BREACHING OF THE FRESH WATER SUPPLY DAM AND RECLAMATION OF THE FORMER RESERVOIR, FARO MINE, FARO, YUKON

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ABSTRACT

The fresh water supply dam at the Faro Mine was constructed in 1968 to store up to approximately 5.6 million cubic metres of water for use as the winter mill water supply. The dam was a 410 m long, 20.5 m high zoned earthfill structure with an upstream sloping core founded on a sequence of competent predominately silty sand and gravel glacial terrace and till.

A water recycling system was installed in 1997 which replaced the reservoir as the primary water supply to the mill. Since 1998 the mine has been in receivership and operating in a care and maintenance mode. Based on the redundancy of the dam and the risk it presented to the downstream receiving environment including the tailing impoundment, a decision involving various regulatory stakeholders was taken in late 2002 to breach the dam. In early 2003, an application was filed with DIAND, DFO (Fisheries and Navigable Waters) and Yukon Water Board for the removal of the dam. The water level in the reservoir was lowered by approximately 6 m in the summer of 2003 and re-vegetation of the upper part of the reservoir was initiated. Upon receipt of the required approvals for this project, the excavation of the dam breach began on November 11, 2003 and dam removal (notch, armoring and channel construction) was completed on December 16, 2003. Post-decommissioning monitoring has commenced and will continue for several years.

This paper focuses on the historical operation of the reservoir, the recently completed breach construction activities and the environmental monitoring results throughout the breach and post-breach period.

1.0 INTRODUCTION

The Faro mine is located in the central Yukon, approximately 200 km north-northeast of Whitehorse. The Faro mine site is approximately 22 km north of the Town of Faro, as shown on Figure 1. The fresh water supply dam (FWSD) and reservoir (FWSR) are located south of the main access road to the Faro mine site, approximately 5 km from the mine gatehouse. The FWSD was constructed in 1968 to store up to approximately 5.6 million cubic metres of water for use as the winter mill water supply.

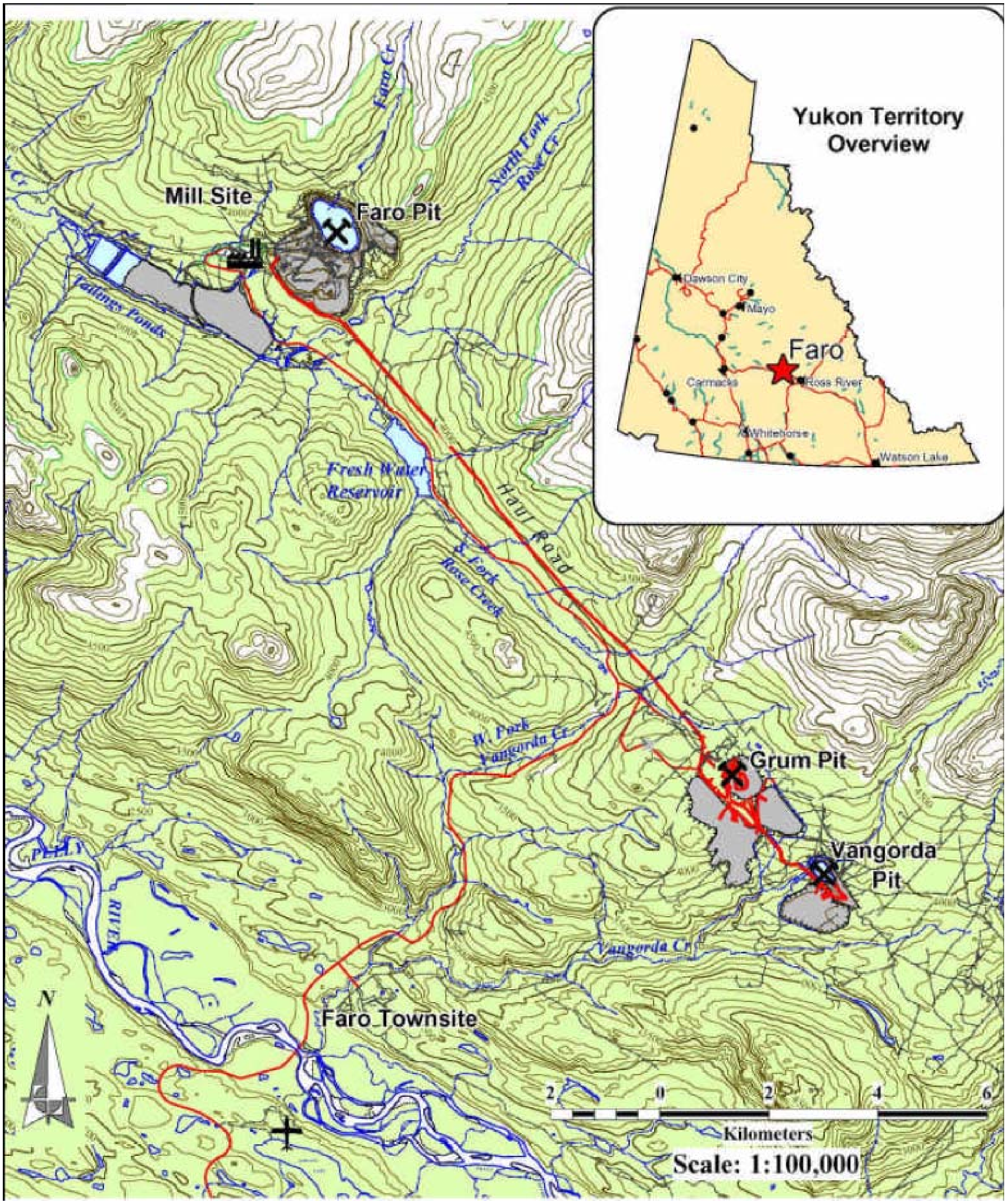

Figure 1 Location of the Faro Mine Site.

Following first reservoir filling during the 1969 freshet, and throughout its operating life, the FWSD had a history of performance problems, including toe boils, cracks on the dam crest and wear concerns related to a decant pipe that extended through the dam.

A water recycling system was installed in 1997 which replaced the reservoir as the primary water supply to the mill. Since 1998 the mine has been in receivership and operating in a care and maintenance mode. Based on the redundancy of the dam and the risk it presented to the downstream receiving environment including the tailings impoundment, a decision involving various regulatory stakeholders was taken in late 2002 to breach the dam.

The design of the dam breach was undertaken using a collaborative approach between the interim receiver, engineering team and the regulatory organizations. Weekly or twice monthly conference calls were made to update all parties on the progress, depending on the project needs. Additionally during the active design process and key document preparation, meetings were held in which the design team presented progress and preliminary results. Comments were taken into account and incorporated into the design. This collaborate approach between the proponent, engineering team and the regulatory bodies allowed the completion of this project (from initial regulatory submission to completion of construction) within one calendar year.

2.0 BACKGROUND INFORMATION

2.1 Climate

Data from the Anvil climate station (which was operated by Environment Canada between 1967 and 1980 and was located at the mine site at an elevation of 1158 m amsl) indicates that the mean annual temperature is -3.4°C. July is the warmest month, with a mean daily temperature of 11.5°C, and January is the coldest month, with a mean daily temperature of -19.8°C.

The mean annual precipitation (MAP) at the Faro airport station, elevation 720 m amsl, (operated by Environment Canada) is 305 mm, based on precipitation data from 1978 to 2001. This total comprises roughly equal proportions of rainfall and snowfall as water equivalent. For the period of record, the driest and wettest months are typically April and July, respectively. The greatest monthly precipitation measured over the period of record was 116.2 mm in August 2000.

The Rose Creek snow course at the site was operated by DIAND from 1975 to 1985. The snow course was located near and at a similar elevation (1080 m) as the tailings impoundment area. The accumulation of snow at the tailings impoundment typically begins in October, and the snow has generally melted by the end of April, although in 1985, it persisted into May. At maximum snowpack in March or April, the density of the snowpack is about 200 kg/m^3.

2.2 Hydrology

The Rose Creek watershed covers an area of approximately 340 km^2 and is a significant part of the 980 km^2 Anvil Creek watershed which drains the southeast slopes of the Anvil Range Mountains. All of the Faro Mine site facilities are within the Rose Creek watershed.

Two local stream gauging stations have been operated by site staff since 1996: Stn. R7 (drainage area of 95 km^2) which is located on the North Fork of Rose Creek upstream from the mine site and Stn. X14 (drainage area 230 km^2) which is located on Rose Creek downstream from the mine site. The catchment area of Station R7 is comparable to that controlled by the FWSD, both in drainage area (95 km^2 vs. 67 km^2) and catchment median elevation (1470 m vs. 1420 m). The flows at Station R7 are representative of a natural condition, having had experienced minimal influence from mining and other human activity.

A summary of the estimated monthly inflow to the reservoir is included in Table 1. The monthly inflow to the reservoir was estimated based on the gauged stream flow at R7. The data from this station were scaled by the ratio of drainage areas (67/95) to estimate flow into the reservoir. The data are presented as minimum, average and maximum scaled flow values encountered between 1996 and 2001.

Table 1 - Estimated Monthly Inflow to the FWS Reservoir

	Estimated Monthly Flow (m^3/s)		
Month	**Minimum**	**Average**	**Maximum**
January	0.08	0.16	0.22
February	0.06	0.14	0.20
March	0.06	0.13	0.18
April	0.11	0.16	0.18
May	0.94	1.38	1.91
June	0.94	1.96	2.92
July	0.64	1.01	1.25
August	0.59	0.96	1.48
September	0.53	0.97	1.72
October	0.39	0.61	1.23
November	0.22	0.29	0.37
December	0.12	0.20	0.25

A regional analysis, based on seven gauging stations, was performed to estimate the peak inflow events to the FWS reservoir. The results of the analysis are summarized in Table 2.

Table 2 - Estimated Peak Inflow Events at the FWSD

Return Period	Flood (m^3/s)
2-year	5.6
10-year	17
100-year	39
500-year	63

The regional analysis found that spring freshets (snowmelt events) defined the peak flood events at all stations. Therefore the events listed with a specific return period are spring freshet events.

The regional analysis also examined the period between December and March in order to estimate the winter baseflow conditions to be managed throughout construction. This analysis determined that no significant rainstorms or early snowmelt events were recorded in this timeframe. The baseflow can be expected to be highest at the beginning of the construction period and then follow a recession curve through the remainder of the year, a situation encountered at Station R7. In a typical year, a peak daily inflow of 0.20 m^3/s could be expected, with an average inflow over the four-month period of 0.11 m^3/s. The corresponding flows for a 100-year wet year would be 0.56 m^3/s and 0.28 m^3/s.

2.3 Reservoir Sediments

The estimated amount of sediment within the reservoir was between 3,700 and 5,000 m^3 assuming that the reservoir had an average sediment thickness of 15 mm to 20 mm spread evenly through the reservoir surface area of 486,600 m^2. This estimate was made based on the results of a sediment testing program performed in February 2003.

3.0 DAM AND RESERVOIR

3.1 Dam Design

The dam was constructed as a 410 m long, 20.5 m high zoned earthfill structure with an upstream sloping core founded on sequence of competent predominately silty sand and gravel glacial terrace and till. The slope of the upstream face of the dam was approximately 2.6H:1V (horizontal: vertical) and the slope of the downstream face of the dam was 2H:1V.

Figure 2 shows plan and section views of the FWSD. The zoned earthfill dam consists of a low permeability compacted core and upstream blanket material (Zone 1), a broadly graded granular shell (Zone 2) and a compacted random fill zone (Zone 3). Zone 1 includes a partial upstream cut-off that does not extend to bedrock. The base elevation of the partial cut-off was terminated at elevation 1079.9 m amsl (approximately coincident with the creek thalweg) to ensure that the excavation was completed in the dry. The Zone 1 material was extended approximately 80 m into the reservoir, forming an upstream blanket to reduce seepage under the dam. The seepage blanket is 1.5 m thick and is covered by a 0.6 m thick layer of gravel.

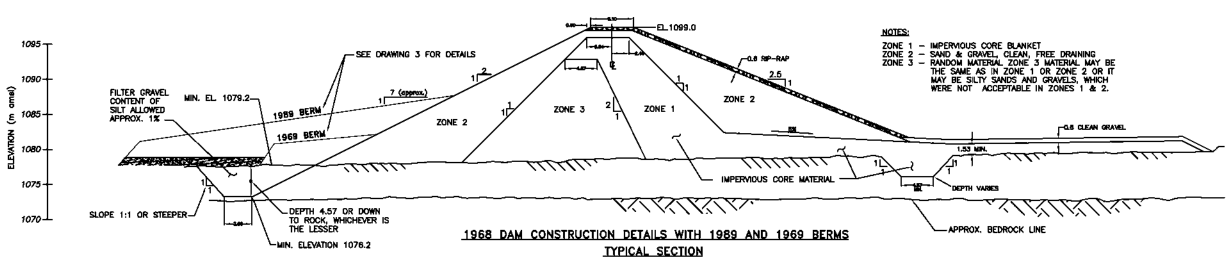

Figure 2 Cross Section of the Fresh Water Supply Dam

Water was released from the reservoir by two means: an overflow spillway located on the crest of the dam near the north abutment and a low-level outlet pipe, which runs through the base of the dam near the south abutment.

3.2 Dam Performance

Seepage was noted at the downstream toe of the FWSD immediately following first filling of the reservoir, during the 1969 freshet. The near-surface groundwater table and anticipated increase of pore pressure from the construction of the dam lead designers to expect seepage to occur at the downstream toe of the dam. Shortly after construction was completed, the appearance of seepage and accompanying sand boils lead to the design and construction of a downstream toe drain/berm in 1969. The location of the berm is shown in plan on Figure 2. The designers noted that the total amount of seepage observed at the toe was less than expected.

Following a stability assessment in 1988, another toe berm which included drainage measures, was placed for enhancement of the downstream slope stability. The berm addition contains a preferentially pervious lower section (0.5 m thickness) that provides discharge capacity for artesian seepage. The 1989 toe berm was 55 m long, approximately 7 m high at the original toe of the dam, and slopes downstream at 7.5H:1V to a seepage collection trench at the toe.

Significant longitudinal cracking has been encountered on the upstream side of the dam crest for nearly 20 years. Investigations indicated that the cracking was attributable to frost action on the upstream face and crest of the dam. The investigation traced the cracks to a depth of almost 2 m.

3.3 Reservoir

The FWSR occupies part of the base of the Rose Creek valley. The reservoir is approximately 1,454 m long with an average width of 315 m and an average depth of 8 m. Three tributaries, shown on Figure 1, flow into the reservoir. The largest of the three is the main channel of the South Fork of Rose Creek. Two smaller tributaries, North Tributary and the Southeast Tributary, are located near the east end of the reservoir.

The presence of the reservoir has shortened the lengths of the tributaries that formerly existed in the reservoir area. The length of South Fork of Rose Creek that has been either submerged or modified as part of the dam construction is about 2,420 m (1,900 m was submerged in the reservoir). About 190 m of the Southeast Tributary and 440 m of the North Tributary are submerged by the reservoir.

3.4 Reservoir Operations

During operations, between 0.45 and 0.53 m^3/s of water were pumped from the pumphouse pond to the mill as make-up water. Inflows to the pumphouse pond included the South Fork of Rose Creek (water released from the FWSD), the North Fork of Rose Creek and water wells near the pumphouse. The water balance for the water supply was very tight and the mill personnel were concerned that they would run out of water each winter (personnel communication with site staff). Water outflow from the reservoir was kept to a minimum due to this concern. Despite minimizing the outflow from the reservoir, the reservoir was regularly drawn down by 6 m and, occasionally, by as much as 10 m by the end of the winter. The reservoir would typically (during mine operations) fill completely (to 1096.1 m amsl) and water would flow through the spillway from June through late fall. Due to the water balance concerns, in 1976, steel I-beams were placed within the spillway to allow for the addition of stop logs to raise the retained reservoir elevation. Stop-logs were typically placed across the spillway in the fall to provide increased water storage capacity. In 1999, DIAND instructed that the stop-log system be removed due to concerns that the excess water pressure caused by a higher reservoir elevation could lead to increased seepage at the downstream toe and exacerbate cracking of the crest.

4.0 BREACH PROJECT DESIGN

The design of the dam breach was undertaken using a collaborate approach between the proponent (Deloitte & Touche Inc. the interim receiver for Anvil Range Mining Corporation), engineering team and the regulatory organizations (DIAND, DFO, YTG and their specialist consultants). During the designing and key document preparation meetings were held in which the design team presented progress and preliminary results. Comments were taken into account and incorporated into the design.

In early 2003, an application was filed with DIAND, DFO (Fisheries and Navigable Waters) and Yukon Water Board for the removal of the dam.

4.1 Design Concept

In December 2002 a meeting with the proponent, engineering team and the regulator bodies was held to define the objects and then conceptual designs that could meet these objects. The objectives for the FWSD breach project were:

- Keep water levels within the range of natural fluctuations.
- Avoid long duration inundation.
- Avoid fish stranding in higher ponds.
- Respect dam stability constraints on dewatering rates.
- Provide fish passage for up to 10-year flood.
- Minimize risk of ice blockages downstream of the pumphouse, specifically by avoiding increases in flow rates after ice formation.
- Control sediment releases.
- Avoid creation of small volume pond that would result in winter fish kill.
- Consider construction, maintenance, future construction, and appurtenant costs.

The following alternatives were considered and evaluated against the objectives:

- French drain;
- Existing 42-inch culvert (LLO), open full;
- Continual pumping;
- Broad crested weir;
- Complete removal of the FWSD;
- Embankment notch; and
- Bedrock notch.

Four of the alternatives (“French drain”, “42-inch culvert”, “broad-crested weir”, and “continual pumping”) were subsequently rejected for their inability to meet the objectives. The remaining three, all of which are variations of a dam breach, were judged to be capable of meeting the listed objectives. The main difference between these three alternatives is cost. The “complete removal” alternative would be significantly more costly for achievement of the same benefit than the either of the “notch” alternatives and was therefore rejected. Similarly, based on cost and construction considerations (primarily requirements for blasting) the “bedrock notch” was rejected in favour of the “embankment notch”.

4.2 Design Criteria

The 1 in 500-year flood was proposed in discussions involving DFO, DIAND, Environment Canada and the Interim Receiver and accepted as the design flood. The channel edges need to be stable for this flood value. The 1 in 500-year flood event corresponds to a snowmelt event and has an instantaneous flood peak of 63 m^3/s.

There were four criteria related to fisheries habitat requirements:

- A potion of the fish living in the reservoir would be moved to suitable local habitat.
- The breach design should produce habitat for arctic grayling.
- Fish passage should be possible up to a 10 year flood, or 17 m^3/s. Beyond this level, the water velocity will exceed the capability of the fish to swim upstream.
- To the extent possible, there should be sufficient water to allow fish passage under normal low river flow conditions.

The following criteria were used to define the embankment stability criteria during different phased of the breach project:

- The upstream stability during reservoir drawdown. Minimum factor of safety of 1.3 (CDA 1999 and Mitchell 1983).
- The upstream and downstream stability of the dam at the end of drawdown and in the long term. Minimum factor of safety of 1.3 for deep seated failure, 1.1 for shallow failures and 1.0 for pseudo-static earthquake loading (BC Mine Waste Rock Pile Research Committee 1991).

- The stability of the sides of the breach, particularly where the existing dam height is significant. Minimum factor of safety of 1.3 for deep seated failures, 1.1 for shallow failures and 1.0 for pseudo-static earthquake loading (BC Mine Waste Rock Pile Research Committee 1991).

4.3 Breach Components

The breach components for this project consisted of an engineered breach through the body of the dam along the approximate alignment of the original creek channel and re-establishment of the pre-construction creek. The breach project included the concept of adaptive management for the work required in both the former reservoir and the channel area downstream of the breach. Some of the key considerations of the design were:

- Sediment from the former reservoir is to be controlled through re-vegetation of the reservoir base.
- The breach and channel, inclusive, is approximately 315 m in total length. The sideslopes of the breach are 2.5H:1V (horizontal to vertical).
- Grade control in the re-constructed channel is provided at the inlet and at the five riffles other locations within the channel base are not protected from erosion.
- Erosion protection is provided on the sideslopes of the floodplain only; there is no specific elements constructed to prevent erosion of the channel within the floodplain. The riffles are angled to the main alignment of the floodplain and had a low point in the middle of the riffle. These elements were in place to train the channel within the floodplain.
- The fresh water channel downstream of the breach works was not modified as part of this breach construction.

5.0 BREACH CONSTRUCTION

Upon receipt of the required approvals for this project, the excavation of the dam breach began on November 11, 2003 and dam removal (notch, armoring and channel construction) was completed on December 16, 2003. Prior to the initiation of the breach construction the following activities were completed:

- completion of the first phase of the re-vegetation, and
- fish salvage from the reservoir.

The construction related activities involved in breaching the dam included:

- Management of creek and construction water including environmental testing;
- Excavation of the breach and the channel;
- Placement of riprap for floodplain erosion protection;
- Construction of the riffles and inlet structure; and,
- Clean up.

Figure 3 shows plan and section views of the completed construction of the breach. Figure 4 shows various photos during the construction of the breach.

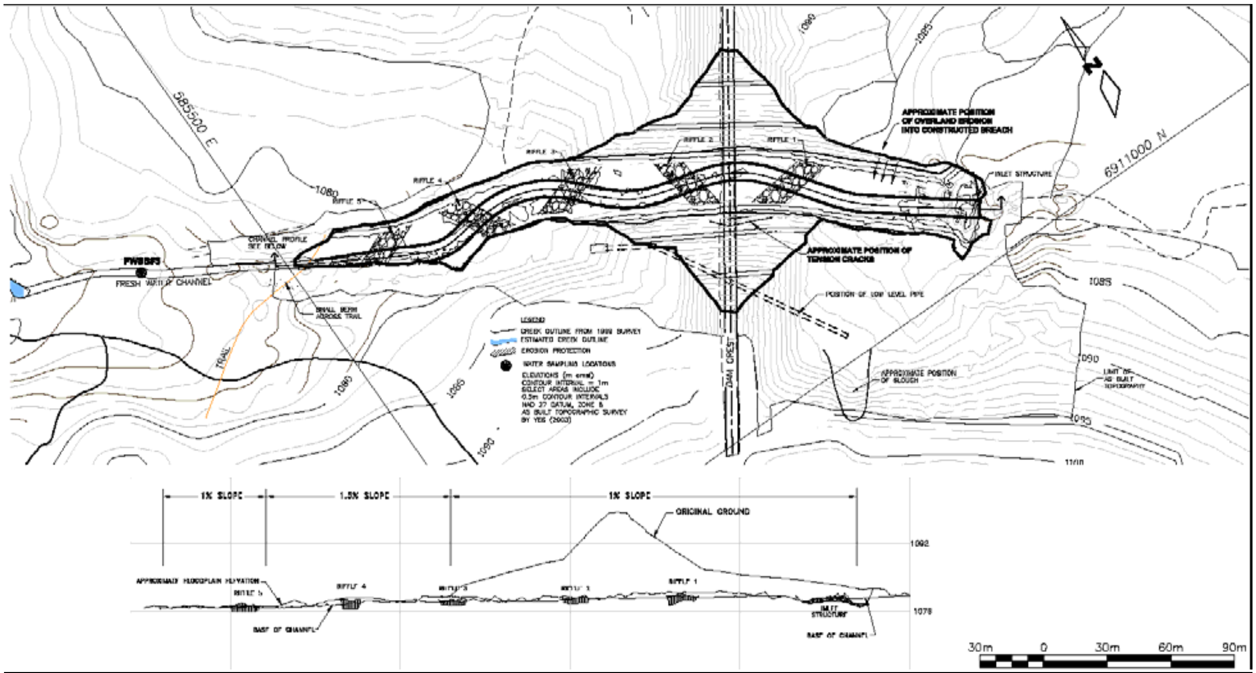

Figure 3 Plan and Section View of the Completed Breach Project

Figure 4 Photographs taken during construction of the breach

The creek water was managed by using a combination of pumps and PVC pipes. Initially water was allowed to drain down through the existing low level outlet. Later the water was pumped through the LLO, lowering the water level on the upstream side of the construction area. An approximately 400 m long PVC pipe was installed over the crest of the dam which allowed for the abandonment of the LLO as the entire creek flow was pumped through it. Near the completion of the project a second 320 m long PVC pipe was used to divert the creek flow, until finally upon completion of construction the creek flow was allowed to pass through the completed construction area.

Initiation of the excavation of the bulk excavation for the breach (material above the floodplain) began on November 10 and was largely completed by November 28 (not including the coffer dam area). Excavation for erosion protection, the channel, the riffles and the inlet structure (the channel elements) commenced on November 27 and was completed on December 15.

Three types of fill material were placed for this project; geotextile, rip rap and common fill. The fill placement commenced on December 2 and was completed on December 16, 2003. Geotextile was used as a separation layer between the excavation surface and the rip rap. Rip rap was used in the riffles, inlet structure and erosion protection. Common fill material was used to cover the LLO the fresh water channel and portions of the riffles and inlet structure.

The contractor for this project was Pelly Construction Limited of Whitehorse, Yukon. The construction was completed using two 10 hour shifts per day through the majority of the project. The main components of the construction activities included: mobilization, 15.1 Hectares of spoil area preparation, 65,500 m^3 of bulk excavation, 11,500 m^3 of specialized excavation, 5,500 m^3 of fill placement, 4,500 m^3 of rip rap placement (underlain by geotextile), water management, abandonment of the low level outlet pipe and demobilization. The cost to complete this construction project was $1,060,000.

During the spring and summer of 2004 the re-vegetation of the reservoir, the riparian zones and the construction area was completed.

6.0 PERFORMANCE

In general, the channel section through the breach worked as designed. The majority of the creek flow was concentrated in the channel section, even during the highest flow period of 2004. During the high flow period, erosion of some of the soil placed on top of the riffles and inlet structure occurred, as shown in Figure 5. Additionally, some erosion occurred along the edges of the channel; this level of erosion was expected and was allowed as part of the adaptive management scheme for this project.

Figure 5 View of the completed breach, Summer of 2004.

The predicted range of sediment release during the first spring freshet was that the total suspended solids (TSS) would range between 80 to 330 mg/L. Previous TSS measurements at locations upstream of mine disturbance have ranged from 4 to 698 mg/L.

A monitoring program consisting of measurements of flow quantity and TSS was performed in 2004. This program consisted of twice monthly sampling during the period from April to August. Two sample locations were used: FWSB 1 is located at the gun club bridge approximately 1.5 km upstream of the limit of the former reservoir and FWSB 5 is located downstream of the limits of the 2003 construction area.

A summary of the results obtained for FWSB 1 is contained in Table 3. Flow measurements were not collected during the initial part of 2004 due to ice cover and dangerous conditions in the creek for the in-stream measurements during the high flow period. The results for FWSB 5 are contained in Table 3. Similar to the results for FWSB1, the high TSS values correspond to the high flow period.

Table 3 – Monitoring Results for FWSB 1 and FWSB 5

	FWSB 1		FWSB 5	
Date	**TSS (mg/L)**	**Flow (LPS)**	**TSS (mg/L)**	**Flow (LPS)**
April 13, 2004	<1		4	
April 30, 2004	1		6	
May 11, 2004	1		18	
May 25, 2004	26		96	
June 14, 2004	8		25	
June 22, 2004	<1		3	
July 6, 2004	<1	464	1	555
July 15, 2004	<1	384	<1	361
August 18, 2004	<1	245	1	234
August 30, 2004	<1	400	<1	420

Based on these results it can be stated that TSS is generally higher downstream of the former reservoir (maximum TSS of 96 mg/L) and breach works than upstream (maximum TSS of 26 mg/L). This result confirms the expectation in design, given that the south fork of Rose Creek is finding its original channel through the former reservoir. The highest TSS measured at FWSB 5 was 96 mg/L during the spring freshet period compares well with the predicted range of 80 to 330 mg/L for peak TSS from the former reservoir.

7.0 CONCLUSION

The "embankment notch" at the FWSD was completed from design to completion of construction within one calendar year. The collaborative nature of the design process allowed for this project schedule to be met. Construction of the breach project met the objectives stated for this project. The construction was completed as per the originally envisioned schedule and for less than the estimated cost. The performance of the breach and the re-vegetation efforts within the base of the FWSR has helped to keep the water quality at acceptable (and predicted) limits during and following construction.

8.0 ACKNOWLEDGEMENTS

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