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Indian and Northern Affairs Canada

ABANDONED CLINTON CREEK ASBESTOS MINE

RISK ASSESSMENT REPORT

UMA Engineering Ltd.
Engineers and Planners

INDIAN AND NORTHERN AFFAIRS CANADA
ABANDONED CLINTON CREEK
ASBESTOS MINE
RISK ASSESSMENT REPORT

APRIL, 2000

PREPARED BY
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UMA JOB NO. 41 01 4440 038 01 02

Our File: 41 01 4440 038 01 02

April 14, 2000

Indian and Northern Affairs Canada
345 – 300 Main Street
Whitehorse, Yukon
Y1A 2B5

Attention: Mr. Brett Hartshorne

Dear Sir:

Reference: Abandoned Clinton Creek Asbestos Mine - Risk Assessment Report

Attached is our Report summarizing the results of our Risk Assessment Study carried out for the abandoned Clinton Creek Asbestos Mine, Yukon Territory. Sufficient information was available to evaluate the potential risks to human life and property associated with sedimentation and flooding from a catastrophic breach of waste rock and tailings channel blockages. A similar evaluation of the chronic human health and ecological risks is beyond the scope of this report, however, the hydrological events modelled provide the basis for broader risk assessments should they be required.

For the risks identified in this report, it will be an important step to determine what level of risk should prompt a risk management or remedial strategy. In this regard, immediate measures might include preventing access to and camping in high hazard areas in close proximity to the mine site. Decisions on future actions may require that the direct costs of mitigative measures be compared against the economic consequences of damage to or losses of valued ecosystem components.

Thank you for the opportunity to assist you with this most interesting project. Should you have any questions or require any additional information or follow-up engineering services please contact the undersigned or Mr. Ken Skaftfeld, P.Eng.

Yours truly,

UMA ENGINEERING LTD.

J. A. Terris
Vice President & Manager
Manitoba & Northwestern Ontario
KS/dh

T. Wingrove, P.Eng.
Director
Earth & Environmental Division

EXECUTIVE SUMMARY

The abandoned Clinton Creek Asbestos Mine is located about 100 km north-west of Dawson City in the Yukon Territory, 9 km upstream of the confluence of Clinton Creek with the Forty Mile River. From 1968 until depletion of economic reserves in 1978, approximately 12 million tonnes of serpentine ore was extracted from the bedrock in three open pits. Over 60 million tonnes of waste rock from the open pits was deposited over the south slope of the Clinton Creek valley at what is referred to as the Clinton Creek waste rock dump. The ore was transported by an aerial tramway to the mill located on a ridge along the west side of Wolverine Creek, a tributary of Clinton Creek. Over the same period of time, about 10 million tonnes of asbestos tailings from the milling operation were deposited over the west slope of the Wolverine Creek valley (Wolverine Creek Tailings Piles).

Since closure of the asbestos mine, concerns have been raised with respect to the physical condition of the site, in particular downstream hazards associated with channel blockages resulting from landslides of the Clinton Creek waste rock dumps and Wolverine Creek tailings piles. In areas with significant relief such as the Clinton Creek Mine Site, flooding from failures of channel blockages can be especially dangerous and their occurrence can be unrelated to normal precipitation events that would be expected to produce flooding conditions.

UMA Engineering's 1999 survey appears to confirm the observations made in 1986, that is, the movement rates of the waste rock dump are decreasing over time. As down-cutting of the channel continues, sideslopes on both sides of the channel will become oversteepened resulting in localized instabilities which will deposit material into the stream course. The tailings piles continue to be unstable, although no massive displacements, similar to those observed shortly after initial failure, have been observed for many years. Wolverine Creek appears to have the capacity to remove the tailings and deposit them downstream at a sufficient rate to keep up with downslope movement of the tailings.

The most likely mode of failure for possible breach scenarios for both the waste rock dump (Clinton Creek) and the tailings pile (Wolverine Creek) is overtopping and rapid erosion of channel blockages. In this regard, progressive incising of the Clinton Creek channel downstream of the Hudgeon Lake outlet has increased the likelihood of the development of a full breach of the waste rock material. The failure mode could be triggered at any time in the foreseeable future and is not considered susceptible to any particular precipitation event i.e. a relatively minor inflow could trigger the failure mechanism necessary to initiate a breach. On-going downslope movement of tailings will continue to result in minor blockages which are quickly washed away with insufficient time for the storage of a large quantity of water upstream of the closure. Should increased slope movements create a sudden blockage of the channel, development of a breach will rapidly occur as the reservoir fills and overtops the blockage.

A full breach of a waste rock blockage at the Hudgeon Lake outlet would result in a peak discharge of approximately 500 m^3/s and a maximum flow velocity of 3.5 to 4 m/s. The flood peak quickly attenuates however, reaching a base flow level at the valley constriction downstream of Wolverine Creek. In the event of a breach of a tailings blockage, the peak discharge at the end of the Wolverine Creek channel is estimated to be approximately 350 m^3/s. The peak flow in Wolverine Creek is fairly high due to the short breach time, the steep channel profile and the lack of flood plain storage areas along the creek. This is very dissimilar to the conditions along Clinton Creek where the grade is relatively flat and the flood plain is very wide in proportion to the channel. As a

result, the full volume of the breach outflow from Wolverine Creek will be carried down to Clinton Creek and go into storage on the Clinton Creek flood plain.

Existing and future conditions at the abandoned Clinton Creek Asbestos Mine potentially expose individuals, property and the environment to some degree of risk associated with downstream channel sedimentation and flooding. These risks can be broadly placed into *ecological* and *human health* risk categories. This report is limited to evaluating the potential risks to human life and physical property downstream of the mine site in the event of a catastrophic breach at the channel blockages (flooding risks). The hydrological events modelled however, provide the basis for broader ecological risk assessments. In this regard, preliminary observations and recommended follow-up activities with respect to these issues are discussed by Royal Roads University in their March, 1999 Environmental Review Report. It is important to recognize that conditions at the mine site have evolved since a Downstream Hazard Assessment Report was completed in 1987, in particular the condition of the Clinton Creek Channel at the Hudgeon Lake outlet. In our opinion, the destruction of the rock weirs in 1997 and continued channel incising has greatly increased the potential for the development of a breach.

A qualitative assessment of risk scenarios and human and ecological exposure levels associated with a channel blockage breach has been provided in this report. A quantitative estimate of risk is not considered appropriate given the considerable uncertainty in parameters necessary to arrive at precise predictions of risk under various scenarios and circumstances. There is however, sufficient reliability in the results presented in this report to determine the acceptability of potentially hazardous activities and develop guidelines for appropriate risk management strategies. In this regard, the level of risk downstream of the mine site has been categorized as high, medium or low based on the severity of flooding within each zone. The inherent risk to human health and potential loss-of-life is dependent upon the potential for human exposure within these zones.

The potential for loss-of-life is the greatest immediately downstream of the mine site in the area potentially inundated by a full breach of the waste rock pile, or within the Wolverine Creek valley in the event of a breach of a tailings blockage. Farther downstream along Clinton Creek, the risks are somewhat less as the increase in creek water levels will largely be confined to the creek valley below the road where human exposure (occupancy) is considered unlikely. The risk to human health is considered low at the next most likely downstream area of occupancy in the vicinity of the Clinton Creek Town-site where the valley widens considerably.

For each of the ecological or human health risks identified, it is important for the current land manager to determine what level of risk should prompt a risk management or remedial strategy. In this regard, immediate measures might include:

- Preventing vehicle access to high hazard areas i.e. barricading the road between the Town-site and the Mine Site
- Prohibiting camping in high hazard areas (including the eviction of current occupants)
- Posting warning signs in medium and high hazard areas
- Providing camping facilities on sufficiently high ground in designated areas within medium and low hazard areas

For the components of the ecosystem potentially at risk, it is important for the appropriate decision makers, in association with the land manager, to first decide if the demonstrated risks identified in this report warrant the development and/or implementation of risk management or remedial strategies. As pointed out in the Royal Roads 1999 Environmental review, future actions may require that the direct costs of mitigative measures be compared against the economic consequences of damage to or losses of valued ecosystem components

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1.0 INTRODUCTION

This report summarizes the results of our Risk Assessment Study carried out for the abandoned Clinton Creek Asbestos Mine in the Yukon Territory. The purpose of the investigation was to determine the potential downstream hazards and risks associated with a breach of channel blockages created by landslides of the waste rock and tailings piles. The terms of reference for the study are outlined in our letter to DIAND dated June 30, 1999. The overall project was divided into two Phases to avoid collecting additional site specific data and completing detailed analysis until it had been determined that this level of effort was required. This report includes only the results of the Phase 1 program which utilized existing information, supplemented by current site surveys and photogrammetric mapping, to complete the hydrologic and risk assessment for the Clinton Creek and Wolverine Creek channel blockages. Dam breach scenarios were evaluated and the downstream consequences of the breaches (downstream hazards) were determined. Upon completion of this Phase 1 Program, the project will proceed based on one of three possible scenarios as shown in Figure 1-1. Evaluation of a potential breach of the Porcupine Creek waste rock dump was not included in this study as the consequence of such a breach is considered to be significantly less severe than would be expected for Clinton and Wolverine Creeks.

Three unique tasks were undertaken as part of the Phase 1 Program. Each task is described in more detail as follows:

<u>TASK 1: Data Review and Collection</u>

Data related to precipitation, hydrology, seismic activity, etc. was collected for use in the hydraulic modelling. Any relevant flow measurement records for Clinton and Wolverine creeks and for the Forty Mile and Yukon rivers necessary for the hydraulic modelling was obtained. Previous work completed pertaining to the hydraulic modeling and breach assessment was reviewed, in particular:

- Channel geometry;
- Geotechnical characteristics of the waste rock and tailings piles;
- Configuration of any control structures, i.e., weirs, culverts etc.

A site survey was undertaken to re-establish the position of existing movement monitors, water elevations and channel geometries. The survey included the installation of benchmarks and control points necessary for photogrammetric mapping. The scope was subsequently expanded to include aerial photography of the mine site and Clinton Creek channel to the Forty Mile River and photogrammetric mapping of these areas. A literature search was completed to determine breach characteristics of man-made dams and natural valley blockages in order to develop a range of likely breach scenarios for the Clinton Creek site.

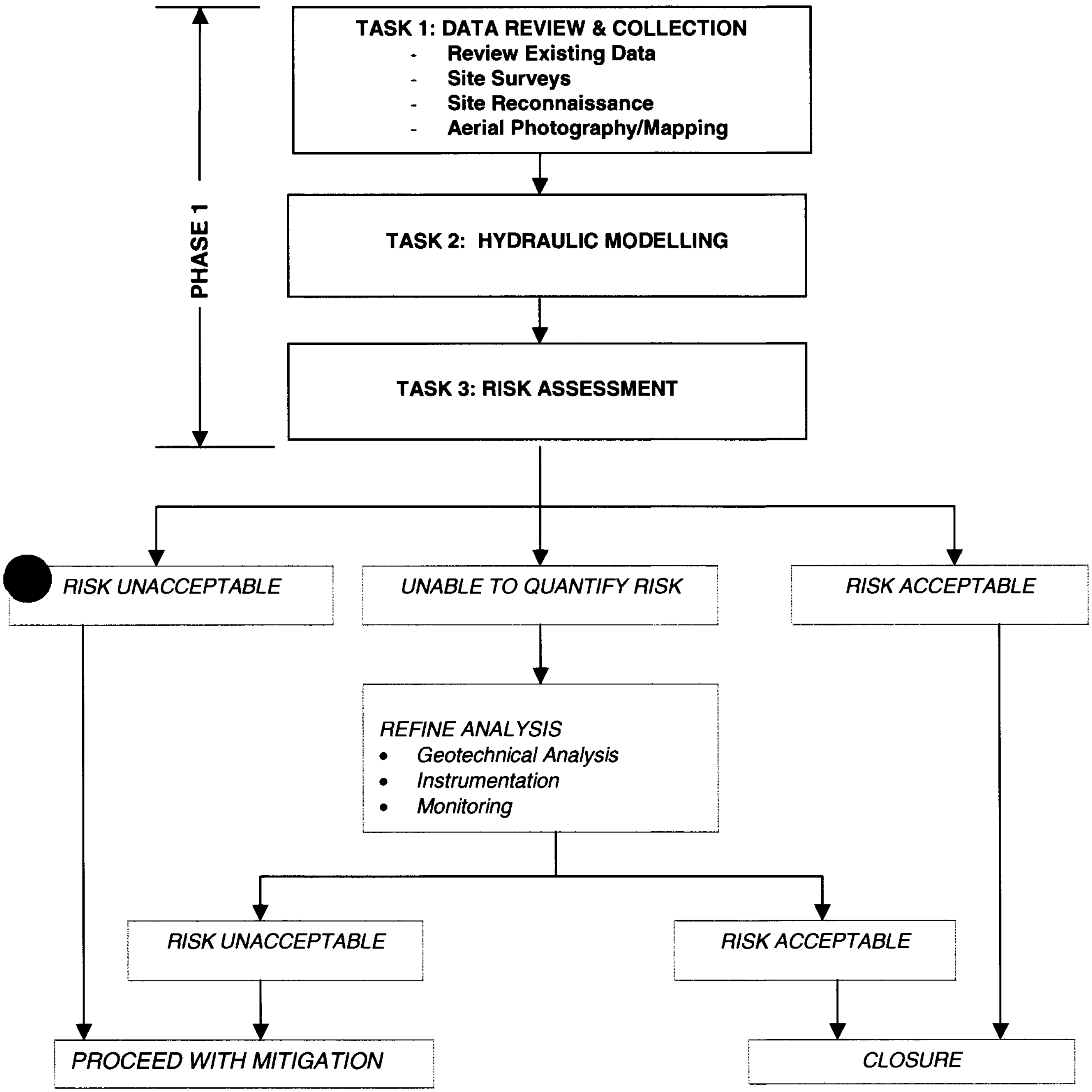


Figure 1-1
Overall Project Organization

TASK 2: Hydraulic Modeling

A dam breach model was developed to determine the implications of a breach of the Clinton Creek and Wolverine Creek channel blockages. A range of potential dam breach geometries were evaluated to assess the consequences from a variety of breach scenarios. The implications in terms of water levels, extent of area under inundation, warning period and sediment transport for the breach conditions were quantified.

TASK 3: Risk Assessment

The vulnerability of downstream reaches of the Clinton and Wolverine Creek valleys as far as the Yukon River was assessed for the breach scenarios. The assessment considered the exposure of individuals, property and the environment to the risks associated with downstream sedimentation and flooding. The level of risk downstream of the mine site was subsequently categorized.

2.0 BACKGROUND

2.1 General

The abandoned Clinton Creek Asbestos Mine is located about 100 km north-west of Dawson City in the Yukon Territory, 9 km upstream of the confluence of Clinton Creek with the Forty Mile River (Figure 2-1 & Drawing 01). The mine consists of three open pits (Porcupine, Creek and Snowshoe), two waste rock dumps (Porcupine and Clinton Creek) along the south side of Clinton Creek, and a tailings pile on the west side of Wolverine Creek (Drawing 02). From 1968 until depletion of economic reserves in 1978, approximately 12 million tonnes of serpentine ore was extracted from the bedrock by the Cassiar Mining Corporation.

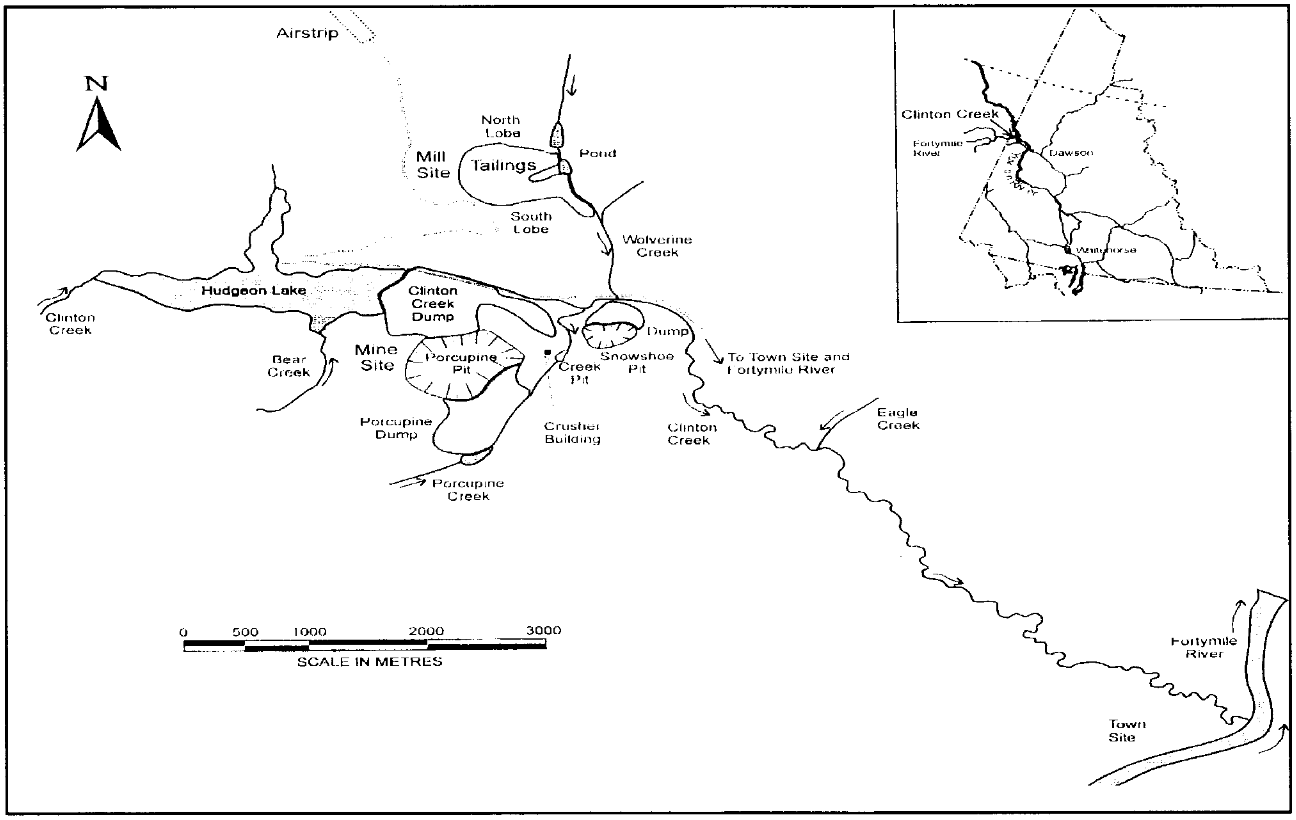


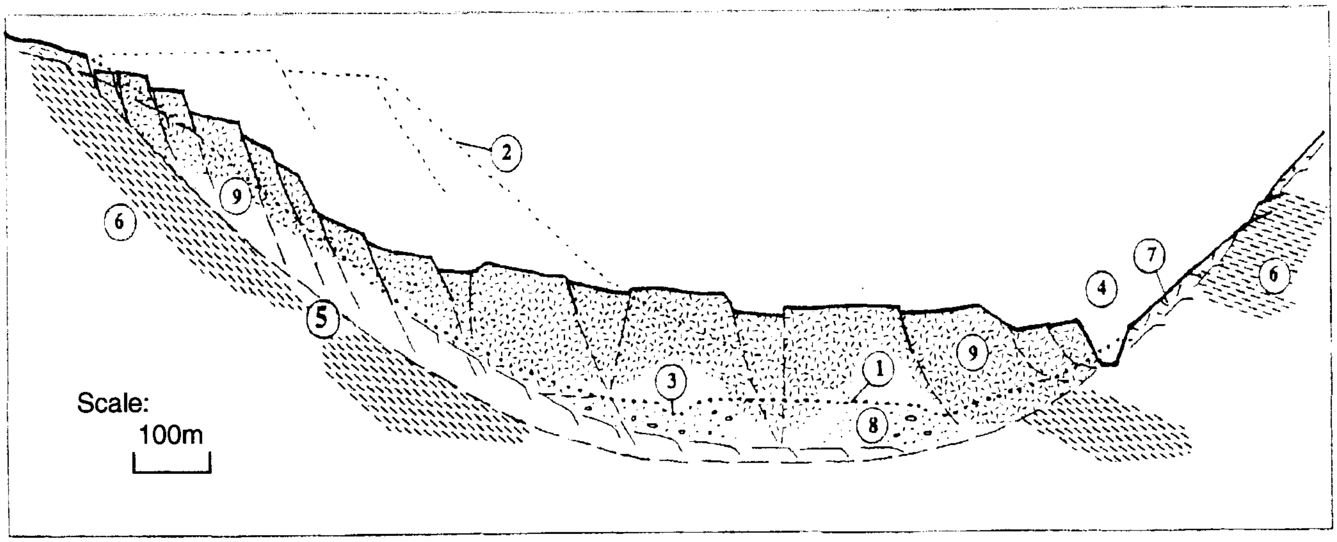
Figure 2-1

Location Plan (Royal Roads University, 1999)

Over 60 million tonnes of waste rock from the open pits was deposited over the south slope of the Clinton Creek valley at what is referred to as the Clinton Creek waste rock dump. The ore was transported by an aerial tramway to the mill located on a ridge along the west side of Wolverine Creek, a tributary of Clinton Creek. Over the same period of time, about 10 million tonnes of asbestos tailings from the milling operation were deposited over the west slope of the Wolverine Creek valley (Wolverine Creek Tailings Piles). Since closure of the asbestos mine, concerns have been raised with respect to the physical condition of the site, in particular downstream hazards associated with channel blockages resulting from landslides of the Clinton Creek waste rock dumps and Wolverine Creek tailings piles. In areas with significant relief such as the Clinton Creek Mine Site, flooding from failures of channel blockages can be especially dangerous and their occurrence can be unrelated to normal precipitation events that would be expected to produce flooding conditions.

2.2 Clinton Creek Waste Rock Dump and Channel (Drawing 03)

A significant slope failure of the waste rock dump into the Clinton Creek valley occurred in 1974 (Figure 2-2). The resulting landslide dam blocked natural drainage through the valley creating a 74 ha lake (Hudgeon Lake) as shown in Photo 2 (Klohn, 1986). A new creek channel (UMA Photo 7-17) was subsequently formed along the interface between the landslide material and north valley slope, some 25 metres above the original valley bottom at the Hudgeon Lake outlet. Within the area now occupied by the waste rock dump, the creek channel is approximately 700 m long with a gradient ranging from 3 to 5.5 percent compared to its natural gradient of approximately 0.075 percent.



(From Stepanek & McAlpine, 1992)

Figure 2-2
Waste Rock Slide
Looking Upstream

1-Original Ground Surface, 2-Initial Waste Rock Configuration, 3-Original Creek Channel, 4-Present Creek Channel, 5-Probable Slip Plane, 6-Bedrock, 7-Colluvium, 8-Alluvium, 9-Slide Debris

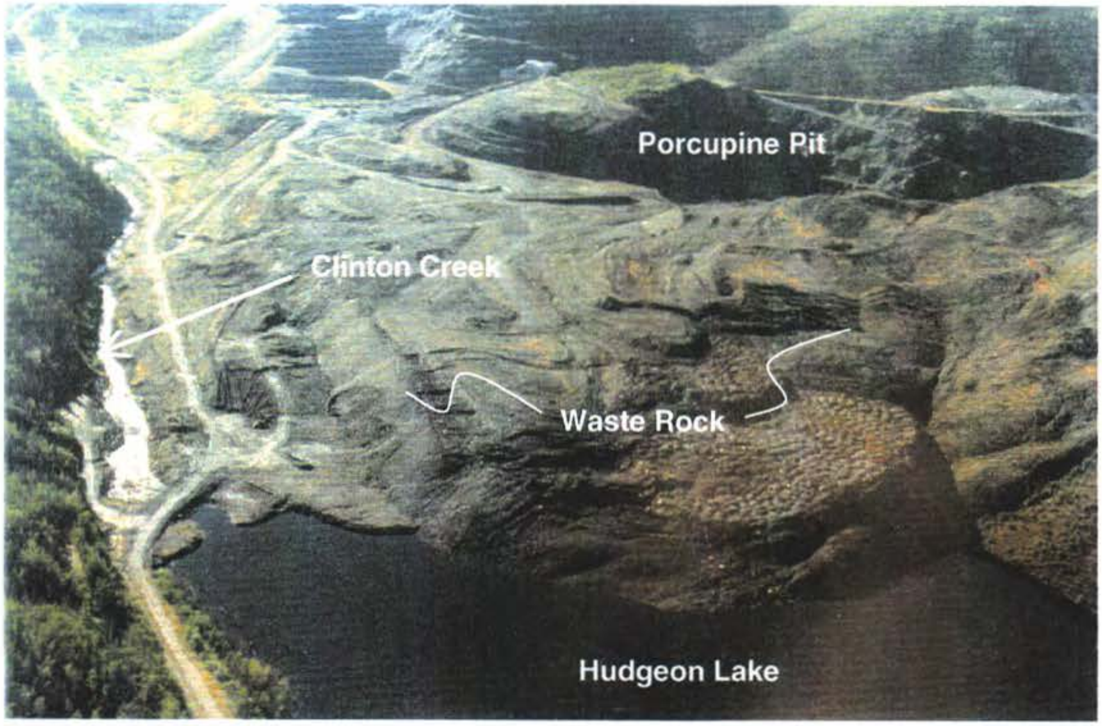


Photo 2
Clinton Creek Waste Rock Dump (1986)

UMA Photo 7-17
Clinton Creek Channel Downstream of Hudgeon Lake Outlet

Monitoring of waste rock movements was carried out on an annual basis beginning in 1977 and ending in 1986. Over this period it was concluded that while downslope movements of the Clinton Creek waste rock dump were continuing, the movement rates were decreasing (Klohn,1987). The last reported data from 1985/86 indicated movement rates had reduced from 1.2 m/yr in 1977/78 to approximately 0.3 m/yr in 1986. During that time, it was evident that channel erosion generally kept pace with the advancing waste rock material i.e. the channel width was maintained by side channel erosion. Creek channel profiles surveyed in 1983, 1984 and 1986 did not indicate that any significant down-cutting of the channel through the waste rock was occurring.

Channel erosion protection measures were constructed between 1979 and 1984, including a rock weir and channel armouring just downstream of the Hudgeon Lake outlet (Photo 5, Geo Eng., 1987). These erosion control works have since proven to be largely unsuccessful and were almost completely destroyed in the spring of 1997. Since that time, significant erosion of the channel, in particular, down-cutting near the Hudgeon Lake outlet has occurred (UMA photo 8-13). The extent of the downcutting is evident when comparing the channel profile in 1999 with the profiles generated in 1983, 1984 and 1986 (Drawing 04). Up to 2 to 3 metres of incising has occurred immediately downstream of the outlet where the channel bed is bounded to the south by waste rock and to the north by natural colluvial soils overlying bedrock on the valley slope. Farther downstream, less down-cutting is evident, likely because of the less erodible exposed bedrock bounding the channel at lower elevations and/or downstream sediment transportation and deposition.

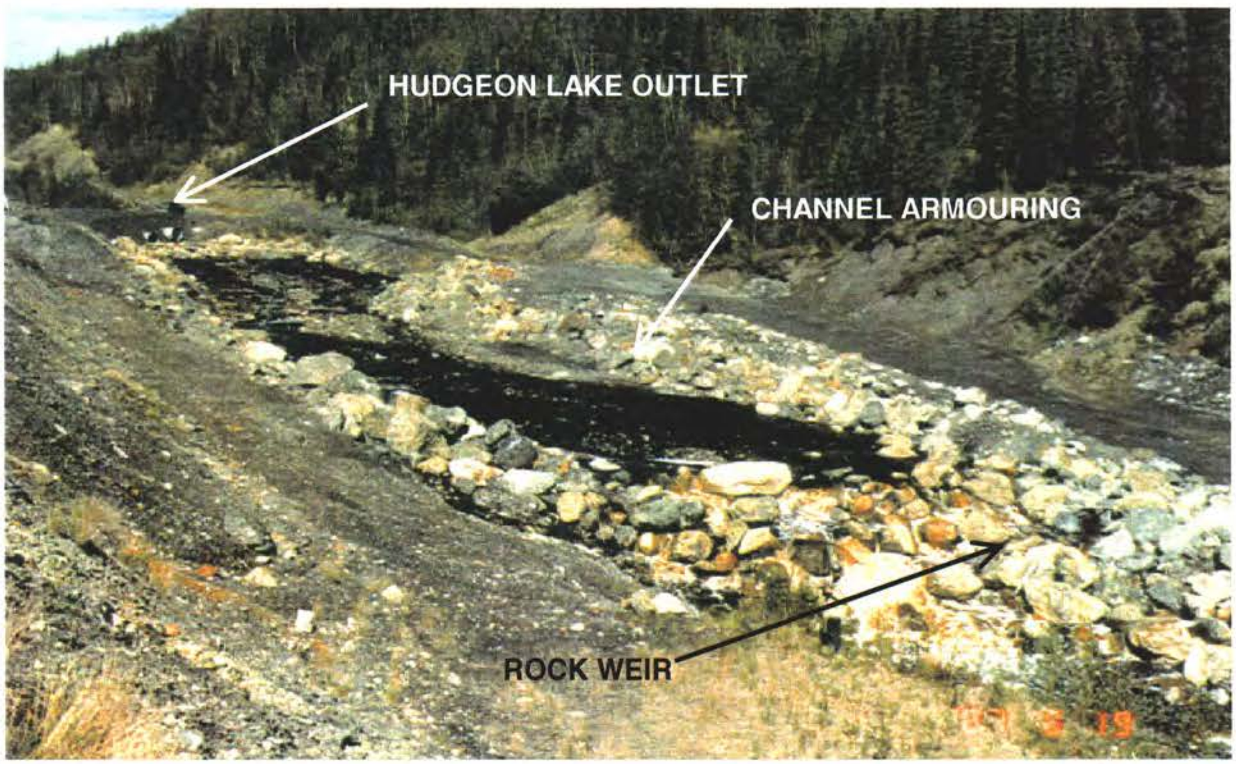
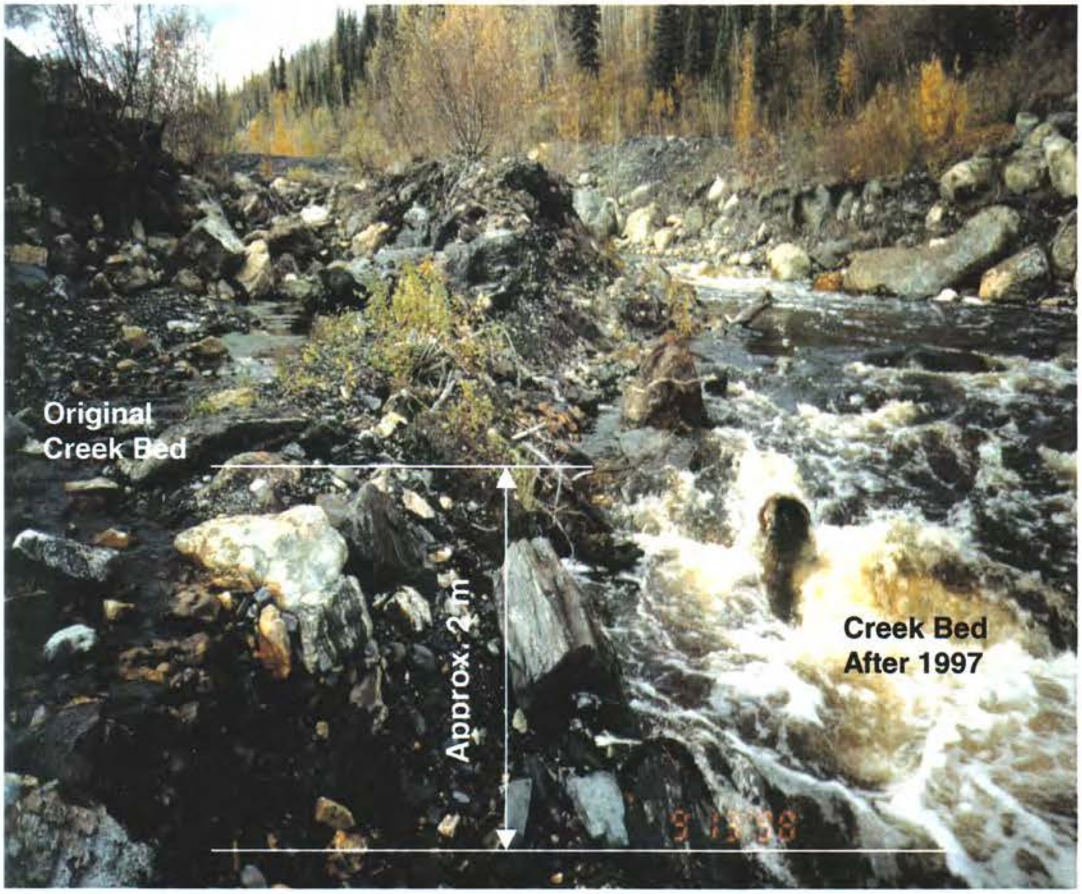


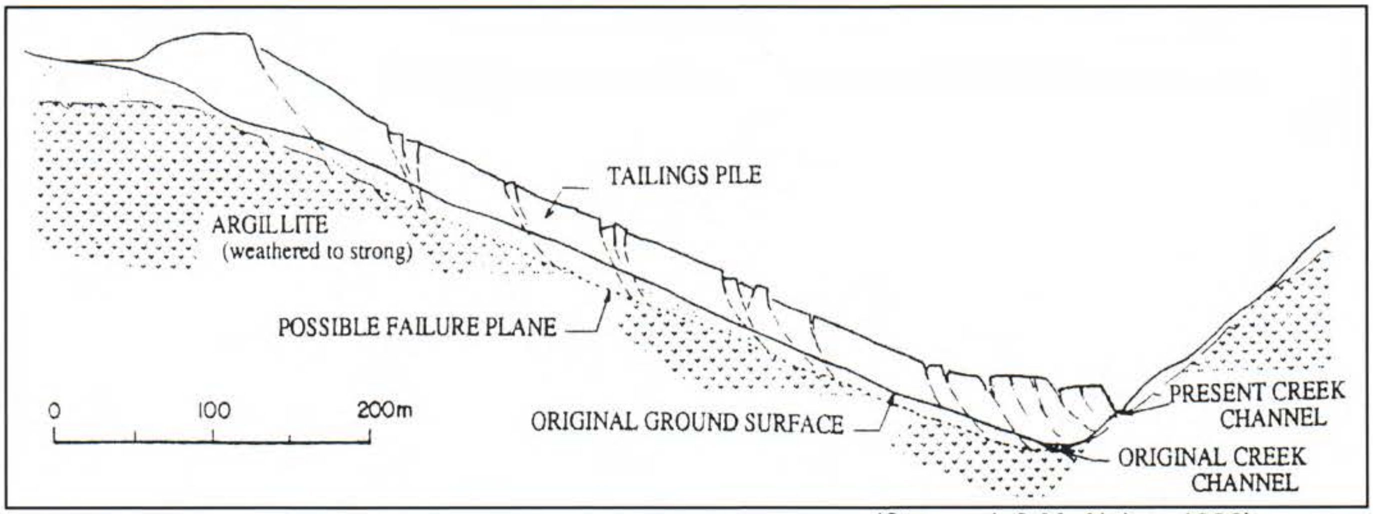
Photo 5
Rock Weir and Channel Armouring



UMA Photo 8-13
Channel Down-cutting Immediately Downstream of Hudgeon Lake Outlet

2.3 Wolverine Creek Tailings Piles (Drawing 05)

The southerly portion of the tailings pile (south lobe) failed suddenly in 1974, completely blocking the existing Wolverine Creek channel (Figure 2-3). Upon formation of a small upstream lake, the blockage was breached releasing a significant amount of water borne tailings downstream of the tailings piles. Following the 1974 event, the north tailings lobe failed (UMA Photo 3-5). A series of rock weirs were subsequently constructed downstream of the tailings piles to minimize erosion, and to date, these measures remain intact. Remedial measures to stabilize the tailings lobes, including slope flattening and terracing were unsuccessful. Downslope movements of the tailings pile lobes are still occurring, resulting in continued erosion of landslide material at the downslope toe.



(Stepanek & McAlpine, 1992)

Figure 2-3
Section Through South Tailings Lobe

UMA Photo 3-5
Asbestos Tailings Pile

3.0 DATA COLLECTION

3.1 Literature Search

To evaluate potential dam breach scenarios and the consequences of allowing continued natural erosion of the creek channels, case histories relating to breaches of natural and man-made dams were reviewed. Relevant papers researched include:

- *Visser, P.J. et al, 1990:* The results of a field experiment on sand dyke breach erosion are described, information which is useful in assessing breach characteristics for the mill tailings material.
- *AlQaser, G., et al, 1993:* The progressive failure of an overtopped dam is simulated and described. The results are compared with more conventional assumptions used for dam break models.
- *Blown, I., et al, 1985*: In 1983, a moraine dam impounding Nostetuko Lake in British Columbia breached, draining the enitre lake in about 5 hours. Similarities can be made between the geometry and material properties of the moraine failure and the Clinton Creek waste rock dump.
- *Clague, J.J., et al, 1985*: The breaching of a moraine dam in the early 1970's on the Klattasine River in British Columbia is described.
- *Evans, G.E., 1986*: The nature and magnitude of outburst floods are described to develop a relationship between maximum discharge and the volume of water released.
- *McDonald, T.C., et al, 1984*: Data on a number of historical dam failures is presented and a graphical approach to predict breach characteristics is described.
- *McMahon, G.F., 1981*: Assumptions adopted for dam breach geometry are described.
- *Ryder J.M., et al, 1990*: The mechanics of rock avalanches and the engineering properties of argillite are described (argillite is the bedrock formation at the Clinton Creek Mine Site).
- *Geological Survey of Canada Bulletin 464, 1994*: Case histories on the formation and failure of natural dams in the Canadian Cordillera, including the Clinton Creek Mine site.

3.2 Site Reconnaissance

A site inspection was carried out by UMA Engineering in July 1999 to further evaluate conditions observed in our 1998 Site Reconnaissance (UMA Report dated April, 1999) and assist with site surveys. Photographs (Rolls 14 and 15) and video were taken, in particular from the north side of the Clinton Creek Valley. The major observations made in our July 1999 inspection are summarized as follows:

- Slumping of the north valley slope within the immediate vicinity of the creek channel is evident, in particular along the lower half of the reach through the waste rock. Retrogressive slump blocks 2 to 3 metres high have developed about 500m downstream of the lake outlet exposing the weathered argillite bedrock along the backscarps (UMA Photo 14-2A). Significant slumping has also occurred about 350m downstream of the outlet where a 5 m backscarp and vegetated lower bench are clearly visible (UMA Photo 14-12A). Photo locations are indicated on Drawing 03.

UMA Photo 14-2A
Valley Slope 20m W of Piezometer P4

UMA Photo 14-12A
Valley Slope 30m Upstream of Section A-AA

- Recent slumping of the oversteepened waste rock slope can be seen from the north side of the creek channel, in particular in the vicinity of cross-channel reference line A-AA (UMA Photos 14-11A). The localized slides typically block about one half of the creek channel bottom and active erosion is evident at the toe of the slide debris in the channel.

UMA Photo 14-11A
Waste Rock Slumping at Sec A-AA

- The creek channel was dry at the Hudgeon Lake outlet with flow occurring through the 2m diameter culvert which is badly out of round. The channel remnant (which was flowing during our 1998 reconnaissance) is about 18-20m wide.

- Open channel flow in Clinton Creek terminated at the east end of the waste rock dump just before reaching the washed out bridge. The channel is dry from this point to about 100m downstream of the bridge (UMA Photo 15-4A). The water in the channel at this location (the old bridge) was at least 0.5 to 1m deep in 1998 during our site reconnaissance (UMA Photo 11-10).

UMA Photo 15-4A
Clinton Creek Channel Downstream of Bridge

UMA Photo 11-10
Creek Channel in September 1998

- Flow from Wolverine Creek normally discharges into Clinton Creek through a 1200mm diameter steel plate (19mm thick) culvert elevated about 2m above the channel bottom (UMA Photo 15-10A) . The culvert is in good condition. No flow was visible through a corrugated metal culvert which was partially embedded into the channel bed, nor was any flow occurring through the 1200mm culvert set at a higher elevation. Interestingly there was a significant flow in Clinton Creek just upstream of Wolverine Creek in comparison with little to no flow observed just downstream of the old bridge.

UMA Photo 15-10A
Wolverine Creek Outlet Culvert

- Eagle Creek drains into Clinton Creek through a 1600mm diameter corrugated metal pipe about 3 km downstream of the mine as shown on Drawing 01 (UMA Photo 15-15A). Discharge from the culvert at the time was estimated to be 7 l/sec. The culvert has been vertically deformed by about 300mm beneath the roadway. An old timber bridge is located about 20m upstream of the culvert, likely along a previous access road alignment (UMA Photo 15-16A). The timber bridge is in poor condition.

UMA Photo 15-15A
Eagle Creek Culvert

UMA Photo 15-16A
Eagle Creek Timber Bridge

3.3 Site Surveys

Site surveys were undertaken by Underhill Geomatics of Whitehorse to:

- Establish mine grid coordinates of photo-identifiable points for photogrammetric mapping,
- Tie in movement monitoring targets and channel closure sections along Clinton Creek and,
- Establish representative creek channel cross sections and profiles.

Attempts to locate previous mine site benchmarks were largely unsuccessful. As a result, new benchmarks were established and reconciled to the mine grid by establishing coordinates of fixed points i.e. foundations from available record drawings. Checks were completed in the field to confirm that reasonable horizontal accuracy was achieved. A Global Position Survey (GPS) was used to establish UTM coordinates of ground targets and a geodetic elevation for survey control. Photo identifiable targets were established at the crusher building area, mill site and Clinton Creek Town Site.

A number of the movement monitors at the waste rock dump were located and tied into the survey. Cross-channel reference lines (closure sections) J-JJ, F-FF, K-KK, G-GG, A-AA and E-EE were also re-established. These reference lines consist of an iron bar on the waste rock side of the channel and a permanently mounted prism on the valley slope. The locations of all instrumentation, including standpipe piezometers P1 to P5, installed in 1978 by Golder Assoc. are shown on Drawing 06.

A channel profile along Clinton Creek was surveyed from the culvert at the Hudgeon Lake outlet to the bridge downstream of the waste rock dump for comparison with similar surveys conducted in 1983, 1984 and 1986 (Drawing 04). Representative channel cross sections were surveyed at cross-channel reference lines J-JJ, F-FF and K-KK. A fourth cross section (Section Ken) was surveyed between lines J-JJ and F-FF, at a location where the elevated creek channel remnant is clearly visible (Drawing 07). Cross section surveys were not possible farther downstream because of hazardous side slopes. A survey in the vicinity of the Clinton Creek/Wolverine Creek confluence was also completed to tie in the channel profiles and culvert invert elevations.

3.4 Aerial Photography and Photogrammetric Mapping

Smoke from forest fires and poor weather in July and August prevented the site from being flown until September, 1999. Geographic Air of Edmonton completed the aerial photography, flying three lines across the mine site in an east west alignment. The centre line was extended along the Clinton Creek channel to its confluence with the Forty Mile River. Stereo pairs of photos at a 1:10,000 scale were produced.

UMA Geomatics produced the following:

- Five separate digital orthophoto image mosiac files in TIF format. The entire flown area at the mine site was tiled into four files (one file per quadrant). The central mine site area was isolated into a fifth file.
- Five separate AutoCAD Drawing Files formatted with 1m contour intervals overlying the entire flown area.
- Orthophoto image files and AutoCAD drawings of the Clinton Creek channel from the mine to the Forty Mile River.

4.0 PHYSIOGRAPHIC SETTING

4.1 Regional and Local Geology

The Clinton Creek Mine site is located in the Klondike Plateau Ecoregion, dominated by low-elevation terrain lying between 100 to 1000 m above sea level. The characteristic terrain features include smooth unglaciated rolling plateau topography that is intersected by deep and narrow V-shaped valleys. Permafrost is widespread and discontinuous in the region with medium ice content in fine-textured valley deposits. The valley slopes at the mine site are mostly covered with silty sands and gravel (colluvium). Alluvial soil deposits (sand and gravel) are typically found in the valley bottoms. Bedrock is relatively shallow (<15m) and consists of clay shale, referred to as argillite. Bedrock outcrops are visible in the lower portions of the Clinton Creek and Wolverine Creek valleys. The upper layer of the bedrock is weathered (highly fractured and jointed) and erodible. Although there is no site specific information with respect to the aerial extent and thickness of permafrost, its presence has been confirmed beneath the waste rock and tailings piles (Golder, 1978). It is believed, however, that the permafrost conditions have been altered as a result of mining activities and significant thawing has occurred beneath the waste piles.

4.2 Local Climate

The mean annual precipitation in the region ranges from 300 to 450 mm. At the mine site, the mean annual precipitation is approximately 300 mm, based on the Hydrological Atlas of Canada (Fisheries and Environment, 1978). The mean annual temperature for the region is -5.5°C with the summer and winter mean temperatures being +10.5°C and -23°C. The short, warm summers are in sharp contrast to the long, very cold winters.

4.3 Vegetation

The vegetation is typical of the boreal environment with open black and white spruce forests mixed with aspen and occasionally lodgepole pine. Black spruce and paper birch prevail on slopes underlain by permafrost and balsam poplar occurs along the floodplains. In the sub-alpine sections, from valley bottoms to well above the treeline, scrub birch and willow form extensive stands.

5.0 DRAINAGE BASIN

5.1 Clinton Creek Drainage Basin

The Clinton Creek drainage basin crosses the international boundary into Alaska, U.S. The main drainage basin and several sub-basins on Canadian territory were first delineated on the 1:50 000 scale NTS map sheets (map sheets 116C/10 and 116C/7 in UTM Zone 7, NAD27) and then digitised and imported into ArcView. The portion of the drainage basin located in the U.S. was delineated on a DEM (Digital Elevation Model) built from USGS (U.S. Geological Survey) DEM data. The delineated drainage basins are shown in Figure 5-1 and the computed basin areas are summarised in Table 5-1.

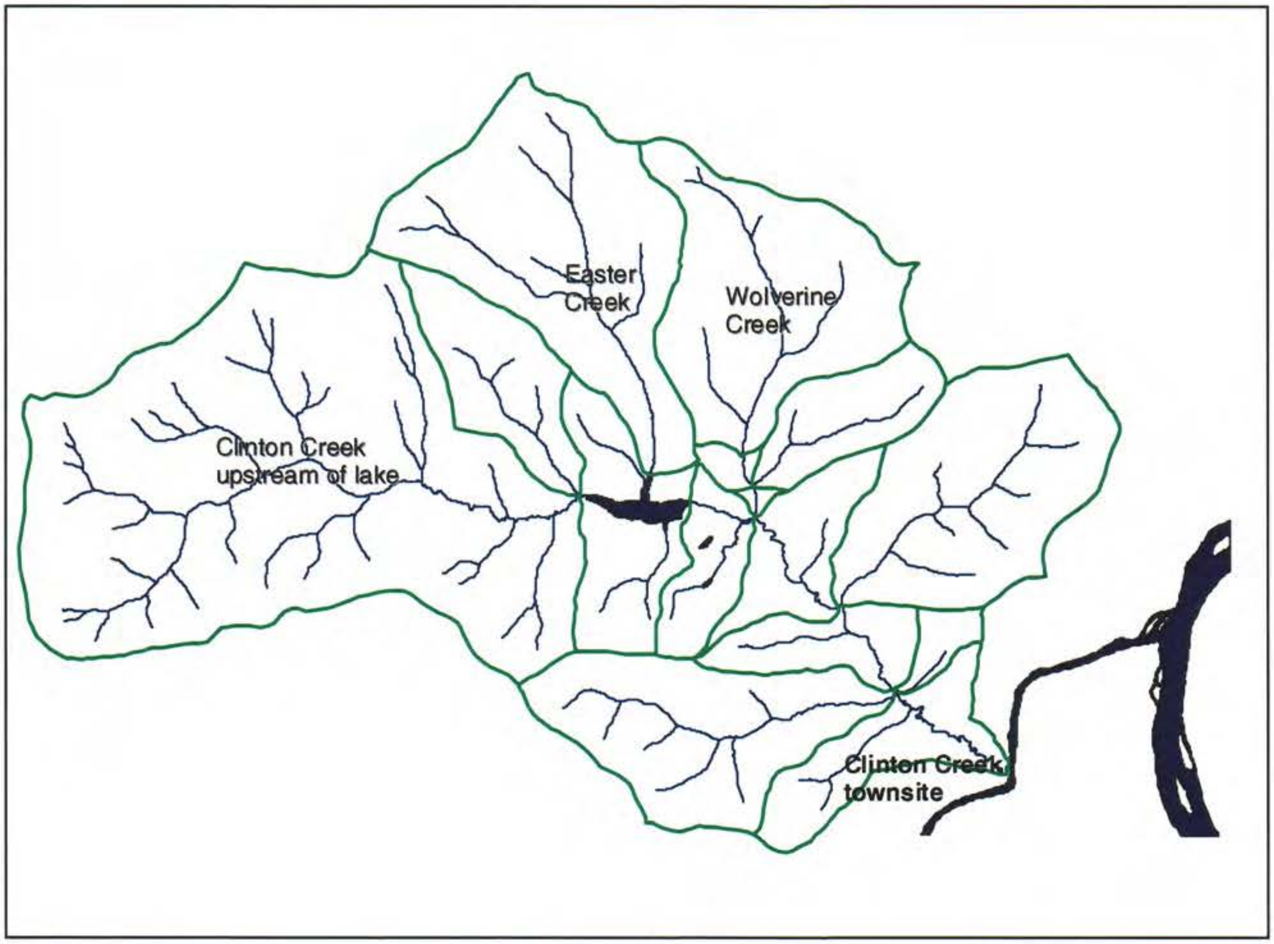


Figure 5-1
Clinton Creek Drainage Basin

Table 5-1
Clinton Creek Drainage Basins

Location on Clinton Creek	Sub-Basin	Sub-Basin Drainage Area [km^2]	Clinton Creek Cumulative Area [km^2]
	West of US border (assumed)	4.3	
International border			4.3
	Main stem	63.1	
	Unnamed creek #1	8.6	
	Hudgeon Lake	9.6	
	Easter Creek	26.3	
Hudgeon Lake outlet			111.9
	Main stem, incl. Porcupine Creek	4.7	
U/S of Wolverine Creek			116.6
	Wolverine Creek – U/S of waste pile Wolverine Creek – waste pile area Wolverine Creek – SE tributary Wolverine Creek – D/S of SE tributary Wolverine Creek basin	21.0 0.9 6.4 0.3 28.6	
D/S of Wolverine Creek			145.2
	Main stem Unnamed creek #2 Main stem Unnamed creek #3 Unnamed creek #4 Main stem Wolverine Creek to road crossing	6.3 20.5 5.3 1.6 17.1 7.8 58.6	
Road crossing			203.8

The drainage area at Hudgeon Lake outlet is 111.9 km^2. In comparison, Klohn Leonoff, (1987) reported the drainage area of Clinton Creek at Hudgeon Lake to be 106 km^2. The difference in the area estimates is most likely due to a better delineation of the drainage basin within Alaska that is now possible thanks to digital elevation data for Alaska now being readily available over the Internet.

5.2 Wolverine Creek Drainage Basin

The Wolverine Creek drainage basin has an area of 28.6 km^2 and drops about 500m over its 9.2 km length, from the drainage basin divide to the Clinton Creek confluence. The channel is well defined in V-shaped valleys in the lower reaches, becoming intermittent in the upper reaches. The basin is densely treed with less dense vegetation in the headwaters.

6.0 HYDROLOGY

The design flood estimation necessary for the flow modeling was based on available discharge data. Since the completion of the *Yukon River Flood Risk Study* (UMA, 1983) and the Klohn Leonoff (1987) study, 10-15 years of additional discharge data has become available. This additional data greatly improved the quality of the estimated discharges used for previous studies.

6.1 Hydrologic Data

Several WSC (Water Survey of Canada) and USGS (U.S. Geological Survey) hydrometric stations are located in the general vicinity of the project. All stations that were considered for the project analysis are shown in Figure 6-1 and listed in Table 6-1 And 6-2 (Appendix A) together with their locations, drainage areas and record periods. Some additional stations are located on large rivers in the vicinity of the project area but, due to their relatively large drainage areas, these stations were not considered as they would not improve the discharge estimates for the relatively small Clinton Creek drainage basin. All stations with a drainage area of 10 000 km^2 or less were considered for the analysis.

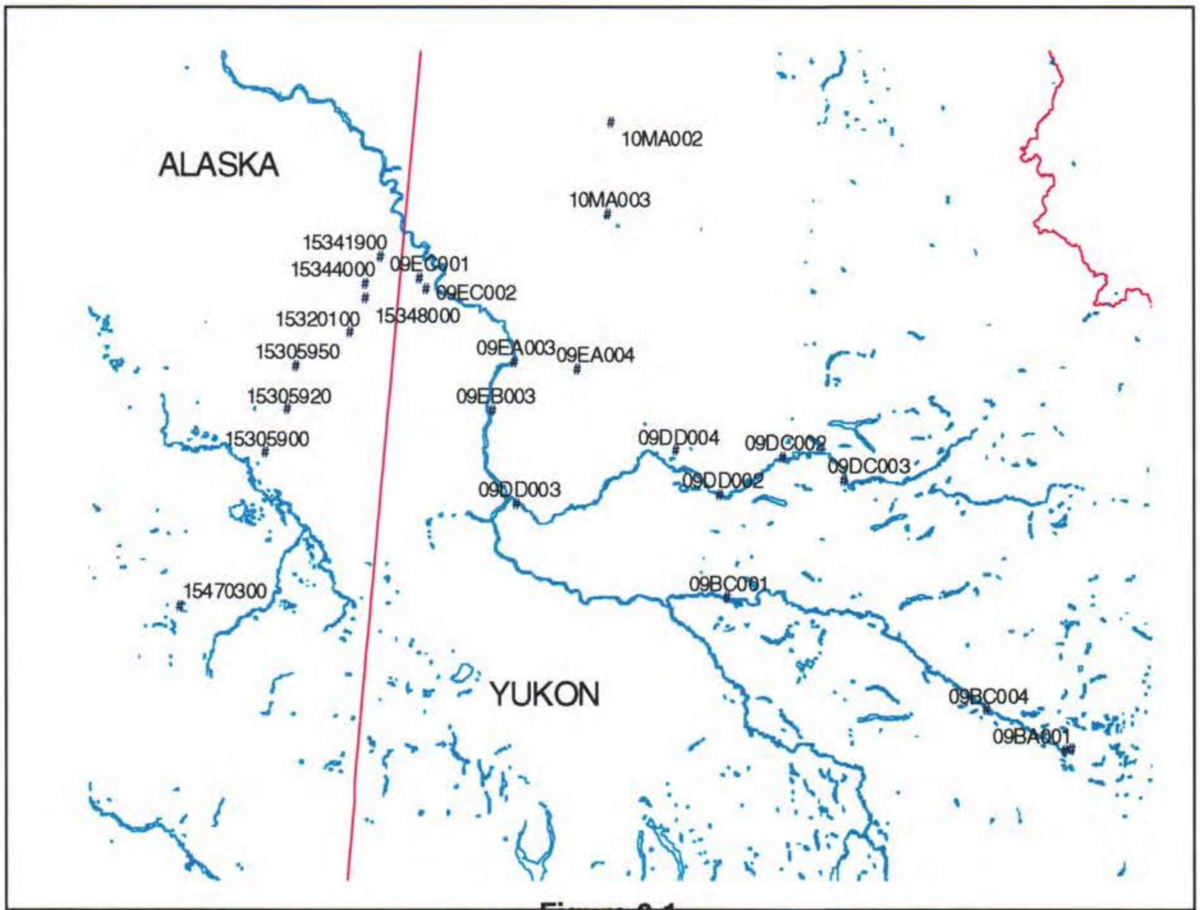


Figure 6-1
Hydrometric Stations Location Map

The quality of the maximum instantaneous discharge data for all stations considered for the study was checked with respect to dependence, trend, randomness, homogeneity, outliers and high frequency distribution skew. The stations considered suitable for use in the analysis were:

- WSC 09EA003, Klondike River above Bonanza Creek; 7800 km^2; 30 years of records
- WSC 09EA004, North Klondike River near the mouth; 1100 km^2; 22 years of records
- WSC 09EB003, Indian River above the mouth; 2220 km^2; 12 years of records
- USGS 15305920, Wf Tr Nr Tetlin Junction Ak; 2.6 km^2; 25 years of records
- USGS 15344000, King C Nr Dome Creek Ak; 15.2 km^2; 22 years of records
- USGS 15470300, L Jack C Nr Nabesna Ak; 17.4 km^2; 21 years of records

The maximum instantaneous discharge data for the six selected stations were analysed using the CFA (Consolidated Flood Frequency Analysis) program, developed by WSC (Water Survey of Canada). The estimated 100- and 200-year flood peaks were extracted and a regression analysis was done on the corresponding unit discharges. From the regression analysis, it was found that the 100- and 200-year maximum instantaneous unit discharges can be estimated using the equations:

$$q_{100} = 1.4701 \times A^{-0.3117} \qquad \text{(correlation coefficient = 0.9706)}$$

$$q_{200} = 1.7494 \times A^{-0.3202} \qquad \text{(correlation coefficient = 0.9758)}$$

where q_N = maximum instantaneous unit discharge [m^3/s per km^2] for N-year return period and A = drainage area [km^2]

The estimated instantaneous unit discharges for the six stations and the computed regression lines are shown in Figure 6-2. Using the derived drainage area to instantaneous unit discharge relationship, the 200-year flood peak at Hudgeon Lake outflow was estimated to be 43 m^3/s. In comparison, Klohn Leonoff (1987) estimated the 200-year peak inflow rate to Hudgeon Lake to be 78 m^3/s, based on record periods up to year 1983. The difference in discharge estimates is attributed to the 13 years longer record periods used in the current analysis and the inclusion of smaller drainage basins in Alaska in the general vicinity of the project. Using Figure 6-2, the 200-year flood peak for the Wolverine Creek basin was estimated to be 17.1 m^3/s.

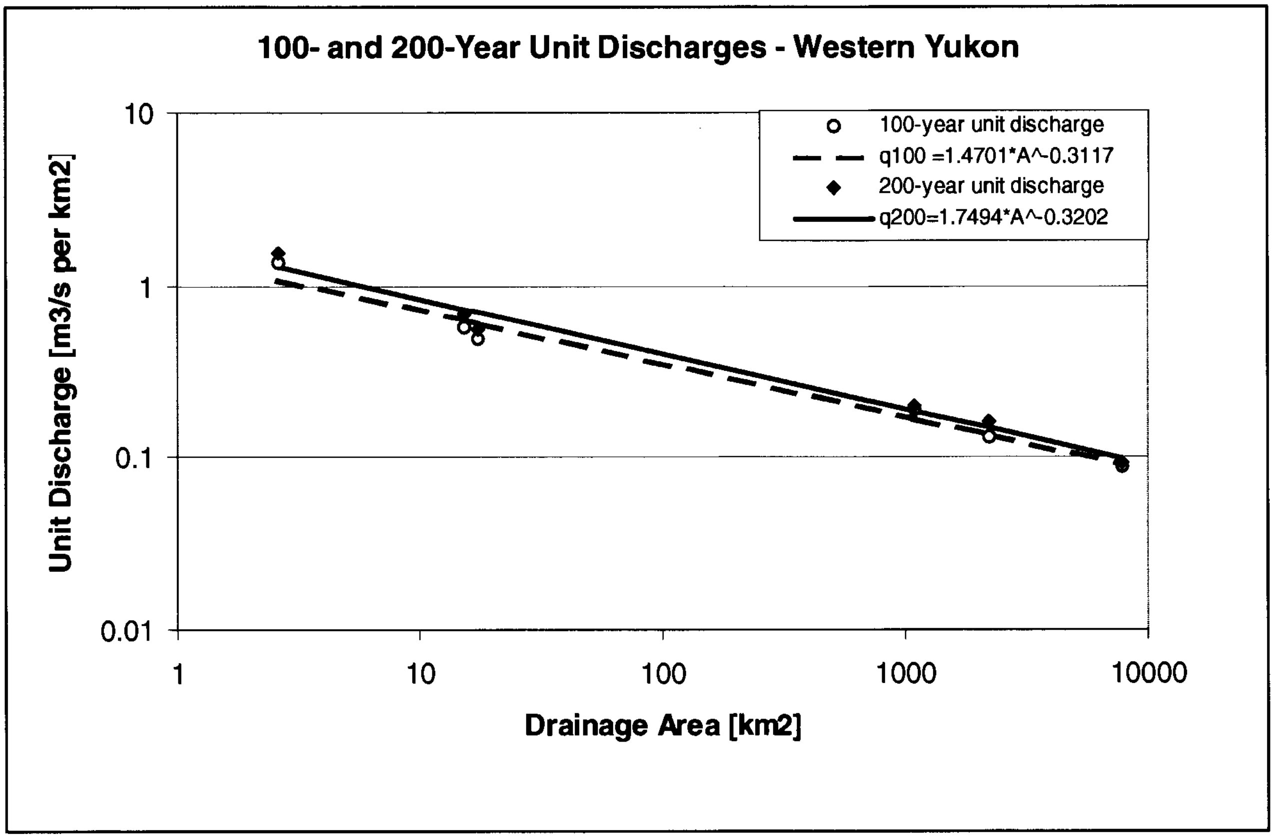


Figure 6-2
Maximum Instantaneous Unit Discharge For 100 and 200 Year Return Periods

7.0 DAM BREACH ANALYSIS

7.1 Reservoir Volume

7.1.1 Clinton Creek Reservoir Volume (Hudgeon Lake)

The leading edge of the waste rock landslide blocking Clinton Creek thereby creating Hudgeon Lake, is about 25 m higher than the original valley floor. Bathymetric surveys were completed by Royal Roads University as part of their 1999 Environmental review. One longitudinal and five transverse transects were run using an echo sounder to obtain depth profiles which were used to generate the lake bottom contours shown in Figure 7-1. Based on the bathymetric survey results and the water volume distribution in Figure 7-2, the lake volume is estimated to be approximately 12 million m^3.

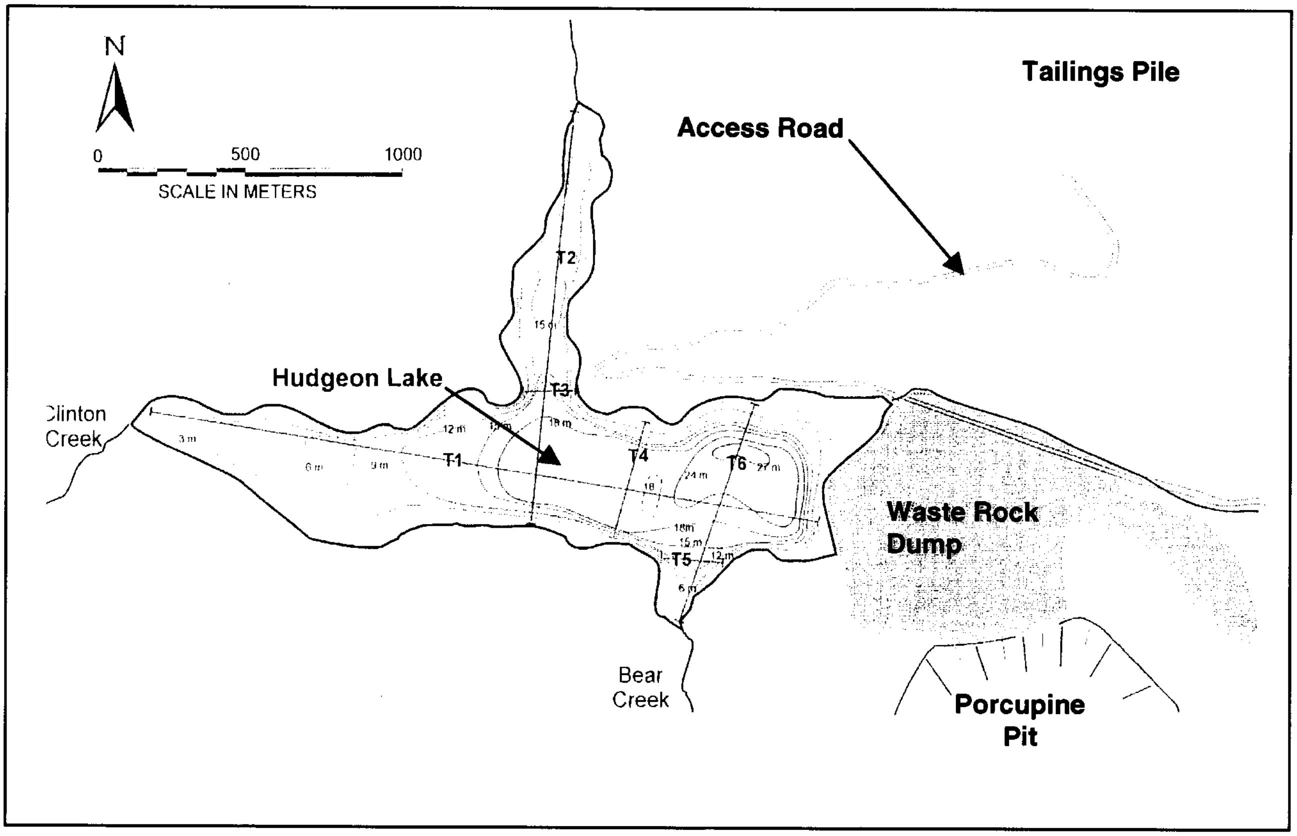


Figure 7-1
Bathymetric Survey Results (Royal Roads University, 1999)

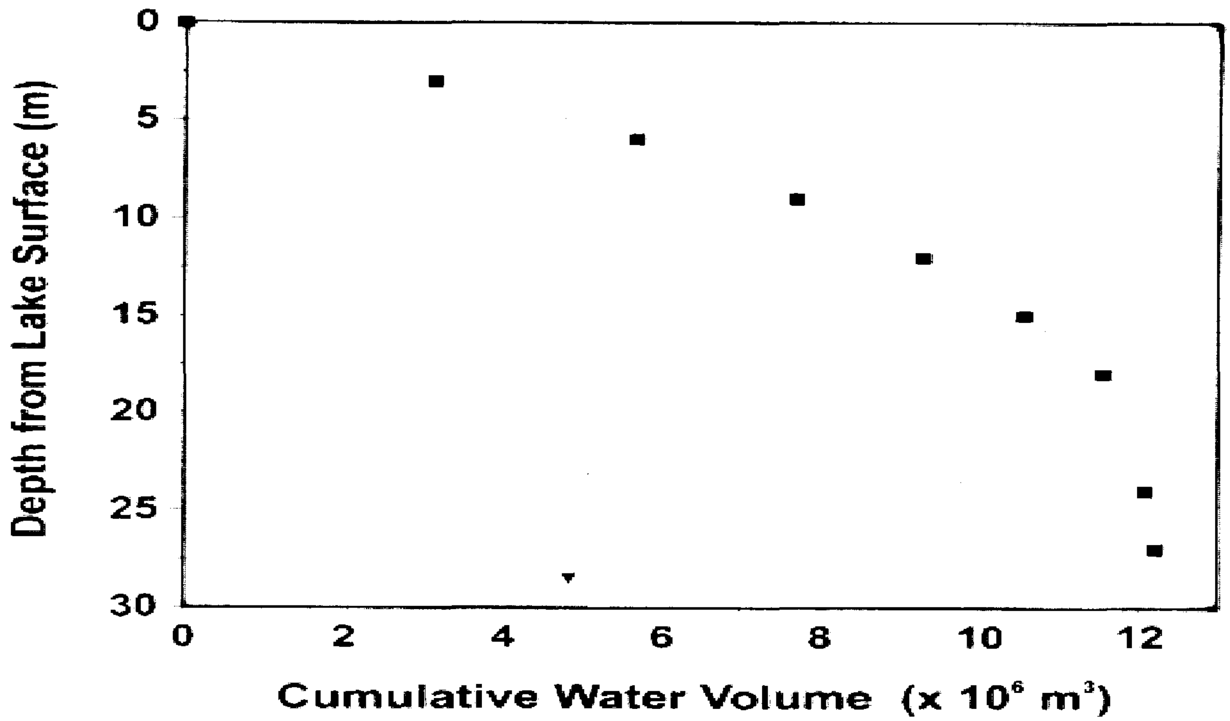


Figure 7-2
Lake Volume Distribution (Royal Roads University, 1999)

These results were corroborated by UMA using elevation contours from a 1959 edition 1:50 000 scale NTS map sheet (116C/7) as summarized in Table 7-1. At the current reservoir elevation of approximately 415 m, the linearly interpolated reservoir volume of Hudgeon Lake is estimated to be 9.4 million m^3 (compared with the 12 million cubic metres estimated from the bathymetric survey).

Table 7-1
Clinton Creek Reservoir (Hudgeon Lake) Volume

Elevation [m]	Water Surface Area [km^2]	Cumulative Volume [10^6 m^3]
400 (estimated)	0	0
396.24 (1300' contour)	0.0375	0.234
426.72 (1400' contour)	0.525	15.093
457.20 (1500' contour)	1.20	35.667

7.1.2 Wolverine Creek Reservoir Volume

A very small reservoir has formed upstream of the tailings pile on Wolverine Creek. To estimate the volume of this reservoir, the horizontal area defined by the available contours and a line across the channel constriction at the south lobe was determined. It was assumed that the surface area is zero at the natural creek bed elevation at that location. The measured areas and calculated volumes are listed in Table 7-2. The total reservoir volume impounded by the tailings at the time of a breach is estimated to be approximately 1 X 10^6 m^3.

Table 7-2
Wolverine Creek Reservoir Volume

Elevation [m]	Water Surface Area [km^2]	Cumulative Volume [10^6 m^3]
420 (contour)	0.164	1.808
415 (contour)	0.115	1.111
410 (contour)	0.066	0.659
390 (estimated)	0	0

7.2 Channel Cross Sections

Representative cross-sections were extracted from the DEM (digital elevation model) that had been built from aerial photography, as a part of this project. The cross-sections were initially formatted into HEC-2 format for the steady state modelling and then weeded and reformatted into the format used for the dynamic flow modelling. A total of 62 cross sections were used along the Clinton Creek channel and 22 along the Wolverine Creek channel.

7.3 Breach Characteristics

7.3.1 General

In general, the likelihood of a breach and the magnitude of outflow depend largely on the size of the embankment, materials forming the dam, in particular gradation and cohesion and the method of placement or deposition. Breach triggering mechanisms often include one or more events including overtopping due to large in-flows (exeedance of natural reservoir capacity) or by a mass movement (ice avalanche, landslide) generated wave, seismic activity and failure due to piping (internal erosion) conditions. In most dam breach failures, including natural landslide dams, the resulting breaching mechanism involves the erosion of the embankment material by the flow of water over or through the blockage.

The rapid release of impounded water associated with breaches of natural and man-made dams has been responsible for significant disasters in mountainous regions of the world (Evans, 1986). In this regard, previous work by Hardy Associates (1978) and Klohn Leonoff (1987) reviewed case histories in the literature describing slide-formed lakes and breach-type failures when assessing potential downstream hazards. While it is recognized that the conditions described in the case histories may not be entirely representative of conditions at the Clinton Creek mine site, they are of assistance in predicting the likely behaviour of valley blockages. Of particular interest are the following observations made by Hardy Associates from their literature search:

- "Lake barriers formed by slides, and which were not eroded away, appear to be located on grounds which have sufficient permeability to convey inflows, i.e. the barriers are not overflown."

- "The most common type of destabilizing effect is that caused by rivers or streams eroding side slopes or valley blockages."

- "The erosion of man-made slopes by streams is a major cause of land instability."

Recognizing that dam breach mechanisms for natural or man-made dams, are not well understood, breach scenario development based on empirical data from reported case histories is believed to be the most reliable method of providing input parameters for the hydraulic modeling. In this regard, the literature search was expanded by UMA to supplement the case histories described in previous reports.

Floodwave modeling (FLDWAV) assumes the breach geometry has a trapezoidal cross-section that reaches a final size over a finite time interval. The final breach bottom width, breach side slope and breach bottom elevation are user-specified parameters that are dependent on the dam material. Earthen dams do not tend to completely fail nor do they fail instantaneously. Fully formed breaches tend to have an average breach width (*b*) in the range of $0.5h \leq b \leq 8h$, where *h* is the height of the dam. The breach widths are therefore usually much less than the total length of the dam crest. The time of failure of an earthen dam may be in the range of a few minutes to usually less than half an hour. In FLDWAV, this is the duration from the time between the first breaching of the upstream dam face until the breach is fully formed. For over-topped dams, the breaching of the upstream dam face occurs after the downstream face of the dam has eroded away and the resulting head-cutting has progressed to the upstream face of the dam (Figure 7-3).

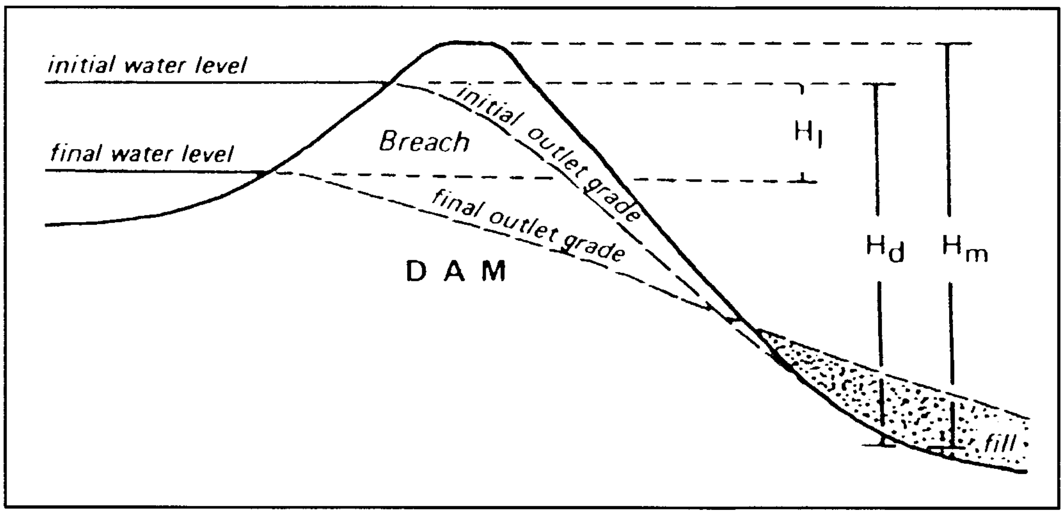


Figure 7-3
Dam Geometry Before and After Breach (Blown, 1985)

7.3.2 Clinton Creek Waste Rock Dump

7.3.2.1 General

The waste rock dump consists of stripped overburden material (likely colluvial soils) and argillite waste rock consisting of sand, gravel and cobble sizes containing occasional boulder size material (Figure 7-3). Given the sequence of open pit development, it is likely that the excavated overburden material is buried deep beneath the waste rock, likely some distance back from (south of) the existing creek channel. The dump material is believed to overlie ice rich alluvial material in the bottom of the original valley (Golder, 1978). Durable boulder size material from the waste rock has accumulated over time along the bottom of the Clinton Creek channel, providing resistance to erosion under normal flow conditions. Boulders from the remnants of the rock weir and channel repairs just downstream of the Hudgeon Lake outlet also help armour the creek channel at this location. Bedrock on the north flank of the downstream portion of the stream also offers resistance to erosion although over the long term, significant incising through the bedrock is evident, in particular through the weathered surface. The freshly exposed waste rock material comprising the south creek bank within the waste dump is considered to be highly susceptible to erosion, even under normal flow conditions.

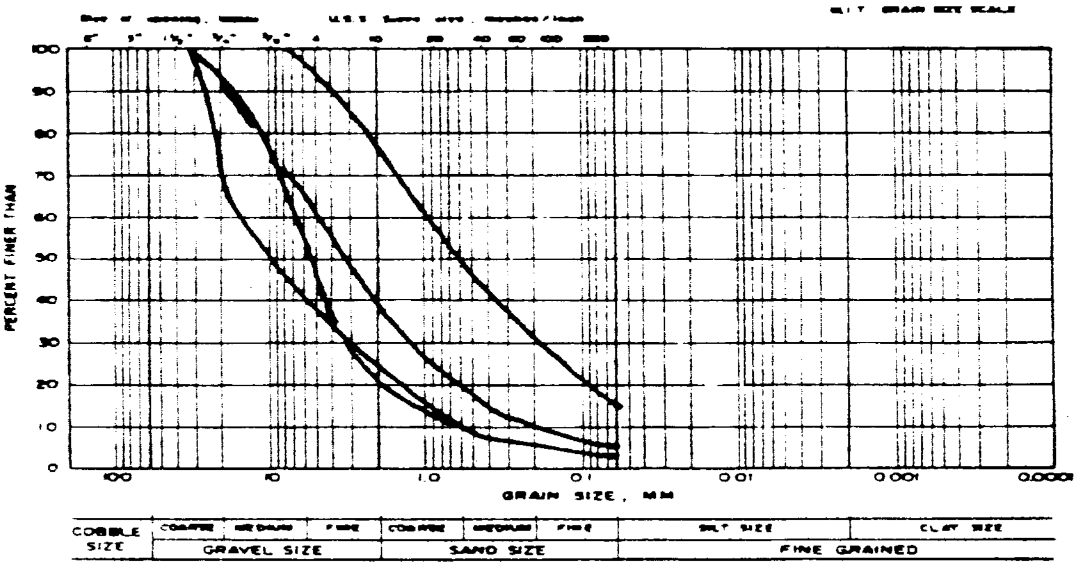


Figure 7-3
Waste Rock Gradations

7.3.2.2 Waste Rock Dump Stability

To develop an understanding of potential breach scenarios, it was considered important to determine the current physical stability of the waste rock dump and channel and compare these conditions with those last reported in Klohn Leonoff's 1987 Downstream Hazard Assessment. For the 1987 assessment, channel profiles were surveyed in 1983, 1984 and 1986 to monitor the rate of down-cutting. Based on these results, the amount of down-cutting was considered at that time (1986) to be minimal. A comparison of the previous surveys however, with the 1999 channel profile (completed following the destruction of the rock weirs) indicates that significant incising of the channel has occurred, with up to 3 m of down-cutting evident (Drawing 04). Of particular concern is the portion immediately downstream of the lake outlet where the channel bottom is about 2 m lower than was measured in 1986.

Monitoring of horizontal and vertical movements at a number of reference points on the waste rock dump was routinely carried out from 1976 to 1978. At the same time, relative movements of points on each side of the Clinton Creek channel were measured along cross-channel reference lines (channel closure sections). In 1987, Klohn Leonoff observed that horizontal movements of the waste rock towards the creek channel were decreasing over time and predicted the waste dump was approaching a stable state. Over the 10 year observation period, movement rates decreased from 1.2m/yr in 1977-78 to about 0.3m/yr in 1985-86. No monitoring was carried out between 1986 and our 1999 survey.

Intact waste rock targets and cross-channel reference lines were surveyed in 1999 (Drawing 06). The monitoring results are illustrated on Drawing 06 where target movements are plotted with arrows to indicate the direction and magnitude of movement since 1986. The current horizontal distances of cross-channel reference lines are also indicated on Drawing 06. Where baseline information was available, the average movement rates over the 13 year period from 1986 to 1999 have been determined and compared with previous data. Over the last 13 years, the average rate of movement for the waste rock targets and channel closure sections is about 0.1m/yr. The trend in movement rates is illustrated on Figure 7-4. It should be noted that the movement indicated at waste rock target 19B (3.57m) was not used in the average for 1999; It is not clear if the monument tied in is consistent with that used for previous surveys i.e. two pins were located close to one another (19 and 19B). Baseline information with respect to cross-channel reference lines was only available for sections J-JJ and K-KK and therefore only these two readings are reflected in the average for 1999. While it is recognized that these 1999 averages do not include data used in previous surveys, they are believed to be a reasonable indication of overall behaviour of the waste rock dump.

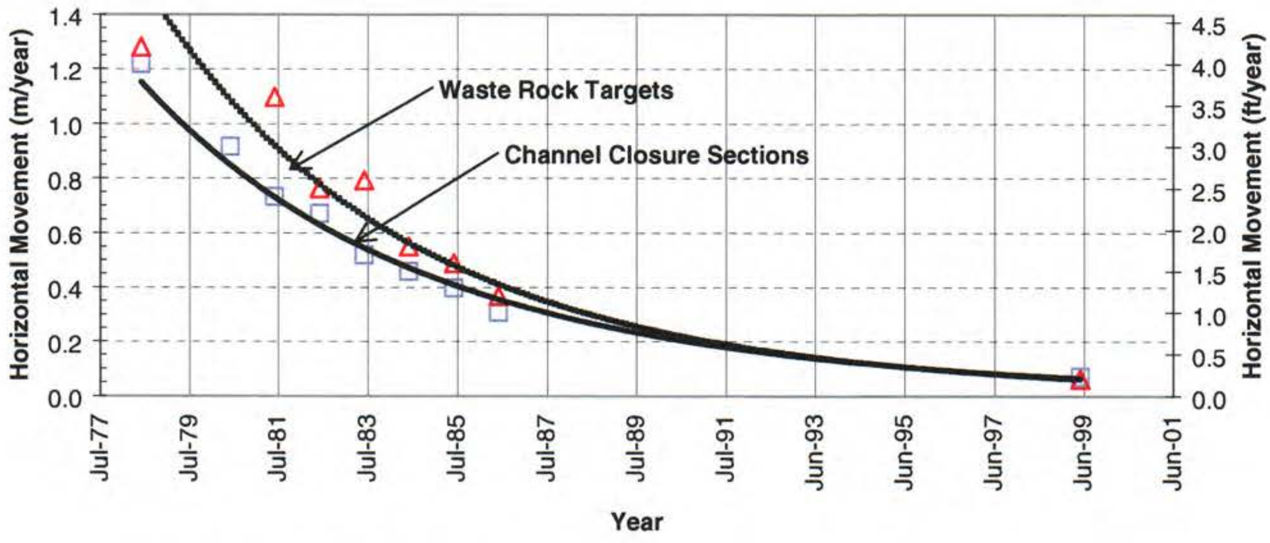


Figure 7-4
Average Annual Movement Rates

The 1999 survey appears to confirm the observations made by Klohn in 1986, that is, the movement rates are decreasing over time. With a reduced rate of waste rock movement, the supply of material from the waste rock dump to feed the creek channel erosion process is diminishing. As down-cutting of the channel continues however, sideslopes on both sides of the channel will become oversteepened resulting in localized instabilities which will deposit material into the stream course. It is likely that intermittent channel blockages at this time are much more likely to occur as a result of these instabilities rather than from larger scale waste dump movements, an observation which is borne out by recent site inspections by Geo Engineering and UMA Engineering. Given the limited volume of water which could be impounded in the confines of the channel upstream of localized failures, the resulting breach would not likely produce a significant downstream flow increase. It should be recognized however, that continued down-cutting of the channel may eventually cause an acceleration in horizontal movement of the waste dump as a result of a reduction in overall slope stability.

7.3.2.3 Breach Failures

<u>Triggering Mechanisms</u>

If a profile along the Clinton Creek channel through the waste rock is considered, the Hudgeon Lake dam has a very long and flat downstream face (Drawing 04). Because of this geometry, a breach failure due to over-topping of the dam crest is considered much more likely than a failure due to internal erosion (piping). The mode of failure for dam breach scenarios considered was therefore taken to be over-topping. Seismic activity[1] and a mass movement generated wave have been ruled out as probable triggering mechanisms. The maximum width of the breach is expected to be limited by the natural valley slope to the north and the waste rock mound to the south of the outlet, a distance of about 140 m, referred to as the dam crest width (Drawing 08). It is doubtful that the relatively flat upstream slope extending into Hudgeon Lake will provide much erosion resistance once a breach is initiated. This material likely consists of poorly consolidated materials from the leading edge of the waste rock dump and fine grained sediments transported from higher up in the water shed.

<u>Case Histories</u>

Observed breach failures of natural moraine dammed lakes in British Columbia offer a reasonable indication of potential breach scenarios at the Clinton Creek waste rock dump (Evans, 1986). Similarities between the Nostetuko Lake moraine dam and the Clinton Creek dam (Blown and Church, 1985) were previously reported by Stepanek and McAlpine in 1992, in particular the width of the dams (Figure 7-5). Material properties of the waste rock and moraine are also somewhat similar; both consist of bouldery non plastic sand and gravel size particles. Gradations of the two materials are compared in Figure 7-6. Both materials are relatively stable against internal erosion but would experience rapid surface erosion due to lack of plasticity (cohesion).

[1] *Based on R.M. Hardy & Associates Stabilization and Reclamation Study (1978), Clinton Creek is borderline between Seismic Zones 2 and 3 as described in the National Building Code of Canada (1990).*

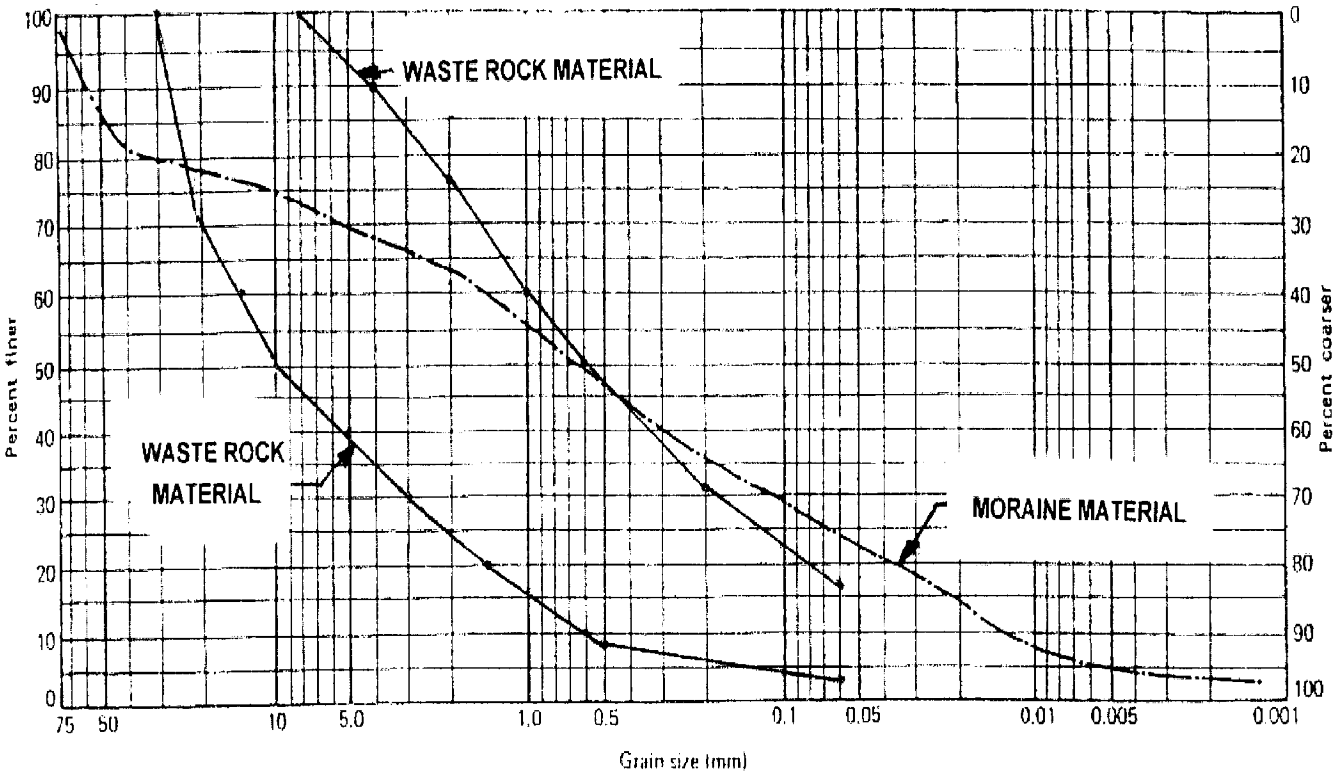


Figure 7-6
Waste Rock and Moraine Gradation Curves

Nostetuko Lake drained through a steep channel cut through a 40 m high landslide moraine on a gradient of 0.19, floored by large boulders derived from the moraine (Photo 7-1). The frequency of boulders, however, was too small to permit re-armouring before erosion became catastrophic. When the moraine breached, almost the entire lake drained into the downstream valley in 5 horrs. Very rapid down-cutting and the draining resulted from sudden channel erosion. Once down-cutting commenced, lowering of the outlet permitted increased flow from the lake, increasing erosion. The moraine breach volume was 1.2 X 10 ^{6} m^{3}. The volume of water released was 6.5 X 10 ^{6} m^{3}. A similar breach failure occurred in a moraine dam on the Klattasine Creek in the early 1970's (Blown and Church, 1985, Clague et al, 1985).

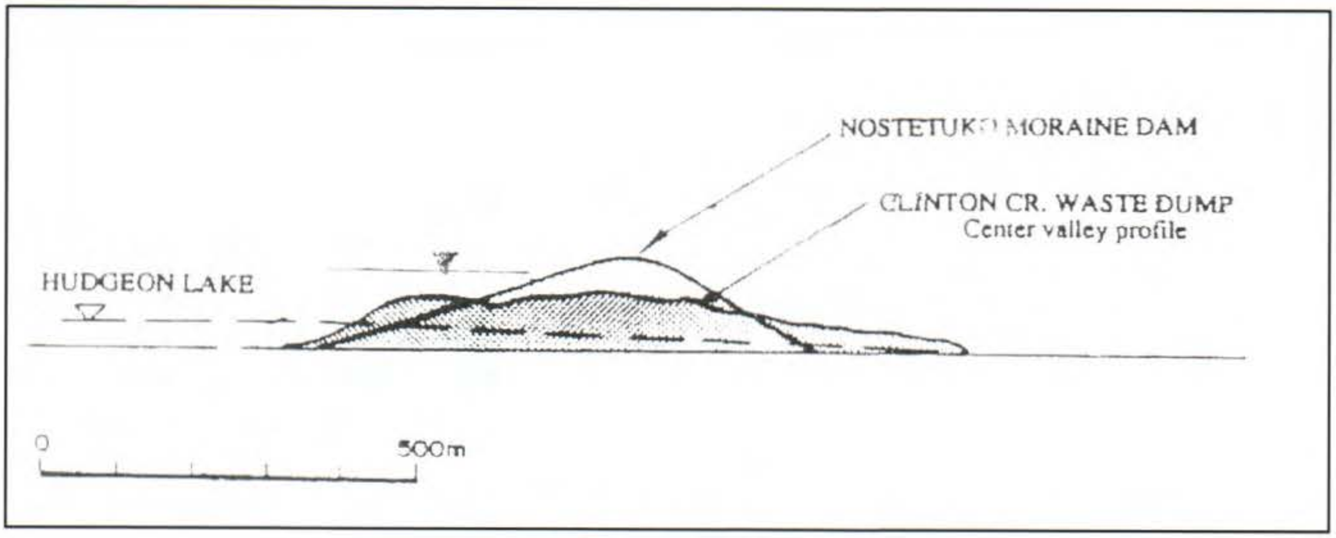


Figure 7-5
Comparison of Clinton Creek Waste Rock and Nostetuko Moraine Dams
(Stepanek & McAlpine, 1992)

Photo 7-1
Nostetuko Moraine Dam
After Breach Failure
(Photo From Geological Survey of Can., Bulletin 464)

Breach Scenarios

Four Breach Scenarios were considered to develop an idea of the range of potential downstream floods. Each scenario is described separately as follows:

Breach Scenario 1: *Full Breach Based on Empirical Data*

Froelich (1987) analysed the properties of 43 earthen dam breaches ranging between 4.5 and 87 m in height. Based on his analyses, he proposed the following relationships:

$$b_{avh} = 9.5\, k_o\, (V_R\, h_d)^{0.25}$$
$$T = 0.8\, (V_R / h_d^2)^{0.25}$$

where b_{avg} = average breach width [feet]
T = time of failure [h]
k_o = 0.7 for piping and 1.0 for over-topping
V_R = reservoir volume [acre-ft]
h_d = height of water over breach bottom (usually approximately the dam height)

Note: *The selection of breach parameters, introduces a varying degree of uncertainty in the downstream flooding results produced by the FLDWAV model. Sensitivity testing has shown that for a moderately large reservoir ($V_R = 309 \times 10^6$ m^3, $h_d = 79$ m and $A_s = 8.1$ km^2), the peak outflow (Q_p) varies in proportion to b_{avg} but varies by less than 20% of the variation in T. For a fairly small reservoir ($V_R = 0.6 \times 10^6$ m^3, $h_d = 12$ m and $A_s = 0.04$ km^2), Q_p varies by less than 20% for a 50% variation in b_{avg} while a 50% variation in T resulted in a 40% variation in Q_p. Thus it may be generalised that for large reservoirs Q_p is quite sensitive to b_{avg} and rather insensitive to T while for very small reservoirs Q_p is somewhat insensitive to b_{avg} and fairly sensitive to T. However, these errors are dampened as the flood wave advances downstream. The extent of dampening is related to the size of the downstream floodplains (the wider the floodplain is the greater the dampening will be). For conservative forecasts, the selected breach bottom width and sides slopes should produce an average breach width (b) in the uppermost range. Similarly, the failure time should be selected in the lower range to produce a maximum outflow.*

Applying the relationship proposed by Froelich and assuming the breach extended to the base of the landslide dam (about 25 m), the average breach width at the point of breaching would be about 80 m and the time of failure would be 0.8 hours. According to McMahon, 1981, the breach shape should be approximately 4 times the dam height at the top and twice the dam height at the bottom yielding sideslopes of 1:1. Applying these formulae, the breach at the widest point would be in the order of 100 metres with a base width of 50 m, corroborating the values predicted by Froelich.

Breach Scenario 2: *Full Breach, Bedrock Controlled*

The more competent bedrock underlying the colluvial soils at the channel outlet however, will likely control the depth of the breach. Since the bedrock dips to the south, erosion during a breach would become progressively deeper in a southerly direction, rapidly exposing the waste rock material on the south side of the armoured outlet (Drawing 08). For modelling purposes, the breach geometry could be represented by the equivalent cross section shown on Drawing 08 with an average breach width of 100m (top width=125m, depth=25m, base width=75m). This is considered to represent a worst case scenario.

Breach Scenario 3: *Channel Down-Cutting*

Earlier reports (Klohn Leonoff, 1987) concluded the most likely scenario in which a sudden flood wave could be created downstream would be down-cutting of the Clinton Creek channel through the waste rock dump as a result of a particularly large rainfall event. Based on a 200 year flood event, the measured channel geometry and profile and a Mannings "n" of 0.05, it was determined that there would not be sufficient sediment carrying capacity to catastrophically down-cut the channel through the waste rock dump. The maximum rate of down-cutting was estimated to be 1.6m in 24 hours. Of all potential scenarios, this likely represents a best-case scenario and would not be considered a dam break in the traditional sense. It is possible that the event which occurred in the spring of 1997 resembled the mechanism described above.

Breach Scenario 4: *Partial Breach*

The sediment transport mechanism described however, does not recognize the continual channel degradation (down-cutting) downstream of the outlet observed since 1986. Degradation of the downstream slope is described by AlQaser, 1993, and involves the formation of a number of overfalls or steps as seen during inspections at Clinton Creek. As this process continues downstream of the lake outlet, headward cutting continues and the plug at the outlet becomes increasingly susceptible to a sudden failure in the classical dam breach fashion. While the breach associated with an overtopping of the plug would not initially be as large as described in the worst-case scenario, the volume of water suddenly released could greatly accelerate degradation (erosion) of the downstream channel, leading to additional breach development (Figure 7-6). The presence of springs along the edge of the channel just downstream of the outlet could further contribute to the channel erosion at this critical location.

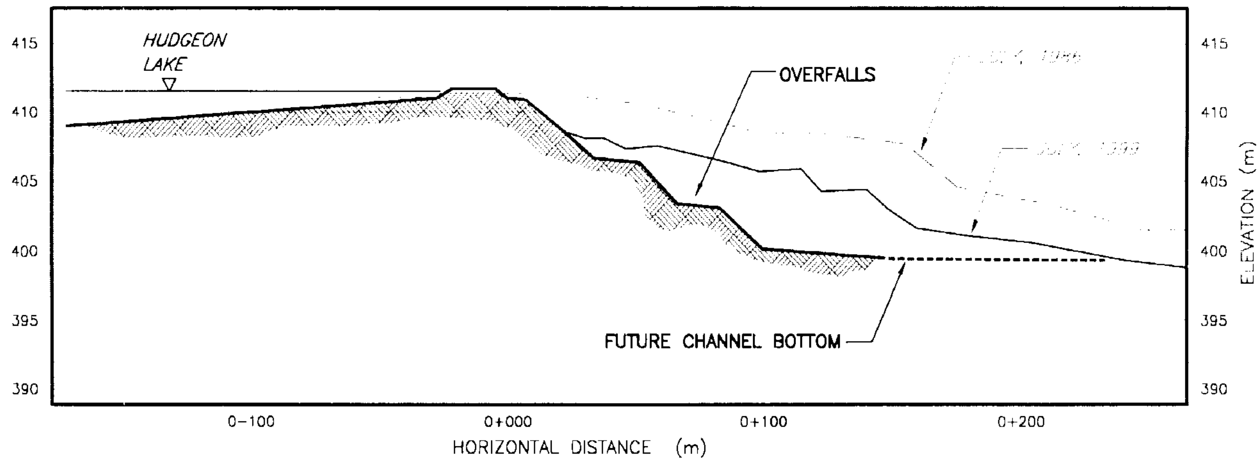


Figure 7-6
Outlet Erosion

If overtopping of the plug does not initiate a breach, it is possible that the continued degradation of the channel immediately downstream of the plug will create an increasingly unstable geometry at the outlet dam. Rudimentary slope stability analysis indicates the factor of safety against slope failure could reach unity (1.0) with an additional 4m of down-cutting which would create a dam in the order of 7m high. If the entire slope failed into the channel, the resulting initial breach would be in the order of 10 m deep, 50m wide at the top and 30m wide at the base. A sudden release of water in this scenario, however, could quickly exceed the ability of the channel to armour itself against the rapid development of a lager more catastrophic breach.

7.3.3 Tailings Piles

7.3.3.1 General

Asbestos tailings from the mill were deposited over the west slope of the Wolverine Creek valley with a stacker conveyor. The original valley slopes at about 17 degrees, dropping in elevation approximately 200 m. The natural soil profile consists of an organic layer overlying silty sandy gravel (colluvial) and weathered argillite bedrock (Golder, 1978). The Colluvium layer taper from15m near the top of the valley to almost absent at the bottom of the valley. The mill tailings generally consist of well graded crushed serpentine rock with some asbestos fibre not removed during milling (Figure 7-7).

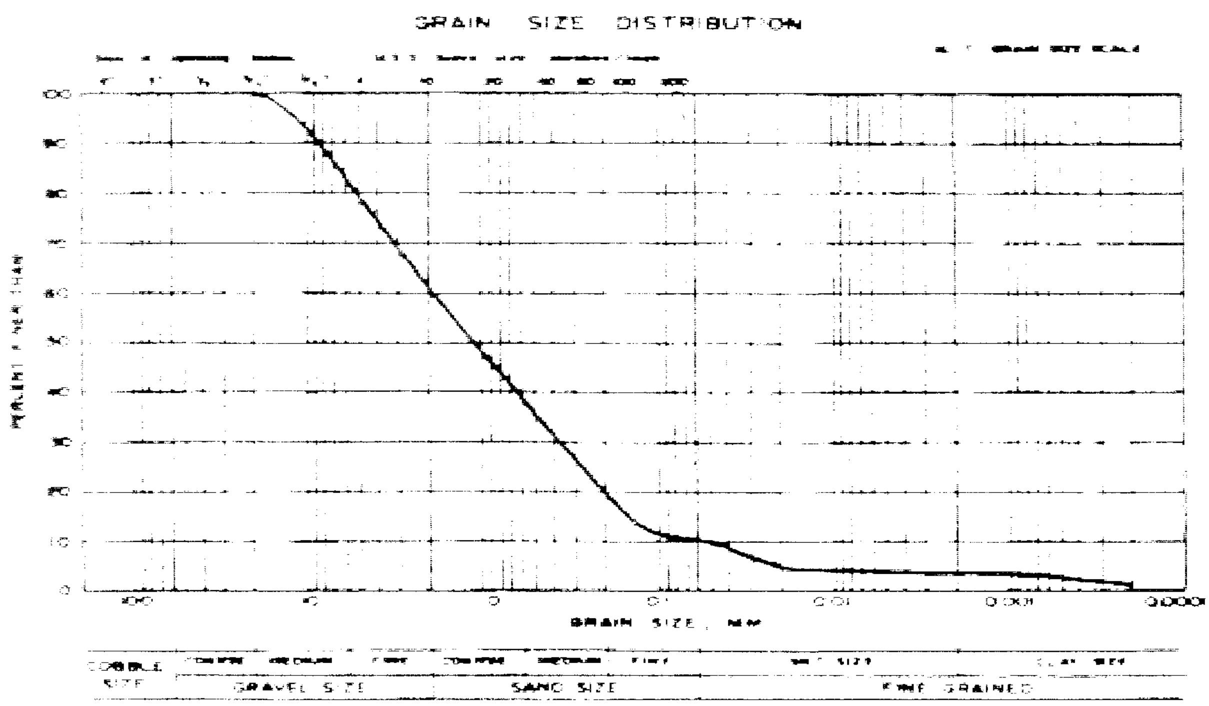


Figure 7-7
Mill Tailings Gradation

7.3.3.2 Tailings Pile Stability

Routine site inspections have concluded that the tailings piles continue to be unstable, although no massive displacements, similar to those observed shortly after initial failure, have been observed for many years. Although a detailed survey of movement monitors was not completed in 1999, camparisons of the physical changes are possible by comparing aerial photograpgy and representative cross sections surveyed by Klohn in 1986 with the 1999 photogrammetric mapping. If the 1988 aerial photography (taken 2 years after the Klohn survey) is compared with the 1999 photography, very little if any discernable changes in the footprint of the tailings lobes are evident (Figure 7-8).

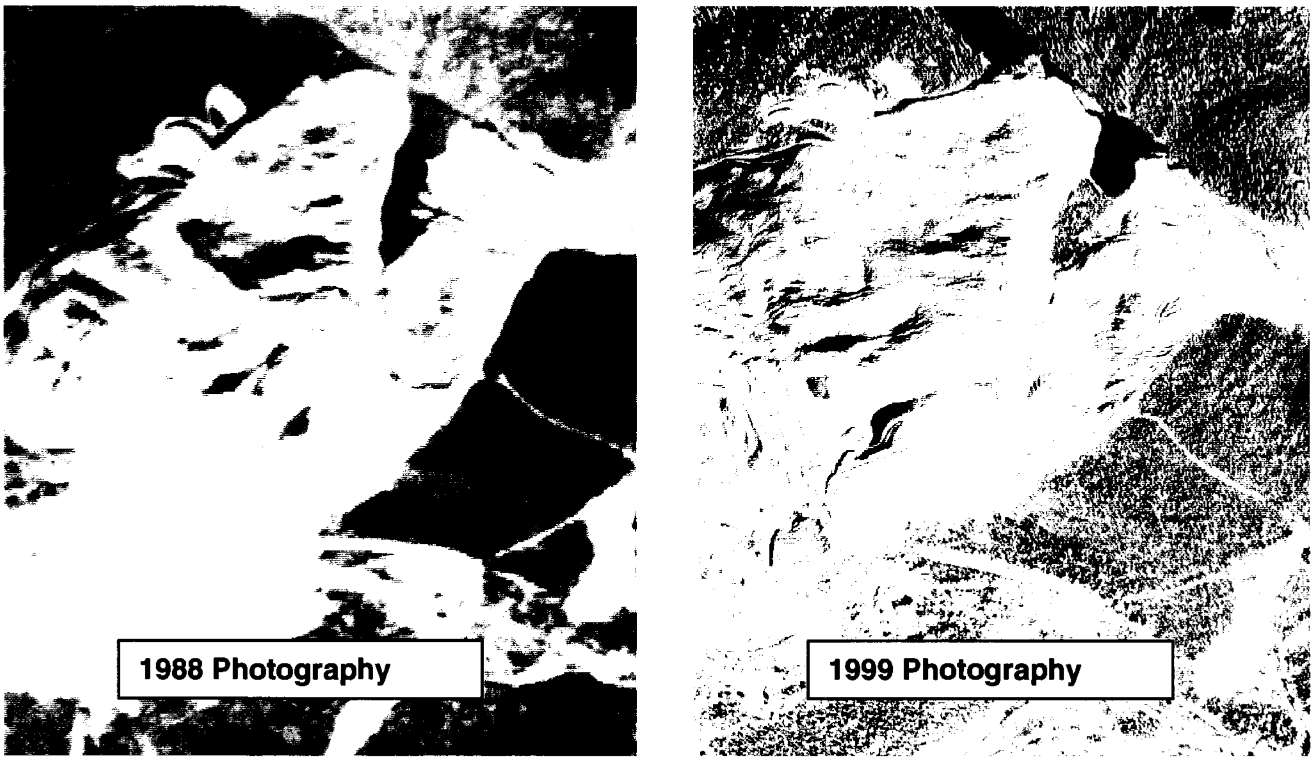


Figure 7-8
Aerial Photography of Tailings Pile Configurations

Cross sections through the north and south lobes generated from the 1999 photogrammetric mapping indicate that although some downslope adjustments of the tailings has occurred since 1986, the movements are small in comparison to those observed in the first few years following the initial failure(s) (Drawing 09). The elevation of the tailings at the toe of the north and south lobes is about 410m. Previous slope stability analysis by Klohn Leonoff (1985) concluded that the tailings piles would reach equilibrium with the toe elevation at 411.6 m.

7.3.3.3 Breach Scenario

Based on Froelich (1987), the breach parameters would be expected to be:

Top Width :	44 m	Bottom Width:	6 m
Average Width: (b)	25 m	Height (h):	19 m
Side slopes:	1H:1V		

Klohn's 1987 Downstream Hazard Assessment however, assumed an impoundment elevation of 411.6 m with the base of the breach at the original valley bottom. Based on our observations of the performance of the tailings piles and estimated depth to bedrock (which will control the depth of the breach), we concur with this assumption and therefore, have based our modeling on the breach geometry assumed by Klohn. In any case, the assumed breach geometry will not significantly alter the outflow conditions because of the relatively small upstream reservoir volume. The assumed breach geometry is summarized as follows and is illustrated on Drawing 10.

Top Width :	46 m	Bottom Width:	24 m
Average Width: (b)	35 m	Height (h):	11.6 m
Side slopes:	1H:1V		

In event of a closure and subsequent breach, there a large supply of fine grained material available on the west stream bank to contribute to the closing of the breach. During minor closures, the closures will be washed away within minutes and there will insufficient time for storing any large quantity of water upstream of the closure. The worst case scenario would be a sudden full blockage of the channel to the maximum toe elevation of 411.6 m. Using the relationships proposed by Froelich (1987), the estimated breach time is 0.3 hours. However, given the resulting length of a sudden large blockage, it is believed a breach time of 0.5 hours is more appropriate and this values was used in the breach simulations.

7.4 Pond Inflow and Downstream Base Flow

7.4.1 Clinton Creek

The Snyder method was used for estimating the lag-time. This method was considered preferable as it, to some extent, takes into account the shape of the drainage basin. Using the Snyder equation:

$$t_{lag} = C_t\,(L * L_c / S^{0.5})^{0.38}$$

where t_{lag} = lag time [h]
C_t = Snyder's time coefficient = 0.902 for mountainous areas (1.2 for Imperial units)
L = length along principal channel, from upstream boundary to point of interest [km]
L_c = length along principal channel, from basin centroid to point of interest [km]
S = slope of principal channel [m/m]

The lag-time was estimated to be 8.3 hours. Using the dT equal to $t_{lag}/5.5$, the estimated time-to-peak becomes 9.1 hours and the resulting time of recession is 16.7 hours, for a total flood duration of 26 hours. The base for Clinton Creek flow, before and after the model flood, was taken to be 10 m^3/s. In the modelling the base flow is of less importance than the flood itself since the dam breach will be initiated by the flood. The resulting flood in the channel downstream of the dam will be driven by the volume of water released from the failed dam rather than the inflow hydrograph.

7.4.2 Wolverine Creek

The hydrograph parameters for the Wolverine Creek basin was estimated in the same way as for the Clinton Creek basin (see Section 7.4.1). The estimated lag-time is 6.3 hours, which gives a time-to-peak of 6.9 hours and a time of recession of 12.6 hours, resulting in a flood duration of 19.5 hours. A uniform base flow of 3 m^3/s was applied before and after the flood to maintain a wet channel during the Wolverine Creek flow simulation.

7.5 Mannings n

The channel roughness, defined by Manning's n, was taken to be 0.030 for the low flow channel. The level around the top of bank was set to 0.040. All levels above top of bank were set to 0.050. In sub-critical flow studies, the magnitude of Manning's n may significantly affect the computed water surface level and a sensitivity analysis is often conducted. However, both Clinton Creek and Wolverine Creek are steep, causing a mixed-flow situation with short sub-critical flow reaches intermixed with critical and super-critical flow reaches. Because of this it was concluded that a sensitivity analysis would not contribute to a better solution.

7.6 Modelling Results

7.6.1 Steady-State Flow Modelling

The output from a dynamic model, with respect to the flow conditions at specific locations along the river, is inherently more difficult to evaluate compared to that of a steady state flow model. To gain a better understanding of the flow conditions along Clinton Creek, between Forty Mile River and the Wolverine Creek confluence, the steady state flow conditions were assessed using the HEC-2 computer program. The channel cross-sections used for the steady-state flow analysis were extracted from the contours created based on aerial photography. The HEC-2 analysis included a total of 62 selected cross-sections along Clinton Creek.

The HEC-2 modelling confirmed that Clinton Creek does behave very much like a mountainous stream. The flow expands and contracts and the slope changes between steep and flat over short distances causing the flow to pass through critical depth at numerous locations. The computed water surface profiles for 20, 30 and 40 m^3/s are shown in Figure 7-9. As seen in Figure 7-9, there is very little difference in water surface profiles within this range of flows. Numerous transition sections where the creek flow passes through critical flow are also evident. From the HEC-2 analyses it was concluded that:

- the dynamic flow model must be set to mixed flow, accommodate both critical and sub-critical flow; and
- critical depth can be anticipated for all discharges within the discharge range used for the dynamic flow modelling

7.6.2 Unsteady Flow Modelling

The NWS (U.S. National Weather Service) FLDWAV model was selected for the dam breach and dynamic flow modelling as it is the most widely used dam breach model in North America. FLDWAV is the replacement for the older NWS DAMBRK model and it combines the dam breach capability of DAMBRK (Dam-Break Flood Forecasting Model) with the dynamic flow modelling capability of NWS DWOPER (Dynamic Wave Operational Model) and adds additional features. DWOPER was developed in the early 1970's and enhanced in the early 1980's. DAMBRK was developed in the mid-1970's and improved throughout the 1980's. Development of FLDWAV started in the mid-1980's and version 1.0 was released in November 1998.

FLDWAV is a generalised flood routing (unsteady flow simulation) model. The governing equations are the complete one-dimensional Saint-Venant equations of unsteady flow which are coupled with internal boundary equations representing the rapidly varied flow through structures, e.g. dams, which can develop a user-specified time-dependent breach. The system of equations is solved by an iterative, non-linear, weighted four-pointed implicit finite-difference method. The flow may be sub-critical or super-critical or a combination of both and may vary in time and space. It should be noted here that the FLDWAV model (and its predecessor DAMBRK) was developed for simulation of river flows and not small streams like Clinton Creek. Because of this, the reliability of results at the low end of the discharge is considered questionable. For this reason, steady state flow computations, which are considered more reliable under these conditions, have been included in assessing downstream flows and hazards.

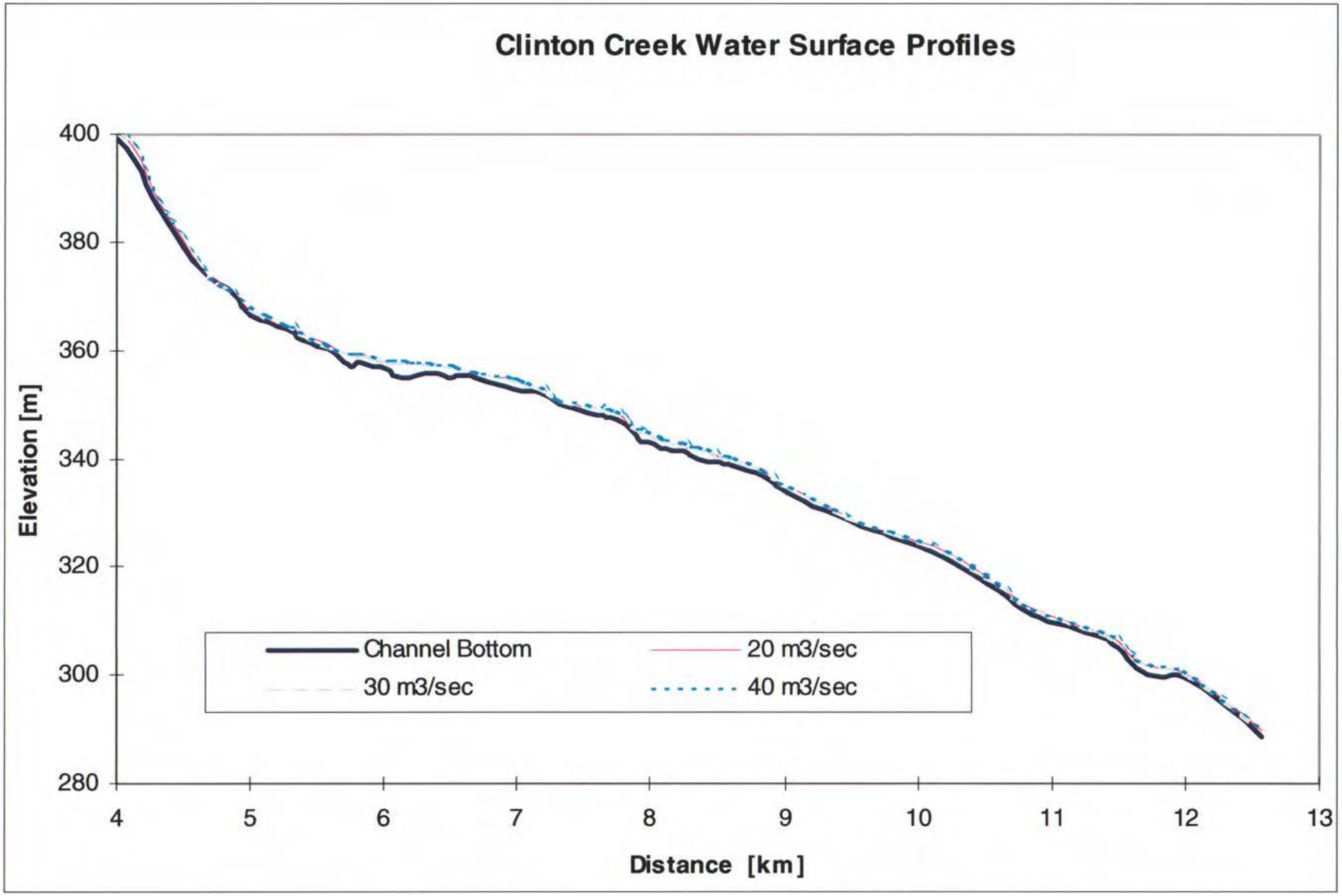


Figure 7-9
Computed Steady-State Clinton Creek Water Surface Profiles

It should be noted that the driving force during any breach on Clinton Creek or Wolverine Creek will be the volume of water stored in the reservoir behind the waste rock and tailings piles. The triggering mechanism could be in the form of an extreme runoff event or any failing blockage at the lake outlet, such as an ice or log jam, that generates a sufficiently large and sudden dam overflow to induce the breaching. In this modelling, an extreme run-off event was used as the triggering mechanism.

7.6.3 Clinton Creek

7.6.3.1 Breach Parameters

The assumed parameters for the breach scenarios considered are summarised in Table 7-3, based on a dam crest width of 140m and breach side slopes of 1H:1V. Scenario 3 is not included as it is not considered to represent a mechanism comparable to a dam breach.

Table7- 3
Hudgeon Lake Dam Breach Parameters.

Parameter	Scenario 1	Scenario 2	Scenario 3	Scenario 4
Dam crest elevation [m]	415	415	NA	415
Dam toe elevation on reservoir side [m]	390	390	NA	390
Reservoir water surface elevation at start of breaching [m]	415	415	NA	415
Top width of breach at end of breaching [m]	106	125	NA	50
Bottom elevation of breach at end of breaching [m]	390	391	NA	405
Bottom width of breach at end of breaching [m]	56	75	NA	30
Average Breach Width (m)	81	100	NA	40
Breach Depth (m)	25	24	NA	10
Time from start to end of breaching [h]	0.8	0.8	NA	0

7.6.3.2 Outflow Hydrographs

The flood peak resulting from the dam breach scenarios considered are summarized as follows. Channel distances (in kilometres) and locations referenced in Tables 7-4, 7-5 and 7-6 are summarized on Drawing 11. Kilometre 4.0 on the horizontal axis is located just downstream of the Hudgeon Lake outlet within the waste rock dump. XS refers to Cross Sections used in the model i.e. XS-62 refers to Cross Section 62. Outflow hydrographs are attached in Appendix B.

Breach Scenario 1 (Full Breach)

The results of the analysis including peak flow, elevation and velocity and time to peak flow are summarized in Table 7-4 as follows:

Table 7- 4
Sumamry of Outflow Hydrograph – Scenario 1

Channel Distance (km)	Peak Flow (m^3/s)	Peak Elev. (m)	Peak Vel. (m/s)	Time To Peak Flow (h)	Comments
4.00	496	415	3.5	0.25	Breach Opening (XS-62)
4.65	202	370.3	2.6	0.25	Downstream Toe of Waste Rock Dump (XS-58)
5.13	111	366.8	1.6	0.25	Confluence with Wolverine Creek
5.74	6	358.8	1.2	0.25	Valley Constriction (XS-52)
7.90	2	345.4	1.1	0.25	Eagle Creek (XS-28)
9.38	2	329.8	0.8	0.25	Valley Widening (XS-13)
11.98	2	300.3	0.3	0.25	Clinton Creek Town-site Bridge (XS-3)

The flood peak rapidly attenuates as the flood peak moves down the channel from the breach. Just downstream of the waste rock dump, the flood reaches a peak discharge of approximately 202 m^3/s and a peak water level of 370.3 m. At the confluence of Wolverine creek, the discharge and flood levels are 111 m^3/s and 366.8 m respectively. At approximately km 5.74, the Clinton Creek valley becomes narrow and constricts the flow, thereby increasing upstream water levels while decreasing flow rates and water levels downstream. The inundation within the stretch upstream of the constriction is illustrated on Drawing 12. Downstream of the valley constriction, the flow decreases to base flow level and will not reach the shoulder of the road. Due to the steep channel bed profile, the channel flow in this reach will be fast and shallow and the magnitude of the discharge will be similar to the base flow. There is no measurable impact on flood levels in the Forty Mile River.

Breach Scenario 2 (Full Breach – Bedrock Controlled)

The outflow hydrograph for Scenario 2 is nearly identical as that resulting from the breach geometry in Scenario 1. The results are summarized in Table 7-5 as follows:

Table 7- 5
Sumamry of Outflow Hydrograph – Scenario 2

Channel Distance (km)	Peak Flow (m^3/s)	Peak Elev. (m)	Peak Vel. (m/s)	Time To Peak Flow (h)	Comments
4.00	543	415.0	4.1	0.33	Breach Opening (XS-62)
4.65	442	371.5	3.0	0.33	Downstream Toe of Waste Rock Dump (XS-58)
5.13	135	366.9	1.8	0.33	Confluence with Wolverine Creek
5.74	7	358.9	1.1	0.33	Valley Constriction (XS-52)
7.90	2	345.4	1.1	0.33	Eagle Creek (XS-28)
9.38	2	329.8	0.8	0.33	Valley Widening (XS-13)
11.98	2	300.3	0.3	0.33	Clinton Creek Town-site Bridge (XS-3)

Breach Scenario 3 (Sedimentation)

Klohn Leonoff summarized the downstream hazards associated with down-cutting of the creek channel through the waste rock dump in their 1987 report. We concur with the results of this evaluation, in that the channel erosion would occur over a 24 hour period thus precluding a rapid failure. The outflow hydrograph indicates that the down-cutting of the channel in this scenario would not produce a significant enough increase in flow to pose a threat to human life.

Breach Scenario 4 (Partial Breach)

The results of the analysis including peak flow, elevation and velocity and time to peak flow are summarized in Table 7- 6 as follows:

Table 7- 6
Sumamry of Outflow Hydrograph – Scenario 4

Channel Distance (km)	Peak Flow (m^3/s)	Peak Elev. (m)	Peak Vel. (m/s)	Time To Peak Flow (h)	Comments
4.00	516	415.0	3.5	0.37	Breach Opening (XS-62)
4.65	226	371.0	2.7	0.37	Downstream Toe of Waste Rock Dump (XS-58)
5.13	176	367.1	1.8	0.37	Confluence with Wolverine Creek
5.74	5	358.8	1.2	0.37	Valley Constriction (XS-52)
7.90	2	345.4	1.1	0.37	Eagle Creek (XS-28)
9.38	2	329.8	0.8	0.37	Valley Widening (XS-13)
11.98	2	300.3	0.3	0.37	Clinton Creek Town-site Bridge (XS-3)

As with Breach Scenarios 1 and 2, the flood peak rapidly attenuates as the flood peak moves down the channel from the breach. In the breach, the computed peak discharge is 516 m^3/s and downstream of the waste rock dump, the flood reaches a peak discharge of 226 m^3/s with a peak water level of 371.0 m. At the confluence of Wolverine Creek, the computed peak discharge and flood levels have decreased to 176 m^3/s and 367.1 m respectively.

Similarly to Scenarios 1 and 2, the peak discharge in the channel downstream of the valley constriction (km 5.74) is close to the base flow discharge and the flow will most likely be contained within the existing channel and floodplain. There is no measurable impact on water levels in the Forty Mile River.

7.6.3.3 Summary of Results

In all cases, the flow through the breach reaches a peak discharge of approximately 500 m^3/s and a maximum flow velocity of 3.5 to 4 m/s. It can be seen that the flood peak quickly attenuates and reaches a base flow level at the valley constriction downstream of Wolverine Creek. The flow velocity between the toe of the blockage and the valley constriction varies between and 1.1 and 3.0 m/s, which is sufficiently high to move coarse bed material ranging in size (diameter) from approximately 0.03 to 1.4m respectively. Due to the turbulence in the channel flow, fine grained particles will be carried in suspension past the valley constriction.

From the valley constriction and downstream to the top of the granular outwash fan leading down to Forty Mile River, it is believed the flow is mainly confined within the channel and its floodplain, based on the photogrammetric mapping. The flow passes through critical depth at several locations where the flow velocity will be high, thus causing bed degradation and depositing of the eroded material farther downstream. In the low velocity pools upstream of these critical flow sections, a part of the suspended material will settle out while the finest particles will remain in suspension and be carried downstream. Between the top of the granular outwash fan and the Forty Mile River, the channel profile indicates the channel passes through a series of alternating flat and steep grades. Typical to a stream on a granular material fan, the channel is unstable.

7.6.4 Wolverine Creek

7.6.4.1 Breach Parameters

The assumed parameters for the breach scenarios considered are summarised in Table 7- 7.

Table 7- 7
Tailings Pile Dam Breach Parameters.

Parameter	Value
Dam crest elevation [m]	411.6
Dam toe elevation on reservoir side [m]	400
Reservoir water surface elevation at start of breaching [m]	411.6
Top width of breach at end of breaching [m]	46
Bottom elevation of breach at end of breaching [m]	400
Bottom width of breach at end of breaching [m]	24
Average Breach Width (m)	35
Breach Depth (m)	11.6
Time from start to end of breaching [h]	0.5

7.6.4.2 Outflow Hydrographs

The results of the analysis at the downstream end of Wolverine Creek at the Clinton Creek confluence and a short distance downstream along Clinton Creek are summarized in Table 7-8. Outflow hydrographs are attached in Appendix B.

Table 7- 8
Sumamry of Outflow Hydrograph – Wolverine Creek

Location	Peak Flow (m^3/s)	Peak Elev. (m)	Peak Vel. (m/s)	Time To Peak Flow (h)
Downstream End of Channel at Clinton Creek Confluence	350	371.1	4.64	0.47
Valley Constriction at km 5.74 in Clinton Creek Channel	326	363.1	1.01	0.62
km 6.64 in Clinton Creek Channel (XS 40)	306	358.9	1.39	0.68

The peak discharge at the end of the Wolverine Creek channel s approximately 350 m^3/s and the peak water level is approximately 371.1 m, corresponding to a flow depth of approximately 3.4 m. The peak flow in Wolverine Creek is fairly high due to the short breach time, the steep channel profile and the lack of flood plain storage areas along the creek. This is very dissimilar to the conditions along Clinton Creek where the grade is relatively flat and the flood plain is very wide in proportion to the channel. As a result, the full volume of the breach outflow from Wolverine Creek will be carried down to Clinton Creek and go into storage on the Clinton Creek flood plain. The water level in Clinton Creek at the valley constriction (km 5.74) peaks at approximately elevation 363.0 m and diminishes as the flood wave progresses further downstream.

8.0 RISK ASSESSMENT

8.1 General

Existing and future conditions at the abandoned Clinton Creek Asbestos Mine potentially expose individuals, property and the environment to some degree of risk associated with downstream channel sedimentation and flooding. These risks can be broadly placed into *ecological* and *human health* risk categories. This report is limited to evaluating the potential risks to human life and physical property downstream of the mine site in the event of a catastrophic breach at the channel blockages (flooding risks). The hydrological events modelled however, provide the basis for broader ecological risk assessments. In this regard, preliminary observations and recommended follow-up activities with respect to these issues are discussed by Royal Roads University in their March, 1999 Environmental Review Report.

It is important to recognize that conditions at the mine site have evolved since Klohn Leonoff's 1987 Downstream Hazard Assessment Report, in particular the condition of the Clinton Creek Channel at the Hudgeon Lake outlet. In our opinion, the destruction of the rock weirs in 1997 and continued channel incising has greatly increased the potential for the development of a breach, the consequences of which are considerably greater than earlier reported by Klohn Leonoff.

The following sections provide a qualitative assessment of risk scenarios and human and ecological exposure levels associated with a channel blockage breach. A quantitative estimate of risk is not considered appropriate given the considerable uncertainty in parameters necessary to arrive at precise predictions of risk under various scenarios and circumstances. There is however, sufficient reliability in the results presented in this report to determine the acceptability of potentially hazardous activities and develop guidelines for appropriate risk management strategies.

8.2 Land Use and Occupancy

Based on discussions with DIAND and observations made during previous site inspections, it is apparent that although the site is remote and virtually uninhabited during the winter (October to April), occasional use during the summer is common. The Clinton Creek Mine Site is accessible by the bridge over the Forty Mile River and the road from the abandoned Clinton Creek Town-site. While much of the activity in the general area of the Town-site and mine is associated with placer mining, hunting, fishing, etc. Along the Forty Mile River, the frequency of visits to the mine site is believed to be greater than estimated in previous downstream hazard assessments.

During site visits in September 1998 and July 1999, several groups of hunters, campers and tourists were encountered. On two separate occasions, hunters travelled through the mine site property traversing the Clinton Creek Channel and Hudgeon Lake outlet in 4-wheel drive vehicles to unknown destinations beyond the tailings piles. Recent and active camping was observed at the end of the access road at the Clinton Creek channel at the washed out bridge. Seasonal camping in tents and limited habitation in abandoned or refurbished buildings at the Clinton Creek Town-site and further downstream along the west bank of the Forty Mile River is evident (although no occupants were encountered at the time). Several vehicles were passed on the road between the Top of the World Highway and the Forty Mile River or were seen parked in the vicinity of the Town-site. It is also our understanding that the Town-site property has been purchased and future re-development of the area is possible. The potential land occupancies are identified on Drawing 11.

8.3 Downstream Risk Scenarios

Development of channel blockages and continued erosion and downstream deposition of waste rock and tailings materials present concerns in the context of *chronic conditions* from on-going sedimentation and potentially *catastrophic conditions* associated with a dam breach.

8.3.1 Chronic Conditions

Although sediment deposition does not pose any direct threat to human life or property downstream of the mine site, some risk to riverine habitats and species may exist if geological slumping and erosion contribute to excessive sediment loads (RRU, 1999). The potential for deleterious effects on fish species and habitats from the chronic transport of sediment from the waste largely depends on the timing of release and downstream extent of sedimentation.

Channel aggradation (deposition) resulting from on-going erosion and out-wash of waste rock and tailings is visually evident immediately downstream of the channel blockages in Clinton Creek and Wolverine Creek. In this regard, we have estimated the volume of material eroded from both sources on an annual basis and speculated as to the downstream fate and the potential physical impact on the channel. Erosion is expected to continue indefinitely, although the rates of erosion may diminish as the waste rock and tailings piles reach equilibrium. It must be recognized however, that the process is dynamic and continued down-cutting will soon re-establish contributions from unstable toe slopes and possible acceleration of mass downslope movements.

<u>Clinton Creek Waste Rock Dump</u>

Erosion of waste rock material is a gradual but continuous process fed from several material sources. The total volume of material eroded since 1986, is estimated to be 15,000 m^3, or about 1,000 m^3 per year based on the following:

1. *Creek bed material* - Approximately 8,000 m^3 from down-cutting. Based on the channel profile in Drawing 04 and an average channel width of 5 m.

2. *Channel widening* - Approximately 6,400 m^3 from the south side of the channel as the waste rock advances. Based on a 700 m long by 7 m high channel and 1.3 m of channel closure since 1986.

3. *Localized sloughing* - Approximately 600 m^3 from incidental slides and sloughing of the waste rock material along the north edge of the road into the channel.

The impact from waste rock erosion and sediment outwash into the downstream channel is most significant immediately downstream of the toe of the waste rock dump. From Figure 7-3, D_{50} for this material can be taken to be approximately 5 mm placing it within the size range of fine gravel. The D_{100} is shown to be less than 35 mm but the material visible in Photo 14-11A tends to indicate that the largest material size is significantly larger. The critical flow velocities for these sizes of material are approximately 0.6 and 2 m/s during laminar flow conditions. During turbulent flow conditions, such as along Clinton Creek, the direct force of the water will move these materials. Movement of boulder size material is possible under turbulent flow from micro-erosion, which undermines the stability of the boulders causing them to tumble in the direction of the flow.

Waste rock material will gradually move downstream towards the Wolverine Creek confluence. In this area, the valley is significantly wider and the coarser material will deposit in pockets of low flow velocity while the finer material will be carried farther downstream. It is likely that a large part of the gravel fraction has deposited in the wide area just downstream of Wolverine Creek and in the two wider and flatter areas along Clinton Creek, just upstream of Eagle Creek. Similarly, it is likely that the coarsest material, such as cobbles and boulders, are accumulating in the vicinity of Wolverine Creek. The sand fractions of the waste material can most likely be found deposited in pockets throughout the length of Clinton Creek, possibly as far downstream as the Forty Mile River.

Through the continuous erosion of waste rock material and deposition of coarse granular material in the general area of Wolverine Creek, Clinton Creek will cut new channels in this area during larger floods, possibly as often as on an annual basis. Along the intermediate reach, between the valley constriction and the top of the granular outwash fan, the channel will remain confined within the V-shaped valley with only minor lateral shifts. Along the granular outwash fan, Clinton Creek is unstable and will continue to seek new alignments indefinitely through an endless cycle of erosion and deposition with a corresponding change in profile.

Wolverine Creek Tailings Piles

Wolverine Creek appears to have the capacity to remove tailings at a sufficient rate to keep up with the downslope movements of the north and south lobes as evidenced by active erosion of the leading edge of the north and south lobes (Drawing 05). Klohn Leonoff's June 1986 report indicated the tailings were continuing to move downslope at a rate of 6 m/yr (south lobe) and 22 m and 2 m/yr at the leading edge and top of the north lobe respectively. In 1987, they indicated these rates of movement were decreasing although no results were provided. Stepanek and McAlpine (1992) estimated downslope movements of the south lobe in the order of 5 to 10 metres per year were occurring.

Assuming downslope movements of 5 to 10 m per year, the approximate quantity of tailings eroded and transported downstream is in the order of 7,500 to 15,000 m^3/yr, based on a total leading edge width of 300 m and a 5 m high creek channel. Sediment transport of asbestos tailings can be clearly seen within the Wolverine Creek channel as far as its confluence with Clinton Creek, in particular immediately upstream of the culvert where the tailings are dammed by the mine site access road (UMA Photo 2-4). Although sediment transport in Clinton Creek is less noticeable (visually), small pieces of tailings can be readily found in the vicinity of the culverts.

From Figure 7-7, it can be see that the mill tailings have a D_{50} of 1 mm and a D_{100} of 20 mm. The D_{50} material has a very low resistance to flowing water with critical flow velocities of approximately 0.3 m/s while the D_{100} material has a critical flow velocity of approximately 1.8 m/s. Based on this gradation and the estimated flow velocities, approximately 50% of the material will be transported during all flows that occur on Wolverine Creek and carried down to Clinton Creek from where it will be carried by the Clinton Creek flow farther downstream. As with the finer material from the waste rock pile, it is likely that the finer fractions of the mine tailings are carried down to Forty Mile River, with the clay fraction possibly remaining in suspension down to Yukon River. Some of the finer tailing material may also have accumulated on the wide bar on the right side of Forty Mile River, immediately downstream of the Clinton Creek bridge across Forty Mile River. This feature is clearly visible on Drawing 13. However, due to the extensive placer mining operations along Forty Mile River, it is uncertain whether this bar has been caused by discharges from the placer mining operations along Forty Mile River or by mine tailing material discharges from Clinton Creek.

8.3.2 Catastrophic (Dam Breach) Conditions

Clinton Creek Channel

A catastrophic dam breach would most likely involve a failure mode where a partial or complete breach of the waste rock channel blockage at the Hudgeon Lake outlet occurs. The breach could develop as a result of a channel blockage from debris or ice, continued incising of the channel bottom, a significant overtopping event or any combination of the above. It must be recognized however, that the failure mode could be triggered at any time in the foreseeable future and is not considered susceptible to any particular precipitation event i.e. a relatively minor inflow could trigger the failure mechanism necessary to initiate a breach.

Outflow hydrographs have been generated for the breach scenarios described in Section 7.6.3.2. Because the differences in the lateral extents of flooding for these scenarios are insignificant, Scenario 2 (full breach – bedrock controlled) has been selected to assess the downstream consequences. The consequences of a sudden release of water associated with a breach of the Clinton Creek channel blockage are potentially life-threatening, in particular immediately downstream of the mine site within the inundated area (flood plain). Water immediately downstream of the waste rock dump will start to rise immediately after the breach has been initiated, peaking about 20 minutes later.

The inundation resulting from a dambreach immediately downstream of the waste rock dump is shown on Drawing 12, which represents Scenario 2, twenty minutes after initiation of the breach. The potential for loss-of-life is dependent upon human exposure within this zone i.e. camping, etc. Farther downstream, the risks are somewhat less as the increase in creek water levels will largely be confined to the creek valley below the road where human exposure (occupancy) is considered unlikely. The risk to human health is considered low at the next most likely downstream area of occupancy in the vicinity of the Clinton Creek Town-site where the valley widens considerably (Kilometer 9.4).

The level of risk downstream of the mine site has been categorised as high, medium or low based on the severity of flooding within each zone. The transition between the high and medium hazard zones is based on the relative elevation of the water surface profile in the creek and the road through the narrow stretch of the Clinton Creek valley. In this regard, the most vulnerable location for human occupancy would be within the creek channel itself or along the road at an elevation lower than the predicted flood peak. To determine the vulnerability along the road under a worst case scenario, its centreline has been plotted against the creek channel and water surface profiles for a base flow of 40 m3/s, a flow exceeding the maximum flood discharge (Figure 8-1). The most vulnerable locations are between the waste rock dump and the Wolverine Creek confluence and in the vicinity of the Eagle Creek confluence where the road is 2 to 3 metres above the creek channel. The remaining stretches of the road are generally well above the water level profile.

The three hazard zones are summarized as follows:

High Hazard Zone – Potential injury, loss of life and destruction of property.

Medium Hazard Zone – Risk to human life considered low. Sufficient warning period is likely and high ground readily available. Possible loss of property or access road in low lying areas.

Low Hazard Zone – No anticipated injury, loss of life or property loss.

Wolverine Creek Channel

The downstream consequences of a breach of the tailings piles are associated with human occupancy within the Wolverine Creek valley. The Wolverine Creek valley has therefore been designated as a high hazard area. Since the peak flow is quickly attenuated once the outflow enters the Clinton Creek channel, the risk to human life within the Clinton Creek valley downstream of Wolverine Creek is considered low.

The hazard ratings developed for both Clinton Creek and Wolverine Creeks have been combined to compile the overall Hazard Rating Map shown on Drawing 13. Based on the location of potential land use occupancies on this map, the risks to public safety and property are summarized in Table 8-1.

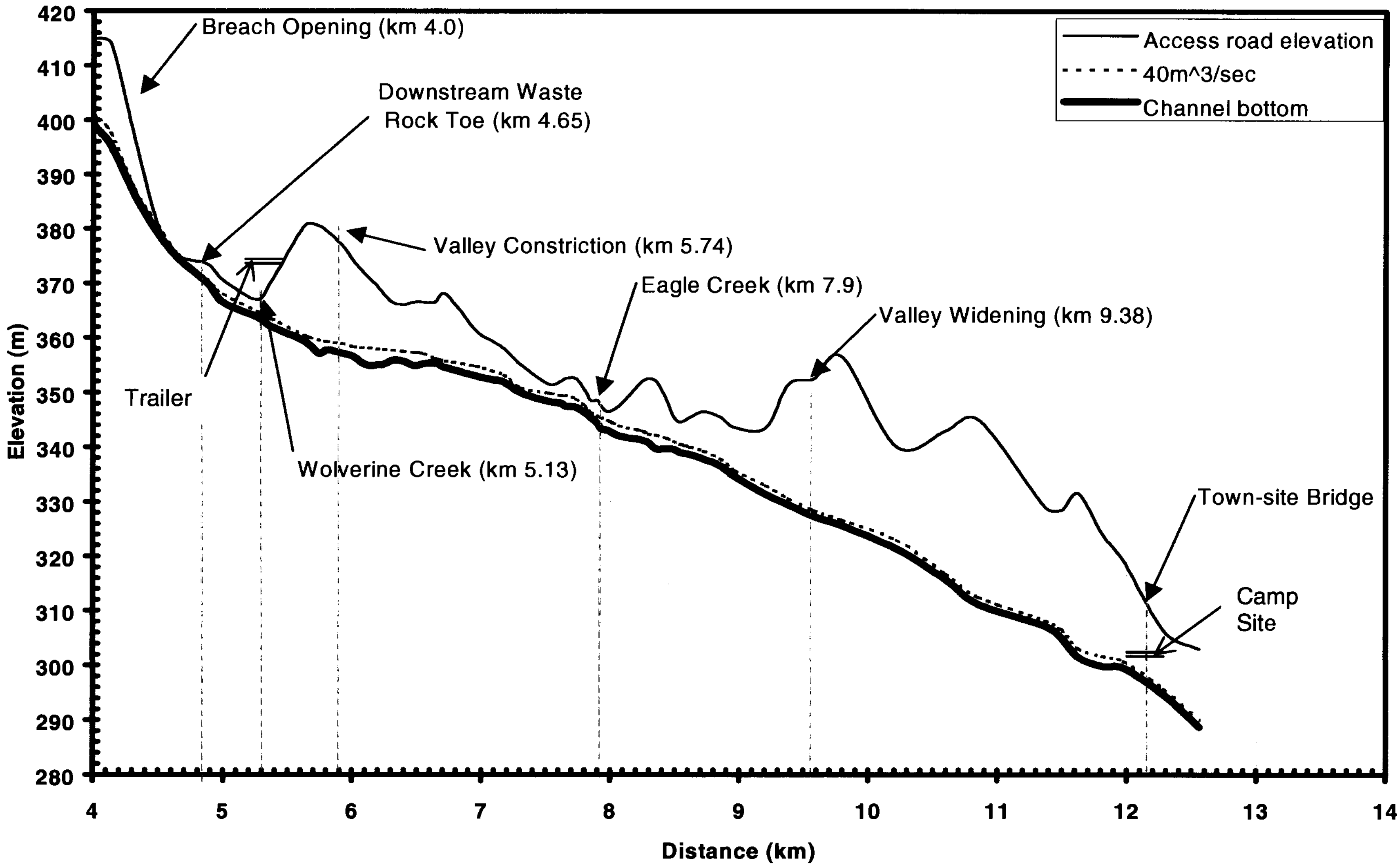


Figure 8-1
Creek, Water Surface and Road Profiles

Table 8-1
Hazard Zone Summary

Potential Occupancy	Hazard Rating	Potential Consequences	Comments
Camping			
• End of Mine Site Access Road at Clinton Creek	**H**	Injury, Loss of Life, Loss of Property	Very little advance warning of flood.
• Road on East Side of Wolverine Creek	**H**	Injury, Loss of Life, Loss of Property	High hazard from either Waste Rock or Tailings Pile Breach.
• Vicinity of Clinton Creek Town-site	**L**	None	No significant impact on water levels. Areas well above flood plain.
Transient Use			Tourists, Hunters, Fishermen
• Immediately Downstream of Mine Site	**H**	Injury, Loss of Life, Loss of Property	Sufficient time to seek high ground may be possible in daylight conditions.
• Mine Site access Road	**M**	Loss of Property	Flow confined to Creek Channel Below Road Elev.
• Vicinity of Clinton Creek Town-site	**L**	None	No significant impact on water levels. Areas well above flood plain.
Placer Mining			
• Existing Camp Site in Wolverine Creek Valley	**H**	Injury, Loss of Life, Loss of Property	High hazard from either Waste Rock or Tailings Pile Breach.
• Forty Mile River	**L**	None	No measurable Impact in Forty Mile River

8.4 Risk Management

For each of the ecological or human health risks identified, it is important for the current land manager to determine what level of risk should prompt a risk management or remedial strategy. In his regard, immediate measures might include:

- Preventing vehicle access to high hazard areas i.e. barricading road between Town-site and Mine Site
- Prohibiting camping in high hazard areas (including the eviction of current occupants)
- Posting warning signs in medium and high hazard areas
- Providing camping facilities on sufficiently high ground in designated areas within medium and low hazard areas

For the components of the ecosystem potentially at risk, it is important for the appropriate decision makers, in association with the land manager, to first decide if the demonstrated risks identified in this report warrant the development and/or implementation of risk management or remedial strategies. As pointed out in Royal Roads 1999 Environmental review, future actions may require that the direct costs of mitigative measures be compared against the economic consequences of damage to or losses of valued ecosystem components.

Thank you for the opportunity to continue working with you on this most interesting assignment. Should you have any questions or require any additional information, please contact either of the undersigned.

Yours Truly,

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APPENDIX A

CANADIAN AND US HYDROMETRIC STATIONS

Table 6-1
Water Survey of Canada Hydrometric Stations

Station Number	Station Name	Latitude (North)	Longitude (West)	Drainage Area [km²]	Record Period
09BA001	Ross River at Ross River	61°59'40"	132°22'40"	7 250	1960 to >1988
09BC001	Pelly River at Pelly Crossing	62°49'47"	136°34'50"	49 000	1952 to >1988
09BC002	Pelly River at Ross River *(discontinued)*	61°59'12"	132°26'54"	18 400	1954 to 1974
09BC004	Pelly River below Vangorda Creek	62°13'20"	133°22'40"	22 100	1972 to >1988
09DC002	Stewart River at Mayo *(discontinued)*	63°35'26"	135°53'48"	31 600	1949 to 1978
09DC003	Stewart River above Fraser Falls	63°28'17"	135°08'06"	30 600	1980 to >1988
09DD002	Stewart River at Stewart Crossing *(discontinued)*	63°22'56"	136°40'59"	35 000	1961 to 1973
09DD003	Stewart River at the mouth	63°16'55"	139°14'58"	51 000	1963 to >1988
09DD004	McQuesten River near the mouth	63°36'40"	137°16'10"	2 870	1979 to >1988
09EA003	Klondike River above Bonanza Creek	64°02'34"	139°24'28"	7 800	1965 to >1988
09EA004	North Klondike River near the mouth	64°01'16"	138°34'58"	1 100	1974 to >1988
09EB003	Indian River above the mouth	63°46'16"	139°37'45"	2 220	1982 to >1988
09EC001	Clinton Creek above Wolverine Creek *(discontinued)*	64°26'54"	140°42'24"	n.a.	1964 and 1965 only
09EC002	Fortymile River near the mouth	64°23'50"	140°36'40"	16 600	1982 to >1988
10MA002	Ogilvie River at KM 197.9 Dempster Highway	65°21'45"	138°17'50"	5 410	1974 to >1988
10MA003	Blackstone River near Chapman Lake Airstrip	64°52'03"	138°17'14"	1 130	1984 to >1988

Table 6-2
U.S. Geological Survey Hydrometric Stations

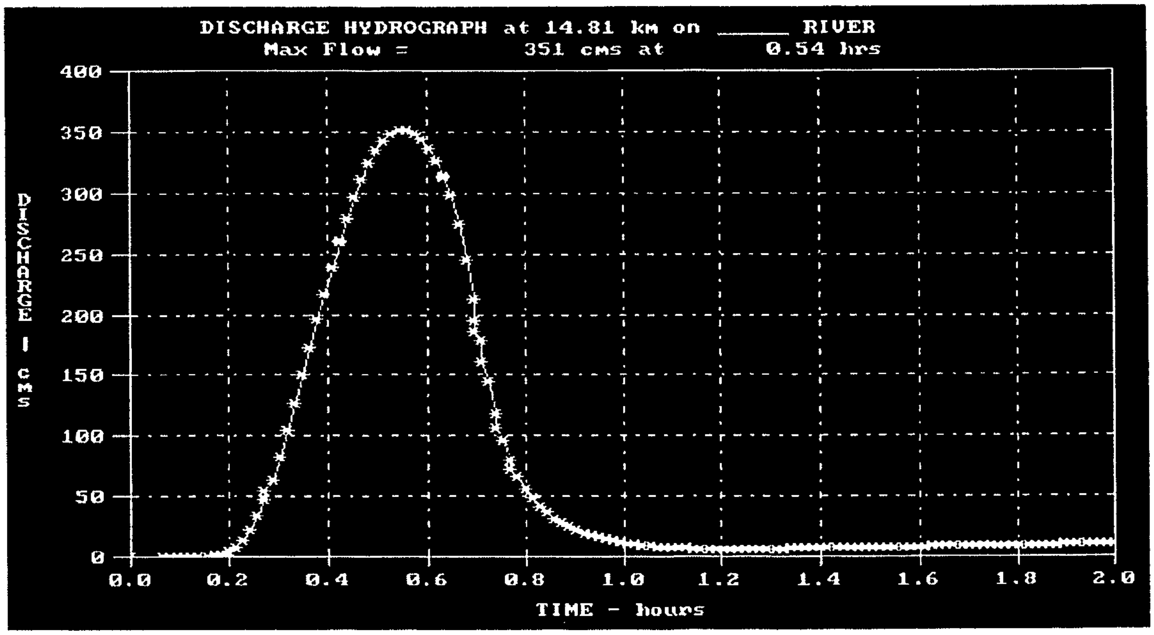
Station Number	Station Name	Latitude (North)	Longitude (West)	Drainage Area [km^2]	Record Period
15305900	Dennison F Nr Tetlin Junction Ak	63°25′24″	142°29′00″	7.6	1964 - 1998
15305920	Wf Tr Nr Tetlin Junction Ak	63°40′03″	142°16′00″	2.6	1967 - 1997
15305950	Taylor C Nr Chicken Ak	63°54′27″	142°12′58″	99.5	1967 – 1991
15320100	Wade Cr Trib Nr Chicken Ak	64°07′06″	141°33′13″	11.0	1995 – 1998
15341900	Nf King Salomon C Nr Eagle Ak	64°32′32″	141°15′00″	47.9	1963 – 1980
15344000	King C Nr Dome Creek Ak	64°23′38″	141°24′43″	15.2	1975 - 1998
15348000	Fortymile R Nr Steele Creek Ak	64°18′33″	141°24′08″	15 229	1911 – 1982
15470300	L Jack C Nr Nabesna Ak	62°32′39″	143°19′22″	17.4	1975 - 1996

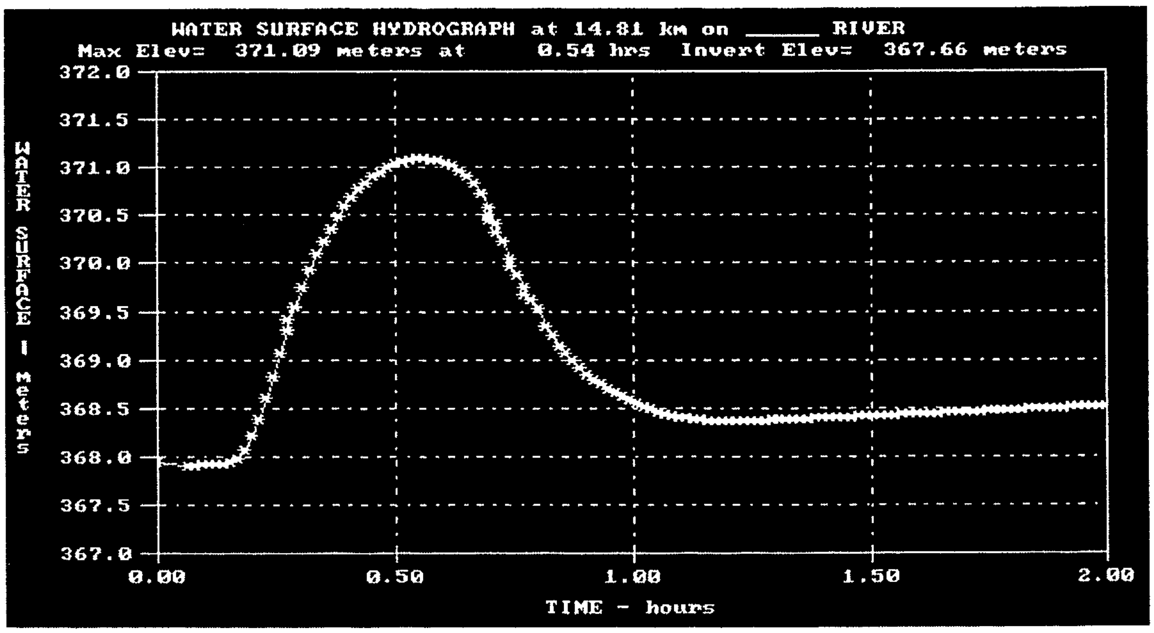
APPENDIX B

OUTFLOW HYDROGRAPHS

TAILINGS PILE BREACH – *OUTFLOW HYDROGRAPHS*

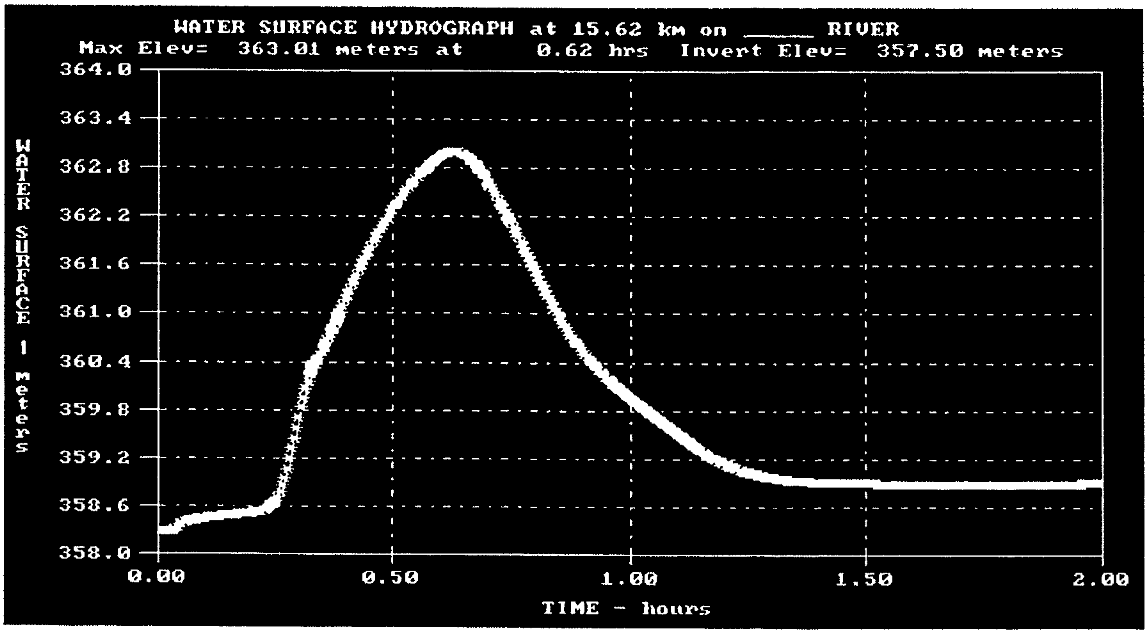
Wolverine Creek - km 14.814at Trailer





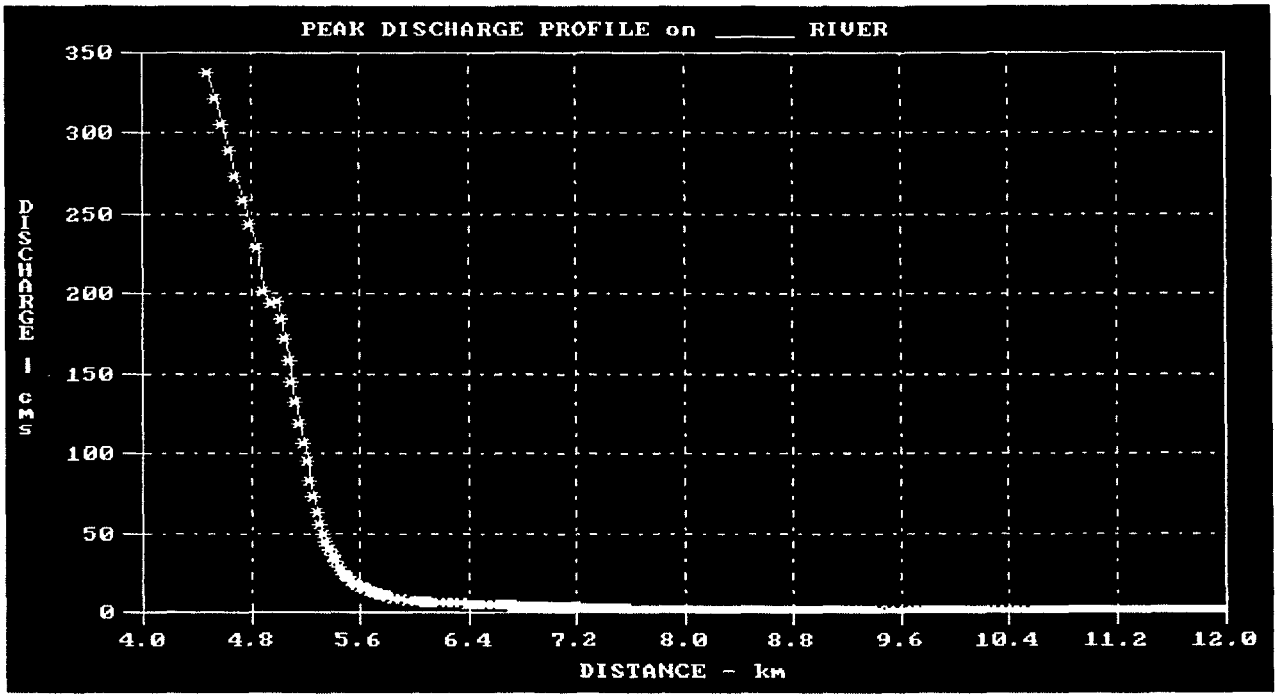
TAILINGS PILE BREACH – *OUTFLOW HYDROGRAPHS*

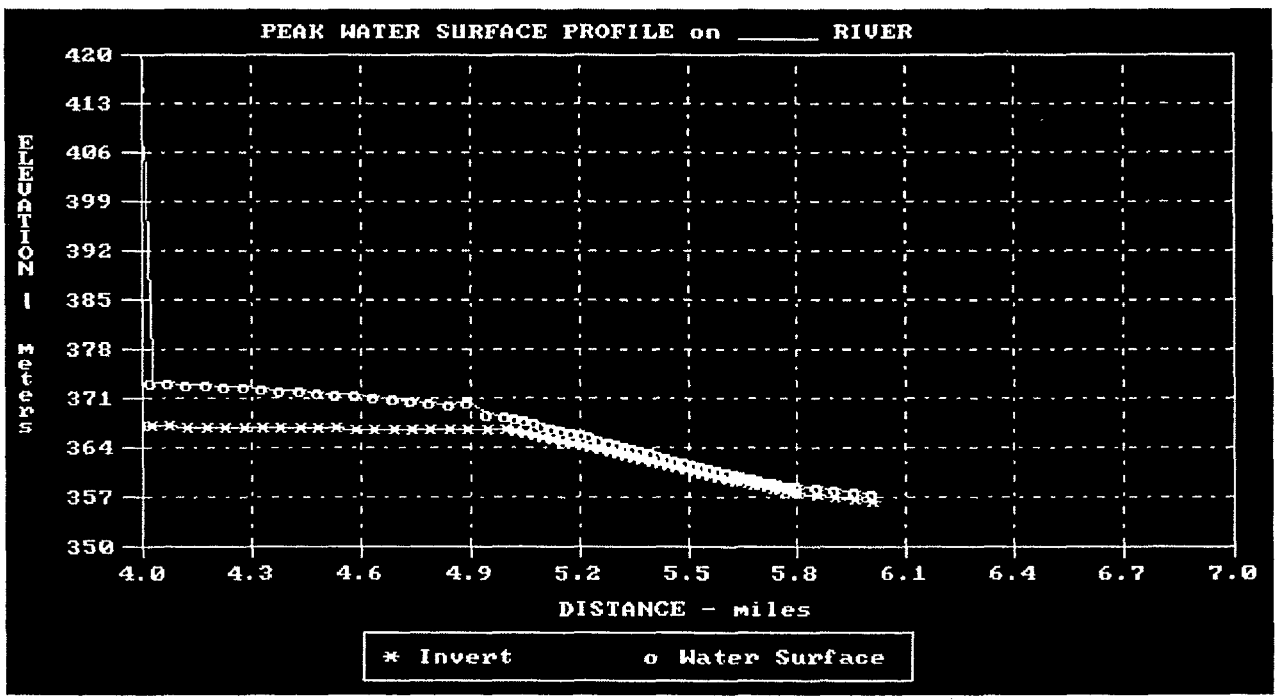
Clinton Creek - km 5.74 at lake valley constriction



WASTE ROCK DUMP BREACH – *OUTFLOW HYDROGRAPHS (Scenario 2)*

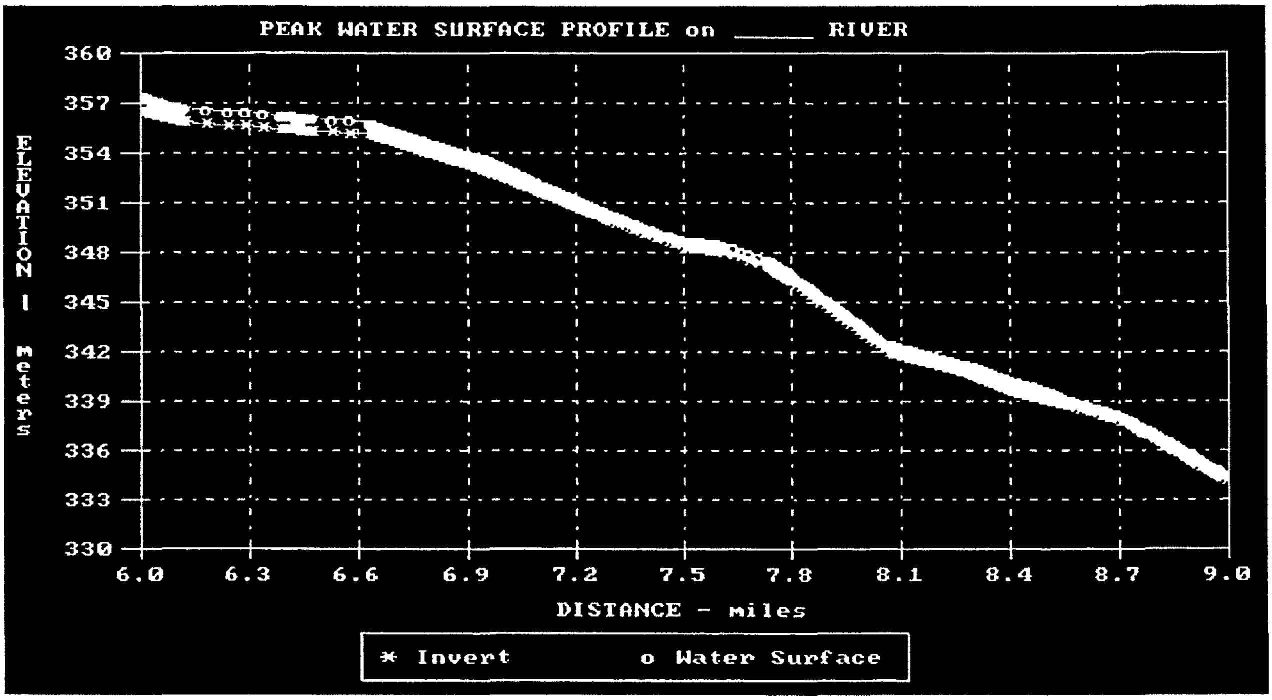
Clinton Creek

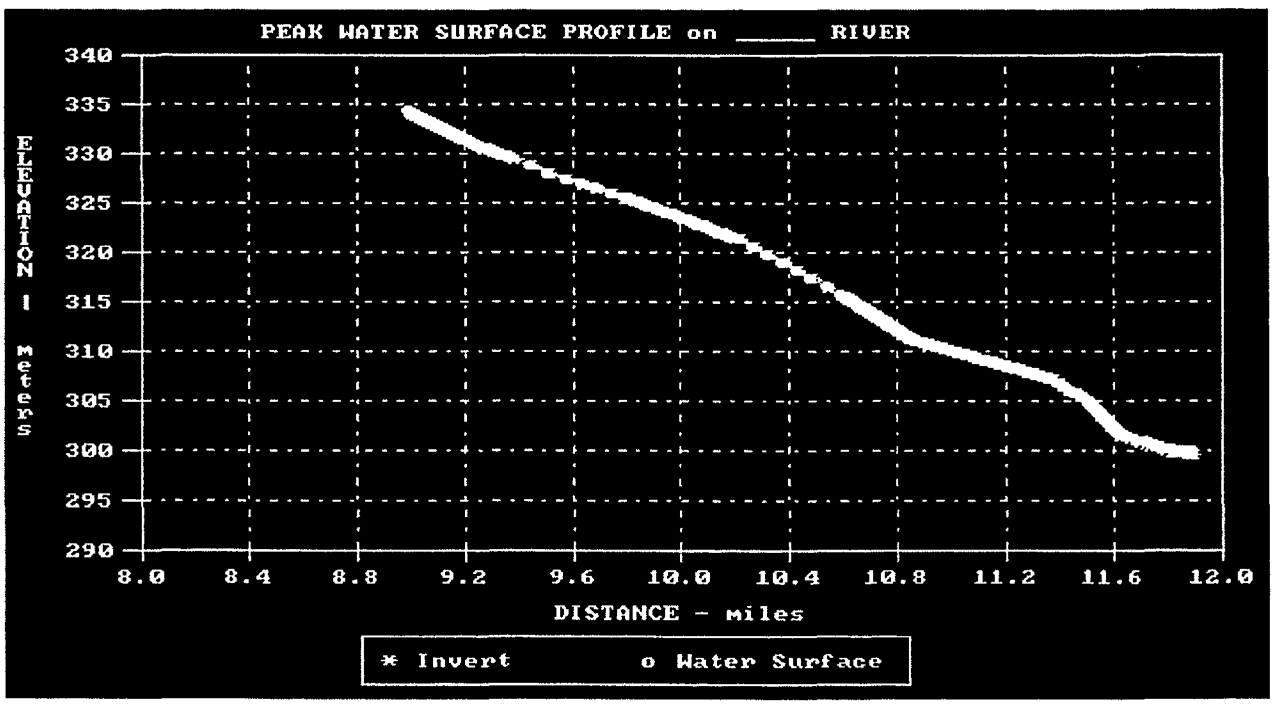




WASTE ROCK DUMP BREACH – *OUTFLOW HYDROGRAPHS (Scenario 2)*

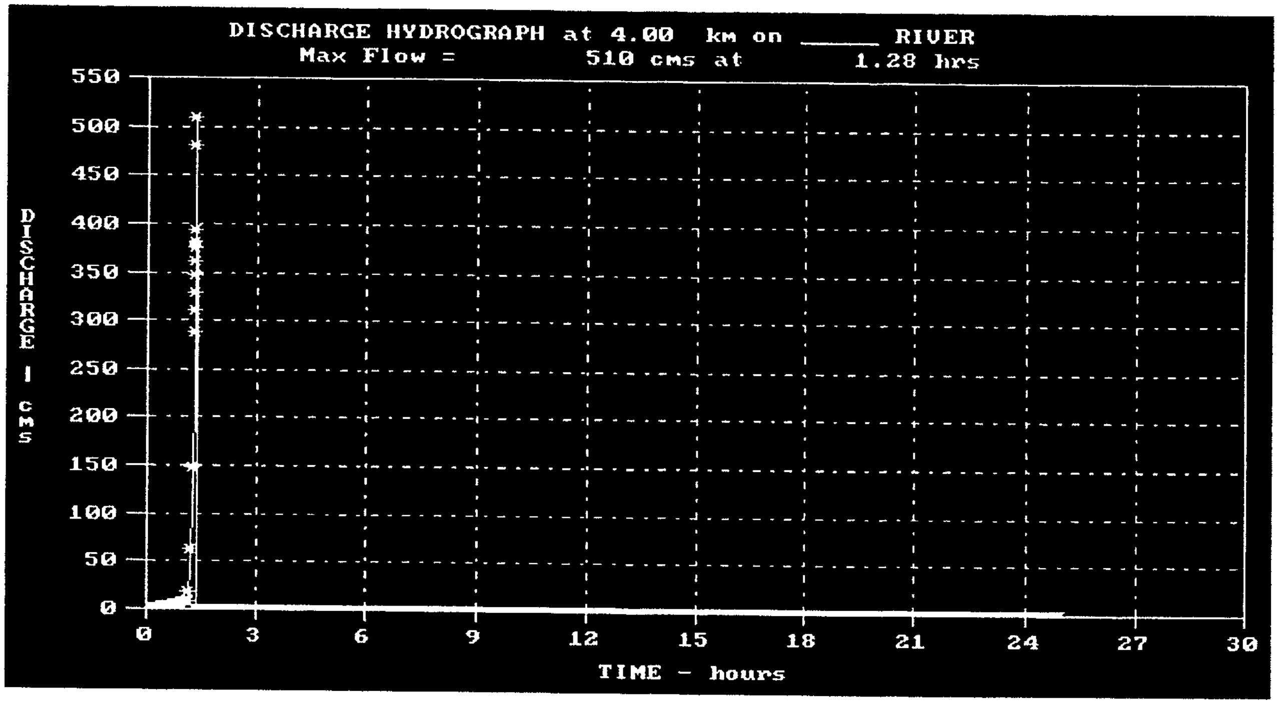
Clinton Creek





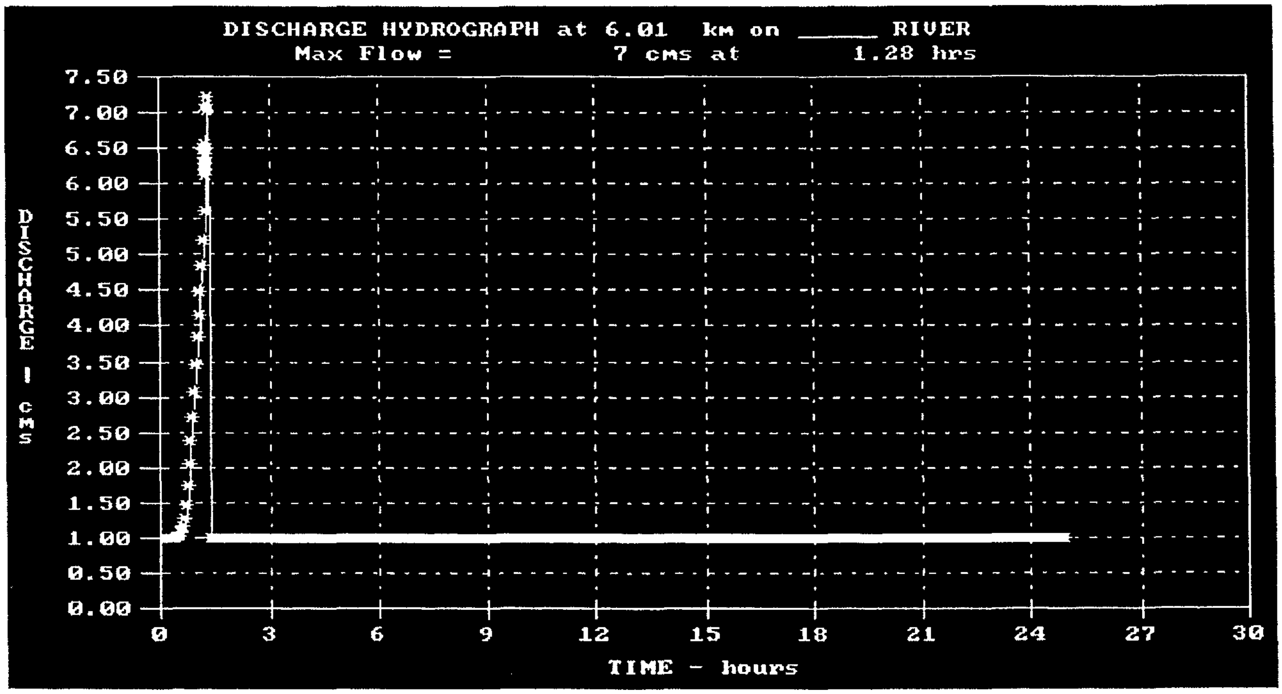
WASTE ROCK DUMP BREACH – *OUTFLOW HYDROGRAPHS (Scenario 2)*

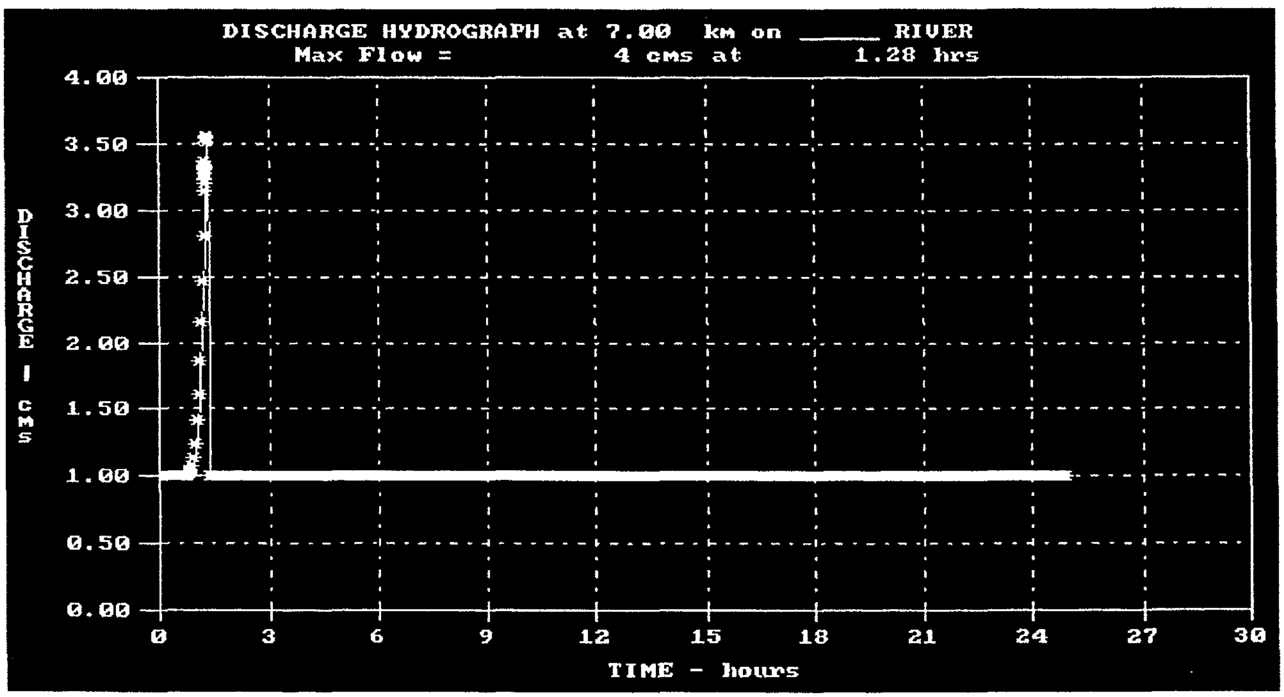
Clinton Creek



WASTE ROCK DUMP BREACH – *OUTFLOW HYDROGRAPHS (Scenario 2)*

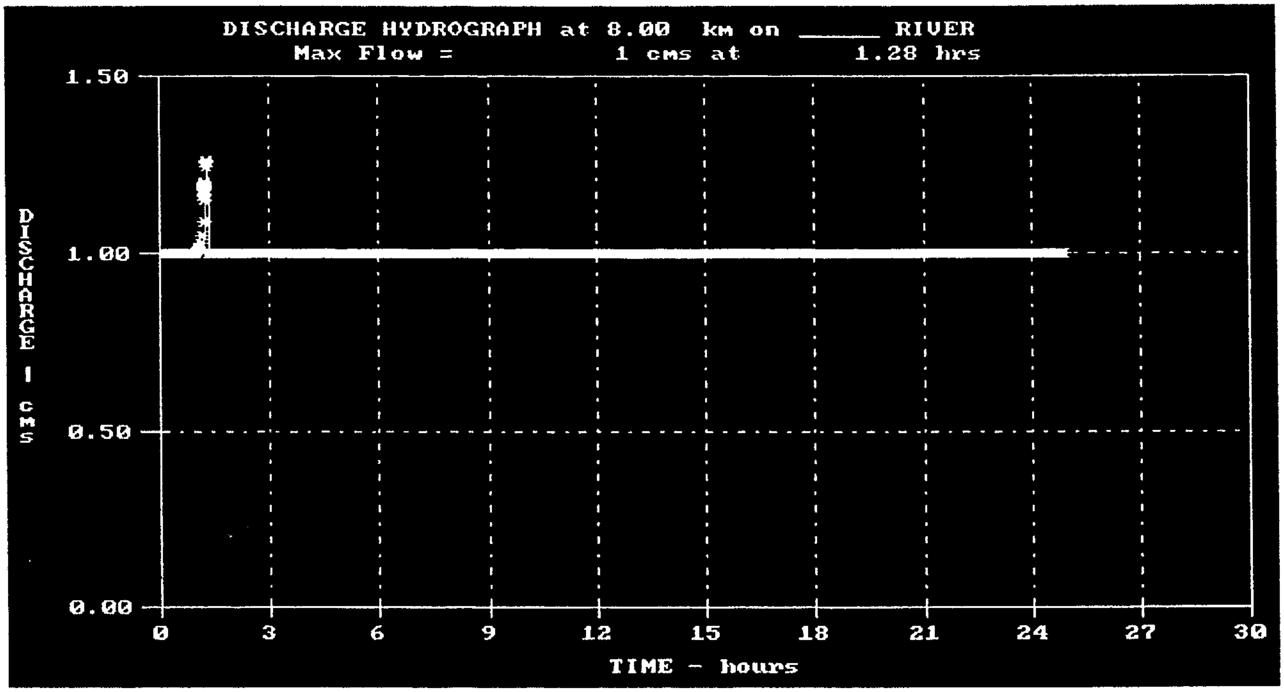
Clinton Creek





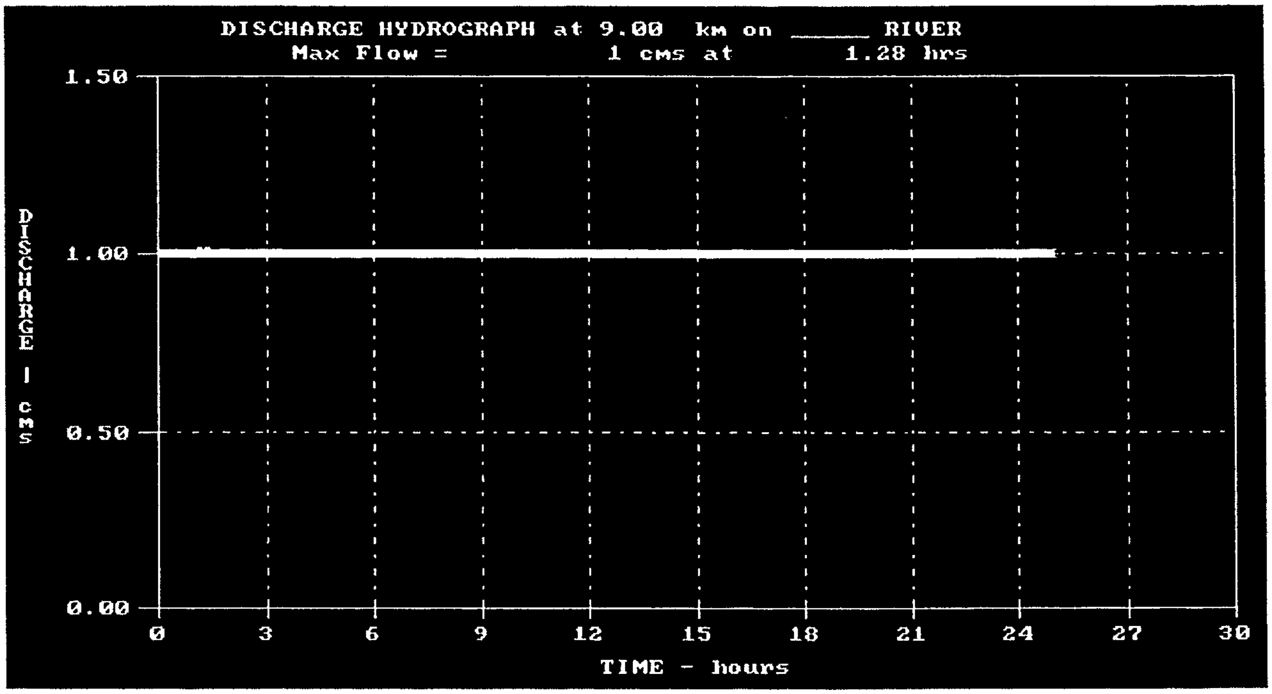
WASTE ROCK DUMP BREACH – *OUTFLOW HYDROGRAPHS (Scenario 2)*

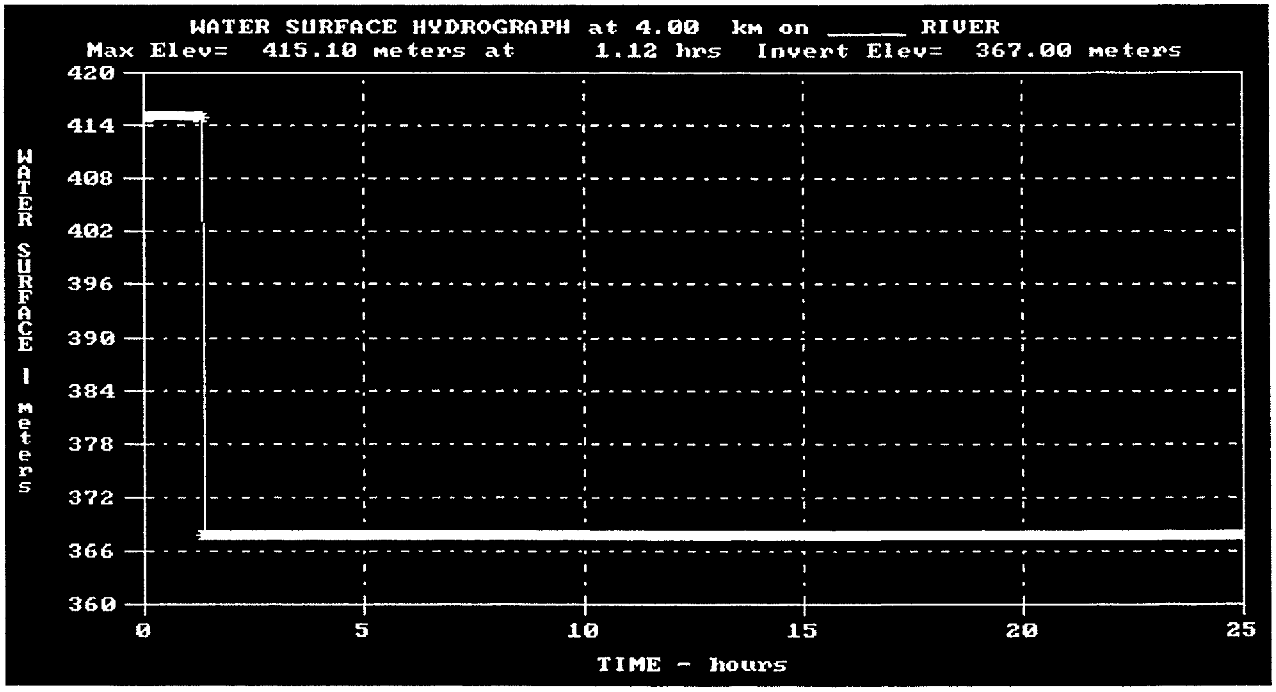
Clinton Creek



WASTE ROCK DUMP BREACH – *OUTFLOW HYDROGRAPHS (Scenario 2)*

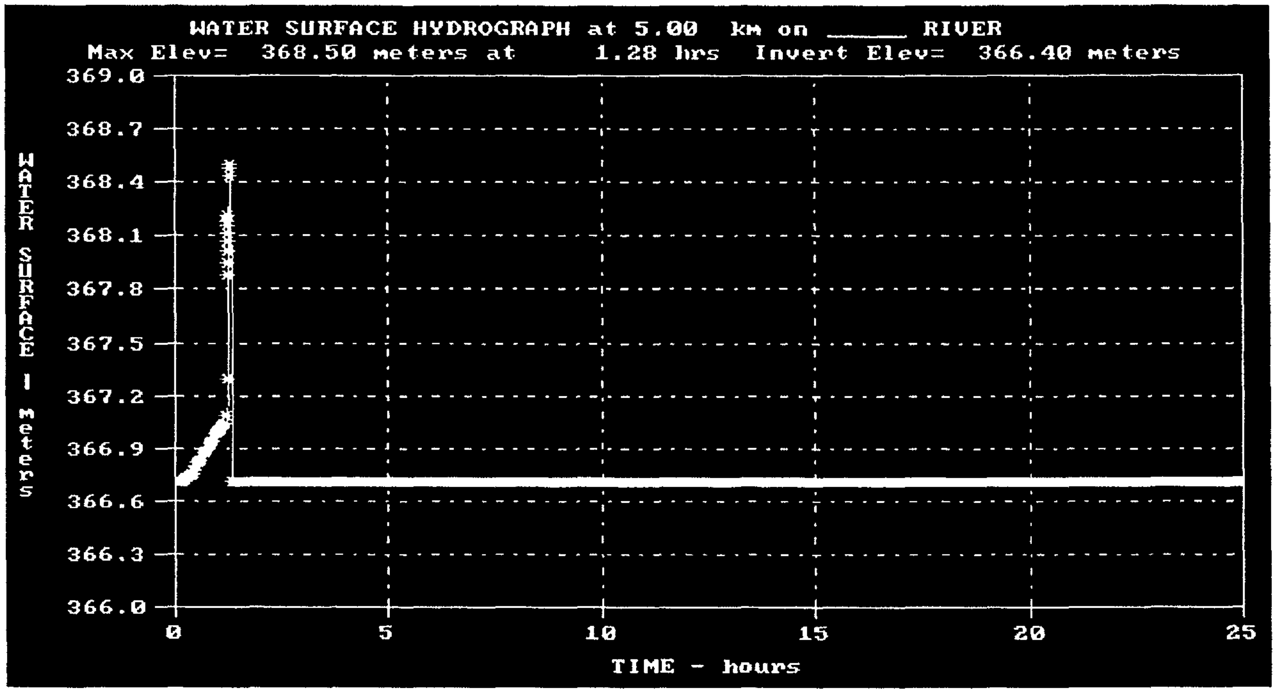
Clinton Creek

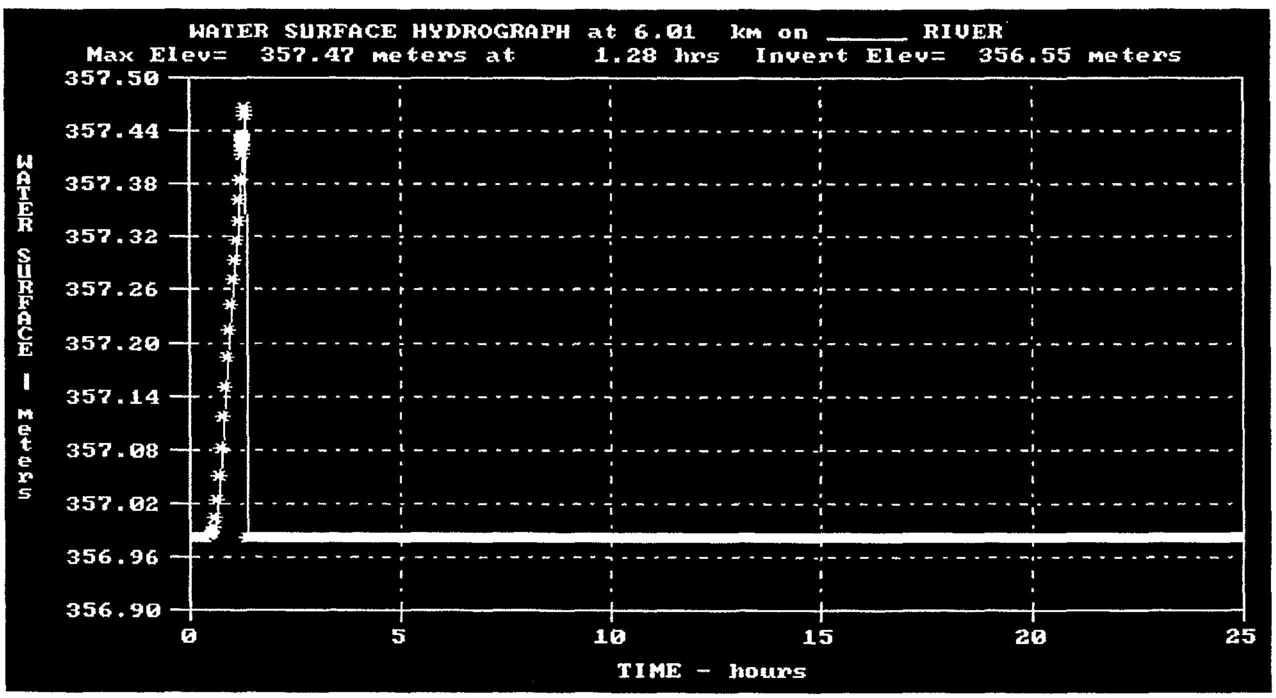




WASTE ROCK DUMP BREACH – *OUTFLOW HYDROGRAPHS (Scenario 2)*

Clinton Creek





WASTE ROCK DUMP BREACH – *OUTFLOW HYDROGRAPHS (Scenario 2)*

Clinton Creek