This may further aggravate the existing issue of periodic very low summer flows at the outlet of the lake and the channel downstream. An example of low lake outlet flows is illustrated in Photograph D-3.

Retention of Hudgeon Lake at its present elevation will retain its buffering capacity on downstream flows. Beaver activity between the mine site and the mouth of Clinton Creek is expected to continue at or near the same level of intensity. At present in-channel beaver ponds fill with sediment in 1-3 years and are then abandoned. This is due to in part to fine material from the waste rock deposit, the north valley wall of the canyon, and tailings from Wolverine Creek being transported downstream by streamflow and deposited in the beaver ponds. Stabilization of these source areas will reduce the sediment supply to the creek and allow dams to persist for longer periods of time. Most fish can generally pass over most dams on most occasions: however, a series of dams across a stream tends to have a cumulative effect on numbers of fish migrating upstream.

Photo D-3. August 8, 2007. Summer low flows at the downstream end of Drop Structure 4.

Effects of beaver

Beaver may dam the outlet of Hudgeon Lake. Beaver occupy the lake or have done so in the recent past (WMEC, 2008). None have tried to build a dam across the existing outlet: as noted in Appendix C, they have dammed outlets of natural lakes as large, or larger than, Hudgeon Lake. It is considered to be only a matter of time before this occurs at the outlet of Hudgeon Lake, particularly if active reclamation of lake shore or waste rock deposits is undertaken with the deciduous trees or shrubs favoured by beaver for food- and construction materials. Floating structures further from shore, such as log booms or similar emplacements will not increase the risk of damming.

Dams can exceed 2 meters in height but are generally lower. It is unlikely that a dam built across the proposed outlet channel would result in total obstruction of the outflow during low water conditions. However, rapid increases in flow in response to precipitation events have occurred in Clinton Creek in the past and may be anticipated in the future. The reduced capacity of the outlet channel could result in overtopping of waste rock material adjacent to the channel during major precipitation events. Overtopping could also occur in the spring as the beaver dam could be frozen in place and the spring freshet would, at least initially have to flow over or around it. Seepage under- or through the dam in winter could result in significant aufeis buildup in the downstream channel. In a worst case scenario the dam and downstream aufeis would be frozen together and fill the channel.

The typical channel design gradient of 4.5% exceeds the range of stream gradients generally dammed by beaver in the Yukon.

There is the potential for a rapid failure of a beaver dam at the lake outlet and a catastrophic release of water. Construction materials used by beaver generally include smaller stems and branches from deciduous trees and shrubs. These effectively tie the larger stems in the dam together. A new dam built of these materials is generally very resilient to overtopping flows or other disturbances. When subjected to wet/dry cycles the smaller stems and branches tend to decompose quickly and the dam weakens. An older dam may fail in the absence of an obvious triggering event, resulting in a rapid draining of the water impounded by the dam. Downstream effects may be catastrophic to both natural systems and infrastructure. Assuming that Hudgeon Lake has an area of 79 hectares, the collapse of a 1 meter high dam could result in the rapid release of 790,000 m^3 of water.

Measures to discourage beaver during the design phase of mine reclamation have only recently received much attention. An example which focusses on the Alberta Tar Sands may be accessed at https://era.library.ualberta.ca/downloads/8g84mm39n. Reference to a potential source of information on lake outlet characteristics and potential vulnerability to beaver dams may be pursued through opening this link: http://www.geotechnical.ca/Events/Docs/talk%202002%20Dec%2010.pdf.

Maintenance and renewal of channel and related structures

Most Options are presented as not requiring any further maintenance or rebuilding. With the exception of Options E3 and F, this position must be considered questionable. Over the past decades there were repeated difficulties in anticipating the response of structures to Clinton Creek's ability to deform, degrade and, on occasion, destroy them. If maintenance is not committed to on the channels for the remaining Options to ensure that the channels remain as designed, the risk to long term upstream fish passage is considered to be high.

Potential usage by fish.

With the exception of Option I2, which has an unacceptably steep gradient, upstream fish passage to the outlet of Hudgeon Lake and beyond will likely be attainable after construction. Most age classes of Arctic Grayling and by juvenile Chinook Salmon will be able to swim up the channel. This is contingent on design details such as measures to concentrate the flow during low(er) flow conditions, and riprap large enough to break the flow of the stream being part of the design and construction of the channel.

The 4.5% gradient for the channel approaches the limit of what is considered to be generally acceptable for upstream migration by Arctic Grayling or juvenile Chinook Salmon. However, both species have repeatedly demonstrated their ability to successfully migrate upstream through the canyon to the downstream end of Drop Structure 4. Arctic Grayling were able to reach and enter Hudgeon Lake prior to completion of the gabion structure, and had to ascend shorter sections of the canyon with gradients in excess of 4.5% to do so. Arctic Grayling in the canyon have been observed holding in pocket habitats behind boulders and large pieces of broken bedrock. Juvenile Chinook Salmon are believed to use a similar strategy to migrate upstream through the canyon. They can use smaller pockets due to their smaller size: a larger grayling weighs about 400 grams and is ~300 mm long, while a young-of-year Chinook weighs about 5 grams and is ~75 mm long. Slimy Sculpin are expected to colonize the channel and may, if there are areas of the channel that remain watered through the winter, become resident within it.

Most Arctic Grayling migrate upstream after the spring freshet, during the period when the flows are still high but are falling. A portion of the Arctic Grayling population is expected to enter Hudgeon Lake. Some individuals will spend the summer in the aerated surface water layers of the lake. Others will likely pass through the lake and utilize upper Clinton Creek and possibly the lower sections of Easter Creek if channel conditions permit.

Juvenile Chinook Salmon enter Clinton Creek and migrate upstream later in the summer. The first individuals may arrive at the downstream end of the channel in early July. It is expected that most individuals will remain in the channel to feed for the summer, as juvenile Chinook prefer moving water rather than still water environments. Some may cross Hudgeon Lake and ascend Clinton Creek upstream of the lake if channel conditions permit.

Flow volumes at the lake outlet and, by extension, within the channel may be very low in July and early-mid August. Stratification of the lake is considered most extreme under calm, warm, sunny conditions. Water entering the channel from the lake may be very warm, approaching or exceeding either species' tolerance levels. This may be mitigated by minor seeps entering the channel.

As autumn progresses, the great majority of Arctic Grayling will move downstream to overwintering habitats in the Fortymile River and beyond. Falling temperatures and the start of ice formation in the channel will result in most of the Chinook moving downstream to more favourable overwintering areas such as those in the vicinity of the confluence with Wolverine Creek.

The longer term usage of the proposed channel and upstream waters will depend on the continued integrity of the physical structure of the channel bottom, and particularly the stability of the larger riprap sizes. The greater the risk that pieces of riprap large enough to break the flow of water in the channel will not remain in place for the design life of the channel (effectively for ever), the greater the risk that fish will not be able to access the entire length of the channel, the lake, and waters upstream of it.

Review of Options

Option C3 – Retain present Hudgeon Lake surface elevation: remove existing gabion structures; construct armoured channel ~700 meter long with a nominal average gradient of 4.5% extending to downstream valley floor. Long term monitoring of the channel will occur, with maintenance and periodic reconstruction of the channel as required.

Effects of North valley wall instability – general comments apply
Effects of aufeis – general comments apply
Effects of retention of the surface level of Hudgeon Lake – general comments apply
Effects of beaver – general comments apply

Potential usage by fish – general comments apply
Maintenance and renewal of channel and related structures – periodic maintenance and reconstruction reduce the risk that long term passage will not be sustained. However, passage may be interrupted during periods after channel degradation but prior to maintenance and reconstruction.

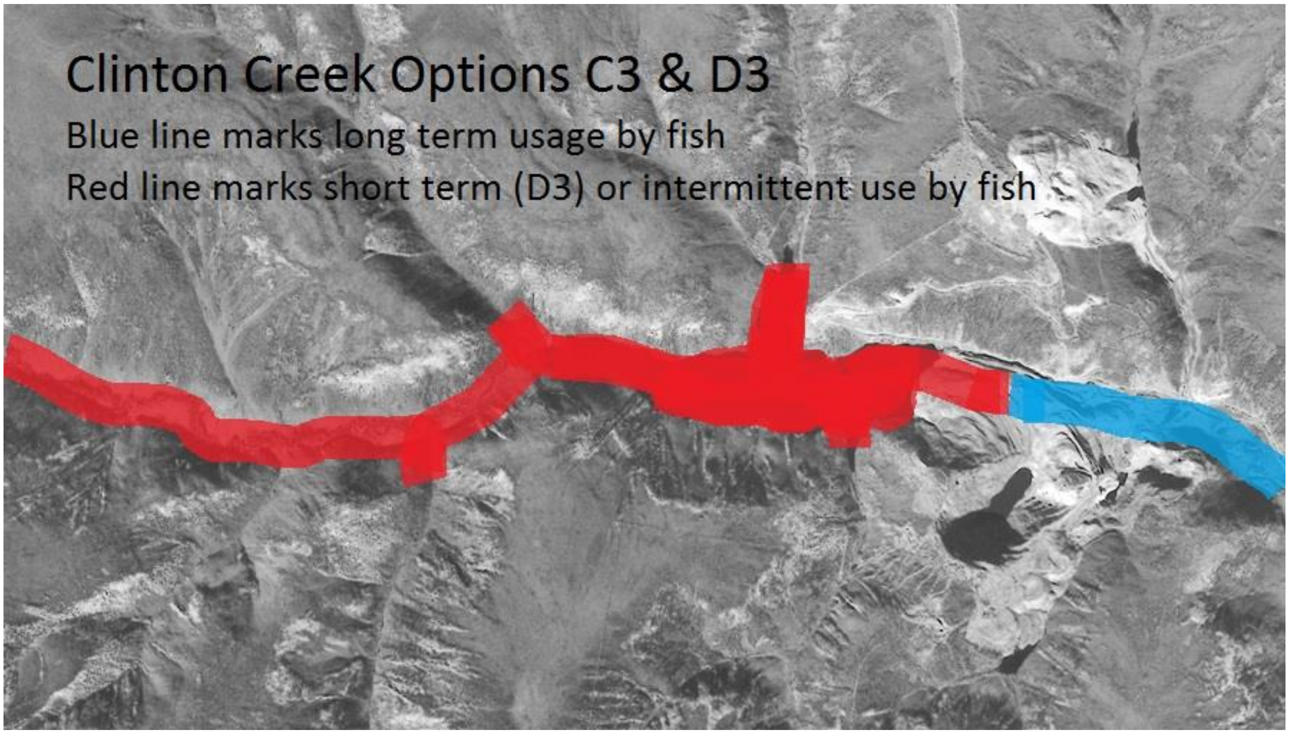


Figure 4-1 – Potential usage by fish, Options C3 & D3

Option D3 – Retain present Hudgeon Lake surface elevation: remove existing gabion structures; construct armoured channel ~700 meter long with a nominal average gradient of 4.5% extending to downstream valley floor. Long term monitoring of the channel will occur, but no maintenance is proposed. Differs from C3 in that waste rock will be excavated and disposed of in Porcupine Pit.

Effects of North valley wall instability – general comments apply
Effects of aufeis – general comments apply
Effects of retention of the surface level of Hudgeon Lake – general comments apply
Effects of beaver – general comments apply
Maintenance and renewal of channel and related structures – general comments apply
Potential usage by fish – general comments apply

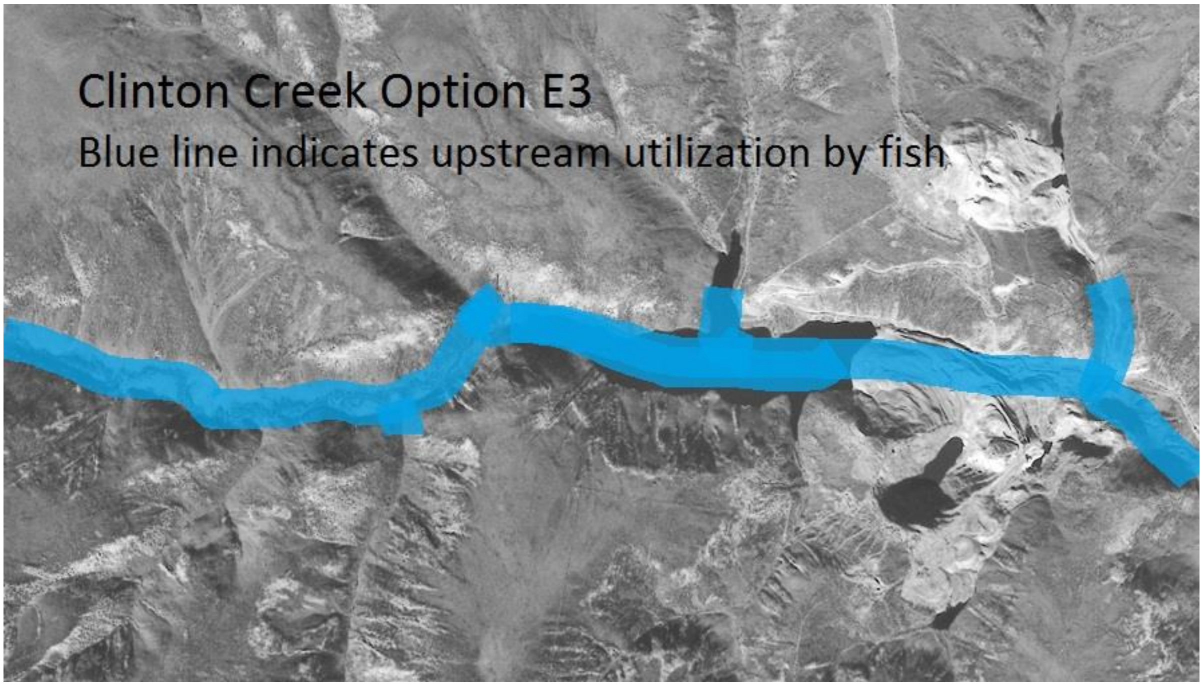


Figure 4-2 – Potential use by fish, Option E3

Option E3 – Siphon lake to an elevation of 398 m asl; lower waste rock to elevation ~400 m asl; construct new Hudgeon Lake outlet; construct a channel, or canal, from the outlet approximately 200 meters long, and tie back into the existing channel at or near the downstream end of Drop Structure 4; riprap the existing channel downstream for approximately 500 meters. Long term monitoring of the channel will occur, but no maintenance is proposed.

Effects of North valley wall instability. This option lowers the channel to the approximate level of the existing bedrock exposure below Drop Structure 4. There is some uncertainty as to whether a channel will be constructed to the typical design, or whether riprap will be added to the existing channel. If the former, the standard comments will apply. The current channel of Clinton Creek has proven itself capable of moving any material that has eroded from the north valley wall and is likely to continue to do so. Note that a portion of the channel has flowed through a bedrock confined channel (i.e. bedrock on both sides of the stream) since prior to 1999, and the length of the bedrock confined channel has increased since then.

Effects of aufeis – general comments apply in the channel downstream of where the new channel ties back into the existing channel. However, if the new outlet channel is designed as a canal, with a very low gradient, sufficient depth and a sill at the downstream end, an ice cover will form and icing risk will be reduced upstream of the tie between the constructed and current channel.

Effects of retention of the surface level of Hudgeon Lake – Reducing the surface elevation of Hudgeon Lake reduces the surface area of the waste dump through which seepage can enter, and the elevation (head) of the lake level above the valley below the waste rock deposits. This reduces the potential for current and future seepage from the lake and should result in an increased surface flow from the lake during extreme low flow periods.

Effects of beaver –The potential for beaver damming of the lake outlet and the channel/canal will be higher than for other options due to the length and low gradient of the channel/canal.

Maintenance and renewal of channel and related structures – The channel/canal from the lake to the approximate end of the outlet channel should require little maintenance if the channel gradient is low. All upstream sediment sources are far enough away that there is little risk of infill of the channel. An engineered channel from the downstream end of present Drop Structure 4 may pose some temporary risk to upstream migrating fish if it fails, but – based on past experience – the condition will not persist. Fish passage is highly likely under most or all conditions. Maintenance of the channel is unlikely to be required.

Potential usage by fish – This Option will result in a reduction in the volume of potential fish habitat in Hudgeon Lake and in the amount of thermal energy that the lake can store and release: however, it would also be the first step in restoring Clinton Creek to a naturally functioning aquatic environment in a non-glaciated area. Surface waters of the lake are expected to aerate annually, although the depth (or thickness) of the aerated layer is expected to change to some extent, at least in the short term. Some of the sediments that were deposited over the last 40 years and now form the current deltas of upper Clinton and Easter Creek will be mobilized as stream channels are re-established. The eroded sediments will be transported further into the lake and deposited there. As the existing sediments are unconsolidated, erosion should be rapid. Fish may not be able to access upper Clinton Creek until the channel develops. A wave cut bench has been eroded along the south side of the lake, and no landslides have occurred as a result. This addresses the concern that lowering the lake will result in slides extending above the current lake level, although some downslope movement of the newly exposed shoreline will occur. There may be slumps of saturated material into the lake from the waste rock deposits bordering it, but this should have little effect on fish utilization.

Other – consideration should be given to starting the drawdown of the lake as early in the season in the year of construction as possible. This would serve to create capacity in the lake should there be summer precipitation events and increase the aeration of lower levels of lake water. It could also reduce the potential for large numbers of fish to enter the worksite, as flows could cease early in the upstream migration period or even before it. Water would have to be withdrawn from the aerated zone near the lakes surface. A means of discharging the water in such a manner as to increase the rate of aeration should be considered. Monitoring of water quality and active management of the siphon intake will be required.

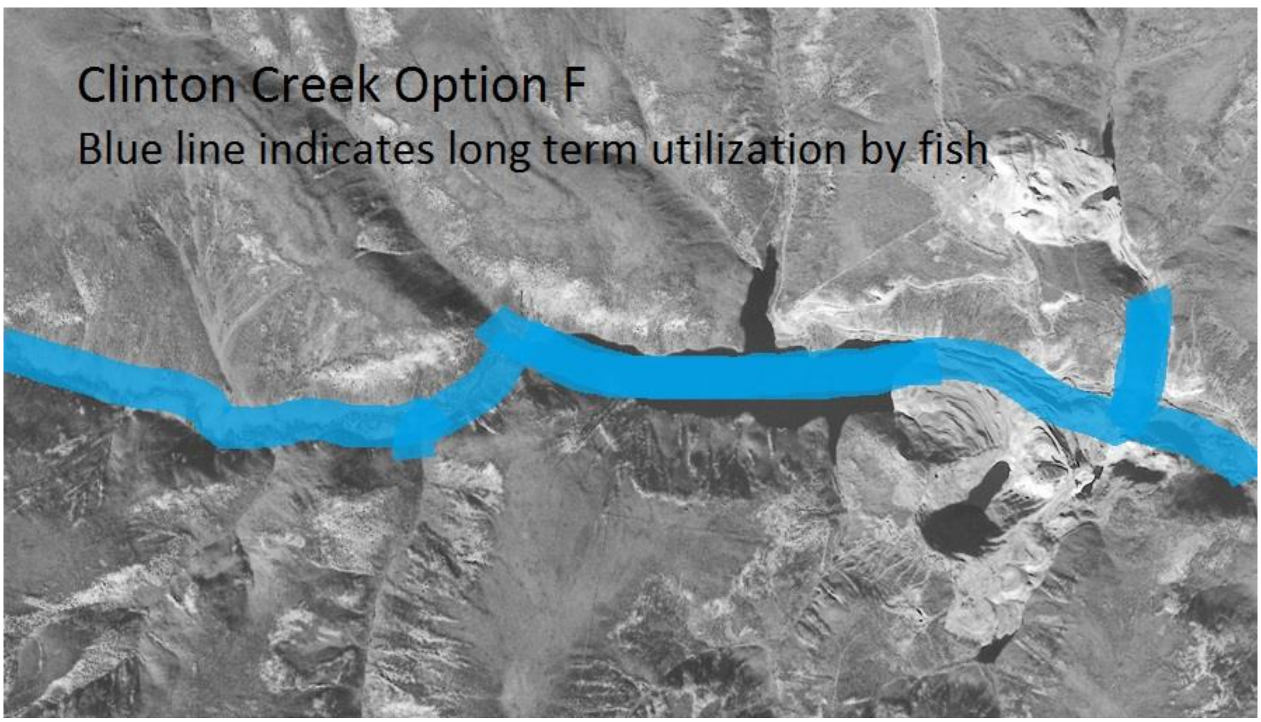


Figure 4-3 - Potential usage by fish, Option F

Option F - Restore the creek to the valley bottom in the area of the existing failed waste rock dump; return 5 million m^3 of waste rock to the Porcupine Pit, and place 4.5 million m^3 of waste rock along the south margin of the valley in the area now flooded by Hudgeon Lake; fully drain Hudgeon Lake; construct a short term channel to the north of the original, pre-lake channel. Monitoring at 2 year intervals is proposed, but no costs for maintenance or replacement would not be a requirement.

This Option is notable for which activities and undertakings are not described. This results in a number of uncertainties in attempting to determine the potential usage of the creek by fish in the short- or mid-term. These uncertainties include:

Stability of the waste rock slopes after the removal of the 9.5 million m^3 of waste rock – it is possible that moisture levels in the deeper portions of the waste dump will be high. A zone of saturated waste rock in the lower dump could result in slope failures extending to or over the constructed channel and potentially causing a temporary obstruction to upstream migrating fish. Sediment will be deposited in Clinton Creek and carried downstream.

Lateral stability of the "natural" channel - the proposed "natural" channel is shallow and lacks any armouring. It is assumed that it will develop a "meandering" pattern: should this occur the channel is likely to meander toward the deepest part of the pre-existing valley. This is the old creek channel and will remain under the waste rock pile after the proposed excavation. Erosion of the toe of the waste rock dump can be expected and landslides anticipated as a result. Sediment will be deposited in Clinton Creek by the development of the meandering channel and by any erosion of the remaining waste rock and carried downstream.

Burying of the pre-lake channel of Clinton Creek - the 4.5 million m^3 of waste rock placed along the south valley margin will bury the pre-lake channel of Clinton Creek and possibly Bear Creek. A new channel excavated to the north of the pre-lake Clinton Creek channel, will pose the same challenges as the "natural" channel proposed for the valley bottom in the section that is currently covered by waste rock. Allowing Clinton Creek to develop its own channel across the floor of the dewatered lake bottom poses similar risks to the long term stability of the waste rock. Additionally, all sediment and organic matter eroded in the development of the new channel – regardless of whether it is built or left to develop on its own - will be carried downstream.

Stabilization/removal of sediment and organic material deposited in Hudgeon Lake - the lake has been functioning as a settling pond for sediments and organic materials washed downstream by Upper Clinton Creek and other tributaries for more than 40 years. Some of these materials are visible in the form of the advancing delta of upper Clinton Creek. Finer sediments are expected to have been deposited as a blanket over the lake bottom. The pre-existing creek channel is in the deepest section of the lake bottom at any point and the sediment blanket will be deepest there. Liebau (2010) characterized bottom sediments as being a "fine almost jelly-like consistency with a strong sulfide smell". These sediments are expected to flow downward as the lake is lowered and then into the creek. The sediments in deltas, on the valley bottom and in the pre-existing channel will mobilize during lake draw down or the following summer if the proposed winter drawdown is conducted. Once mobilized, much or most of the sediment and organic material will be deposited in Clinton Creek and carried downstream.

Risks to downstream fish and other aquatic life from anoxic and sulphide rich water from winter drainage of Hudgeon Lake. Although the falling lake levels will result in periodic collapses of the lake's ice cover and consequent exposure of some of the water surface to air, the rate of aeration is expected to be low. In the absence of artificial aeration/destratification of Hudgeon Lake prior to and during winter drainage, it is likely that anoxic water will be released into Clinton Creek as the upper layer of water is drained. Increasing levels of sulphides will be released as deeper layers are drained. This will negatively affect the juvenile Chinook Salmon overwintering in the creek and the Slimy Sculpin and invertebrates that are resident there and may result in a fish kill. If the rate of discharge is kept relatively constant an ice cover will form over Clinton Creek between the mine site and the mouth, reducing the potential for aeration and extending the downstream area of effect.

Reduction of ground water storage and releases. Removal of the waste rock dump (and redistributed material in the developing alluvial fan downstream of the canyon) will effectively destroy most of the aquifers that currently support overwintering juvenile Chinook Salmon in the area of the mine site. The Porcupine Creek aquifer will remain and will provide a degree of overwintering potential.

Potential usage by fish.   In the long term this Option will allow fish access to the limits of pre-mine distributions. However, it is likely that it will take an extended period for the full distribution to occur due to the expected lengthy period of instability of the dewatered land surface and the new channel(s) between what is now the downstream end of the waste rock dump and the current upstream extent of Hudgeon Lake. Significant and long term releases of sediment are likely due to erosion of the dewatered lake bottom, development of new channels, and erosion of waste rock piles resulting from channel migrations or slope failures. These sediment releases will affect Clinton Creek downstream of the mine and will extend to the Fortymile River.

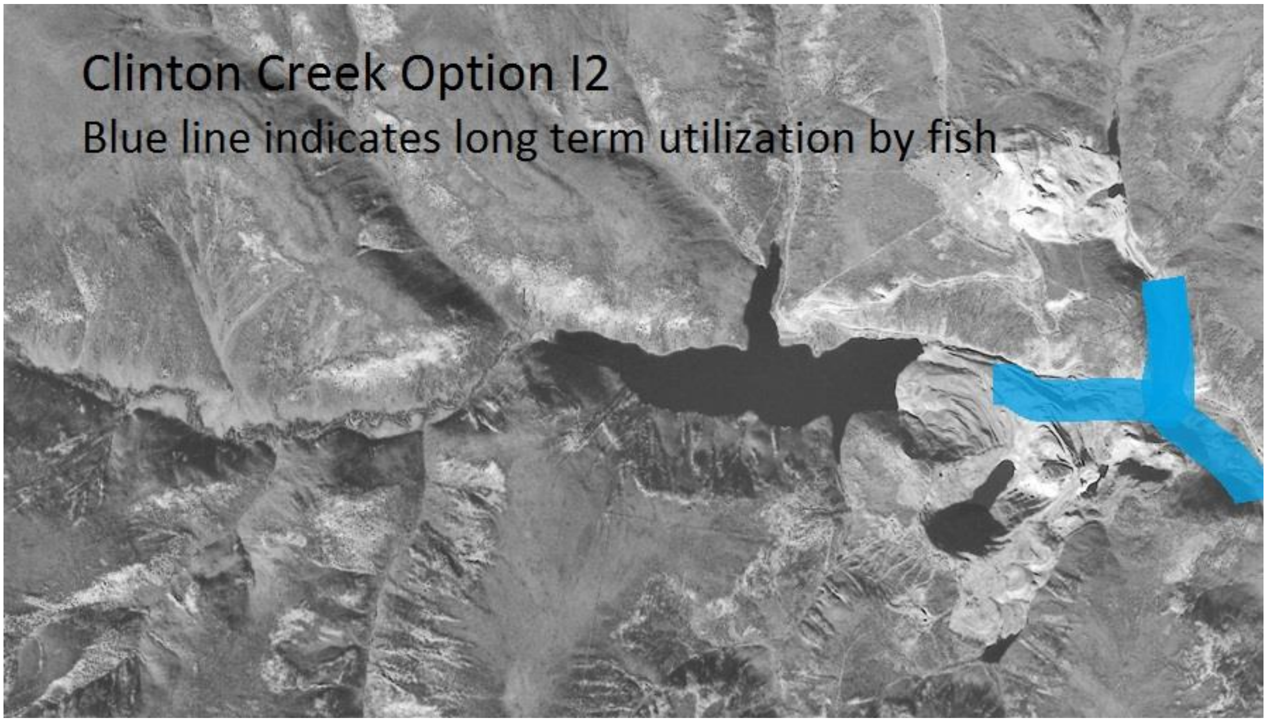


Figure 4-4 Potential usage by fish, Option I2

Option I2 - Retain present Hudgeon Lake surface elevation: construct a new lake outlet and riprap channel located south of the existing channel; include a 300 meter section of channel at an 8% slope.

Effects of north valley wall instability – Concerns will be fully addressed as the channel will be constructed away from the north valley wall, and the lower part of the wall will be backfilled with waste rock.

Effects of aufeis – general comments apply

Effects of retention of the surface level of Hudgeon Lake – general comments apply

Effects of beaver – general comments generally apply, although the 2% section downstream of the lake outlet is within the range of slopes that beaver often dam. This increase the risk of damming in this area.

Maintenance and renewal of channel and related structures – general comments apply for the two sections of the channel with 2% slopes. The section with an 8% grade poses a higher risk due to the potential for erosion due to increased energy of water conveyed through the steeper channel.

Potential usage by fish – a 300 meter slope at 8% would obstruct most or all Arctic Grayling or juvenile Chinook Salmon. It is possible that some adult Arctic Grayling would be able to ascend to the upstream end of the 8% section under favourable flow conditions. Juvenile Chinook Salmon would be able to enter the 8% section, but migration upstream to the top of the section is unlikely.

References for Appendix D

Hemmera Envirochem Inc. and Ecological Logistics & Research Ltd (HEI & ELR). 2016 Fall Clinton Creek Surface Water Quality and Hydrological Monitoring Program. Report Prepared for Government of Yukon Assessment and Abandoned Mines 34 p. & Tables & Appendices

Laberge Environmental Services. 2011. Summary of Environmental Monitoring Activities at the abandoned Clinton Creek Asbestos Mine. Prepared for Assessment and Abandoned Mines Energy Mines and Resources Yukon . 27 p. & Appendices.

Stepanek, M and H.F. McAlpine. 1994. Landslide Dams at Clinton Creek. Water Report #378. 8 p.

WESC (White Mountain Environmental Consulting). 2008. Clinton Creek Mine Site Fisheries and Benthic Invertebrate Assessment Monitoring 2007. Prepared for: Hugh Copland, YG Assessment and Abandoned Mines. 27 p. & Appendices.

WorleyParsons. 2014. Clinton Creek Site Life Cycle Cost Analysis for Remediation Options. Prepared for Yukon Energy Mines and Resources, Assessment and Abandoned Mines. 63 p. & Appendices.

Appendix E

Potential upstream limit of fish migration in Wolverine Creek.

Summary

Fish cannot enter Wolverine Creek at present but are believed to have done so in the past. Removal of the existing culvert will restore access to the creek.

Wolverine Creek has an acceptable gradient and sufficient flow under most conditions to allow long term seasonal use by Arctic Grayling and juvenile Chinook Salmon as far upstream as the mouth of the first tributary entering from the East. The downstream end of the rock-lined channel in middle Wolverine Creek is immediately upstream of this point. The rock-lined channel has a nominal gradient of 15% and is too steep to allow upstream migration by fish.

The upstream limit of migration by fish in Wolverine Creek is considered to be the mouth of the first tributary entering from the East.

Potential usage by fish

A culvert currently obstructs fish access into Wolverine Creek (WMEC, 2008). There are no records of past use of the creek by fish. However, the lower section of the creek has a low gradient. There is sufficient flow to allow fish to enter the after the existing culvert is removed. Wolverine Creek is cooler than Clinton Creek during the open water period (von Finster, 2007; WMEC, 2008). Arctic Grayling have been documented in the cold water plume extending downstream from the mouth of Wolverine Creek during warm water periods (Roach and Ricks, 2003).

Wolverine Creek has a total drainage basin of 28.6 km^2. Lower Wolverine Creek is extends upstream from the mouth to the confluence with the first tributary entering from the east. Wolverine Creek upstream of this point includes the existing rock lined channel, the valley-bottom tailings deposits, and the developing channel against the north west valley wall. The watershed area of Wolverine Creek above the confluence is 22.2 km^2, of which 21 km^2 are upstream of the tailings deposits.

The gradient of lower Wolverine Creek increases slowly from the mouth to the confluence with the first tributary entering from the east. The rock lined channel starts immediately above this confluence has a gradient of ~15% for ~150 meters. This gradient is considered to be well beyond the ability of Arctic Grayling and juvenile Chinook Salmon to ascend.

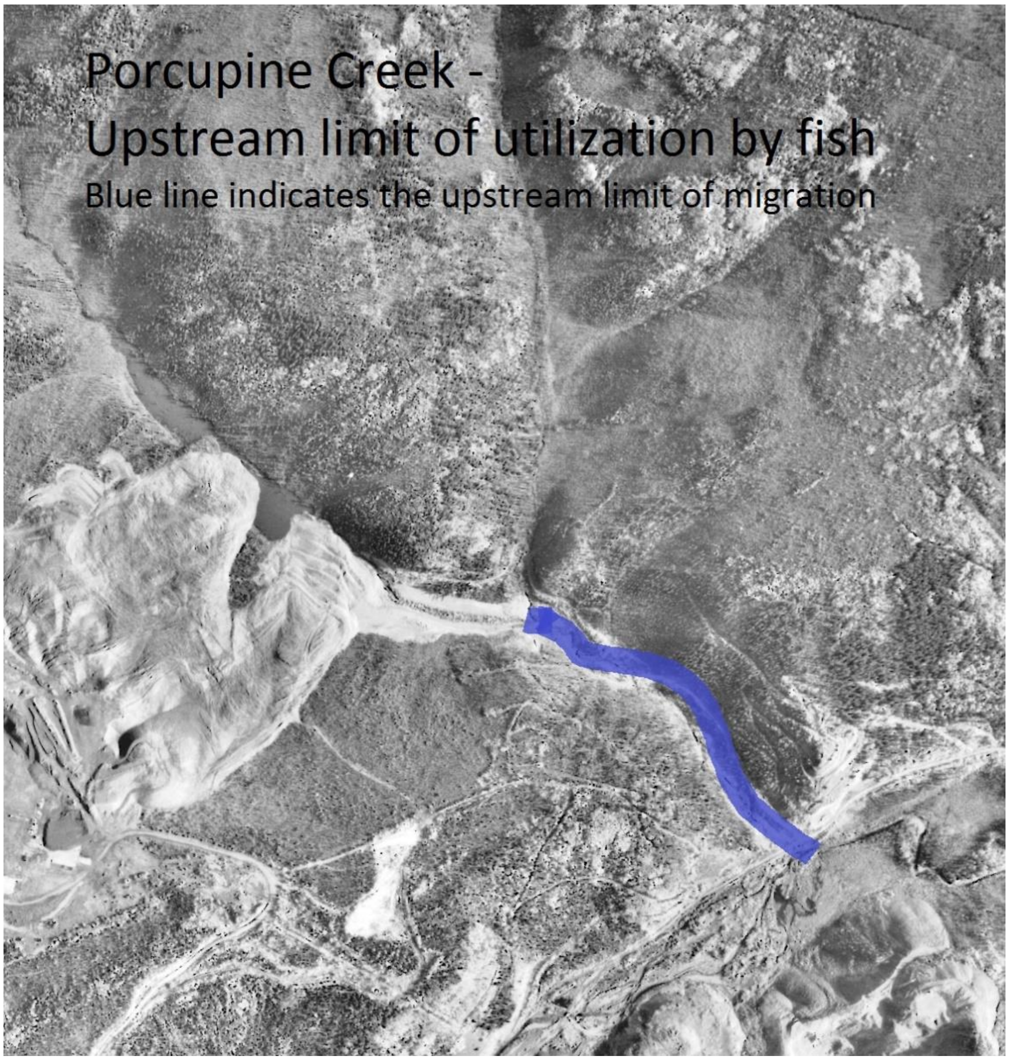


Figure E-1 Upstream limit of utilization of Porcupine Creek by fish.

The limit of upstream migration in Wolverine Creek is therefore considered to be the confluence with the first tributary entering from the East. The tributary itself has a drainage basin of less than 7 km^2, which is insufficient to produce flows sufficient to support fish.

Eagle Creek is slightly smaller than Wolverine Creek, is adjacent to it, enjoys the same aspect, and is undisturbed. The characteristics of the Eagle Creek channel could serve as a template for the design of a channel for Wolverine Creek if the pre-existing channel has been dozed or similarly destroyed.

Roach, P., and R. Ricks. 2003. Abandoned Clinton Creek Asbestos Mine - Fish Salvage July 31-August 02, 2003. License 03-19. Northern Affairs Program. 9 p.

von Finster, A. December 23, 2007. Clinton Creek, tributary to the Fortymile River, Yukon River North Mainstem sub-basin – record of 2007 activities. Memo to file. DFO OHEB. 12 p.

WESC (White Mountain Environmental Consulting). 2008. Clinton Creek Mine Site Fisheries and Benthic Invertebrate Assessment Monitoring 2007. Prepared for: Hugh Copland, YG Assessment and Abandoned Mines. 27 p. & Appendices.