

**APPENDIX 6-C
GALORE CREEK SURFACE HYDROLOGY ASSESSMENT
BASELINE REPORT**

Galore Creek Surface Hydrology Assessment Baseline Report



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EXECUTIVE SUMMARY



Executive Summary

This report outlines the baseline surface water hydrology of the Galore Creek Project area. The report describes methods and results of a comprehensive field monitoring program undertaken during 2004 and 2005. It also provides estimates of key hydrological parameters for watersheds and sub-watersheds in the study area, for use in the EIA process and to assist in engineering design.

The Galore Creek Project area is located within the Coast Mountains of northwestern British Columbia a region characterized by high annual snowfall and precipitation totals. The watersheds typically have steep, mountainous topography, and many have glaciers in their headwaters. The project area lies in a transition zone between the very wet coastal region and the drier interior of British Columbia. The regional hydroclimate of northwestern British Columbia is dominated by weather systems generated from the Pacific Ocean, and is also strongly influenced by orographic effects caused by the local mountainous topography. This results in complex interactions between incoming weather systems and local topography that produce a high degree of spatial variability in snowfall and precipitation. In addition, the presence of large glaciated areas can impact snowmelt rates and produce high runoff volumes during summer months.

Due to the number of competing runoff generating processes and their varying spatial and temporal influences on stream flow hydrographs the hydrological regime of the region is very dynamic, temporally and spatially variable, and difficult to predict. Any hydrological assessment is dependant on the quality and quantity of available historical meteorological and stream flow data relevant to the study area. Due to the mountainous topography, and the distance from large population centres, there are only a limited number of meteorological and hydrological monitoring stations in northwestern British Columbia. Information on flows in smaller, glaciated watersheds is particularly lacking in regional stream flow datasets.

To address the requirements for site-specific hydrologic information, a network of 25 hydrometric stations were installed and monitored during 2004 and 2005. Monitoring stations were established in Galore Creek, More Creek, and Sphaler Creek, as well as reference stations in the Scud and Iskut watersheds. Watersheds that were monitored ranged in size from 3.3 to 876 km².

A regional hydrological analysis was undertaken to derive values of key hydrological parameters for the study area; namely, annual runoff totals, monthly flows, flood flows and low flows. The regional assessment used available data from Water Survey of Canada monitoring stations, combined with the field data collected during 2004 and 2005. In addition, UBC Watershed Models were developed for More Creek and Galore Creek in order to better understand runoff generating process and to make estimates of the relative contributions of snow-melt, rain-fall, glacial melt and groundwater to the annual flow hydrograph.

Based on data provided from the extensive baseline hydrological monitoring program, UBC Watershed modelling, and comprehensive regional assessment of hydrological conditions in north-western British Columbia; estimates of the key hydrological parameters of the Galore Creek Project area were obtained. A summary of the results are provided in Tables 1 to 4.

A number of Appendices are also included that describe additional studies undertaken in support of the main hydrological work component. Appendix 1 describes an assessment of sediment transport rates within the study area. Appendix 2 provides quantitative estimates of the potential impact of climate change on precipitation, temperatures and runoff for the study area based on results of the UBC Watershed Model run using global climate model predictions. A description of the development of UBC Watershed Models of Galore Creek and More Creek is provided as a separate report.

Table 1
Key Hydrological Parameters of the Galore Creek Area: Annual Runoff

Return Period	Annual Runoff (mm)					
	Galore Creek at the Mout)	More Creek at the Mouth	Sphaler Creek at the Mouth)	Porcupine River at the Mouth	Scud River at the Mouth	Iskut River at the Mouth
1 in 100 dry year	1590	1380	1620	1580	1590	1060
1 in 50 dry year	1660	1420	1720	1670	1680	1120
1 in 20 dry year	1780	1490	1810	1760	1770	1180
1 in 10 dry year	1920	1580	1930	1880	1880	1290
1 in 5 dry year	2060	1660	2060	2010	2020	1390
Average	2340	1820	2320	2260	2270	1580
1 in 5 wet year	2620	1980	2580	2510	2520	1760
1 in 10 wet year	2760	2060	2710	2640	2650	1860
1 in 20 wet year	2900	2150	2830	2760	2770	1970
1 in 50 wet year	3020	2220	2920	2850	2860	2030
1 in 100 wet year	3090	2260	3020	2940	2950	2090

Table 2
Key Hydrological Parameters of the Galore Creek Area: Estimated Mean Monthly Flow

	Mean Monthly Flow (m ³ /s)											
	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec
Galore Creek at the mouth	1.3	1.3	1.3	2.6	10.3	23.2	29.7	27.1	16.8	10.3	3.9	1.3
More Creek at the mouth	6.1	6.1	6.1	12.1	48.5	115	146	115	72.8	48.5	18.2	12.1
Sphaler Creek at the mouth	2.9	2.9	2.9	5.8	23.1	52.0	66.4	60.6	37.5	23.1	8.7	2.9
Iskut River at the mouth	56.8	56.8	56.8	170	511	1,080	1,190	1,020	682	511	227	114
Scud River at the mouth	9.6	9.6	9.6	19.1	86.1	201	210	163	105	76.5	28.7	19.1
Porcupine River at the mouth	6.4	6.4	6.4	12.7	57.3	134	140	108	70	50.9	19.1	12.7

**Table 3
Key Hydrological Parameters of the
Galore Creek Area: Peak Flows**

Watershed	Watershed Area (km ²)	Q ₂ (m ³ /s)	Q ₁₀ (m ³ /s)	Q ₁₀₀ (m ³ /s)
Galore Creek at the mouth	145	110	170	300
More Creek at the mouth	876	330	640	1280
Sphaler Creek at the mouth	327	200	320	560
Iskut River	9400	2630	4150	9200
Scud River	1130	500	800	1410
Porcupine River	740	370	580	1030

**Table 4
Key Hydrological Parameters of the Galore Creek Area: Low Flows**

Flow Estimate	Annual 7-Day Low Flow	Jun-Sep 7-Day Low Flow	Annual 7-Day Q ₁₀	Jun-Sep 7-Day Q ₁₀
Galore Creek at its mouth	0.77	10.7	0.48	6.04
More Creek at its mouth	4.84	41.4	3.46	20.2
Sphaler Creek at its mouth	1.51	19.1	0.96	11.0
Iskut River	46.8	404	33.0	2.61
Scud River	4.90	52.6	3.25	31.3
Porcupine River	3.35	37.9	2.19	22.3

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1. INTRODUCTION



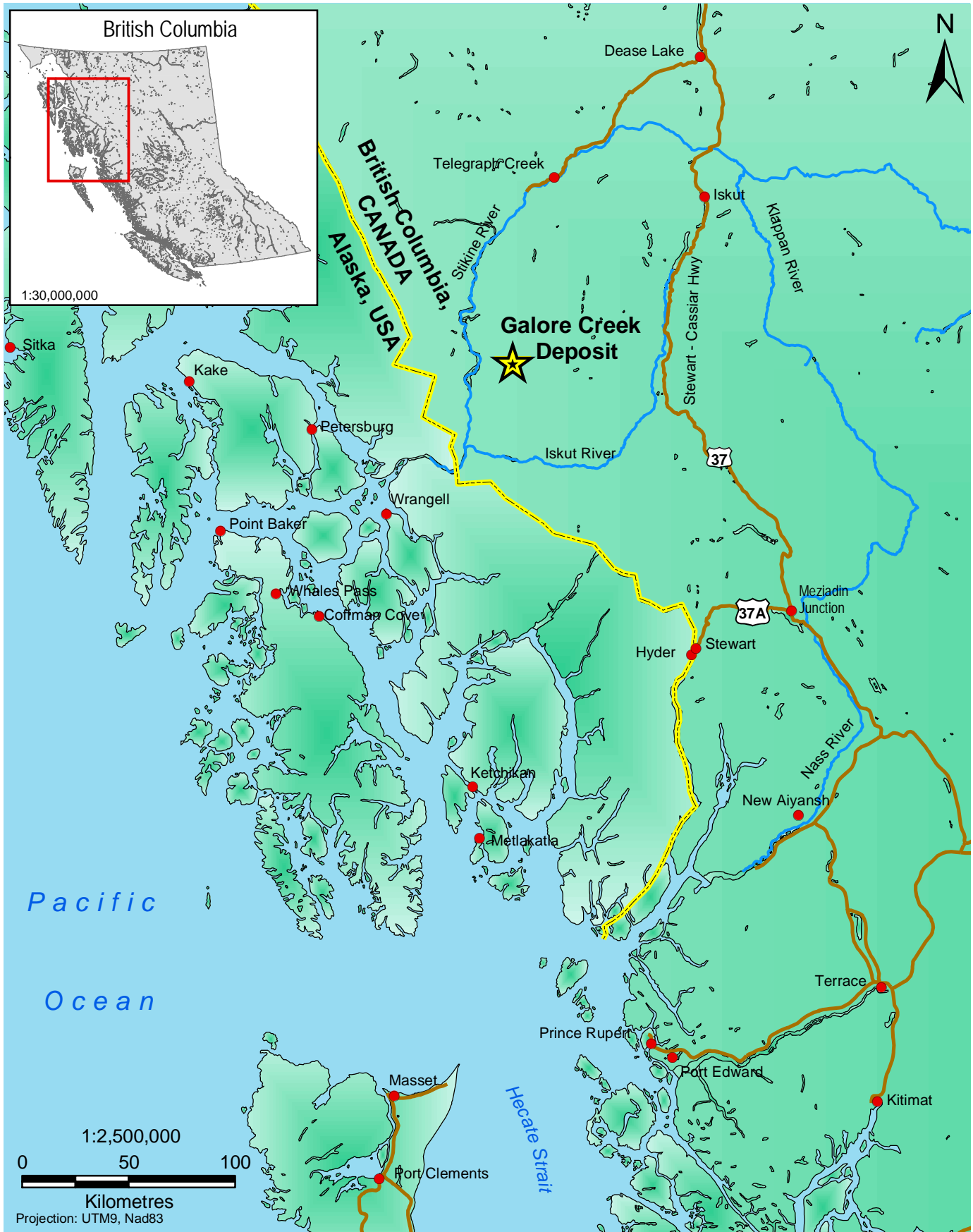
1. Introduction

The Galore Creek Project is located within the Coast Mountains in northwestern British Columbia, approximately 260 km northwest of Stewart (Figure 1-1). This region has steep and rugged topography, characterized by high annual snowfall and precipitation. Many watersheds in the area also have glaciers within their headwaters. These physical and meteorological conditions result in very high annual runoff rates and high average stream flows. Due to large fish and wildlife populations, abundant riparian habitat and traditional uses of the river systems, surface water flows are an important resource both locally and regionally. In addition, due to high runoff rates, water management is a critical issue for mine plan development and during the operation of the mine.

This report describes the hydrological baseline conditions within the Galore Creek watershed and within other, neighbouring watersheds likely to be impacted by the mine site development and the access corridor to the mine. The report provides results of an extensive field monitoring program, as well as a review of available long-term hydrological datasets for rivers close to the study area. The data are used to prepare estimates of key hydrological parameters (e.g. mean annual flow, monthly flows, flood flows) that describe hydrological conditions within the study area for use in the EIA and to assist in engineering design. The main body of the report is divided into three sections:

- Description of the hydrological setting of the project site;
- Summary of field data collection program; and
- Analysis of available regional hydrological datasets and derivation of hydrological parameters

The report also includes Appendices that describe additional studies undertaken in support of the main hydrological work component. Appendix 1 describes an assessment of sediment transport rates within the study area. Appendix 2 provides quantitative estimates of the potential impact of climate change on precipitation, temperatures and runoff for the study area based on results of the UBC Watershed Model. Descriptions of the development of UBC Watershed Models of Galore Creek and More Creek are provided as a separate report.



Location Map for Galore Creek Project

FIGURE 1-1



2. HYDROLOGICAL SETTING

2. Hydrological Setting

This section provides some general statements about the hydrological regime within the study area, discusses the main flow generating processes and outlines available data sources.

The Galore Creek Project is located within the coastal mountains of northwestern British Columbia (Figure 1-1). The proposed mine site is situated at an elevation of 600 m within the Galore Creek watershed, a tributary of the Scud River. The proposed access road to the mine site follows the course of More Creek, a tributary of the Iskut River, and also impacts the headwaters of the Porcupine River (Sphaler Creek and Scotsimpson Creek). All these rivers eventually join the Stikine River, one of the major river systems of British Columbia, which drains into the Pacific Ocean, near Wrangell, Alaska. The location of the key watersheds and the main river systems potentially impacted by the mine development are shown in Figure 2-1. Key characteristics of the main watersheds considered in this assessment are provided in Table 2-1.

**Table 2-1
Key Characteristics of Main Study Watersheds**

Watershed	Area (km²)	Maximum Elevation (m)	Glacier Coverage (%)	River is Tributary of	Project Impact
Galore	145	2350	25	Scud River	Proposed mine site, including waste rock and tailings facilities located within the Galore Creek watershed
More	876	2555	30	Iskut River	Access corridor for mine site to pass through More Creek watershed
Sphaler	327	2660	43	Porcupine River	Access corridor for mine site to pass through Sphaler Creek watershed
Scotsimpson	49	2,240	21	Porcupine River	Access corridor for mine site to pass through Scotsimpson watershed
Scud	1,107	2900	21	Stikine	No direct impact
Iskut	9,450	2555	13	Stikine	No direct impact
Porcupine	740	2660	18	Stikine	No direct impact
Stikine	51,593	-	-	-	No direct impact

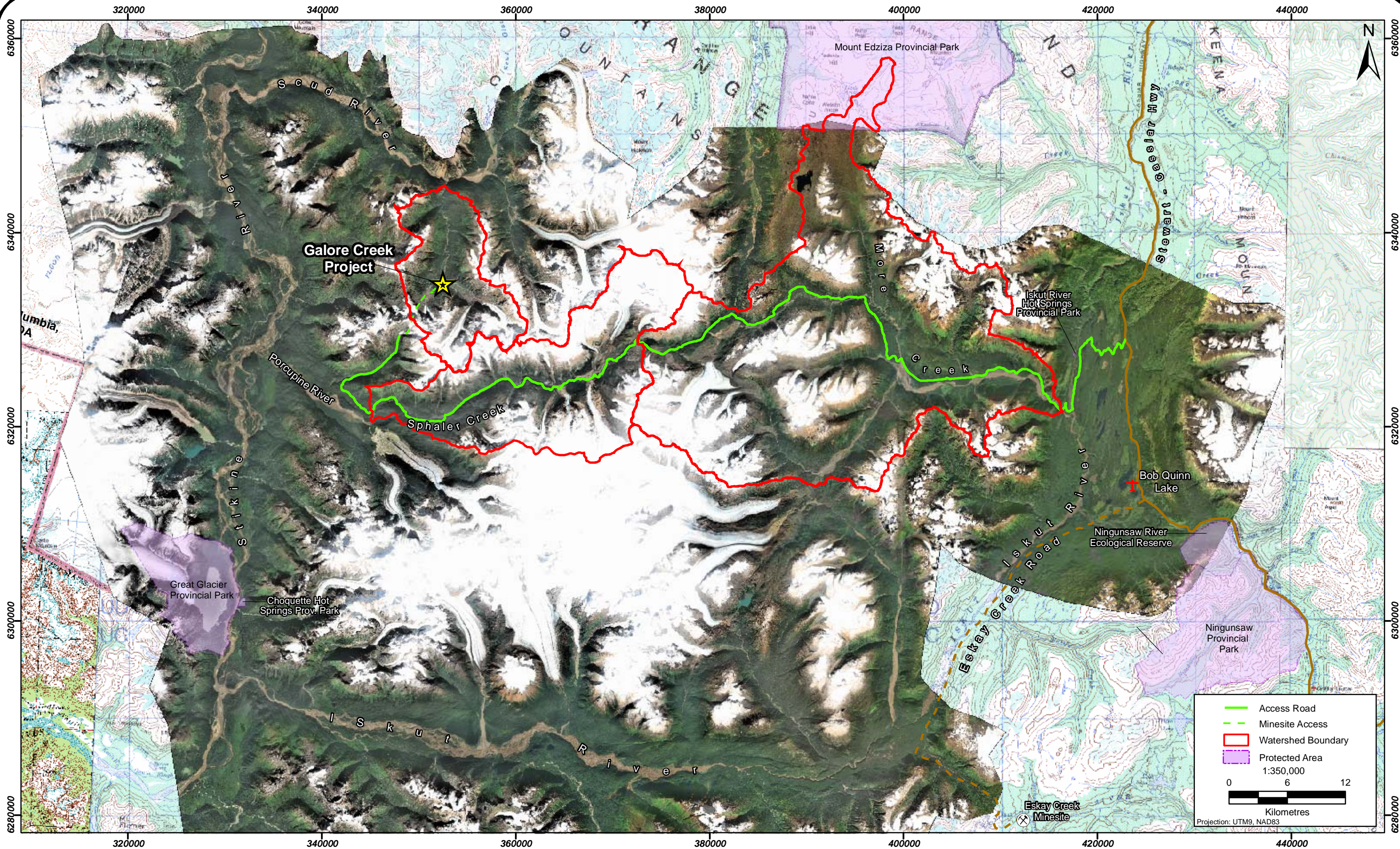
Plates 2-1 to 2-4 provide views of the main watersheds and illustrate the physiography of the study area. Galore Creek, More Creek, Sphaler Creek and Scotsimpson Creek lie within steep mountainous watersheds. These are high energy environments, dominated by braided and gravel-bed rivers. A relatively large proportion of the watershed areas are covered by glaciers and permanent snow and ice patches. The watersheds are characterised by high runoff rates producing potentially high discharge rates and stream flow velocities. The larger Scud, Iskut and Porcupine Rivers are large gravel-bed rivers, which lie within wider but still steep-sided valleys.



Plate 2-1 East Fork, Upper Galore Valley, view from above exploration camp looking south-east.



Plate 2-2 Three valley junction along More Creek, view looking south.



Major Rivers and Watersheds Near the Galore Creek Project



Plate 2-3 Icebergs in Porcupine Lake, headwaters of the Porcupine River, view looking towards Porcupine Glacier.



Plate 2-4 A bend along the Stikine River; view looking north near Great Glacier, between the Porcupine and Iskut Rivers.

A typical hydrological year for watersheds in the study area can be divided into four main flow periods:

- Winter – characterized by ice covered streams with low to negligible stream flow, depending on the elevation of the stream and watershed area;
- Spring/freshet – characterized by high flows due to snowmelt. This can be the period which contains the annual peak flow;
- Summer – characterized by steady, moderate to high flows supplied by rainfall, melt water from residual snow patches and glacial melt water. Flows influenced by glacial melt are characterized by diurnal variations reflecting the impact of temperature on glacial melting rates. Rainstorms can result in short-term flow peaks;
- Fall – characterized by generally moderate to low flows, but interrupted by rain fed storm events, which can have peak flows in excess of freshet flows. The most extreme flood events typically occur during this period.

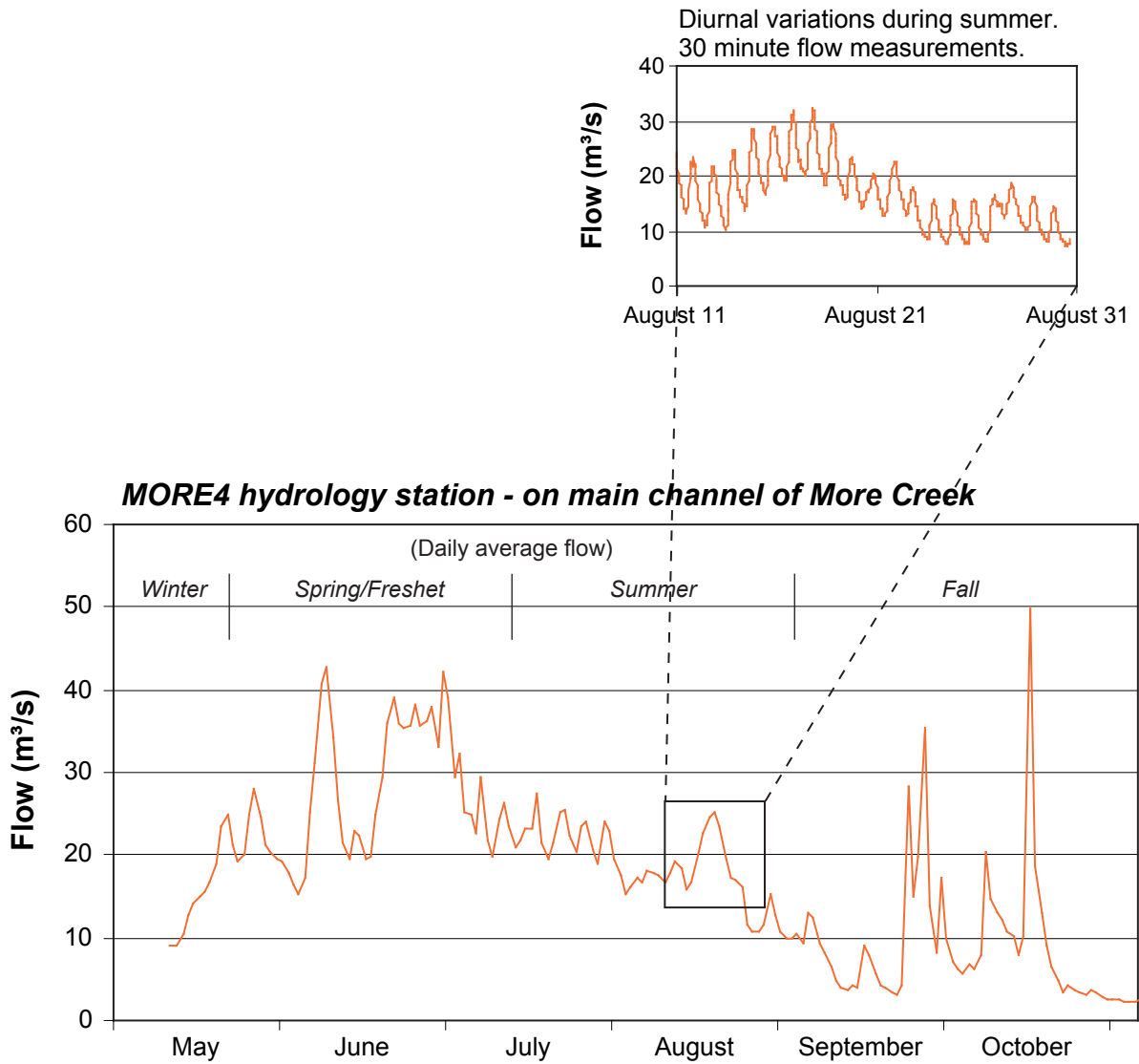
A typical annual flow hydrograph for the study area is illustrated in Figure 2-2.

The project area lies in a transition zone between the very wet coastal region and the drier interior of British Columbia. The regional hydroclimate of northwestern British Columbia is dominated by weather systems generated from the Pacific Ocean, and is also strongly influenced by orographic effects caused by the local mountainous topography. This results in complex interactions between incoming weather systems and local topography that produce a high degree of spatial variability in snowfall and precipitation. Local topography also has an influence in controlling temperatures and the rate and timing of snowmelt. In addition, the presence of large glaciated areas can impact snowmelt rates and produce high runoff volumes during summer months.

Due to the number of competing runoff generating processes and their varying spatial and temporal influences on stream flow hydrographs, the hydrological regime of the region is very dynamic, temporally and spatially variable, and difficult to predict. Examples of variation in the shape of the annual flow hydrograph are provided in Figure 2-3, from the historical time series data for More Creek Water Survey of Canada hydrology station.

Any hydrological assessment is dependant on the quality and quantity of available historical meteorological and stream flow data relevant to the study area. Due to the mountainous topography and the distance from large population centres, there are only a limited number of meteorological and hydrological monitoring stations in northern British Columbia.

In British Columbia, meteorological stations are operated by Environment Canada. The location of key stations close to the proposed mine site are shown in Figure 2-4 and details of each station are outlined in Table 2-2. A more detailed discussion of the meteorological data is provided in the Meteorology, Air Quality and Noise Baseline Report.

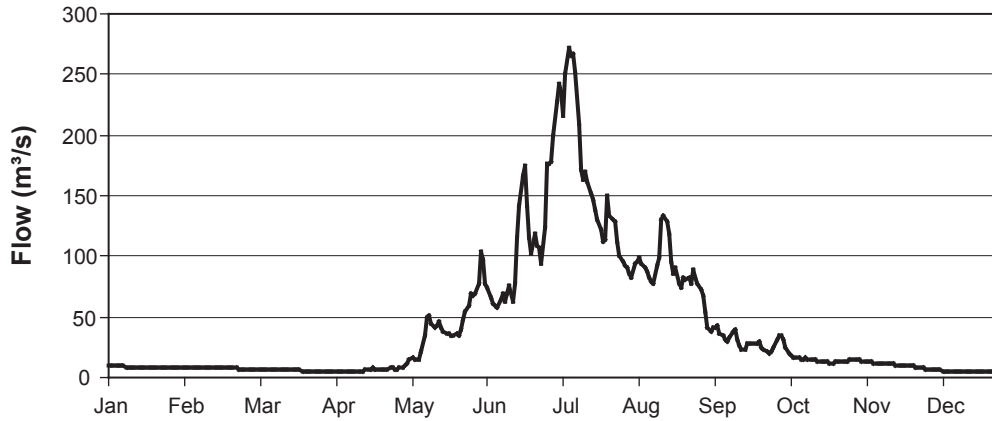


Schematic of Typical Annual Flow Hydrograph for North-Western B.C.

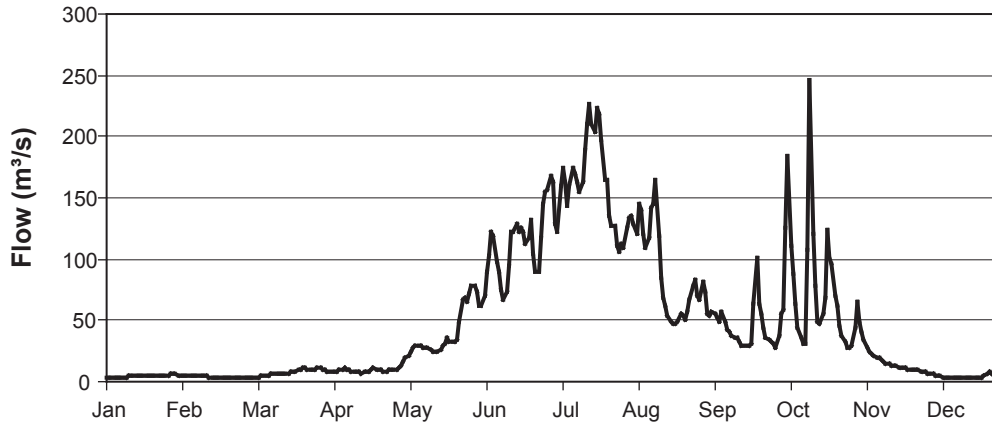
FIGURE 2-2



A - More Creek WSC 1975: high freshet flows, limited flow in fall



B - More Creek WSC 1986: high flows in freshet flows and fall



C - More Creek WSC 1994: low freshet flows, high flow in fall

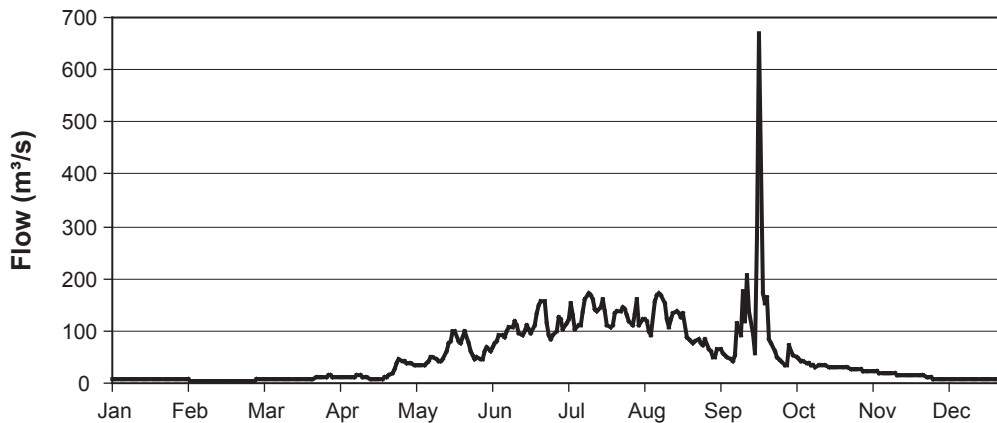
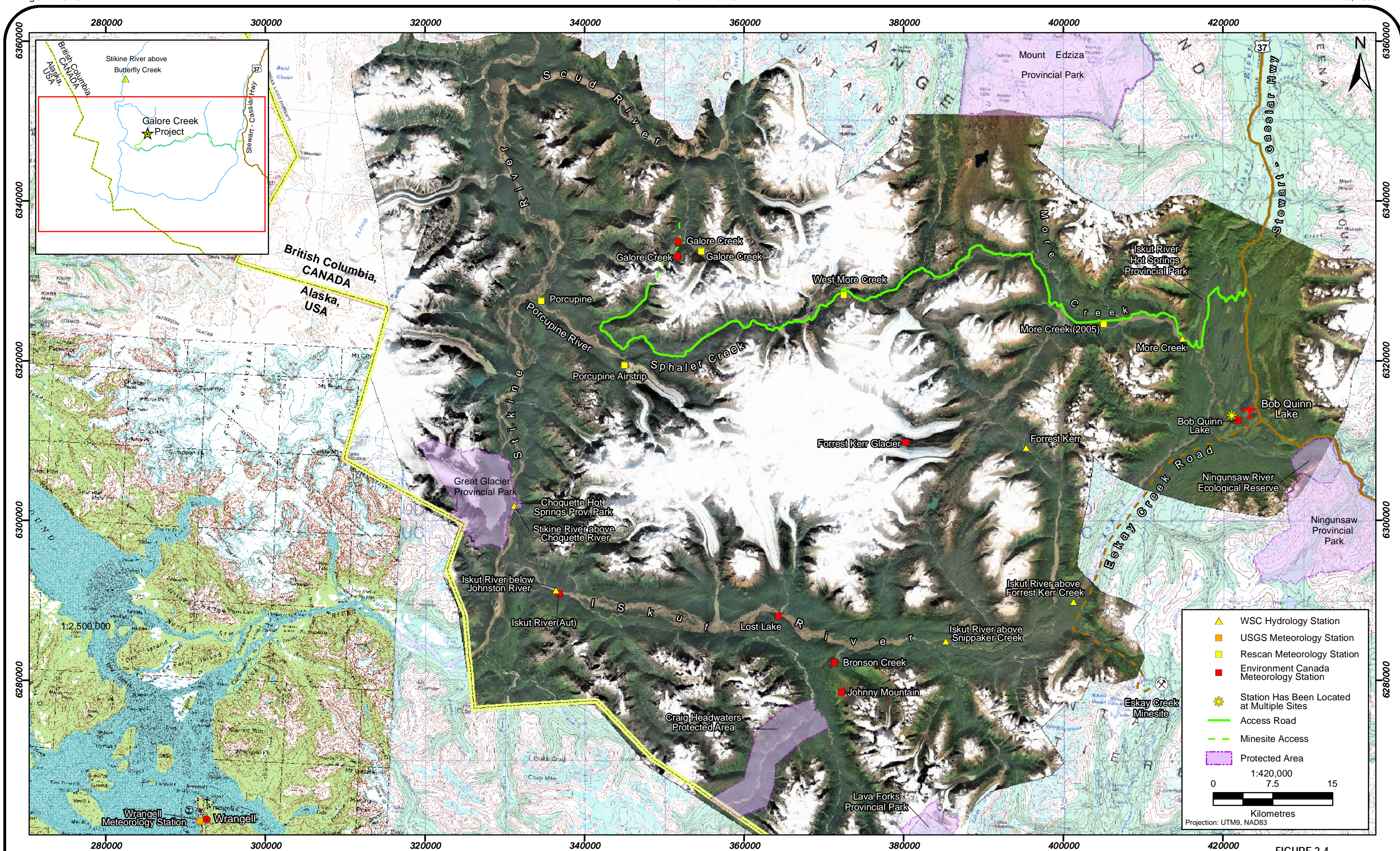


FIGURE 2-3

**Annual Hydrographs for More Creek WSC Station
showing Range of Hydrological Processes**





▲ WSC Hydrology Station
 ■ USGS Meteorology Station
 ■ Rescan Meteorology Station
 ■ Environment Canada Meteorology Station
 ★ Station Has Been Located at Multiple Sites
 — Access Road
 - - Minesite Access
 ■ Protected Area
 1:420,000
 0 7.5 15
 Kilometres
 Projection: UTM9, NAD83

Regional Hydrological and Meteorological Stations

FIGURE 2-4

**Table 2-2
Summary of Regional Hydrometric and Meteorological Stations**

Station Name	Monitoring Organization	Station ID	Watershed Area (km²)	Years of Operation
<u>Hydrometric Stations</u>				
Stikine above Butterfly	WSC	08CF001	36,000	1971 - 1995
Stikine at Telegraph Creek	WSC	08CE001	29,300	1954 - present
Iskut below Johnson	WSC	08CG001	9,350	1959 - present
Iskut above Snippaker	WSC	08CG004	7,230	1966 - 1995
Iskut at Kinaskan	WSC	08CG003	1,250	1964 - 1996
Bear	WSC	08DC006	289	1976 - present
Forrest Kerr	WSC	08CG006	312	1972 - 1994
Kispiox	WSC	08EB004	1,870	1963 - present
Lime	WSC	08DB010	40	1976 - present
Lindeman	WSC	09AA010	250	1954 - 1993
More	WSC	08CG005	844	1971 - 1994
Nass	WSC	08DB001	18,500	1949 - present
Patsy	WSC	08DB012	6	1987 - present
Sloko	WSC	08BB002	427	1954 - 1979
Surprise	WSC	08DA005	220	1967 - present
Klappan	WSC	08CC001	3,540	1962 - 1996
Unuk	WSC	08DD001	1,480	1957 - present
Harding	USGS	15022000	175	1951 - 2002
Stikine near Wrangell	USGS	15024800	51,593	1976 - 2002
Cascade	USGS	15026000	60	1917 - 1973
Farragut	USGS	15028300	391	1977 - 1994
Skagway	USGS	15056100	376	1963 - 1986
<u>Meteorology Stations</u>				
Unuk River	EC	1078L3D	-	1989 - Present
Stewart	EC	1067742	-	1974 - Present
Bob Quinn Lake	EC	1200R0J	-	1977 - Present
Echo Lake	EC	1202635	-	1923 - 1924
Forrest Kerr Glacier	EC	1072900	-	1979 - 1984
Galore Creek	-	1203046	-	1966 - 1968, 1973
Iskut River	EC	120C6PK	-	1991 - Present
Johnny Mountain	EC	120CPNA	-	1988 - 1992
Lost Lake	EC	120DP19	-	1991

Networks of hydrometric stations in northwest British Columbia are maintained by the Water Survey of Canada (WSC), and stations in Alaska are maintained by the United States Geological Survey (USGS). Stations located close to the study area are listed in Table 2-2 and shown in

Figure 2-4. Only approximately half of the stations are currently in operation. The station at the mouth of More Creek, the site closest to the study area, was in operation from 1971 – 1994.

The major limitation of any hydrological assessment in northwest British Columbia arises from the general lack of historic data within this area. Given the locally variable meteorological and hydrological conditions, the density of stations is insufficient to provide detailed information on the range of regional hydrological processes operating at different scales. Hydrometric stations are almost entirely located on larger river systems (>200 km²), and regional results may not be applicable to smaller watersheds. There is a lack of data for small headwater streams and especially watersheds where runoff is heavily influenced by glacier melt. In order to try overcome these challenges this study undertook an extensive field monitoring program, detailed analysis of available regional datasets and hydrological modelling.

3. FIELD DATA COLLECTION

3. Field Data Collection

3.1 Introduction

An extensive field data collection program was undertaken with the purpose of collecting site-specific hydrological data within watersheds potentially impacted by the mine development. In total, twenty-five flow monitoring stations were constructed and operated over the 2004 and 2005 open water seasons. Eleven stations were installed in the Galore watershed, nine in the More watershed, two in the headwaters of Porcupine River within the Sphaler watershed, and three within reference watersheds. In addition to the monitored stations, a manual flow measurement was also conducted in 2005 on the Porcupine River during approximately bank-full flow conditions.

This section describes the rationale, methodology and results of the monitoring program. In Section 4 the results of the field program are combined with regional data from WSC and USGS stations to calculate key hydrological parameters for the study area.

3.2 Rationale for Monitoring Program

The field monitoring program was designed to collect sufficient on-site hydrological data to allow a description of the hydrological regime of the study area and to provide local data, which could be compared to hydrological parameters (e.g. annual average runoff) derived from regional flow datasets.

For most projects, it is the norm for there to be only limited historical flow data for watersheds impacted by the project development. For watersheds of interest to the present study, WSC undertook flow monitoring at the mouth of More Creek from 1971 – 1994 and there is ongoing monitoring on the Iskut River and the Stikine River. However, there are no flow records for the other key watersheds. In northwestern British Columbia is general there is a low density of WSC monitoring stations, especially given the expected complexity in hydrological response across the region due to a large regional precipitation gradients, mountainous topography and glaciated watersheds. Information on flows in small glaciated watersheds is particularly lacking in regional stream flow datasets.

Hence, the current project required the construction and operation of;

- Flow monitoring stations within the key watersheds potentially impacted by the project, including multiple stations within the same watersheds, to provide information on local hydrological variability; and
- Reference stations to provide baseline data for watersheds not directly impacted by mine development and which could serve as potential long-term monitoring stations if the mine were to go to production.

Monitoring stations were constructed in the Galore, More and Sphaler watersheds. It was not possible or practical to operate stations on the main channels of the Scud, Iskut or Porcupine Rivers, as each has wide, dynamic, braided channels with mobile beds and there were few sites

onto which a station could be securely fastened. However, WSC operates monitoring stations on the Iskut River and data from these sites were obtained for 2004 and 2005. In addition, no suitable location was identified along Scotsimpson Creek.

Multiple stations were constructed within the Galore, More and Sphaler watersheds. Sites chosen included, main channels, main tributaries, headwater streams and canyons crossed by the proposed access road. As well as providing information on sub-watershed hydrological response, the operation of multiple stations provided some redundancy in network design, due to the likelihood of station damage in such a high energy environment.

Three reference stations were constructed on watersheds in the Scud and Iskut River basins. As well as acting as reference sites these stations also provided more information on the hydrology of the Scud and Iskut watersheds.

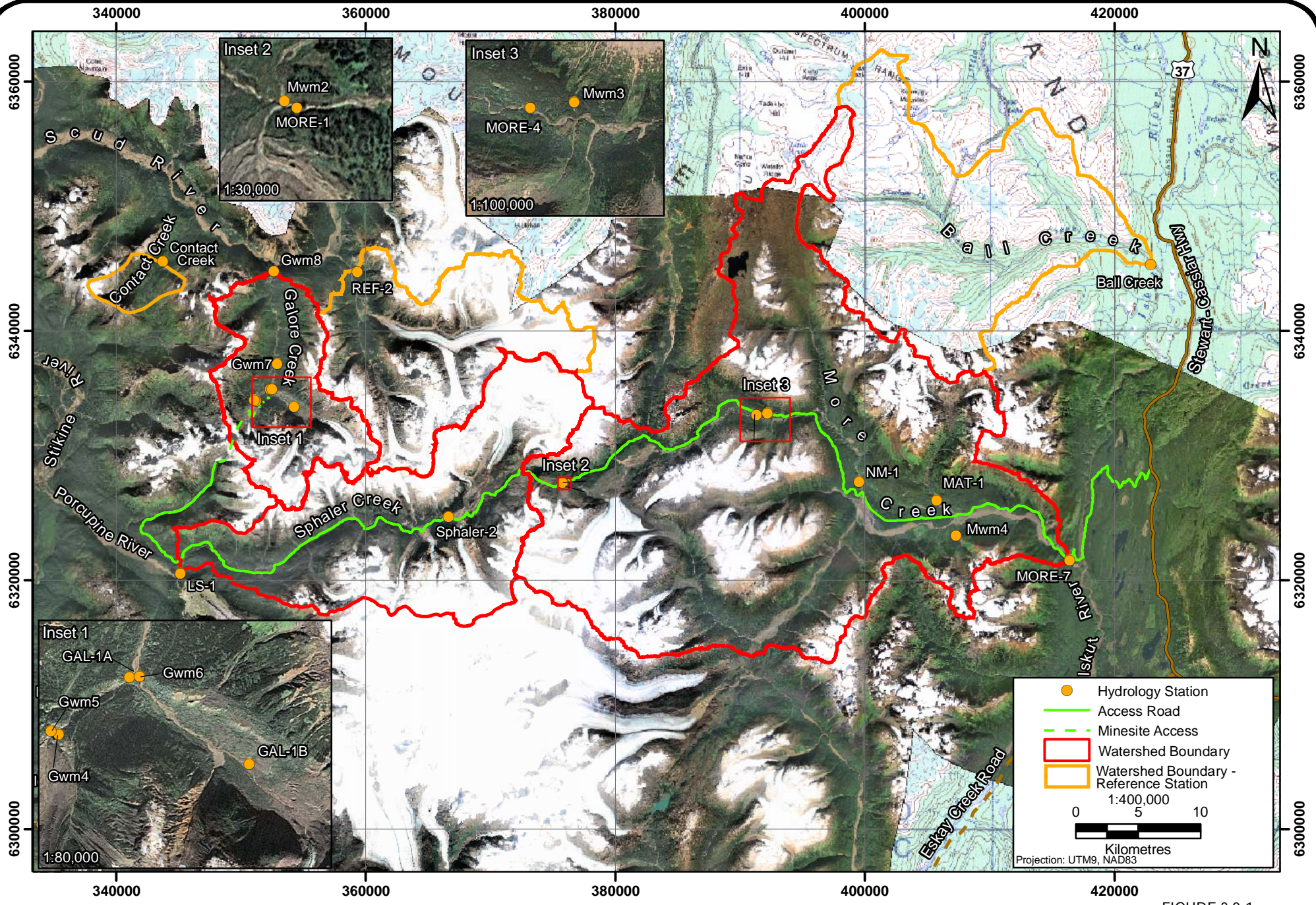
The locations of all the hydrological monitoring stations operated during this study are shown in Figures 3.2-1 to 3.2-4.

3.3 Site Selection

There are a number of factors that make hydrological monitoring on mountain streams particularly challenging, specifically, high flow volumes, high velocities and dynamic channels (*i.e.*, high sediment transport). Site selection for hydrological monitoring requires a balance between locations that are ideal from a hydraulic perspective (*e.g.*, well constrained channel, relatively stable bed, straight channel section, low turbulence) and those which offer security for the station (*e.g.*, bedrock exposure to attach station onto) and for the hydrologist accessing the site and making manual flow measurements. Hence, although channel hydraulics is the primary consideration when selecting a site for a hydrology gauging station, site selection is also determined by practical and safety considerations. Problems in site selection are exacerbated in headwater streams where narrow and steep sided canyons can restrict access, instantaneous flow velocities can be higher resulting in more dangerous flow conditions and mass sediment transport events are possible resulting in damage to the station.

Great care was taken during site selection for each monitoring station. Where possible, sites were located at confined, straight channel sections. In a number of cases, bedrock canyons, provided channel constraint and provided a secure platform to attach the station onto. However, in headwater reaches there were often limited locations that were hydraulically ideal and practical considerations came to the fore. Issues related to site selection and flow measurement on mountain streams were discussed with staff at the Water Survey of Canada. Historically WSC has had difficulty monitoring flows in high gradient streams in British Columbia and there are cases where WSC stations have been destroyed by high freshet flows and rain-driven flood peaks. Due to the difficulties encountered, WSC have stopped their regular programs of flow monitoring in such streams, emphasising the challenges of working in these environments.

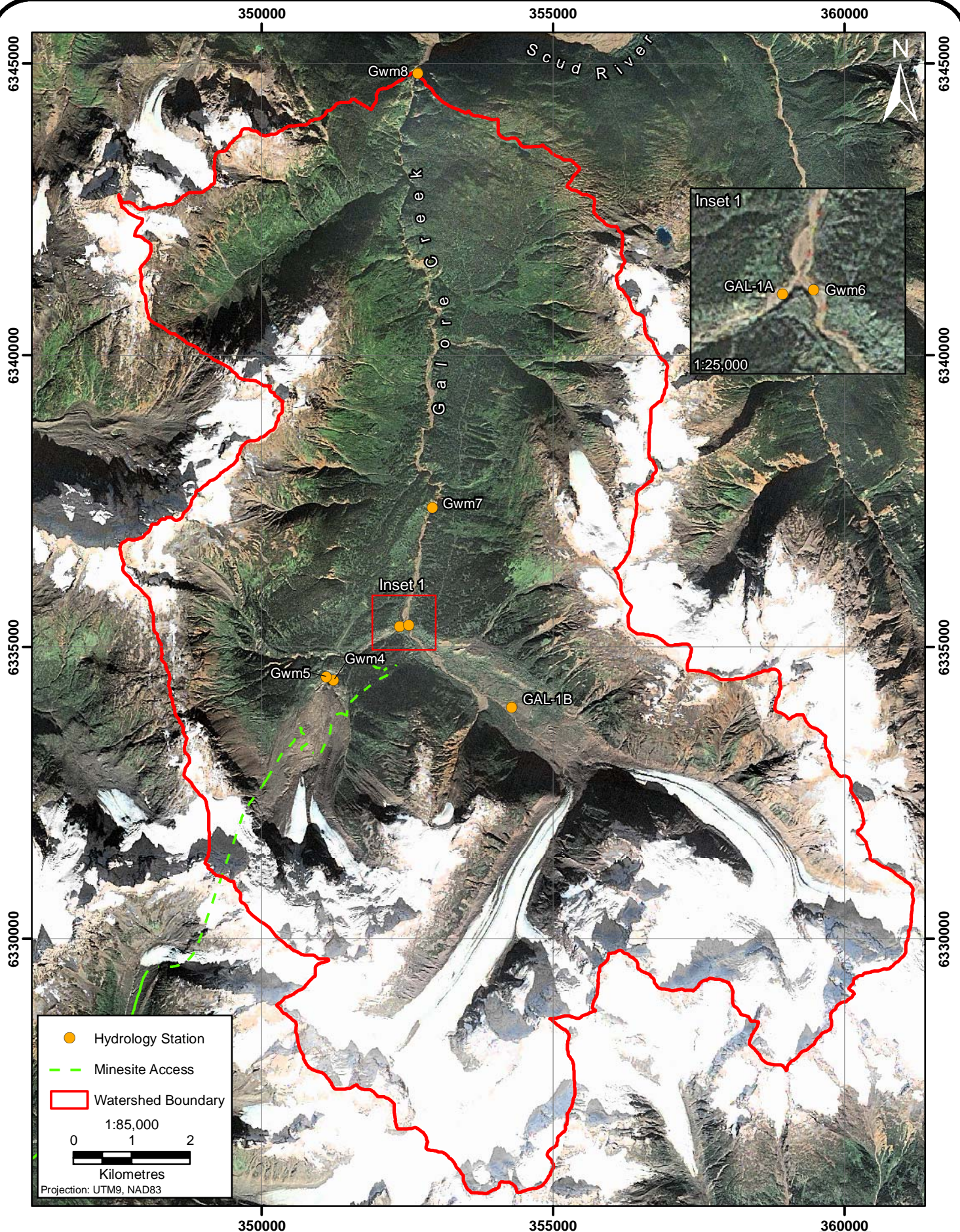
Despite the challenges surrounding site selection, a robust site selection procedure led to the installation of stations at good monitoring locations. A detailed program of manual flow measurement and regular site maintenance enabled the collection of a high quality data set.



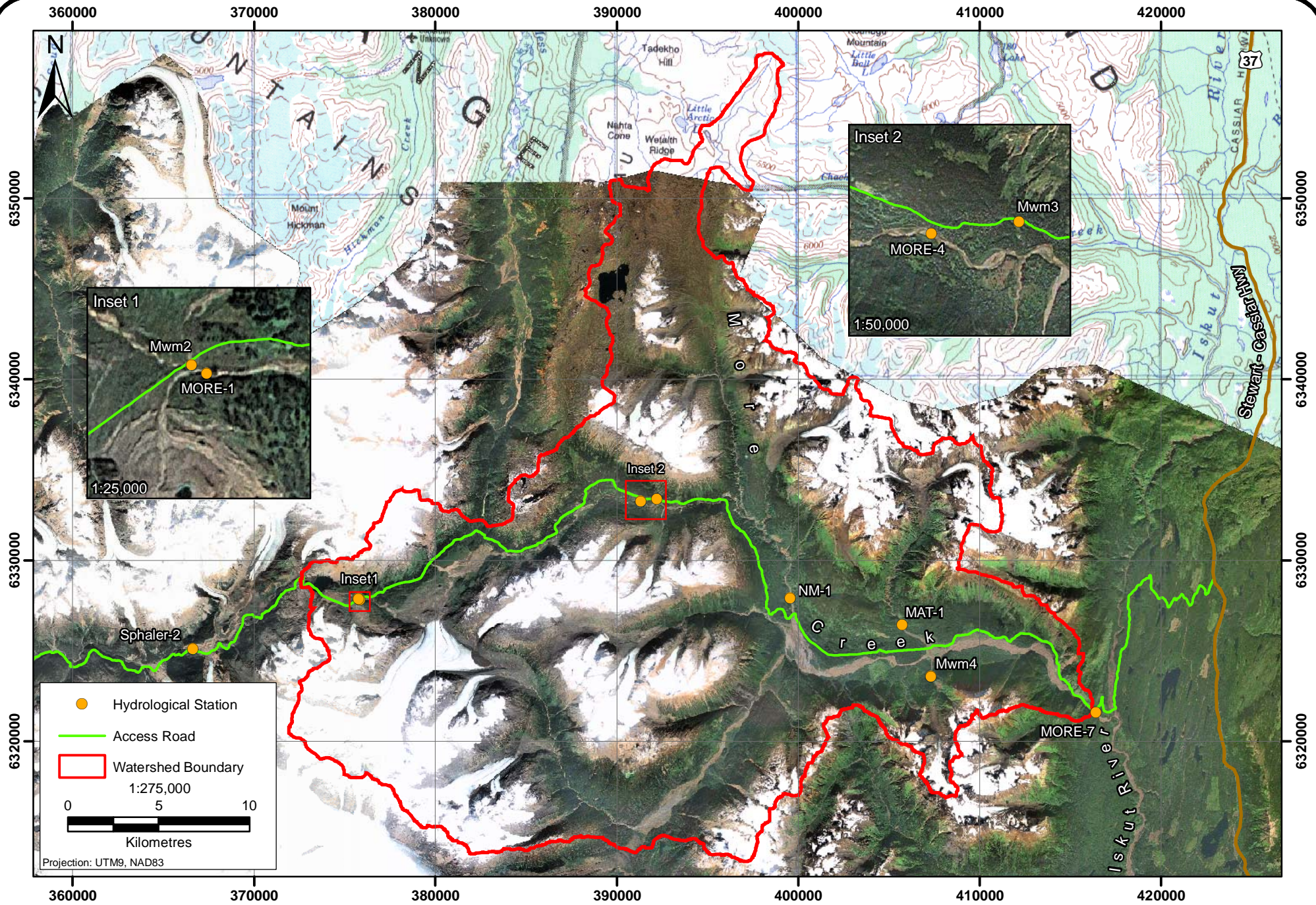
Galore Creek Project: Hydrology Station Network

FIGURE 3.2-1

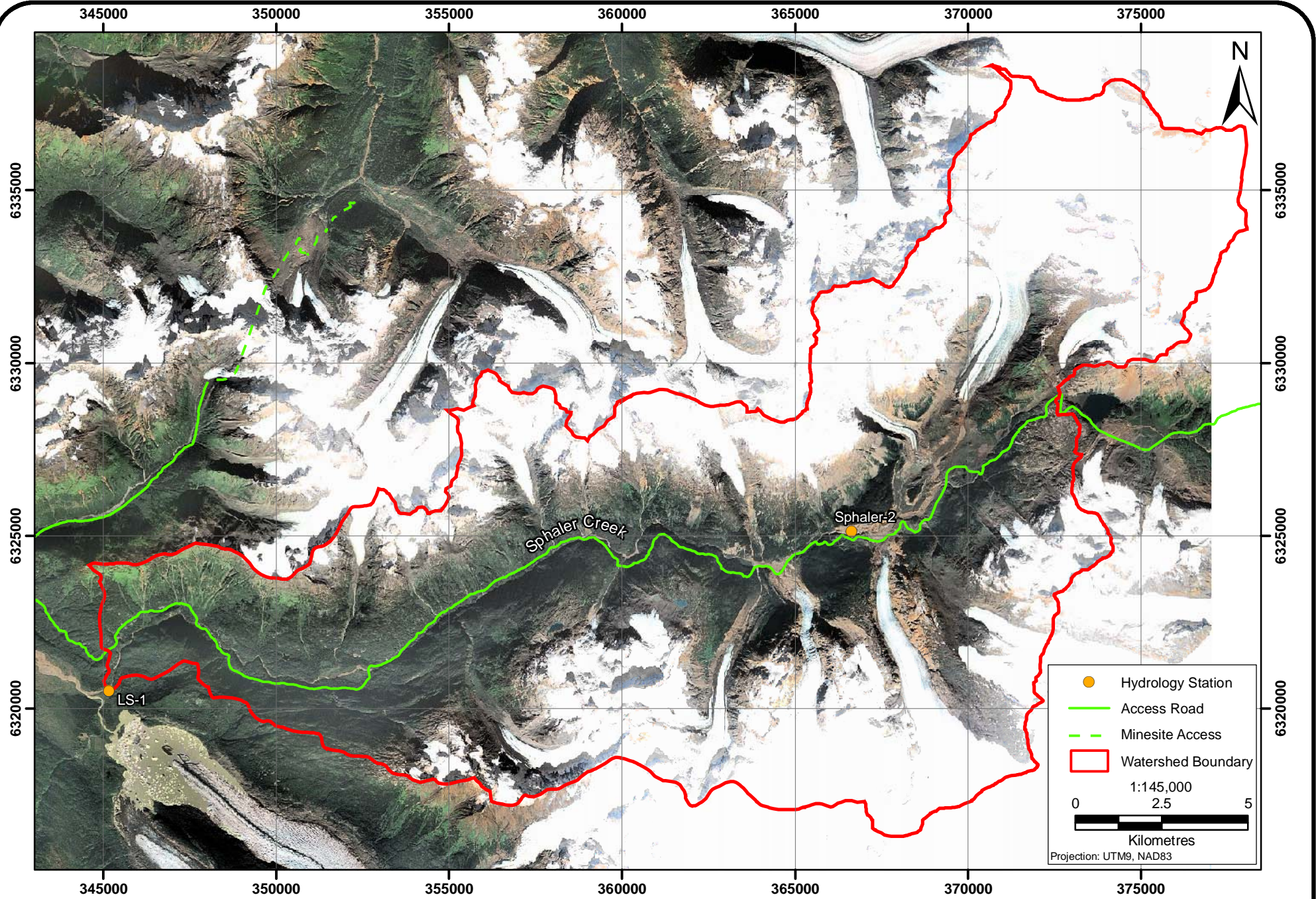




Galore Creek Hydrology Stations



More Creek Hydrology Stations



Sphaler Creek Hydrology Stations

3.4 Methodology

Each hydrological monitoring station consisted of a Terrascience PS9800 pressure transducer, ELF2 data logger and standard WSC staff gauge. The pressure transducers provided a continuous record of water levels at 10 to 30 minute intervals. These components were housed in a robust, secure structure. The pressure transducers and cabling were inserted into a flexible aluminium conduit and one end of the conduit was attached to a piece of angle iron. The end of the angle iron with the tip of the pressure transducer was then placed into the water and the angle iron was bolted onto ¾ inch pieces of threaded rod which were drilled into bedrock (to a depth of at least six inches) and fixed in place with rock epoxy. The data loggers were housed in an aluminium waterproof box situated above the high water mark. A staff gauge was attached to the angle iron to allow for visual measurements of stage. Pressure transducers were installed as deep in the channel as possible to allow for monitoring of low flow conditions. Illustrations of station design are provided in Plate 3.4-1.



Plate 3.4-1 Photographs illustrating hydrology station design.

Survey control points were established at each station in order to compare water level measurements from year to year. During the installation and deactivation of a station, the elevation of the pressure transducer, staff gauge, stream bed, and water level were all surveyed. Channel cross-sections and slope were also surveyed at each site.

The monitoring stations were operated during the open water period (typically May to November) and were decommissioned during the winter months as the Terrascience pressure transducers can be destroyed if frozen in ice. For the 2005 season, two stations at lower elevations were mobilized in April, but other stations were not mobilized until May, or even June, due to snow and ice in the channel. Water level time series recorded at each station can be converted to discharge values using a rating equation (or stage-discharge curve), which relates the observed water levels to stream flows. Rating equations are typically empirical relationships between water depth and discharge generated using a series of manual flow measurements observed over a range of flow conditions. However, flow measurement under high or even moderate flow conditions is often very difficult and dangerous in mountain rivers. Hence, it is common that flow measurements are either lacking or absent at sites with high peak flows and/or steep gradients. In such cases rating equations can be extended through the application of a hydraulic model. The simplest model is the use of Manning's equation for the channel cross-section at the gauging station. However, the use of Manning's equation still requires some flow measurements to calibrate the roughness parameter in the equation (*i.e.*, Manning's n). In addition, Manning's equation is not applicable to all channels and it is not suitable for steep, turbulent headwater streams. In such cases there is no escaping the need for manual flow measurements in order to generate a rating equation.

In total, 152 flow manual measurements were taken during the monitoring program. A number of methods were used to obtain manual flow measurements at each gauging station. Under low to medium flow conditions when it was safe for field personnel to enter the river, flow measurements were made using a hand-held Swoffer gauge. Flow measurements were made by wading while attached to a safety line, or from an inflatable boat attached to a safety line. During each flow measurement, stage was also recorded on the staff gauge and the pressure transducer. In instances when flow was measured when the station was not in operation (*e.g.*, April 2005), stage was calculated based on a level survey of the waterline.

Standard USGS methodologies for manual flow measurements were adopted; current velocities were measured at 60% of the depth of water, as the velocity at this depth is assumed to estimate the mean velocity through a vertical profile at any given location. Typically 20 to 30 measurements were taken across the width of a channel, with the aim of having no one measurement being more than 10% of the total discharge. The accuracy of manual flow measurements is affected by flow and channel conditions at each site, and should be less than 15%.

Under high flow conditions and for channels where high channel velocities made entering the river too dangerous, salt dilution was used as an alternative method for measuring stream flow. Salt dilution is a simple method of calculating flow rates in river systems. A known mass or concentration of common salt (NaCl) is discharged into a stream at a release point some distance upstream of a flow monitoring station. The salt is rapidly diluted with river water due to natural

mixing processes and forms a well-mixed plume that travels downstream. At the monitoring station the conductivity of the stream water is measured and used to calculate the salt loading at that point. The loading at the monitoring station is then compared to the original load released into the river and the amount of dilution that has occurred between the release point and measurement point is a measure of river flow. Comparison of salt dilution and manual flow measurements taken simultaneously at the same location were within 10% of each other. A complete discussion of the salt dilution methodology and a more detailed error analysis are included in Appendix 3.

Due to regulatory concerns over the possible impact of salt on aquatic life, salt dilution was only used on non-fish bearing streams. Hence, at other stations, when stream flow was too dangerous to make manual flow measurements, discharge was estimated either by using a float to measure surface velocity and estimating channel cross-section area, or by making visual estimates of flow based on experience and comparison with salt dilution results made at other stations. The error of these estimates is likely of the order of 50%, and therefore caution needs to be exercised when interpreting results in these situations.

3.5 Results

This section provides a brief description of the results of the hydrological monitoring program. A more detailed discussion of the results is provided in Section 3.6.

3.5.1 Period of Record

The periods of record at each site are summarised in Tables 3.2-1 to 3.2-4. Twenty-two stations were operated during the 2004 open water season. A first group of stations was constructed prior to freshet 2004 and a second group in September 2004. Repairs to some of the original stations were also made through the freshet and summer period as some stations sustained damage during periods of high flow. Adjustments were also made to some stations to address falling water levels during summer months. At five stations (GAL-3, Gwm1, Gwm2, Gwm3, Mwm1) damage curtailed the period of record at each site. These stations were not re-mobilised in 2005. A sensor malfunction occurred at station Gwm8 during September 2004.

For the 2005 open water season, 20 stations were operated; 17 of these were stations that were operated in 2004 and were re-mobilised for 2005. Five of the 2004 stations were abandoned; either due to the likelihood of continued damage to the sites; or because they were superseded by new stations. Three new stations were constructed for the 2005 monitoring season. Only limited station damage occurred during 2005 resulting in a virtually complete set of records for the open water season. However, damage did occur at station Gwm8 early in the monitoring period.

3.5.2 Stage-Discharge Relationships

Manual flow measurements and rating equations for each of the monitoring stations are provided in Appendix 4. Examples of the rating equations for GAL-1A and MORE-4 sites are shown in Figure 3.5-1.

**Table 3.2-1
Hydrological Monitoring Stations, Galore Creek**

¹ Station	Monitoring Location	Watershed Area (km ²)	Monitoring Period	Location (Easting m; Northing m)	Purpose
GAL-1A	Galore Creek near East Fork Confluence	24.4	May 10 2004 - Nov 10 2004; May 22 2005 - Oct 22 2005	352309; 6335284	Monitoring flows from the western tributary of Galore Creek, near the headwaters. This tributary will contain the proposed mine site
GAL-1B	Upper East Fork	52.4	May 11 2004 - Nov 8 2004; May 22 2005 - Aug 9 2005	354361; 6333792	Monitoring flows from the eastern tributary of Galore Creek (East Fork), near the headwaters. This tributary contains the two major glaciated areas of the Galore watershed
Gwm4	Headwaters - Galore	3.3	Sep 16 2004- Nov 9 2004; May 18 2005 – Oct 23 2005	351294; 6334528	Monitoring flows on headwater stream within Galore Creek. Stream is glacier-fed and upstream of proposed mine site
Gwm5	Headwaters - Galore	10.8	Sep 8 2004 - Nov 4 2004; May 17 2005 - Oct 23 2005	351159; 6334426	Monitoring flows on headwater stream within Galore Creek. Stream is glacier-fed and upstream of proposed mine site
Gwm6	East Fork near Galore Confluence	61.3	Sep 13 2004 - Nov 10 2004; May 21 2005 - Oct 23 2005	352538; 6335375	Monitoring flows from the eastern tributary of Galore Creek (East Fork), near the headwaters. Station is located just upstream of the confluence with Galore Creek and downstream of GAL-1B.
Gwm7	Upper Galore Creek	93.3	Sep 16 2004 - Nov 9 2004; May 17 2005 - Oct 22 2005	352736; 6336700	Monitoring flows on the main channel of Galore Creek, near the mid-point of the watershed.
Gwm8	Galore Creek at mouth	144.9	Sep 15 2004 - Sep 23 2004; Apr 18 2005 - Oct 22 2005	352583; 6344800	Monitoring flows at the mouth of Galore Creek, upstream of the confluence with the Scud River

¹Note stations Gwm1, Gwm2 and Gwm3 were constructed in fall 2004 in the headwaters of Galore Creek. However, the stations were destroyed by high flows soon after construction. Due to the likelihood of further damage the stations were not re-mobilised during the 2005 season. Also, GAL-3 was installed in May of 2004, but was damaged during high flows in the summer of 2004. In 2005, GAL-3 was not installed due to unsafe flow conditions at the time of installation. The station was superseded by Gwm7.

**Table 3.2-2
Hydrological Monitoring Stations, More Creek**

¹ Station	Monitoring Location	Watershed Area (km ²)	Monitoring Period	Location (Easting m; Northing m)	Purpose
MORE-1	More Creek headwaters near Round Lake	20.8	May 8 2004 - Nov 7 2004; May 17 2005 - Oct 27 2005	375930; 6327825	Monitoring flows on the main channel of More Creek, near the headwaters.
MORE-4	More Creek upstream of middle canyon	163	May 11 2004 - Nov 7 2004; May 21 2005 - Oct 26 2005	391330; 6333312	Monitoring flows on the main channel of More Creek, near the mid-point of the watershed.

(continued)

**Table 3.2-2
Hydrological Monitoring Stations, More Creek (completed)**

¹ Station	Monitoring Location	Watershed Area (km ²)	Monitoring Period	Location (Easting m; Northing m)	Purpose
MORE-7	More Creek at mouth	876	May 11 2004 - Nov 6 2004; Apr 18 2005 – Oct 26 2005	416457; 6321615	Monitoring flows on the main channel of More Creek, at its mouth. The station is located at the site of the old More Creek WSC gauging station
Mwm2	Headwaters of More Creek	3.4	Sep 17 2004 - Nov 8 2004; Jun 5 2005 - Oct 27 2005	375802; 6327872	Monitoring flows on a small watershed in the headwaters of More Creek. Proposed access road crosses the creek upstream of gauging station
Mwm3	Small tributary in west More Creek	6.2	Sep 19 2004 - Nov 8 2004; May 21 2005 - Oct 26 2005	384157; 6333486	Monitoring flows on small tributary of More Creek, to provide information on peak flows on stream potentially impacted by construction of access road
Mwm4	Tributary in lower More Creek	13.4	Sep 20 2004 - Nov 6 2004; Jun 6 2005 - Oct 26 2005	407316; 6323593	Monitoring flows on small tributary of More Creek, to provide information on peak flows on stream potentially impacted by construction of access road
NM-1	More Creek – middle	397	Jun 8 2005 - Oct 26 2005	399693; 6327926	Monitoring mid-point of More Creek
MAT-1	Matthew Creek - Medium sized tributary in Lower More Creek	73.5	Jun 7 2005 - Oct 26 2005	405759; 6326447	Monitoring flows on Matthew Creek (main tributary of More Creek). Proposed access road crosses the creek upstream of gauging station

¹ Mwm1 was constructed in fall 2004 in the headwaters of More Creek. However, the station was destroyed by high flows soon after construction. Due to the likelihood of further damage the station was not re-mobilised during the 2005 season

**Table 3.2-3
Hydrological Monitoring Stations, Sphaler Creek**

Station	Monitoring Location	Watershed Area (km ²)	Monitoring Period	Location (Easting m; Northing m)	Purpose
Sphaler-2	Upper Sphaler Watershed	142	May 7 2004 - Nov 8 2004; May 22 2005 - Oct 27 2005	366583; 6325072	Monitoring flows in upstream reach of Sphaler Creek
LS-1	Mouth of Sphaler Creek	327	Jun 5 2005 -Oct 27 2005	346299; 632081	Monitoring flows at mouth of Sphaler Creek, near confluence with Porcupine River

**Table 3.2-4
Hydrological Monitoring Stations, Reference Stations**

Station	Monitoring Location	Watershed Area (km²)	Monitoring Period	Location (Easting m; Northing m)	Purpose
Contact Creek	Near mouth of Contact Creek	25.3	Jun 29 2004 - Nov 5 2004; May 21 2005 - Oct 22 2005	345629; 6348055	Monitoring flows on reference watershed located immediately to the west of Galore Creek.
Reference Creek	Mouth of Reference Creek	216	May 10 2004 - Nov 8 2004; May 19 2005 – Oct 22 2005	358897; 6345045	Monitoring flows on reference watershed located immediately to the east of Galore Creek.
Ball Creek	Mouth of Ball Creek	356	May 11 2004 - Nov 6 2004; May 21 2005 - Oct 20 2005	423023; 6345325	Monitoring flows on reference watershed located immediately to the north of More Creek.

Due to the limited amount of data, the rating curves for most sites were calculated using stage and discharge data from 2004 and 2005 combined. However, at GAL-1A, the station location was changed in 2005, and therefore separate rating curves were calculated for each year. Where there was sufficient data the rating equations were based on best-fit curves through the data. For sites with more limited data a rating curve was calculated using Manning’s equation, with the value of Manning’s n calibrated using the available stage and discharge data points, and using best judgement.

There are a number of sources of error in the development of rating equations for each monitoring station:

- Error in flow measurement. Likely to be around ± 5 to 15% for measurements made using Swoffer gauge and salt dilution. The error is higher for flow estimates made using the surface velocity method and is estimated to be $\pm 50\%$. The relevant error bars are shown on the rating curve figures.
- Error in stage measurement. Water level oscillations at the gauge site due to turbulence or wind waves result in some error in reading the staff gauge during manual flow measurement. Although care was taken to install stations at sites with limited turbulence this was not always possible. Errors are likely to be of the order of ± 1 to 3 cm depending on field conditions at the time of measurement.
- Due to high sediment transport rates there is the likelihood of changes to the channel cross-section over time. Where possible stations were located at sites with well-confined channels and it had to be assumed that the channels were in a steady-state with erosion being balanced by deposition. However, changes in channel form are possible within a hydrological year and from year to year, producing error in the rating equation. For example, inconsistent data in 2005 at MORE-7 was likely due to changes in bed form at that location during freshet flows.

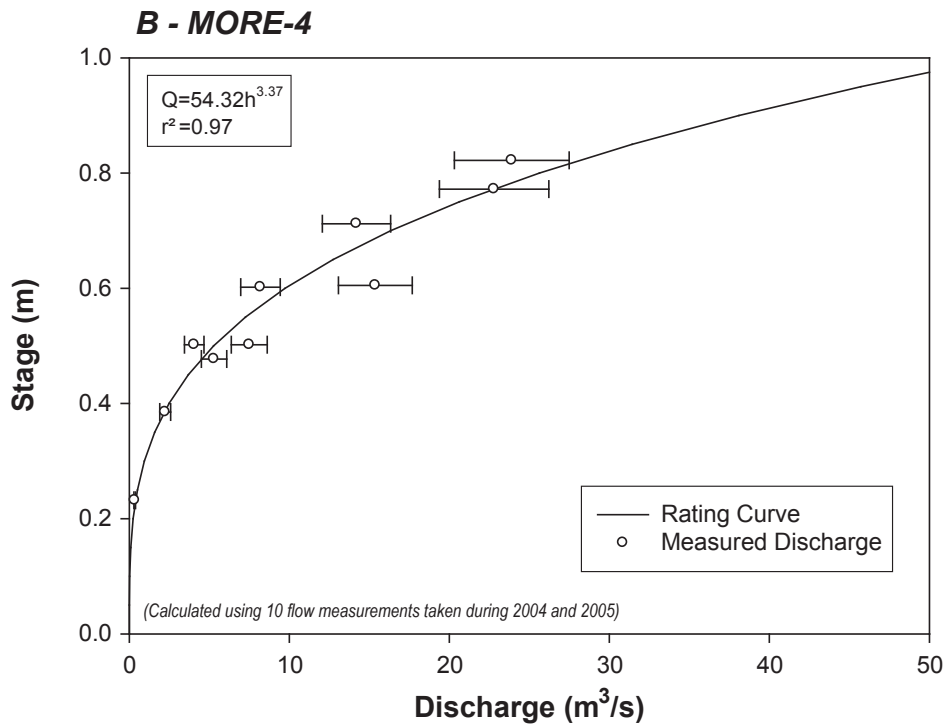
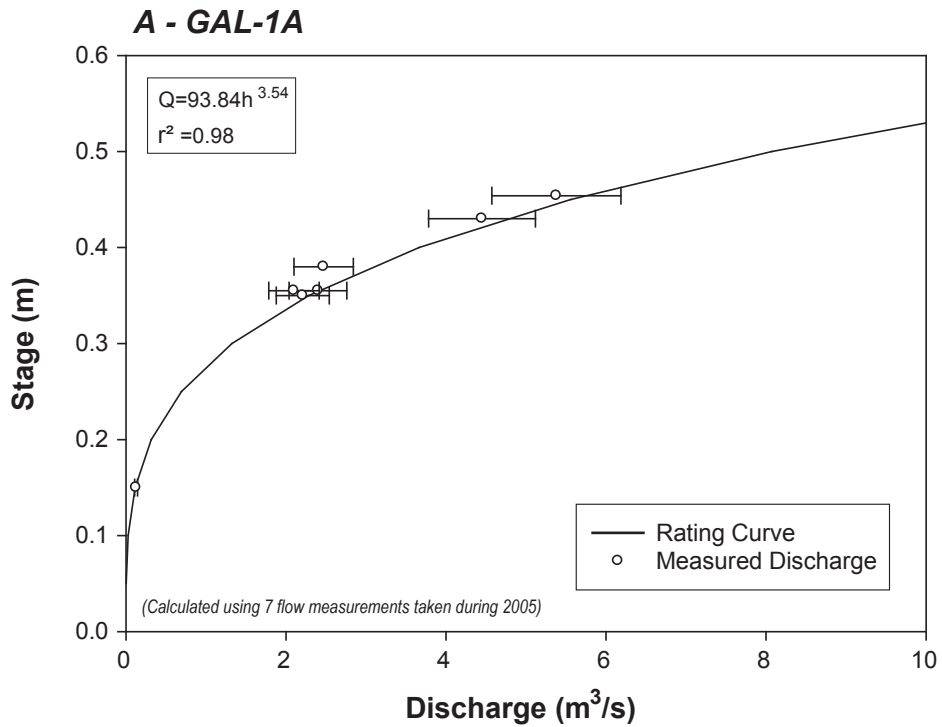


FIGURE 3.5-1



GAL-1A and MORE-4 Rating Curves for 2004 and 2005