Kiggavik Project
Final Environmental Impact Statement

Tier 3 Technical Appendix 5A:
Hydrology Baseline

September 2014

History of Revisions

Revision Number	Date	Details of Revisions
01	December 2011	First Issue with Draft Environmental Impact Statement
02	September 2014	Issued for Final Environmental Impact Statement – No updates

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ABBREVATIONS AND ACRONYMS

AREVA	AREVA Resources Canada Inc.
ATV	all-terrain vehicle
AWR	all-weather road locations
BEAK	BEAK Consultants Ltd.
CSP	corrugated steel pipe
DEMS	digital elevation models
DFO	Fisheries and Oceans Canada
EC	Environment Canada
ESRI	Environmental Systems Research Institute, Inc.
GIS	geographic information system
Golder	Golder Associates Ltd.
LiDAR	Light Detection and Ranging
LSA	local study area
NRCAN	National Resources Canada
NTS	national topographic system
PVC	polyvinyl chloride
RSA	regional study area
USDA	United States Department of Agriculture
UTM	Universal Transverse Mercator
WSC	Water Survey of Canada

UNITS OF MEASURE

dam^3	cubic decametre
cm	centimetre
km	kilometres
km^2	square kilometres
m	metres
m^3/s	cubic metres per second
$m^3/s/km^2$	cubic metres per second/square kilometer
mm/year	millimeters per year

1 INTRODUCTION

1.1 OVERVIEW

In 2007, Golder Associates Ltd. (Golder) was retained by AREVA Resources Canada Inc. (AREVA) to initiate a baseline hydrological monitoring program in the vicinity of the Kiggavik Project (the Project), located approximately 80 kilometres (km) west of Baker Lake, Nunavut. Hydrological data were collected by Golder over the open water periods of 2007, 2008, 2009 and 2010. Site data were also previously collected by BEAK Consultants Ltd. (BEAK) in 1988, 1989, and 1991. This report contains a compilation of all hydrological data that have been collected in support of the Project, including stream discharge and water surface elevations near the Project, and stream surveys along the proposed all-weather road route.

1.2 PURPOSE

The purpose of a baseline hydrology program is to document hydrological data prior to the operational period, as this allows for comparison throughout the operations period and following decommissioning. Stream flow data may be used for a number of water management purposes and impact assessments including, but not limited to, the following:

- calculating flood magnitude and frequency for design purposes (culverts, bridges, water treatment ponds, tailings facilities, freshwater diversion channels);
- linking data collected on-site to re-established Water Survey of Canada (WSC) hydrometric station data to allow the site data to be extended back in time to synthesize historical data records;
- establishing rainfall/snow melt runoff relationships for water management purposes;
- predicting changes in flow volumes for local streams, bogs and ponds;
- providing input to water quality assessments, including dilution potential, contaminant loading and plume delineation;
- conducting water supply assessments;
- evaluating potential impact to aquatic organisms from changes in water quality and quantity;
- preparing operational site water management and sediment control;
- re-establishing pre-development watersheds and flow regimes at mine closure;
- providing options for cross-drainage structures along road routes; and
- supporting monitoring programs and adaptive management initiatives.

The hydrology baseline program may also be used to monitor and document hydrological data in areas that have been identified as areas of concern or traditional land use through collection of Inuit Qaujimajatuqangit (traditional knowledge).

1.3 SCOPE

The scope of the baseline assessment is divided into regional, local, and stream crossing assessments of the streams intersecting the proposed all-weather road between the Project and Baker Lake. Regional data include water surface elevation and stream discharge data collected by WSC in Nunavut. The local assessment includes recent hydrological data collected by Golder and historical data collected by BEAK.

A total of 16 locations of stream discharge measurement were monitored by Golder from 2007 to 2010. This assessment included instantaneous stream discharge measurements and continuous water level measurements. Continuous water level sensors (pressure transducers) were installed at 11 of these sites. Two of the eleven continuous measurement sensors were installed at decommissioned historical WSC hydrometric station locations (Aniguq River and Qinguq Creek) in order to provide regional and historical context for the site data that were collected over a relatively short-term. Instantaneous lake water surface elevation measurements were taken at nine lakes in the Project area.

Historical local data that were previously presented include reports by BEAK (1990 and 1992). In 1988 and 1989, stream discharge data were collected at the outlets of the following lakes: Ridge Lake, Pointer Lake, Jaeger Lake, Skinny Lake, Cirque Lake, and Escarpment Lake. In 1991, data were collected for outflow areas of Andrew Lake, Andrew Lake Study Area, Cigar Lake, Judge Sissons Lake, Mushroom Lake, and Pointer Lake.

The stream crossing assessment includes data collected by Golder in 2009. AREVA has proposed an all-weather road to provide site access from the community of Baker Lake. The north road route is approximately 90 km in length and crosses the Thelon River. A second option is a 92 km long winter road from the community of Baker Lake to the Kiggavik site. No hydrology investigations were conducted for the winter route because snow fills and ice bridges would be used to cross streams. In addition, a 20 km haul road connecting the Sissons ore zones in the southern portion of the property to Kiggavik site milling facilities at the north end of the property is planned. The focus of the hydrology investigation was on the collection of physical data in support of preliminary assessments of suitable cross-drainage structure options for each crossing.

2 SETTING

The Project is located within the physiographic region of the Canadian Shield and, as such, the land contains features formed by glaciation, including eskers and boulder moraines (Environment Canada [EC] 2009a, internet site). The topography is gently undulating, and is filled with hummocks and patterned ground resulting from permafrost. Vertical drainage is impeded by the permafrost layer, and wetlands, small ponds, and lakes are common over the landscape. The Project is also located in the Southern Arctic terrestrial ecozone, which is characterized by continuous permafrost that may be present just a few centimeters below the surface (EC 2009a, internet site). Low precipitation and extremely low winter temperatures stunt tree growth in this ecozone (National Resources Canada [NRCAN] 2009, internet site). Summers in the Southern Arctic ecozone are cool and approximately four months in length. This ecozone is bounded to the south by the treeline and the Taiga Shield ecozone and to the north by the Northern Arctic ecozone, which includes most of the islands off the northern shores of Nunavut and the Northwest Territories, as well as the top of the Ungava Peninsula. The terrain is undulating, with numerous lakes and ponds that were formed by the melting glaciers of the last glaciation. The types of vegetation that may be found here in the Southern Arctic ecozone include low-lying shrubs such as willow (*Salix* spp.), shrub birch (*Betula nana exilis*) and Labrador tea (*Ledum groenlandicum*), and lichens and mosses (EC 2009a, internet site).

Climate and permafrost play an important role in the hydrological regime of this area. Peak stream discharges in the region are a result of spring melt, which can account for most of the total annual runoff. Throughout the summer and fall, the active layer of permafrost increases, thereby increasing the amount of storage available within the ground. Secondary peaks are common in the late summer or early fall periods, due to precipitation later in the season. Smaller streams may freeze completely to their channel bottoms throughout the winter, and begin to flow again overtop of the anchor ice as a result of spring melt. Lake ice thickens over winter, reaching a depth of approximately 2 metres (m). Thus, many shallow lakes freeze completely and a substantial portion of the volume of larger lakes is frozen by late winter.

3 STUDY AREAS

3.1 REGIONAL STUDY AREA

The Project is located within the headwaters of the Aniguq River drainage area. The Aniguq River is a tributary to Baker Lake, which is located within the Hudson Bay drainage basin. The numerous tributary streams within the Aniguq River watershed eventually flow into the Aniguq River, which drains into the western edge of Baker Lake. Baker Lake drains into Chesterfield Inlet, which further drains into Hudson Bay. Watersheds that are adjacent to that of the Aniguq River system include the Thelon River and Qinguq Creek, both of which drain into Baker Lake (Figure 3.1-1). Estimates for the contributing drainage areas for Hudson's Bay, Baker Lake (at its outlet), the Thelon River, the Aniguq River, and Qinguq Creek (all at their respective inlets to Baker Lake) are presented in Table 3.1-1.

Table 3.1-1
Estimated Regional Drainage Areas

Basin, Sub-basin, or Waterbody Name	Drainage Area (km^2)
Hudson Bay	3,861,400
Thelon River[a]	154,000
Aniguq River[a]	5,096
Qinguq Creek[a]	432

[a] At the inlet to Baker Lake
km^2 = square kilometre

Within the regional study area (RSA), a number of traditional land use areas as they relate to water have been identified and are further described in Appendix II Inuit Qaujimajatuqangit Baseline. Historical fishing areas, camping areas, and caribou stream crossings located within the RSA are presented in Figure 3.1-2. Historical fishing areas have been identified near Tom Lake, Siamese Lake, Judge Sissons Lake, Sleek Lake, Caribou Lake, Audra Lake, the Aniguq River, Long Lake, and unnamed lakes downstream of Judge Sissons Lake. Camping areas have been identified near Audra Lake, Long Lake, Judge Sissons Lake, and unnamed lakes downstream of Judge Sissons Lake (Figure 3.1-2). Caribou migration routes have been identified to the north of the Project, across the Thelon River.

3.2 LOCAL STUDY AREA

The local study area (LSA) for hydrology includes those drainage areas upstream of the outflow of Judge Sissons Lake, the Kavisilik Lake drainage and the Siamese Lake drainage. The Judge Sissons Lake drainage area is further divided into five sub-basins. Of these, four sub-basins drain to the south and southeast, discharging into Judge Sissons Lake. These are the Boulder Lake system, the Caribou Lake System, the Lower Lake system, and the Willow Lake system. The fifth sub-basin includes Judge Sissons Lake and small tributary drainages flowing directly to the lake (Figures 3.2-1 and 3.2-2).

Most of the Project development will occur within the Lower Lake and Willow Lake drainages. A strong topographic divide passes north of the Kiggavik deposit, trending southwest to northeast. North of this divide, drainage from the Kavisilik Lake drainage is east and southeast toward Audra Lake, which is drained by the Aniguq River. The Siamese Lake sub-basin is immediately east of the Willow Lake drainage. Drainage from the Siamese Lake sub-basin joins discharge from the Kavisilik drainage, prior to draining to Long Lake and Audra Lake, immediately downstream (Figure 3.2-1).

The local drainage areas containing the Kiggavik and Sissons deposits (Willow Lake, and Lower Lake sub-basins, respectively) direct runoff toward Judge Sissons Lake (Figure 3.2-2). In general, the lakes in the vicinity of the southern Sissons deposit are drained by streams flowing east to Judge Sissons Lake, while the lakes in the vicinity of the northern Project deposit flow southward into Judge Sissons Lake. Judge Sissons Lake is drained by the Aniguq River, which passes through Audra Lake and flows eastward to Baker Lake.

3.3 ALL-WEATHER ROAD STUDY AREA

The proposed all-weather road includes a 107 kilometres (km) long section that lies west of the Thelon River. The section of road that lies east of the Thelon River encompasses a number of options that are routed around the community of Baker Lake. The focus of the hydrological investigation for the eastern portion of the all-weather road was on the two routes furthest from the community of Baker Lake; at the time of the survey these were the preferred route options. The Kiggavik all-weather road study area, from a hydrological perspective, includes all streams and/or drainage patterns that may be interrupted by construction of the road. Figure 3.3-1 illustrates the stream crossings located along the length of the road, including their flow directions and estimated drainage boundaries. In total, 62 locations were identified that had the potential for cross-drainage. Not all of these streams had well-defined stream channels. Some were locations of overland flow, and some were locations of flow through boulders. The all-weather road passes through five drainage basins as defined by WSC, all of which eventually drain into Baker Lake: Akkutuak Creek, Prince River, Thelon River, Qinguq Creek, and Aniguq River.

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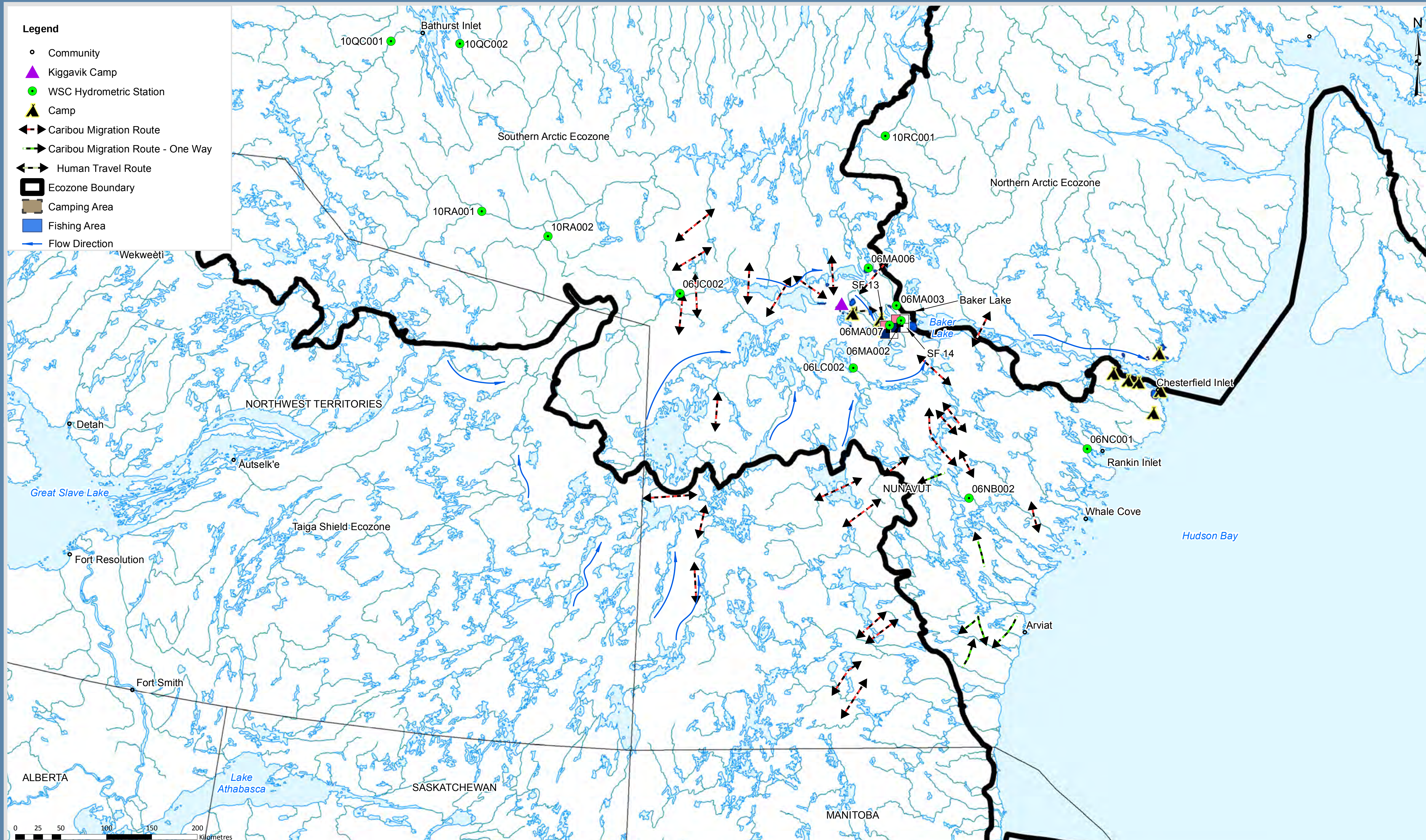

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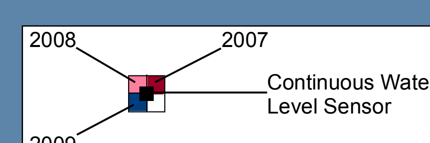
FIGURE 3.1-2
TRADITIONAL LAND USE AREAS WITHIN THE KIGGAVIK HYDROLOGY REGIONAL STUDY AREA

KIGGAVIK PROJECT - EIS



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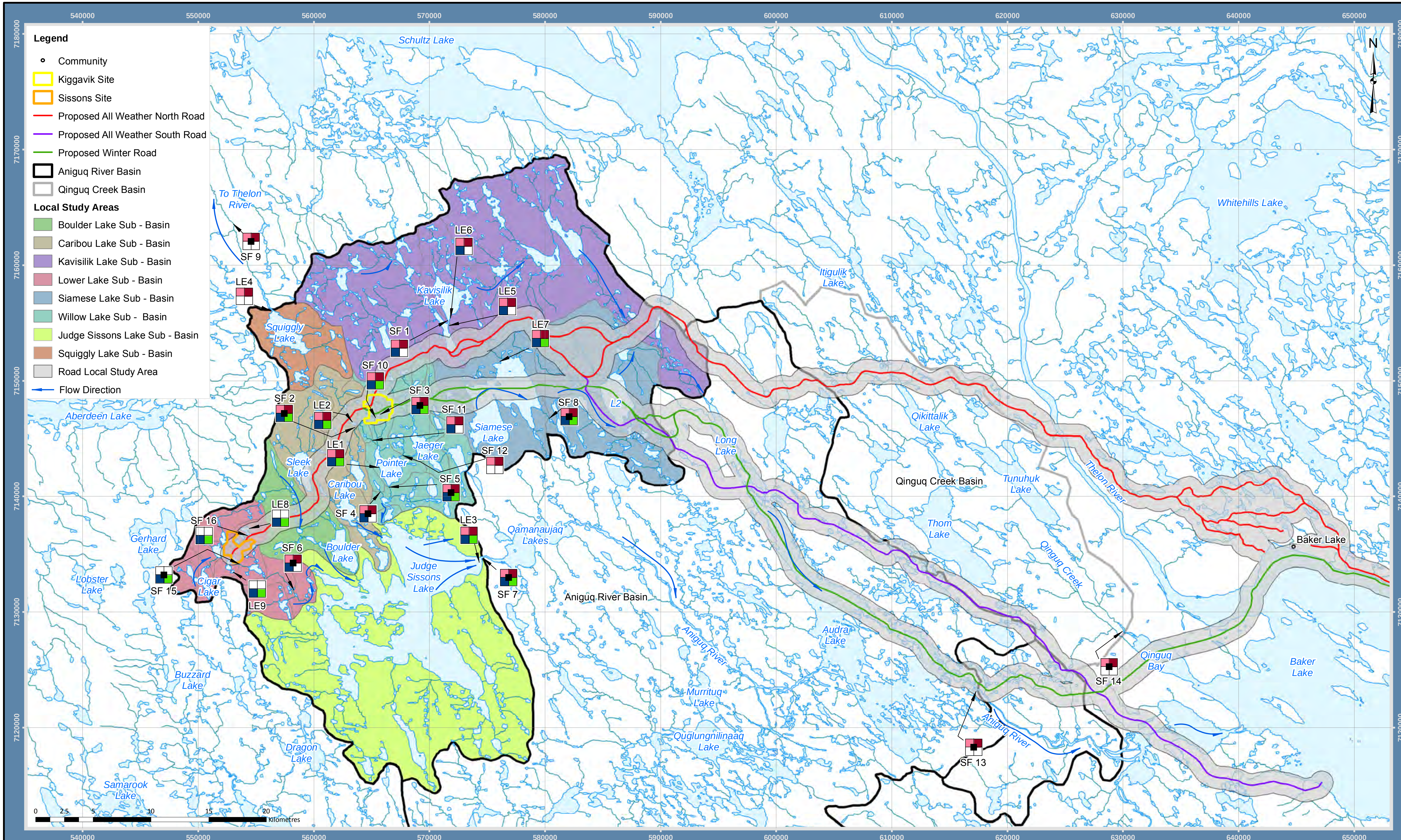

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Data Sources: *NTS Mapsheet 56D, 66A, 66B, AREVA Resources Canada Inc.*

FIGURE 3.2-1
KIGGAVIK HYDROLOGY LOCAL STUDY AREA

KIGGAVIK PROJECT - EIS

2008 2007
Continuous Water Level Sensor
2009 2010

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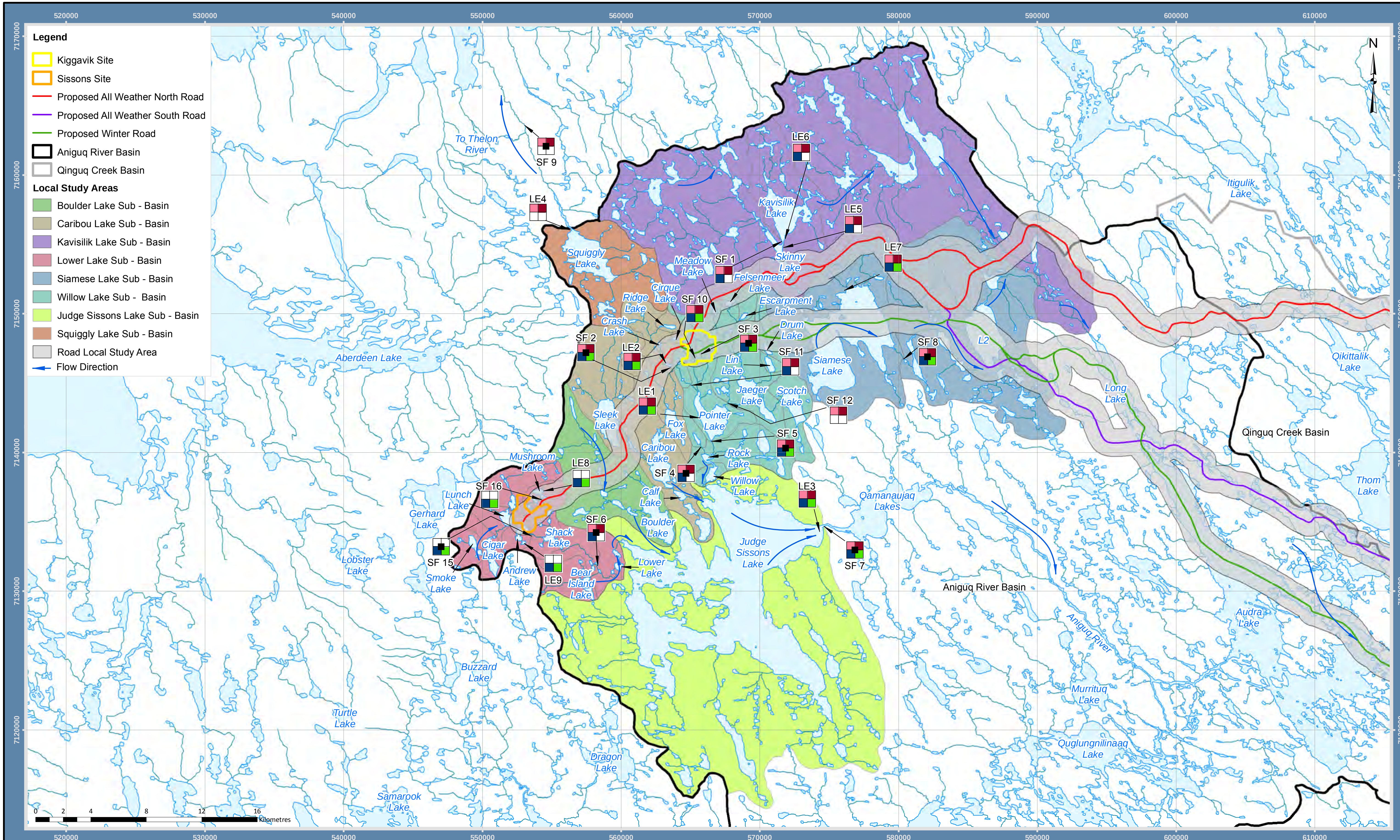

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Data Sources: *NTS Mapsheet 56D, 66A, 66B, AREVA Resources Canada Inc.*

FIGURE 3.2-2
KIGGAVIK HYDROLOGY
DETAILED LOCAL STUDY AREA

KIGGAVIK PROJECT - EIS

2008 2007 2009 2010 — Continuous Water Level Sensor

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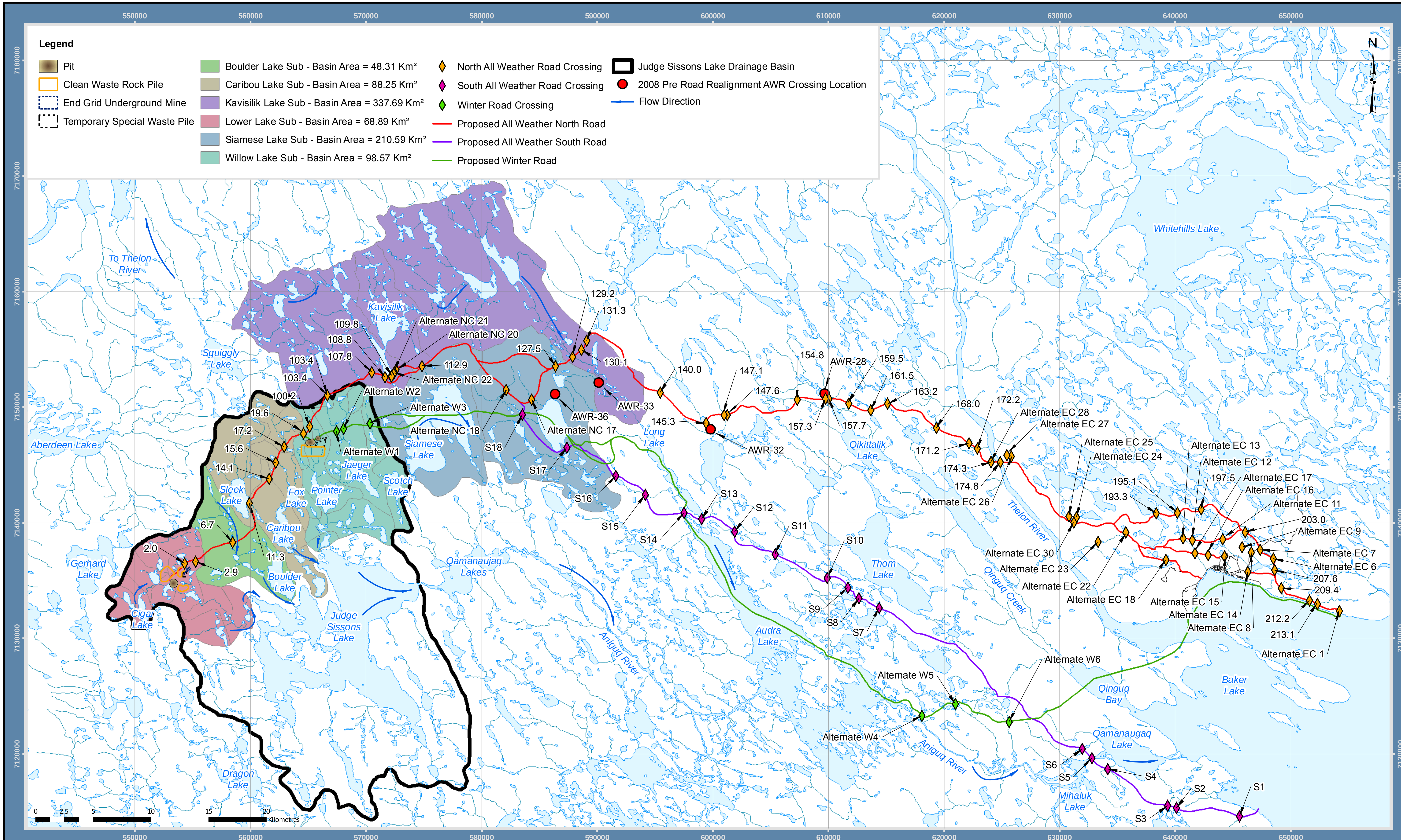

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Creator: MGD
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Data Sources: NTS Mapsheet 56D, 66A, 66B, AREVA Resources Canada Inc.

FIGURE 3.3-1
KIGGAVIK ALL WEATHER ROAD STUDY AREA

KIGGAVIK PROJECT - EIS

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4 METHODS

4.1 DATA SOURCES

4.1.1 Regional Hydrometric Data

Regional hydrometric data were collected from the Water Survey of Canada (WSC) online hydrometric database (EC 2009b, internet site). Each of these regional stations has a varying period of record, and many have been discontinued. Regional stream discharge monitoring locations are presented in Table 4.1-1, and regional lake water surface elevation stations are presented in Table 4.1-2. Regional hydrometric station locations are indicated in Figure 3.1-1. The Project is located in the Southern Arctic ecozone, and data used in this report are limited to hydrometric stations that are mainly located within this ecozone. The hydrometric stations located nearest to the Project are the Aniguq River and Qinguq Creek stations, both of which were discontinued in 1994.

Regional lake water surface elevation monitoring stations that were maintained by WSC included Baker Lake and Marjorie Lake (Table 4.1-2). Both stations were decommissioned in the 1990s and currently there are no regional stations that collect lake water surface elevation data within 100 kilometres (km) of the Project site. The closest WSC lake level monitoring station that is currently operational is located at Ennadai Lake, which is approximately 400 km southwest of the Project site.

Table 4.1-1
Regional Hydrometric Stations Located in the Southern Arctic Ecozone, Nunavut

Station ID	Station Description	Period of Record
06MA007	Aniguq River[(a)] below Audra Lake	1984-1994
10PC002	Atitok Creek near Dismal Lakes	1979-1990
10RA001	Back River below Beechy Lake	1978-2008
10RC001	Back River above Hermann River	1965-2008
10RA002	Baillie River near the mouth	1978-2008
10QC004	Burnside River at outlet of Contwoyto Lake	1993-2008
10QC001	Burnside River near the mouth	1976-2008
10PB001	Coppermine River at outlet of Point Lake (NWT)	1965-2008
10PC003	Coppermine River above Bloody Falls	1983-1986
10PC004	Coppermine River above Copper Creek	1987-2008
06NC001	Diana River near Rankin Inlet	1989-1995
10QD001	Ellice River near the mouth	1971-2008
10PC005	Fairy Lake River near outlet of Napaktulik Lake	1993-2008
06NB002	Ferguson River below O'Neil Lake	1979-1995
10QC002	Gordon River near the mouth	1977-1994
10QB001	Hood River near the mouth	1994-2002
10OC001	Inman River near the mouth	1975-1988
10PC001	Kendall River near outlet of Dismal Lakes	1969-2008
06LC002	Kunwak River below Princess Mary Lake	1977-1994
06MA002	Qinguq Creek near Baker Lake	1969-1994
06MA003	Thelon River above Baker Lake	1973-1982
06JC002	Thelon River above Beverly Lake	1970-2008
06MA006	Thelon River below outlet of Schultz Lake	1983-2008
10QA001	Tree River near the mouth	1968-2008

(a) WSC refers to this station as Anigaq River; however, geographic references to this River have it named Aniguq River (NRCAN 2009, internet site).

Table 4.1-2
Regional Water Survey of Canada Lake Water Surface Elevation Stations

Station ID	Station Name	Period of Record	Location (UTM NAD 83 Coordinates[a])	Approximate Distance from Kiggavik (km)
06KC002	Marjorie Lake at Outlet	1966-1990	Zone 14W 476865 E 7122853 N	90
06MA001	Baker Lake at Baker Lake	1965-1994	Zone 14W 643541E 7135964N	80

(a) in metres (m)
km = kilometers; UTM = Universal Transverse Mercator

4.1.2 Local Hydrometric Data

Past stream discharge monitoring programs in the vicinity of the Project were conducted by BEAK in 1988, 1989, and 1991. These data were presented by BEAK (1990 and 1992), and are summarized in Section 5 of this report. The exact locations of the hydrometric stations during these monitoring programs are not known. The monitoring location descriptions and periods of record for 1988, 1989, and 1991 are presented in Table 4.1-3.

Table 4.1-3
Local Hydrometric Monitoring Locations, 1988, 1989, and 1991

Description	Years Monitored
Andrew Lake	1991
Andrew Lake Study Area	1991
Cigar Lake	1991
Cirque Lake	1988, 1989
Escarpment Lake	1988, 1989
Jaeger Lake	1988, 1989
Judge Sissons Lake	1991
Mushroom Lake	1991
Pointer Lake	1988, 1989, 1991
Ridge Lake	1988, 1989
Skinny Lake	1988, 1989

Golder initiated a hydrological monitoring program at the Project in the spring of 2007. Over the course of four open water periods (2007 to 2010), 16 sites were monitored for stream discharge (including water elevation) and nine sites were monitored for lake elevation. Continuous water level sensors were also placed in some streams in order to generate a complete hydrograph over the measurement period. These monitoring station locations are presented in Table 4.1-4 and illustrated in Figure 3.2-1. Lake elevations were recorded whenever downstream discharges were measured. In 2008, two regional monitoring stations that were historical WSC monitoring sites were added to the hydrological program: Aniguq River and Qinguq Creek. These regional stations were added in order to take advantage of the longer periods of record of the historical WSC monitoring stations by providing coincident temporal data to the local site data.

Table 4.1-4
Local Hydrometric Monitoring Locations, 2007-2010

Station ID	Description	Crossing Location (UTM NAD 83 Coordinates[a])	Continuous Monitoring	Instantaneous Discharge and Level Measurements
Stream Discharge Monitoring Stations				
SF1	Outflow of Skinny Lake	Zone 14 W 571655E 7155266N	-	2007-2009
SF2	Outflow of Unnamed Lake Downstream of Cirque Lake	Zone 14 W 563554E 7146242N	2007-2009	2007-2010
SF3	Northeast Inflow of Pointer Lake	Zone 14 W 565717E 7147088N	2008-2009	2007-2010
SF4	Outflow of Sik Sik Lake	Zone 14 W 565790E 7140386N	2007-2009	2007-2009
SF5	Outflow of Pointer Lake	Zone 14 W 566477E 7140840N	2007-2010	2007-2010
SF6	Outflow of Shack Lake	Zone 14 W 558223E 7131912N	2007-2009	2007-2009
SF7	Outflow of Judge Sissons Lake	Zone 14 W 574605E 7134734N	2007-2010	2007-2010
SF8	Outflow of Siamese Lake	Zone 14 W 580364E 7146775N	2007-2010	2007-2010
SF9	Outflow of Squiggly Lake	Zone 14 W 552993E 7163630N	2007-2008	2007-2008
SF10	Tributary to the Northeast Inflow of Pointer Lake	Zone 14 W 565328E 7146771N	-	2007-2010
SF11	Northwest Inflow of Pointer Lake	Zone 14 W 565015E 7144882N	-	2007-2009
SF12	Outflow of Jaeger Lake	Zone 14 W 567690E 7143581N	-	2007-2008
SF13	Aniguq River	Zone 14 W 617415E 7123391N	2008-2010	-
SF14	Qinguq Creek	Zone 14 W 630101E 7128437N	2008-2010	2009
SF15	Outflow of Andrew Lake	Zone 14 W 553586E 7134121N	2009-2010	2009-2010
SF16	Outflow of Mushroom Lake	Zone 14 W 554181E 7136655N	-	2009-2010
Lake Water Surface Elevation Monitoring Stations				
LE1	Pointer Lake	Zone 14 W 565652E 7142467N	-	2007-2010
LE2	Unnamed Lake Downstream of Cirque Lake	Zone 14 W 563603E 7146244N	-	2007-2010
LE3	Judge Sissons Lake	Zone 14 W 574537E 7134751N	-	2007-2010

Table 4.1-4
Local Hydrometric Monitoring Locations, 2007-2010 (continued)

Station ID	Description	Crossing Location (UTM NAD 83 Coordinates[a])	Continuous Monitoring	Instantaneous Discharge and Level Measurements
Lake Water Surface Elevation Monitoring Stations				
LE4	Squiggly Lake	Zone 14 W 556354E 7156066N	-	2007-2008
LE5	Skinny Lake	Zone 14 W 571626E 7154893N	-	2007-2009
LE6	Kavisilik Lake	Zone 14 W 571712E 7155299N	-	2007-2009
LE7	Siamese Lake	Zone 14 W 576086E 7151648N	-	2007-2010
LE8	Andrew Lake	Zone 14 W 553222E 7134135N	-	2009-2010
LE9	Mushroom Lake	Zone 14 W 554219E 7136721N	-	2009-2010

(a) E is easting (in metres), N is northing (in metres)
UTM = Universal Transverse Mercator

4.1.3 All-Weather Road Data

Golder initiated a stream crossing assessment that included in-stream topographic surveys and stream discharge measurements along the length of the proposed north road alignment in the summer of 2008. In 2008, four stream crossing locations were surveyed. These were referred to as all-weather road locations (AWR) and were at locations identified as likely stream crossings where bridges would be required. Over the winter of 2008/2009, revisions to the road alignment were made and crossings at AWR-33 and AWR-36 were no longer considered potential stream crossings. In addition, the road was moved approximately 600 m north of crossing AWR-32 and was resurveyed as NC13 in 2009. The road alignment was moved several hundred metres south of AWR-28 and the new crossing was resurveyed in 2009 as NC10. All other stream crossing locations were surveyed in 2009 and are presented in Table 4.1-5 and shown in Figure 3.3-1.

Table 4.1-5
Stream Crossing Locations, 2009 (UTM, NAD 83)

Crossing ID	Zone	Easting (m)	Northing (m)
AWR-28	14W	609698	7151158
AWR-32	14W	599843	7148079
AWR-33	14W	590167	7152092
AWR-36	14W	586366	7151107
Alternate EC 1	15W	363782	7131526
213.1	15W	361919	7132308
212.2	15W	361280	7132680
209.4	15W	358935	7133957
207.6	15W	358545	7135569
Alternate EC6	15W	358508	7136556
Alternate EC7	15W	357445	7137442
203.0	15W	356288	7139085
Alternate EC 11	14W	644105	7138584
Alternate EC 12	14W	641474	7138513
Alternate EC 13	14W	640685	7138635
197.5	14W	642213	7141168
195.1	14W	640182	7140853
193.3	14W	638349	7140811
Alternate EC 22	14W	635714	7139152
Alternate EC 30	14W	631259	7140022
174.3	14W	624073	7145242
172.2	14W	622882	7146420
171.2	14W	622154	7146869
168.0	14W	619323	7148232
163.2	14W	615106	7150322
161.5	14W	613663	7149739
159.5	14W	611746	7150326
157.7	14W	610051	7150743
57.3	14W	609738	7150729
154.8	14W	607309	7150666
147.1	14W	600954	7149336
145.3	14W	599423	7148626
140.0	14W	595458	7151276
131.3	14W	589083	7155771
129.2	14W	587880	7154335
127.5	14W	586392	7153545
Alternate NC 17	14W	584334	7150642
Alternate NC 18	14W	582126	7151481
112.9	14W	574831	7153551
Alternate NC 20	14W	572570	7153230
Alternate NC 21	14W	572439	7153009
Alternate NC 22	14W	572403	7152918
109.8	14W	572211	7152678
108.8	14W	571616	7152601
107.8	14W	570495	7153036

Table 4.1-5
Stream Crossing Locations, 2009 (UTM, NAD 83) (continued)

Crossing ID	Zone	Easting (m)	Northing (m)
103.4	14W	566631	7151050
100.2	14W	565113	7148344
19.6	14W	564583	7147734
17.2	14W	562896	7146580
15.6	14W	562197	7145187
14.1	14W	561624	7143798
11.3	14W	559904	7141694
6.7	14W	558454	7138314
2.0	14W	554300	7136489

m = metres

4.2 HYDROMETRIC EQUIPMENT AND FIELD METHODS

4.2.1 Stream Discharge

Stream discharges for all monitoring locations were measured using a current meter. A tag line (cable marked at 0.2 metres [m] intervals) was used to measure the channel width at each discharge measurement cross section. The channels were divided into vertical segments, with each division approximately 5% of the channel width. Velocity was measured with a Price 1210 AA, a Price Pygmy current meter, or a Marsh McBirney flow meter attached to a top-set wading rod. The depth at each interval across the channel was measured with the wading rod; velocity was measured at a depth of 60% of the total depth from the surface. If the water was deeper than 0.70 m, the velocity was measured at 80% and 20% of the depth and the resulting values were averaged. Stream discharge calculations were based on the mid-section method (Terzi 1981). The product of the mean of the depths and the mean of the velocities observed at adjacent verticals was multiplied by the width between the verticals to determine the discharge for each section. This was repeated for each consecutive section across the stream and the total discharge for the stream was then obtained by summing the partial discharges.

4.2.2 Survey Benchmarks

At each monitoring location, an engineer’s rod and level was used to measure water surface elevation relative to an arbitrary benchmark. This allowed continuity in the surface water elevation data from one year to another. The elevation of the benchmark is assumed to be 100.000 m. Benchmarks are typically large, stable boulders located near each monitoring site. The highest point on the boulder was spray-painted to indicate the specific benchmark location. In the case of historical hydrometric monitoring stations, benchmarks that were established by Canada Lands Survey or WSC were used. These benchmarks consist of brass caps installed in bedrock at arbitrary elevations.

Each time stream discharge was measured, the water surface elevation at the monitoring location was also measured. Over time, the relationship between water surface elevation (stage) and discharge at the channel cross section is established and described graphically by the stage-discharge rating curve. Once a number of stage and discharge measurements were collected, the equation for the best-fit curve for the resultant data set was used to estimate discharge using the continuous water surface elevation data.

Thus, the discharge can be predicted by knowing the elevation of the water surface at the monitoring cross section. The accuracy of the stage-discharge relationship improves over time as more points are added to the curve.

4.2.3 Continuous Water Level Recording

Water surface elevations are measured on a continuous basis during the open water period using a pressure transducer/data logger system. The pressure transducers used at all monitoring stations were Leveloggers, manufactured by Solinst Canada Ltd. The Levelogger sensors were programmed to record water levels at 30 minute intervals. Each Levelogger was set inside bracket consisting of a small aluminum pipe that was welded to an aluminum plate. The plate was fixed in place in the streambed, at or near the discharge measurement cross section.

The Levelogger recorded total pressure (atmospheric pressure and water pressure) acting on the sensor and was internally compensated for temperature. Atmospheric pressure was subtracted from the total pressure through a software process that combined data from the Levelogger and data from a Barologger (a separate sensor which measures atmospheric pressure only) to provide water depth data at the monitoring locations. The Barologger was installed in a 1 m long buried polyvinyl chloride (PVC) pipe, with holes drilled into the sides to allow atmospheric pressure to act on the sensor. Two Barologgers were used to correct for barometric pressure: one in close proximity to the Kiggavik Project, and another closer to the WSC historical hydrometric stations.

Once corrected for atmospheric pressure, the software provided the actual water depth above the pressure sensor. The water level data were then used in combination with the stage-discharge rating curves to produce a record of discharges at 30 minute intervals. Prior to converting pressure sensor data to discharge data, the pressure sensor data must be related to the benchmark. The surveyed value from the benchmark and the first pressure sensor reading were collected only a few minutes apart, so these two values were considered to represent the same elevation. For example, if the water surface elevation was measured at 99.500 m from the benchmark and the first data record from the sensor was 0.25 m, the water level (0.25 m) can be considered equal to 99.500 m. The absolute value of any change in water level was then applied to the benchmark water surface elevation reading. If the water surface increased 0.005 m over the next 30 minutes, the increase was also applied to the benchmark level (99.505 m). This correction allowed the stage data, as measured from the pressure sensor, to be converted to water surface elevations relative to the benchmark.

Recorded water levels were converted to discharge using the stage-discharge rating curve that was developed for all streamflow monitoring cross-sections. Using this approach, the continuous water level record was used to generate a continuous discharge record for each monitoring location.

4.2.4 Topographic Stream Survey

Topographic stream surveys were conducted using a total station survey to define channel and floodplain geometry near the centerline of the proposed all-weather road alignment. A local grid was established, in which elevations were recorded at cross sections perpendicular to stream discharge. Cross sections were established at the proposed road centerline, and at approximately 10, 20, 30, 40 and 50 m upstream and downstream of centerline. Elevation points along each cross section were selected to provide information regarding stream geometry, such as location of the thalweg (the deepest point in the stream along a given cross section), stream bankfull level, streambank toe, water surface elevation during the survey, longitudinal gradient, and flood plain. Stream substrate type and discharge were also recorded and measured, respectively, at each crossing location.

4.3 DATA ANALYSIS

All data analysis and presentation were consistent with standard hydrological and hydraulic methods. Standard references texts include those of Terzi (1981), Chow et al. (1988), Chow (1959), Gordon et al. (2004), and Anderson and Mikhail (1998). Much of the hydrological assessment begins with the delineation of drainage boundaries. Drainage boundaries in the local and regional study areas were delineated using 1:50,000 scale national topographic system (NTS) maps or the topographic data that were collected from the Light Detection and Ranging (LiDAR) survey that was conducted in 2009. The topographic data sets were used to form digital elevation models (DEMs) that were used with geographic information system (GIS) software to define drainage boundaries. ArcHydro software, an ArcGIS model for water resources (Environmental Systems Research Institute, Inc. [ESRI] 2008), was used to delineate drainage boundaries and flow pathways.

Culvert sizing was accomplished with the aid of two software programs: FishXing 3 (United States Department of Agriculture (USDA) Forest Service 2009) and Bentley CulvertMaster v3.1 (Bentley Systems Incorporated 2009). Both software programs use standard hydraulic methods to determine culvert sizing requirements; however, FishXing 3 has the additional feature of containing data for fish passage criteria. Culvert Master was used for streams in which no fish were present, and FishXing 3 was used for streams that contained fish.

5 RESULTS

5.1 REGIONAL HYDROMETRIC DATA

5.1.1 Lake Water Levels

The mean daily water surface elevations (relative to an arbitrary datum) over their respective periods of record for Marjorie Lake and Baker Lake are presented in Figure 5.1-1 (EC 2009b, internet site). In both lakes, the maximum mean daily water surface elevation occurs at the start of July (Table 5.1-1). Minimum mean daily water surface elevations are typically observed at the end of May in the case of Marjorie Lake, and during mid-April in the case of Baker Lake.

Table 5.1-1
Estimated Maximum and Minimum Mean Daily Water Elevations for Marjorie Lake and Baker Lake

WSC Station Name	Maximum Water Surface Elevation (m)	Date of Maximum Water Surface Elevation	Minimum Water Surface Elevation (m)	Date of Minimum Water Surface Elevation	Maximum Fluctuation (m)
Marjorie Lake at Outlet	14.13	Start of July	13.55	End of May	0.58
Baker Lake at Baker Lake	8.42	Start of July	7.42	Mid April	1.00

m = metres

5.1.2 Stream Discharge

The Water Survey of Canada (WSC) has operated a number of hydrometric monitoring stations within the Nunavut Territory. Station names, drainage areas and mean annual discharges, discharge volumes, basin yields and unit-area runoff values are summarized in Table 5.1-2. Drainage basin areas for the hydrometric stations range between 217 square kilometers (km^2) (Atitok Creek near Dismal Lakes) to 152,000 km^2 (Thelon River below outlet of Schultz Lake). These drainage areas also correspond to the minimum and maximum mean annual discharges (1.58 m^3/s for Atitok Creek and 928 m^3/s for Thelon River). The relationship between mean annual discharge and drainage areas is evident in the plot illustrated in Figure 5.1-2. The mean unit area runoff value is 0.0058 $m^3/s/km^2$, with runoff values for most streams near this value, regardless of drainage basin size. The linear relationship is described by Equation (1), where Q is the mean annual discharge (m^3/s) and A is the drainage area (km^2).

$$Q = 0.0065A^{0.9852} \quad (1)$$

Table 5.1-2
Regional Hydrometric Station Summary for Nunavut Streams Located in the Southern Arctic Ecozone (EC 2009b, internet site)

Station Description	Drainage Basin Area (km^2)	Mean Annual Discharge (m^3/s)	Mean Annual Discharge Volume (10^6 m^3/year)	Mean Drainage Basin Yield (mm/year)	Mean Unit Area Runoff ($m^3/s/km^2$)
Anigaq[(a)] River below Audra Lake	2,740	17.1	539	197	0.0062
Atitok Creek near Dismal Lakes	217	1.58	50	230	0.0073
Back River below Beechy Lake	19,600	108	3,406	174	0.0055
Back River above Hermann River	93,900	486	15,326	163	0.0052
Baillie River near the mouth	14,500	78	2,460	170	0.0054
Burnside River at outlet of Contwoyto Lake	6,056	38.7	1,220	202	0.0064
Burnside River near the mouth	16,800	134	4,226	252	0.0080
Coppermine River at outlet of Point Lake (NWT)	19,200	108	3,406	177	0.0056
Coppermine River above Bloody Falls	50,700	338	10,659	210	0.0067
Coppermine River above Copper Creek	46,200	261	8,231	178	0.0056
Diana River near Rankin Inlet	1,460	9.07	286	196	0.0062
Ellice River near the mouth	16,900	83.4	2,630	156	0.0049
Fairy Lake River near outlet of Napaktulik Lake	6,442	37.8	1,192	185	0.0059
Ferguson River below O'Neil Lake	12,400	81.3	2,564	207	0.0066
Gordon River near the mouth	1,530	9.05	285	187	0.0059
Hood River near the mouth	(b)	75.6	2,384	(b)	(b)
Inman River near the mouth	3,050	7.61	240	79	0.0025
Kendall River near outlet of Dismal Lakes	2,790	15	473	170	0.0054
Kunwak River below Princess Mary Lake	12,100	74.7	2,356	195	0.0062
Qinguq Creek near Baker Lake	432	2.6	82	190	0.0060
Thelon River above Baker Lake	154,000	757	23,873	155	0.0049
Thelon River above Beverly Lake	65,600	306	9,650	147	0.0047
Thelon River below outlet of Schultz Lake	152,000	928	29,265	193	0.0061
Tree River near the mouth	5,810	35.8	1,129	194	0.0062
Mean				183	0.0058
Median				187	0.0059
25th Percentile				170	0.0054
75th Percentile				196	0.0062

(a) WSC refers to this station as Anigaq River; however, geographic references to this river have it named Aniguq River (NRCAN 2009, internet site)
(b) No drainage area reported by WSC
km^2 = square kilometers; m^3/s = cubic metres per second; m^3/year = cubic metres per year; mm/year = millimeters per year; $m^3/s/km^2$ = cubic metres per second per square kilometre

The regional hydrometric stations that are nearest to the Project are the Thelon River below the outlet of Schultz Lake, Aniguq River and Qinguq Creek. Both the Thelon River and Qinguq Creek drainage basins lie adjacent to the Aniguq River basin. Furthermore, the hydrometric station on the Aniguq River is downstream of the Project. Mean monthly discharge of Aniguq River and Qinguq Creek are presented in Table 5.1-3. These two stations are selected for further analysis due to their proximity to the Project and smaller sized drainage basins.

Mean monthly discharge is zero throughout the winter months at Qinguq Creek and Aniguq River, due to the channel freezing to the bottom. At both Qinguq Creek and the Aniguq River, stream discharge may begin in May and usually peaks in June. In a typical year at Qinguq Creek, stream discharge continues until November, although minimum monthly discharges of zero have been recorded for October. Mean and minimum December discharges for the Aniguq River are also zero; however, discharge may be present in December under wetter conditions.

Table 5.1-3
Mean Monthly Discharge for the Aniguq River and Qinguq Creek (m^3/s)

Date	Qinguq Creek (1969-1994)			Aniguq River (1984-1994)		
	Mean	Max	Min	Mean	Max	Min
Jan	0.00	0.00	0.00	0.00	0.00	0.00
Feb	0.00	0.00	0.00	0.00	0.00	0.00
Mar	0.00	0.00	0.00	0.00	0.00	0.00
Apr	0.00	0.00	0.00	0.00	0.00	0.00
May	0.69	8.05	0.00	0.18	1.92	0.00
Jun	16.9	37.3	6.44	104	146	68.0
Jul	5.61	12.2	1.15	54.8	110.0	19.6
Aug	2.49	9.62	0.35	19.4	46.9	5.62
Sep	3.56	17.1	0.15	20.0	53.7	4.45
Oct	0.57	3.18	0.00	4.51	8.63	1.58
Nov	0.01	0.16	0.00	0.33	0.77	0.04
Dec	0.00	0.00	0.00	0.00	0.01	0.00
Mean	2.63	4.16	1.42	17.0	21.9	12.5

The average, maximum and minimum annual daily hydrographs for Qinguq Creek and Aniguq River are presented in Figure 5.1-3. Maximum and minimum discharge years have been determined based on total annual volumes as well as peak discharges.

5.1.3 Runoff Volumes and Yields

Unit area runoff values are presented for the WSC regional hydrometric stations in Table 5.1-2. The median value for unit area runoff is 0.0059 $m^3/s/km^2$. Unit area runoff values were calculated to be 0.0060 and 0.0062 $m^3/s/km^2$ for Qinguq Creek and Aniguq River, respectively.

Runoff (basin) yields are also commonly presented in units of mm/year (Table 5.1-2). The median basin yields for the regional hydrometric stations range between a low of 79 mm/year at Inman River to 252 millimetre/year (mm/year) at Burnside River. Annual basin yields for Qinguq Creek and the Aniguq River over their periods of record are estimated to be 190 mm/year and 197 mm/year, respectively. Mean, maximum and minimum monthly basin yields for Qinguq Creek and Aniguq River stations are presented in Table 5.1-4 and in Figures 5.1-4.

Table 5.1-4
Mean, Maximum and Minimum Monthly and Annual Basin Yields for Qinguq Creek and Aniguq River

Date	Qinguq Creek (1969-1994)			Aniguq River (1984-1994)		
	Mean Yield (mm)	Maximum Yield (mm)	Minimum Yield (mm)	Mean Yield (mm)	Maximum Yield (mm)	Minimum Yield (mm)
Jan	0	0	0	0	0	0
Feb	0	0	0	0	0	0
Mar	0	0	0	0	0	0
Apr	0	0	0	0	0	0
May	4	50	0	0	2	0
Jun	101	224	39	98	138	64
Jul	35	76	7	54	108	19
Aug	15	60	2	19	46	5
Sep	21	103	1	19	51	4
Oct	4	20	0	4	8	2
Nov	0	1	0	0	1	0
Dec	0	0	0	0	0	0
Annual[a]	192	304	104	196	252	144

[a] Annual values are calculated for years that have a complete monthly discharge record and therefore are not necessarily a sum of the monthly values presented in this table.

mm = millimetres

Runoff ratios may be defined as the total annual runoff divided by total annual precipitation (on a hydrological year, assumed to be October to September). While these ratios vary each year, they give an indication of the percentage of precipitation falling on a drainage area that reports as runoff. The range of the average runoff ratios estimated for the Kivalliq region were between 0.60 and 0.75 (BEAK 1992). The mean runoff ratio was 0.52 for Qinguq Creek near Baker Lake, calculated with annual runoff values provided by the WSC (EC 2009b, internet site) and total annual adjusted precipitation values provided by EC (2009d, internet site), for Baker Lake climate station, calculated for a hydrological year starting in October. The runoff ratios for Qinguq Creek varied from 0.27 in 1977 to 0.81 in 1992. The high runoff ratio determined for 1992 may be related to the above average annual precipitation measured in the preceding few years, resulting in less available storage in lakes and wetlands. The mean runoff ratio for the Aniguq River between 1984 and 1993 was 0.50. Lower mean runoff ratios calculated for Qinguq Creek and the Aniguq River, compared with the earlier estimates by BEAK 1992, may be partially a result of using corrected precipitation data in the current assessment. Corrected precipitation is generally higher because snow gauge undercatch is accounted for.

5.1.4 Low Flow and Flood Magnitude and Frequency

A low-flow frequency assessment is commonly conducted in order to provide estimates for stream discharges during periods of low flow. The one-in-ten year, seven-day low flow event (7Q10) is commonly used as a stream flow condition under which water quality conditions may be assessed. In the case of most streams within the region, however, this value may be assumed to be zero because the streams freeze to channel bottom during the winter. Therefore, an assessment that illustrates a range of flows during each week of the year was chosen to demonstrate lower flow conditions. This assessment was conducted on Qinguq Creek over the periods 1970 to 1978 and 1981 to 1994. Box plots illustrating the range of flow conditions from week 20 to week 48 throughout the year are presented in Figures II-1 to II-7 of Attachment II. Note that for the period of record, discharge outside of this annual range of weeks is zero. The box plots illustrate the median, 25th and 75th percentiles of discharge. The whiskers of the plot denote the outer deciles (10th and 90th percentiles), and the dots denote the two upper and lower extremes.

Flood magnitude and frequency estimates were calculated for Qinguq Creek based on the WSC daily discharge data set (EC 2009b, internet site). These results are provided in Table 5.1-5. The Log-Pearson III distribution was fit to the maximum annual discharge values over a total of 23 years (i.e., 1970 to 1978, 1981 to 1994). All of the annual peak discharge events occurred between the dates of May 28 and June 30 over the period of record.

Table 5.1-5
Flood Magnitude and Frequency Analysis for Qinguq Creek
(1970 to 1978 and 1981 to 1994)

Exceedance Probability	Approximate Return Interval (year)	Mean Daily Discharge (m^3/s)
0.99	1.01	9.4
0.95	1.05	16.8
0.9	1.11	22.1
0.8	1.25	29.8
0.5	2	48.3
0.2	5	70.3
0.1	10	82.3
0.05	20	92.1
0.02	50	102.6
0.01	100	109.2

m^3/s = cubic metres per second

Another flood frequency assessment that is useful is the one-in-ten year, three-day delay (3Q10). This number corresponds to the largest stream discharge over a three-day period that occurs at a ten year return period. This discharge is commonly used in the sizing of cross-drainage structures that allow for fish passage (Katopodis 1992). The 3Q10 was determined for the spring period for Qinguq Creek using a Log-Pearson distribution was 69.0 m^3/s.

5.1.5 Flow Duration Analysis

A flow duration analysis was conducted for Qinguq Creek. Flow duration is useful for the purposes of knowing what percentage of time a stream may flow, either for dilution or water supply purposes. Qinguq Creek ceases to flow during the winter season as the water freezes to the bottom of the stream bed. The flow duration analysis presented in Table 5.1-6 includes the results of 8,572 recorded and infilled daily data over the period 1969 to 1994, and also includes the zero flow conditions over the winter periods. Table 5.1-5 describes the percentage of time that a flow may be exceeded on a daily basis. For example, a discharge of 0.7 m^3/s is expected to be exceeded 30% of the time. A zero flow condition is expected to be exceeded 40% of the time (and conversely, zero flow conditions are expected for 60% of the year).

Table 5.1-6
Flow Duration Analysis for Qinguq Creek

Duration	Mean Daily Discharge (m^3/s)
1%	39.2
2%	26.3
5%	12.0
10%	6.2
20%	2.6
30%	0.7
40%	0

m^3/s = cubic metres per second

5.2 LOCAL HYDROMETRIC DATA

5.2.1 Historical Monitoring Programs (1988, 1989, and 1991)

5.2.1.1 Lake Water Levels

Lake elevation data were not collected during the 1988, 1989, or 1991 field programs. However, in a study by Roulet and Woo (1988), lake elevation data near the Project site were collected on one small lake during part of the open water period in 1983. This study basin was approximately 1.36 km^2 in size and located at Zone 14W 558564E 7147722N (Universal Transverse Mercator [UTM] coordinates, NAD 83 [m]). In relation to the Kiggavik Project, the basin is located between Squiggly and Sleek lakes (Figure 3.2-1). A peak lake water surface elevation was recorded during the second week in June (in response to snow melt), and the lake water surface elevation returned to its pre-melt condition five weeks later. The maximum fluctuation over the monitoring period (first week of June to second week of August) was approximately 0.75 m.

5.2.1.2 Lake Bathymetry and Storage Volume

Lake bathymetry data were collected during field programs in 1988, 1989, and 1991. Surveyed lakes included the following: Andrew Lake, Bear Island Lake, Caribou Lake, Cigar Lake, Cirque Lake, Crash Lake, Drum Lake, Escarpment Lake, Felsenmeer Lake, Fox Lake, Jaeger Lake, Judge Sissons Lake, Kavisilik Lake, Knee Lake, Lin Lake, Lower Lake, Lunch Lake, Meadow Lake, Mushroom Lake, Pointer Lake, Ridge Lake, Scotch Lake, Shack Lake, Sik Sik Lake, Skinny Lake, Smoke Lake, Squiggly Lake and Willow Lake. Contour intervals for these lakes were in the order of 1 to 2 m. Figures illustrating bathymetric data are presented in the Kiggavik Aquatics Baseline Document.

Information that was derived from the historical lake bathymetry data includes estimated lake volumes and surface areas. These values are summarized in Attachment III. Table III-1 of Attachment III also provides estimates for under-ice volumes, lake outflow, mean annual discharges, and lake retention times. Lake retention time is the mean time that water is retained in a lake, calculated by dividing the lake volume by its outflow.

5.2.1.3 Stream Discharge

In 1988 and 1989, stream discharge data were collected at the outlets of the following lakes: Ridge Lake, Pointer Lake, Jaeger Lake, Skinny Lake, Cirque Lake, and Escarpment Lake. Estimated mean monthly discharge and peak discharge (as determined from discharge hydrographs) are presented in Table 5.2-1. Annual hydrographs for 1988 are presented in Figure 5.2-1 and annual hydrographs for 1989 are presented in Figure 5.2-2. In 1988, peak discharge ranged between an estimated 0.13 m^3/s at the outlet of Cirque Lake, to 30.2 m^3/s at the outlet of Pointer Lake. In 1989, the peak discharge was similar to that recorded in 1988 at both locations, with 0.15 m^3/s estimated for the outlet of Cirque Lake, and 28.6 m^3/s estimated for the outlet of Pointer Lake.

Table 5.2-1
Mean Monthly Discharge for 1988 and 1989 as Estimated from Annual Hydrographs (BEAK 1990)

Lake Outlet Name	Mean Discharge (m^3/s)						Instantaneous Peak Discharge (m^3/s)	
	June		July		August			
	1988	1989	1988	1989	1988	1989	1988	1989
Escarpment Lake	0.18	0.09	0.022	0.05	0.02	0.02	0.71	0.50
Cirque Lake	0.04	0.04	0.01	0.02	0.01	0.00	0.13	0.15
Jaeger Lake	3.80	5.22	0.57	0.40	0.05	0.14	12.43	11.8
Pointer Lake	8.93	10.2	1.35	1.20	0.40	0.37	30.2	28.6
Ridge Lake	0.15	0.12	0.01	0.02	0.01	0.01	0.59	0.56
Skinny Lake	6.65	9.22	0.52	1.11	0.10	0.40	18.1	20.5

m^3/s = cubic metres per second

In 1991 data were collected for streams closer to the Sissons deposit (Andrew Lake, Andrew Lake Study Area, Cigar Lake, Judge Sissons Lake, Mushroom Lake, and Pointer Lake). Estimated mean monthly discharges, peak discharges (as determined from discharge hydrographs), are presented in Table 5.2-2. Annual hydrographs for 1991 are provided in Figure 5.2-3. Estimated peak discharges in 1991 ranged between 0.7 m^3/s at the outlet of Mushroom Lake to 81.3 m^3/s at the outlet of Judge Sissons Lake.

Table 5.2-2
Mean Monthly Discharge for 1991 as Estimated from Annual Hydrographs (BEAK 1992)

Lake Outlet Name	Mean Discharge (m^3/s)			Instantaneous Peak Discharge (m^3/s)
	June	July	August	
Andrew Lake	2.92	0.05	0.00	26.1
Andrew Lake Study Area	9.17	0.07	0.00	54.0
Cigar Lake	1.08	0.37	0.93	10.3
Judge Sissons Lake	32.9	7.29	1.74	81.3
Mushroom Lake	0.16	0.02	0.01	0.70
Pointer Lake	6.45	0.18	0.00	29.2

m^3/second = cubic metres per second

5.2.2 Recent Monitoring Programs (2007-2010)

In 2007, Golder commenced its initial site reconnaissance and established 12 stream discharge and seven lake elevation monitoring sites (SF1-SF12 and LE1-LE7, respectively) over the period June 11 to June 18. In addition, seven continuous water level sensors (Levelogger) and one barometric pressure sensor (Barologger) were installed. Continuous water level sensors were installed at SF2, SF3, SF4, SF5, SF6, SF7, SF8 and SF9. The Barologger was installed near Sik Sik Lake (Figure 3.2-1). The summer field program was conducted over the period July 30 to August 3. In September (17 to 20), field staff returned for the final series of measurements and to remove the continuous water level sensors for the season.

Three hydrology field programs were conducted over the course of the 2008 open water season: June 1 to 13, July 21 to 28, and August 31 to September 4. A total of 12 stream discharge monitoring stations, nine continuous water level monitoring stations, and seven lake elevation stations were re-established over the course of the three field programs. In addition to the re-installation of seven water level recorders near the Kiggavik site, water level sensors were installed during the spring field program at the two decommissioned WSC hydrometric stations (Qinguq Creek and the Aniguq River). In the summer and fall programs, stream surveys were conducted on several of the larger streams that are located along the proposed access route and haul road. During the final field program, the continuous water level recorders were removed for the winter.

The 2009 field season began on June 15 due to a later than usual spring snow melt. The spring program continued until July 6, the summer field program was conducted from July 24 to 28, and the fall field program was conducted from August 24 to September 3. Continuous water surface elevation sensors were installed at SF2, SF3, SF4, SF5, SF6, SF7, SF8, SF13, and SF14. Two new sites were established to monitor stream discharge near the outflows of Andrew and Mushroom lakes, and lake elevation on Andrew and Mushroom lakes. A continuous water level sensor was also installed in the outflow channel of Andrew Lake. Stream topographic surveys were conducted as part of each of the field programs in 2009 for stream crossing locations along the proposed north all-weather road route. The locations of all stream discharge, continuous water surface elevation and lake water surface elevation monitoring sites are presented in Table 4.1-3 and Figures 3.2-1 and 3.2-2.

The 2010 site visit occurred on June 15 to June 20 and involved installing continuous water surface elevation sensors at stream monitoring stations SF5, SF7, SF8, SF13, SF14 and SF15, at lake monitoring stations LE3, LE4, LE7, LE8 and LE9, and a Barologger was again installed near Sik Sik Lake. Discharge and elevation measurements were taken at SF2, SF3. SF5. SF7, SF8, SF10, SF15, and SF16 and elevations measurements were taken at SF13 and SF14.

5.2.2.1 Lake Water Levels

Instantaneous lake water surface elevations were measured using an engineer's rod and level during each of the field programs in 2007, 2008, 2009, and 2010 (Table IV-1, Attachment IV). Lakes for which water surface elevations were measured in 2007, 2008, 2009, and 2010 include Pointer Lake, Unnamed Lake downstream of Cirque Lake, Judge Sissons Lake, Squiggly Lake (2007 and 2008 only), Skinny Lake, Kavisilik Lake (2007-2009 only), and Siamese Lake. Two additional lake water surface elevation monitoring sites were added in 2009: Andrew Lake and Mushroom Lake. Lake water surface elevation data may be used with coincident lake outflow (discharge) data to create lake elevation-outflow curves, as presented in Figures IV-1 to IV-8 of Attachment IV.

LE1, Pointer Lake

A total of eleven lake water surface elevation measurements were taken on Pointer Lake over 2007-2010 (Photo I-1). The highest recorded elevation was on June 19, 2010 (99.048 m) and the lowest elevation was surveyed on July 31, 2007 (98.197 m). Of these data, seven coincident lake elevation and discharge measurements were taken. The equation generated through regression for lake elevation versus outflow is as follows:

$$Q = (3.5149H - 344.7986)^{2.1218} \quad (2)$$

Where Q is lake outflow (discharge) (m^3/s) and H is lake elevation (m).

LE2, Unnamed Lake Downstream of Cirque Lake

Fourteen lake elevation measurements were taken on the unnamed lake downstream of Cirque Lake, which is located approximately 1 km southwest of the temporary camp (Photo I-2). The highest recorded elevation was on June 17, 2009 (99.142 m) and the lowest elevation was surveyed on August 2, 2007 (98.738 m). Of these data, eleven are coincident with measured outflow data. The equation representing the best fit line through the coincident data points is as follows:

$$Q = (2.5800H - 254.6963)^{2.1496} \quad (3)$$

LE3, Judge Sissons Lake

Judge Sissons Lake elevation was surveyed near its outflow (Photo I-3). Twelve stage readings were surveyed at this location. The highest recorded elevation was on June 18, 2010 (100.055 m) and the lowest elevation was surveyed on September 17, 2007 (99.546 m). Nine coincident data points were used to generate the stage-discharge curve. Results of regression were a linear fit to the data, as follows:

$$Q = 104.1667H - 10{,}374.0938 \quad (4)$$

LE4, Squiggly Lake

Squiggly Lake elevations were surveyed five times over 2007 and 2008. Lake elevation measurements were taken near the lake's outflow (Photo I-4); however, the location of stream flow monitoring is approximately 8 km downstream, so separate benchmarks were used. The highest recorded elevation was on June 18, 2007 (96.653 m) and the lowest elevation was surveyed on August 31, 2008 (96.416 m). All lake elevation data were used to generate a linear stage-discharge relationship with the following characteristics:

$$Q = 12.9534H - 1248.5052 \quad (5)$$

LE5, Skinny Lake

The elevation of Skinny Lake was surveyed a total of seven times between 2007 and 2009. The highest recorded elevation was on June 18, 2009 (99.601 m) and the lowest elevation was surveyed on August 3, 2007 (99.211 m). Skinny Lake benchmark is located near the lake's outflow (Photo I-5); however it is upstream of the stream discharge measurement location and therefore does not share the same benchmark. Regression analysis for Skinny Lake elevation versus discharge yielded the following equation:

$$Q = (6.9541H - 689.7928)^{1.8695} \quad (6)$$

LE6, Kavisilik Lake

Kavisilik Lake is located immediately downstream of Skinny Lake (Photo I-6), and shares a benchmark with Skinny Lake's outflow cross section. Kavisilik Lake's outflow discharge was not measured; therefore its stage-discharge relationship is not presented. A total of seven lake elevations were surveyed at this location. The highest recorded elevation was on June 18, 2009 (98.540 m) and the lowest elevation was surveyed on August 3, 2007 (98.170 m).

LE7, Siamese Lake

Lake elevation surveys on Siamese Lake began in August 2007 on the northern edge of the lake (Photo I-7). A total of eight survey measurements were taken. The highest recorded elevation was on June 19, 2010 (97.421 m) and the lowest elevation was surveyed on September 19, 2007 (96.980 m). Seven of the eight data points were coincident with stream discharge measurement and were used to generate the stage-discharge relationship. Regression analysis yielded the following equation:

$$Q = (2.5589H - 247.4094)^{2.9036} \quad (7)$$

LE8, Andrew Lake

Andrew Lake elevation monitoring began in the spring of 2009 (Photo I-8). A total of six measurements were taken over the course of the open water period. The highest recorded elevation was on June 17, 2010 (99.529 m) and the lowest elevation was surveyed on July 25, 2009 (98.871 m). All six measurements were used in the stage-discharge relationship, which generated the following equation:

$$Q = (1.6667H - 164.2823)^{3.6982} \quad (8)$$

LE9, Mushroom Lake

Mushroom Lake water elevation monitoring also began in the spring of 2009. Five lake elevation measurements were taken at this location, and a coincident benchmark to the lake outflow was used (Photo I-9). The highest recorded elevation was on June 16, 2010 (99.642 m) and the lowest elevation was surveyed on August 25, 2009 (99.410 m). The equation of the best fit curve through the coincident lake elevation and outflow points is as follows:

$$Q = (0.8956H - 88.3442)^{9.9108} \quad (9)$$

5.2.2.2 Lake Bathymetry and Storage Volume

Bathymetric data were collected in the 2007, 2008, and 2009 field programs. Data were collected for Pointer Lake in 2007; for Rock Lake, End Grid Lake, Calf Lake, and Siamese Lake in 2008; and for Mushroom Lake, Andrew Lake, Sik Sik Lake and a portion of Judge Sissons Lake in 2009. Lake stage-storage volume-area curves for the lakes surveyed in 2007, 2008, and 2009 are presented in Figures V-1 through V-8 of Attachment V.

Lake volumes for lake data collected between 2007 and 2009, including volumes below the 2 m depth contour line (approximate ice thickness), are summarized in Table 5.2-3 and Table III-1 of Attachment III. Lake retention times were estimated by dividing the calculated total volume by the mean annual discharge rate (estimated using Equation 1) from Table 5.2-3. The residence (retention) time is equal to the length of time required to flush the volume of the lake using the annual outflow volume.

The current protocol for water withdrawal under ice-covered waters in Nunavut is 5% of the under-ice volume for lakes whose depths are greater than or equal to 1.5 m below the maximum ice thickness (DFO 2005). However, recent research suggests that a withdrawal threshold of 10% may pose minimal risk to overwintering fish and that the current guideline may be revised (Cott et al. 2008).

Table 5.2-3
Estimates for Surface Areas, Volumes, and Retention Times for Select Lakes within the Kiggavik Project Area

Lake	Estimated Drainage Area (km^2)	Estimated Surface Area (ha)	Total Volume (10^6 m^3)	Volume of water below 2 m contour (m^3)	5% of Under Ice Volume (m^3)	Estimated Mean Annual Discharge (m^3/s)	Retention Time (year)
Andrew Lake	33.6	54	0.0958	n/a	n/a	0.21	0.01
Calf Lake	88.2	35.8	0.214	n/a	n/a	0.54	0.01
End Grid Lake	7.1	13.2	0.103	n/a	n/a	0.04	0.07
Mushroom Lake	4.4	32.0	0.587	284,000	14,200	0.03	0.66
Pointer Lake	79.0	393	5.47E	118,000	5,920	0.48	0.36
Rock Lake	99.2	32.4	0.210	n/a	n/a	0.60	0.01
Siamese Lake	85.2	2,790	115	65,800,000	3,290,000	0.52	7.01
Siamese Lake East Basin	(a)	1,500	62.4	38,000,000	1,900,000	(a)	(a)
Siamese Lake West Basin	(a)	1,290	50.4	27,800,000	1,390,000	(a)	(a)
Sik Sik Lake	1.8	17.5	0.135	n/a	n/a	0.01	0.37

(a) Siamese Lake East and West Basins are each a part of Siamese Lake
n/a = not applicable (lake depth is less than 2 m)
km^2 = square kilometres; ha = hectare; m^3 = cubic metres; m^3/s = cubic metres per second

The portion of a watershed that is occupied by land or water may affect the shape of the downstream hydrograph. For example, a watershed that has a higher percentage of lakes may attenuate runoff, resulting in a hydrograph whose peak is not as responsive to rainfall or runoff as one that has a lower percentage of lakes. A greater portion of lake surface area also allows for a larger evaporative surface (as opposed to evapotranspiration). Of the streams that were monitored near the Project, the lake surface fractions of upstream drainage areas ranged from near zero (SF3 and SF10) to 34% (SF8). Table 5.2-4 indicates the total drainage area upstream of each of the stream discharge monitoring stations and the proportion of lake and land surface therein.

Table 5.2-4
Estimated Total Lake Surface Areas and Fractions of Drainage Basins Near the Kiggavik Project

	Upstream Lake Surface Area (km^2)	Total Drainage Area (km^2)	Upstream Land Surface Area (km^2)	Lake Surface Fraction
Stream discharge Monitoring Station				
SF1	13.9	112	97.9	0.124
SF2	0.986	13.9	12.9	0.0710
SF3	0.00434	3.61	3.61	0.00120
SF4	0.185	2.30	2.12	0.0804
SF5	12.2	79.1	66.9	0.154
SF6	6.034	54.5	48.5	0.111
SF7	165	658	493	0.251
SF8	29.5	86.0	56.5	0.343
SF9	9.63	69.7	60.0	0.138
SF10	0.000	0.625	0.62	0.000
SF11	0.128	3.16	3.03	0.0406
SF12	7.95	55.2	47.2	0.144
SF15	4.23	33.7	29.5	0.125
SF16	0.531	4.03	3.50	0.132
Drainage Basin				
Kavisilik Lake	22.2	148	126	0.150
Willow Lake	16.03	102	86.0	0.157
Caribou Lake	13.7	88.5	74.9	0.154
Boulder Lake	7.59	48.3	40.7	0.157
Lower Lake	7.64	71.6	64.0	0.107
Judge Sissons Lake	165	658	493	0.251
Siamese Lake	29.5	86.00	56.5	0.343

km^2 = square kilometres

5.2.2.3 Stream Discharge

Station SF1, Outflow of Skinny Lake

Outflow from Skinny Lake is monitored at Station SF1, located in the short connecting channel between Skinny Lake and Kavisilik Lake. This drainage basin is located northeast of the Judge Sissons Lake drainage and north of the Siamese Lake drainage area (Figure 3.2-2). The upstream contributing drainage at SF1 is estimated to be 112 km^2.

Discharge monitoring Station SF1 began during the summer field program in 2007 and discharge measurements were taken during both the summer and fall programs in 2007 and 2008. Discharge was not measured in the spring of these two years, as site conditions were unsafe with large amounts of ice and snow built-up over the fast flowing channel beneath. In 2009, the overlying ice and snow had collapsed and discharge in the open channel was measured during all three field programs; however, measurement was taken upstream of the established cross section during the spring program, as the water was too deep to measure at the exact location of SF1.

Skinny Lake discharges via a short channel to Kavisilik Lake, which drains eastward, eventually draining to the Aniguq River via Audra Lake. The channel substrate at SF1 consists primarily of cobble and boulder (Photos I-10 to I-12). A secondary channel exists approximately 50 m to the left (facing downstream) of the main channel and was observed to convey a small amount of discharge during each of the summer and fall programs. The measured water surface elevations and total discharges at SF1 are presented in Table 5.2-5. Stream discharges ranged between 0.02 m^3/s (August 2007) to 7.03 m^3/s (June 2009).

Table 5.2-5
Measured Water Surface Elevation and Discharge at SF1, Outflow of Skinny Lake, 2007, 2008, and 2009

Date	Water Surface Elevation (m)	Discharge (m^3/s)
3-Aug-07	98.201	0.02
19-Sep-07	98.355	0.54
22-Jul-08	98.284	0.27
31-Aug-08	98.392	0.74
18-Jun-09	98.790	7.03
27-Jul-09	98.216	0.10
26-Aug-09	98.411	1.06

m = metres; m^3/s = cubic metres per second

The resultant stage-discharge curve is presented in Attachment VI. The best fit curve through the data set has an R^2 of 0.996. As more data are collected, this curve may become more reliable as a predictor of stream discharge over a wider range of discharges. The following equation describes the discharge-elevation relationship:

$$Q = (3.6219H - 355.4353)^{2.2578} \quad (10)$$

Where Q is discharge in m^3/s, and H is elevation in m.

Station SF2, Outflow of Unnamed Lake Downstream of Cirque Lake

Monitoring station SF2 is located immediately downstream of the unnamed lake that is downstream of Cirque Lake in the headwaters of the Caribou Lake drainage area. The upstream contributing drainage area is estimated to be 14.0 km^2. The channel substrate is comprised of small angular cobble to boulder sized material, and the banks are organic. In the spring, stream discharge tends to spread well beyond the channel into the flood plain. During the spring and fall programs in 2008, at a location downstream of the monitoring station, a small amount of water was observed to be flowing overland into the adjacent Willow Lake drainage area. This was not observed during the lower flow condition in summer 2008. Photos of SF2 are provided in Attachment I, including cross sectional (Photo I-13), upstream (Photo I-14) and downstream (Photo I-15) views.

The measured water surface elevation and stream discharge measured with a current meter are presented in Table 5.2-6, while the stage-discharge curve is presented in Attachment VI. Measured stream discharges ranged between zero flow in the summer of 2007 to a maximum of 1.24 m^3/s during the spring of 2010.

Table 5.2-6
Measured Water Surface Elevation and Discharge at SF2, Outflow of Unnamed Lake Downstream of Cirque Lake, 2007-2010

Date	Water Surface Elevation (m)	Discharge (m^3/s)
14-Jun-07	99.021	0.70
2-Aug-07	98.680	0.00
18-Sep-07	98.732	0.05
2-Jun-08	98.905	0.06
6-Jun-08	98.770	0.02
8-Jun-08	98.910	0.25
23-Jul-08	98.747	0.03
1-Sep-08	98.835	0.26
17-Jun-09	99.006	0.83
20-Jun-09	98.985	0.71
27-Jul-09	98.759	0.04
24-Aug-09	98.870	0.18
17-Jun-10	99.005	1.24

m = metres; m^3/s = cubic metres per second

The best fit curve in Attachment VI gives the following equation for discharge at a given elevation:

$$Q = (1.7812H - 175.3652)^{6.0864} \quad (11)$$

A continuous water level sensor was installed at this location for the 2007-2009 monitoring seasons. Mean daily discharge estimates are presented in Attachment VII, while the hydrographs for 2007, 2008, and 2009 are illustrated in Attachment VIII. The water surface elevation sensors also collect stream temperature data, which are provided in Attachment IX. Table 5.2-7 contains a summary of monthly stream discharge data, including mean, maximum and minimum stream discharge, discharge volumes and basin yields. Monthly basin yields ranged between a low of 9 mm (August 2008) and a maximum of 105 mm (June 2008). Total cumulative volumes estimated over the periods of measurement are also illustrated with the hydrographs presented in Attachment VII. The maximum measured volume of approximately 1.9 million m^3 (1,900 dam^3) occurred in 2007. For this stream, it is estimated that the peak discharge occurred on June 23 in 2007 (1.37 m^3/s) and on June 18 in 2008 (2.41 m^3/s). This stream also experienced secondary peaks that occurred later in the summer, due to rainfall events, as illustrated in the hydrographs presented in Attachment VIII.

Table 5.2-7
Monthly Discharge Summary for SF2, Outflow of Unnamed Lake Downstream of Cirque Lake, 2007-2009

	2007				2008			2009		
	Jun	Jul	Aug	Sept[(a)]	Jun	Jul	Aug	Jun[(b)]	Jul	Aug[(a)]
Mean (m^3/s)	0.84	0.08	0.06	0.05	0.69	0.08	0.05	0.51	0.06	0.15
Maximum (m^3/s)	1.37	0.41	0.38	0.11	2.41	0.56	0.43	0.71	0.25	0.57
Minimum (m^3/s)	0.00	0.00	0.00	0.01	0.02	0.00	0.00	0.30	0.01	0.00
Volume (10^6 m^3)	1.45	0.22	0.17	0.08	1.74	0.22	0.12	0.62	0.15	0.31
Basin Yield (mm)	105	16	12	6	125	15	9	45	11	22

(a) Missing data
(b) Missing peak
m^3/s = cubic metres per second; m^3 = cubic metres

Station SF3, Northeast Inflow of Pointer Lake

Stream discharge monitoring Station SF3 was established on the Northeast Inflow of Pointer Lake during the spring field program in 2007, near the location of the Kiggavik deposit (Figure 3.2-2). The discharge monitoring station consists of a measurement cross section and a continuous recording water level sensor. Substantial overland flow along the channel margins in the vicinity of the stream gauging location was observed during the spring programs each year, though the gauging location was chosen at a site which contained most of the flow within a relatively confined section. The channel substrate was comprised of angular boulders (Photos I-16 to I-18), and the estimated upstream contributing drainage area is 3.6 km^2. Much of the drainage area occurs in an uplands area with flow cascading down a sharp ridge several hundred metres upstream. Outside of the spring runoff period, or freshet, very little flowing water has been observed at this monitoring location. After the spring freshet, standing water was visible within the coarse substrate, and small unmeasurable amounts of water were sometimes observed to flow outside of the channel. Due to lack of, or limited, stream discharge observed during the summer field programs, the water level sensor that was installed at this location in 2008 was moved to another location (on another stream) in order to optimize data collection. The measured water surface elevations and calculated stream discharges at SF3 are presented in Table 5.2-8. Observed discharges ranged between zero (August and September 2007, July 2008 and July 2009) and a peak of 0.46 m^3/s in June 2007.

Table 5.2-8
Measured Water Surface Elevations and Discharges at SF3, Northeast Inflow of Pointer Lake, 2007-2010

Date	Water Surface Elevation (m)	Discharge (m^3/s)
15-Jun-07	99.812	0.46
1-Aug-07	99.423	0.00
19-Sep-07	99.478	0.00
2-Jun-08	99.585	0.02
8-Jun-08	99.649	0.15
23-Jul-08	99.469	0.00
2-Sep-08	99.559	0.03
16-Jun-09	99.714	0.17
20-Jun-09	99.703	0.16
27-Jul-09	99.498	0.00
24-Aug-09	99.617	0.09
17-Jun-10	99.725	0.24

m = metres; m^3/s = cubic metres per second

The resultant stage-discharge curve is presented in Attachment VI and the following equation:

$$Q = (2.0833H - 207.2244)^{2.3256} \qquad (12)$$

Monthly summary data for 2008 and 2009 are presented in Table 5.2-9. Daily discharge estimates, the stream hydrograph, and cumulative volumes over the measurement period are presented in Attachments VII and VIII, respectively. A peak discharge of 0.34 m^3/s occurred on June 13, 2008. The hydrograph for SF3 is similar to that of SF2, and this is likely due to the limited storage available upstream. There are no lakes upstream of SF3; therefore with little or no attenuation, the stream is more sensitive and reactive to runoff or rainfall events. This stream passes through the Kiggavik ore zone and would need to be realigned should the proposed development proceed.

Table 5.2-9
Monthly Discharge Summary for SF3, Northeast Inflow of Pointer Lake, 2008 and 2009

	2008		2009		
	Jun	**Jul[a]**	**Jun[b]**	**Jul**	**Aug[a]**
Mean (m^3/s)	0.15	0.01	0.17	0.01	0.05
Maximum (m^3/s)	0.34	0.06	0.30	0.06	0.20
Minimum (m^3/s)	0.03	0.00	0.07	0.00	0.00
Volume (10^6 m^3)	0.39	0.01	0.22	0.02	0.11
Basin Yield (mm)	107	3	61	6	31

[a] Missing data
[b] Missing peak
m^3/s = cubic metres per second; m^3 = cubic metres

Station SF4, Outflow of Sik Sik Lake

Stream discharge monitoring Station SF4 is located on the Outflow of Sik Sik Lake, which drains into Rock Lake. The Sik Sik Lake sub-basin is estimated to have a drainage area of 1.8 km^2 at the monitoring location. The channel substrate at SF4 is soft organic material, and the bank to bank width is approximately 2.5 m. Stream discharge during the spring field programs spreads outside of the channel banks. Although water was present in the channel at SF4, it was not flowing downstream during the summer and fall programs in 2007, 2008 or 2009 (Table 5.2-10). Photos (I-19, I-20 and I-21) illustrate upstream, downstream, and cross section views of this monitoring location during high flow periods. Photo I-22 illustrates the stream during a zero flow period, taken in the fall of 2007.

The stage-discharge curve was developed based upon five water surface elevation and discharge readings, as presented in Attachment VI. As more data are collected, this curve will become more reliable across a wider range of discharge and elevation. The following formula estimates the discharge at a given elevation:

$$Q = (2.5800H - 256.3844)^{2.0517} \qquad (13)$$

Table 5.2-10
Measured Water Elevation and Discharge at SF4, Outflow of Sik Sik Lake, 2007-2009

Date	Water Surface Elevation (m)	Discharge (m^3/s)
16-Jun-07	99.604	0.36
31-Jul-07	99.203	0.00
18-Sep-07	99.261	0.00
4-Jun-08	99.440	0.03
9-Jun-08	99.527	0.15
23-Jul-08	99.291	0.00
1-Sep-08	99.376	0.00
16-Jun-09	99.574	0.22
26-Jul-09	99.258	0.00
25-Aug-09	99.293	0.00

m = metres; m^3/s = cubic metres per second

A continuous water level sensor was placed at SF4 for each of the three years of monitoring. Daily discharge estimates are provided for each of the years in Attachment VII, and the stream hydrographs and cumulative runoff volumes are presented in Attachment VIII. Cumulative runoff volumes at this location were similar in 2007 and 2008, in the order of 350,000 m^3. In both 2007 and 2008, stream discharge occurred in the channel for a period of 23 days over June and July (2007) and June (2008). The summary of monthly discharge (mean, maximum and minimum), discharge volumes and basin yields is presented in Table 5.2-11. Daily peak discharge values were observed on June 21, 2007 and June 14, 2008.

Table 5.2-11
Monthly Discharge Summary for SF4, Outflow of Sik Sik Lake, 2007-2009

	2007			2008			2009		
	Jun	Jul	Aug	Jun	Jul	Aug	Jun[(b)]	Jul	Aug[(a)]
Mean (m^3/s)	0.21	0.01	0.00	0.14	0.00	0.00	0.05	0.00	0.00
Maximum (m^3/s)	0.34	0.06	0.00	0.34	0.00	0.00	0.16	0.00	0.00
Minimum (m^3/s)	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
Volume (10^6 m^3)	0.34	0.01	0.00	0.35	0.00	0.00	0.07	0.00	0.00
Basin Yield (mm)	148	6	0	151	0	0	29	0	0

(a) Missing data
(b) Missing peak
m^3/s = cubic metres per second; m^3 = cubic metres; mm = millimetres

Station SF5, Outflow of Pointer Lake

Stream discharge monitoring Station SF5 is located approximately 50 m downstream of Pointer Lake. The contributing drainage area is estimated to be 79.0 km^2. During the spring reconnaissance program in 2007, a large portion of Pointer Lake and its outflow remained frozen over until late in the freshet period, when peak discharges had passed; therefore a stream discharge monitoring station was not installed until the summer field program in 2007.

A total of nine discharge and water surface elevation measurements were taken over the 2007, 2008, 2009, 2010 open water seasons, with discharge ranging between a low of 0.06 m^3/s in the summer of 2007 to a high of 13.94 m^3/s during the spring of 2010. The measured water surface elevation and calculated stream discharge for Station SF5 are presented in Table 5.2-12 and illustrated in Figure VI-5 of Attachment VI. The channel bottom near Station SF5 is characterized by cobbles and occasional boulders (Photos I-23, I-24, I-25). The left bank is vertical and organic, whereas the right bank has a shallower slope and lined with cobbles and boulders.

Table 5.2-12
Measured Water Surface Elevations and Discharges at SF5, Outflow of Pointer Lake, 2007-2010

Date	Water Surface Elevation (m)	Discharge (m^3/s)
31-Jul-07	98.441	0.06
18-Sep-07	98.498	0.24
10-Jun-08	98.860	3.30
23-Jul-08	98.521	0.34
1-Sep-08	98.524	0.31
16-Jun-09	99.074	9.27
25-Jul-09	98.511	0.25
25-Aug-09	98.589	0.75
19-Jun-10	99.298	13.94

m^3/s = cubic metres per second; m^3 = cubic metres

The best fit curve in Figure VI-5 of Attachment VI yields the following equation for discharge at a given elevation:

$$Q = (3.8491H - 378.6436)^{2.1128} \qquad (14)$$

A pressure transducer was placed at SF5 in the summer program of 2007, and in the spring programs of 2008, 2009 and 2010. A scatter plot of the stream discharge at SF5 and SF6 in 2008 and 2009 illustrates a strong correlation between discharge observed at SF5 and that at SF6. Therefore, daily stream discharge values were estimated for SF5 for the spring of 2007 based upon data collected at SF6. Estimates for daily peak discharge at SF5 range between 8.77 m^3/s (June 2009) and 12.53 m^3/s (June 2007). Daily discharges calculated from the stage-discharge rating equation are presented in Attachment VII. Daily hydrographs and cumulative runoff volumes over the period of measurement are illustrated in Attachment VIII. The hydrographs at the outflow of Pointer Lake show one main peak that occurs during the spring freshet. Secondary peaks as a result of rainfall later in the open water season are less obvious due to the attenuation provided by upstream lakes, and by Pointer Lake in particular. The monthly discharge summary for Outflow of Pointer Lake is presented in Table 5.2-13. The maximum monthly basin yield during the monitoring period was calculated as 188 mm for June 2007. It is estimated that there were periods of zero flow during August of 2008.

Table 5.2-13
Monthly Discharge Summary for SF5, Outflow of Pointer Lake, 2007-2010

	2007				2008			2009			2010		
	Jun	Jul	Aug	Sept[a]	Jun	Jul	Aug	Jun	Jul	Aug[a]	Jun	Jul	Aug[a]
Mean (m^3/s)	6.02	1.40	0.07	0.30	5.23	0.88	0.05	4.17	0.82	0.27	7.83	3.04	0.43
Maximum (m^3/s)	12.53	3.45	0.23	0.43	9.23	2.63	0.22	8.04	2.02	0.79	16.41	6.31	0.95
Minimum (m^3/s)	0.47	0.07	0.01	0.20	0.00	0.08	0.00	0.00	0.23	0.07	0.00	0.81	0.25
Volume (10^6 m^3)	12.48	3.75	0.20	0.47	10.40	2.36	0.13	7.20	2.21	0.59	14.88	8.13	0.88
Basin Yield (mm)	158	47	3	6	132	30	2	91	28	7	188	103	11

[a] Missing data
m^3/s = cubic metres per second; m^3 = cubic metres; mm = millimetres

Station SF6, Outflow of Shack Lake

Stream discharge monitoring station SF6 is located approximately 3.5 km downstream of Shack Lake, and was established during the spring program in 2007. During the 2007 spring program, stream discharge was well outside of the channel banks (Photos I-26, I-27 and I-28). During the spring program in 2008, flow was within the banks of the channel due to an ice jam that had formed upstream and substantially reduced stream discharge in the main channel. This resulted in much of the spring runoff discharge being redirected across the tundra over a low-lying area and rejoining the main channel approximately 80 m downstream of the measurement cross section. In the spring of 2009, discharge again flooded well outside the banks of the main channel and only a small portion of the discharge was observed to pass through the low-lying area in addition to the main channel (Photo I-29). Bypass discharge was measured at about 10% of the total discharge. Discharge through the bypass area was observed to cease completely as the peak flow passed.

The stream discharge presented for June of 2008 and 2009 (Table 5.2-14) only contains the discharge that was measured within the channel. Stream discharge that bypassed the channel was measured to be 0.66 m^3/s (2008) and 0.60 m^3/s (2009). The channel substrate at this cross section is comprised of sand and cobbles and the channel banks are organic (Photos I-30 to I-32). The contributing drainage area is estimated to be 54.5 km^2. The stream discharge that was measured during the spring program in 2007 was more than one hundred times higher than that measured in the summer, and more than ten times that measured in the fall (Table 5.2-14).

A total of ten water surface elevations and stream discharge measurements were taken for this location in 2007, 2008, and 2009, and the resultant stage-discharge rating curve is presented in Figure VI-6 of Attachment VI.

Table 5.2-14
Measured Water Surface Elevation and Discharge at SF6, Outflow of Shack Lake, 2007-2009

Date	Water Surface Elevation (m)	Discharge (m^3/s)	Discharge - side channel (m^3/s)
16-Jun-07	99.763	2.95	0.00
3-Aug-07	99.247	0.02	0.00
18-Sep-07	99.351	0.23	0.00
6-Jun-08	99.421	0.15	0.00
8-Jun-08	99.365	0.17	0.66
21-Jul-08	99.315	0.22	0.00
1-Sep-08	99.412	0.51	0.00
17-Jun-09	99.774	6.84	0.60
25-Jul-09	99.242	0.08	0.00
25-Aug-09	99.093	0.13	0.00

m^3/s = cubic metres per second; m = metres

The best fit curve in Figure VI-6, Attachment VI yields the following equation for discharge at a given elevation:

$$Q = (1.9091H - 188.9689)^{4.0064} \quad (15)$$

A water level recorder was placed at this location for each of the open water monitoring periods in 2007, 2008, and 2009 (Photo I-33). Peak daily discharges were calculated for June 18, 2007 (8.51 m^3/s), June 14, 2008 (7.76 m^3/s), and June 16, 2009 (5.40 m^3/s). All peak daily discharge values for 2007-2009 are presented in Attachment VII, and the corresponding hydrographs are presented in Attachment VIII. The calculated cumulative volume over the measured period of record was largest in 2008, at approximately 9.77 million m^3. A summary of mean, maximum and minimum monthly discharge values, volumes and basin yields are presented in Table 5.2-15.

Table 5.2-15
Monthly Discharge Summary for Station SF6, Outflow of Shack Lake, 2007-2009

	2007				2008			2009		
	Jun	Jul	Aug	Sept[(a)]	Jun	Jul	Aug	Jun	Jul	Aug[(a)]
Mean (m^3/s)	4.22	0.59	0.12	0.54	3.59	0.70	0.04	2.53	0.29	0.07
Maximum (m^3/s)	8.51	1.82	0.69	0.70	7.76	2.04	0.46	5.40	0.95	0.10
Minimum (m^3/s)	0.00	0.00	0.00	0.33	0.17	0.00	0.00	0.00	0.08	0.04
Volume (10^6 m^3)	6.57	1.58	0.32	0.85	7.75	1.87	0.11	4.59	0.76	0.15
Basin Yield (mm)	120	29	6	16	142	34	2	84	14	3

(a) Missing data
m^3/s = cubic metres per second; m^3 = cubic metres; mm = millimetres

Station SF7, Outflow of Judge Sissons Lake

Station SF7 is located on the upper Aniguq River, approximately 100 m downstream of the outflow of Judge Sissons Lake. The hydrometric station that was once maintained by EC on the Aniguq River is located approximately 55 km downstream of Station SF7. The contributing drainage area to Station SF7 is estimated to be 676 km^2, compared to 2,740 km^2 at the EC hydrometric station. The stream channel at SF7 is approximately 80 m wide (Photos I-34 to I-36) and the substrate is comprised of large cobble and boulders. The measured water surface elevation and calculated stream discharge are presented in Table 5.2-16. The maximum measured discharge occurred in the spring of 2010 (48.69 m^3/s), whereas the minimum measured discharge occurred in the early spring prior to the freshet in 2008 (1.15 m^3/s). The channel was ice covered in early June of 2007, and several holes cut thorough the ice indicated that the ice was largely frozen to the substrate and very little flowing water could be found or heard. BEAK (1992) also reported this condition at the outflow of Judge Sissons Lake and at the outflow of Pointer Lake.

The stage-discharge relationship for SF7 is presented in Figure VI-7 of Attachment VI and the following formula:

$$Q = (5.3706H - 526.8786)^{2.6448} \quad (16)$$

A continuous stage recorder collected data during the open water seasons in each of the four monitoring years. A summary table of monthly data is presented in Table 5.2-17. Daily discharge estimates and the daily hydrographs are presented in Attachments VII and VIII, respectively. The estimated peak daily discharge values are 32.1, 30.5, 35.2 and 42.5 m^3/s in 2007, 2008, 2009, and 2010 respectively.

Table 5.2-16
Measured Water Surface Elevations and Discharges at SF7, Outflow of Judge Sissons Lake, 2007-2010

Date	Water Surface Elevation (m)	Discharge (m^3/s)
14-Jun-07	98.633	6.86
31-Jul-07	98.514	5.64
17-Sep-07	98.458	2.77
5-Jun-08	98.323	1.15
8-Jun-08	98.353	3.36
10-Jun-08	98.502	10.6
23-Jul-08	98.592	12.0
2-Sep-08	98.407	4.30
17-Jun-09	98.771	20.6
25-Jul-09	98.519	8.23
25-Aug-09	98.321	3.89[(a)]
18-Jun-10	98.887	48.69

[(a)] Estimate
m^3/s = cubic metres per second; m = metres

Table 5.2-17
Monthly Discharge Summary for Station SF7, Outflow of Judge Sissons Lake, 2007-2010

	2007				2008			2009			2010		
	Jun	Jul	Aug	Sept[(a)]	Jun	Jul	Aug	Jun	Jul	Aug[(a)]	Jun	Jul	Aug[(a)]
Mean (m^3/s)	19.0	8.6	2.6	1.8	18.6	11.0	5.1	24.9	14.7	8.2	27.7	15.6	2.7
Maximum (m^3/s)	32.1	19.7	3.7	2.1	30.5	20.1	6.6	35.2	23.8	9.4	42.5	22.5	5.9
Minimum (m^3/s)	0.0	4.0	1.4	1.4	2.5	6.8	3.6	0.0	9.2	7.4	0.0	6.3	1.3
Volume (10^6 m^3)	31.1	22.9	7.0	2.6	41.9	29.5	13.7	49.4	39.4	17.7	52.6	41.8	5.6
Basin Yield (mm)	47	35	11	4	64	45	21	75	60	27	80	63	9

[(a)] Missing data
m^3/s = cubic metres per second; m^3 = cubic metres; mm = millimetres

Station SF8, Outflow of Siamese Lake

Station SF8 was established in the summer field program of 2007. This station is located on the outflow of Siamese Lake, which eventually drains into Audra Lake and into the Aniguq River, downstream of the Kiggavik Project site (Figure 3.2-1). The contributing drainage area is estimated to be 86.0 km^2. This drainage area contains the largest proportion of lake surface area of all the stream discharge monitoring stations, at approximately 34% (Table 5.2-5). The lake surface fraction is largely made up of Siamese Lake, which covers nearly 28 km^2. The stream discharge monitoring station is located approximately 800 m downstream of the Siamese Lake outlet. Channel substrate is comprised of sand and cobbles with occasional boulders, and channel banks are vertical and organic (Photos I-37 to I-39). Water surface elevation and calculated stream discharge data are presented in Table 5.2-18. A total of ten stream discharge and water surface elevation measurements were taken over the open water periods in 2007, 2008, 2009, and 2010, and the resultant stage-discharge rating curve is presented in Figure VI-8, Attachment VI. The range of stream discharge was between a minimum of 0.41 m^3/s in the fall of 2007 to a maximum of 6.25 m^3/s in the spring of 2010. Discharge was not measured in either of the spring programs in 2007 or 2008 due to presence of anchor ice within the channel at the time of stream surveys. This outlet is among the latest to become ice free in the spring freshet. High volumes of water were observed flowing over the ice as melt progressed. Siamese Lake outflow tends to be higher in the summer than flow from drainages of comparable size, due the large storage capacity in Siamese Lake. For example, Pointer Lake outflow at Station SF5 drains an area of 79 km^2 and had an estimated mean flow of 0.22 m^3/s in August, 2008, while the estimated mean flow over the same period at SF8 was 0.56 m^3/s.

Table 5.2-18
Measured Water Surface Elevations and Discharges at SF8, Outflow of Siamese Lake, 2007-2010

Date	Water Surface Elevation (m)	Discharge (m^3/s)
2-Aug-07	99.237	0.89
19-Sep-07	99.160	0.41
22-Jul-08	99.302	1.87
24-Jul-08	99.286	1.62
24-Jul-08	99.286	1.56
1-Sep-08	99.194	0.57
18-Jun-09	99.350	2.21
26-Jul-09	99.249	1.03
26-Aug-09	99.235	0.81
19-Jun-10	99.511	6.25

m^3/s = cubic metres per second; m = metres

The best fit curve in Figure VI-8, Attachment VI yields the following equation for discharge at a given elevation:

$$Q = (3.7908H - 375.2070)^{2.6309} \quad (17)$$

A continuous water level sensor was installed at this location in the summer programs of 2007 and 2008, and in the spring programs of 2009 and 2010. A peak discharge of 6.25 m^3/s was measured on June 19, 2010. The shape of the hydrograph at this location has many small peaks that are evident during the summer and fall. This may be due to wind effects on the large water body. A summary of monthly discharge (mean, maximum and minimum), volume of water and basin yield is presented in Table 5.2-19. The daily discharge values are presented in tables in Attachment VII and graphically in Attachment VIII.

Table 5.2-19
Monthly Discharge Summary for Station SF8, Outflow of Siamese Lake, 2007-2010

	2007		2008		2009			2010		
	Aug[(a)]	Sept[(a)]	Jul[(a)]	Aug	Jun	Jul	Aug[(a)]	Jun	Jul	Aug[(a)]
Mean (m^3/s)	0.62	0.61	1.26	0.56	1.76	1.35	0.64	4.10	3.44	0.83
Maximum (m^3/s)	0.89	0.85	1.61	0.89	2.80	1.99	0.94	6.25	5.15	1.89
Minimum (m^3/s)	0.38	0.37	0.89	0.27	0.00	0.85	0.43	0.00	1.68	0.43
Volume (10^6 m^3)	1.60	1.05	0.87	1.50	3.64	3.63	1.38	7.79	9.20	1.73
Basin Yield (mm)	19	12	10	17	42	42	16	91	107	20

(a) Missing data
m^3/s = cubic metres per second; m^3 = cubic metres; mm = millimetres

Station SF9, Outflow of Squiggly Lake

SF9 is located downstream of Squiggly Lake, and eventually drains to the Thelon River. The stream is located within a valley that has a moderate gradient and rapid flows over long channel sections. The stream substrate is comprised of cobbles, and the contributing drainage area is estimated to be 69.7 km^2. The calculated stream discharge in 2007 ranged from approximately 0.2 m^3/s in August to 3.0 m^3/s in June (Table 5.2-20). In 2008, the measured discharge ranged between 0.63 m^3/s (summer) to 0.75 m^3/s (fall). A spring measurement was not taken in 2008 due to presence of ice in the channel at the monitoring location at the time of stream surveys. Cross sectional, upstream, and downstream views of the channel are presented in Photos I-40 to I-42.

Table 5.2-20
Measured Water Elevations and Discharges at SF9, Outflow of Squiggly Lake, 2007 and 2008

Date	Water Surface Elevation (m)	Discharge (m^3/s)
18-Jun-07	99.362	3.00
1-Aug-07	98.965	0.24
19-Sep-07	99.050	0.44
22-Jul-08	99.012	0.63
31-Aug-08	99.044	0.75

m^3/s = cubic metres per second; m = metres

Two stage-discharge rating curves are provided in Figure VI-9, Attachment VI. The linear curve (Equation 18) has been used to estimate discharge at water levels collected by water level sensors outside of the range of observed discharge and elevation, as presented in Table 5.2-20. The power curve (Equation 19) has been used to estimate discharge for water elevations that are within the range of those measured during the field programs. The best fit curves for these data yield the following equations for discharge at a given elevation:

$$Q = 7.2622H - 718.5715 \quad (18)$$

$$Q = \left(\frac{H}{99.1467}\right)^{625} \quad (19)$$

A continuous water level sensor was installed in this stream in 2007 and 2008. Summary data for discharge, volume and basin yield are presented in Table 5.2-21. Daily discharge estimates are also provided in tabular format in Attachment VII and illustrated graphically in Attachment VIII. The hydrograph for SF9 in 2007 demonstrates a primary peak in June and a secondary peak in late August. The continuous recorder was not installed in the spring of 2008; therefore the peak discharge was not recorded in that year. Stream discharge monitoring was not continued at this station in 2009 as the drainage is located outside the local study area (LSA), in the Thelon River Basin.

Table 5.2-21
Monthly Discharge Summary for Station SF9, Outflow of Squiggly Lake, 2007 and 2008

	2007				2008	
	Jun[(a)]	Jul	Aug	Sept[(a)]	Jul[(a)]	Aug
Mean (m^3/s)	0.79	0.79	0.68	0.79	0.79	0.35
Maximum (m^3/s)	5.25	2.24	2.99	1.03	0.53	0.62
Minimum (m^3/s)	2.40	0.28	0.25	0.38	0.35	0.29
Volume (10^6 m^3)	3.78	2.13	1.82	1.02	0.36	0.94
Basin Yield (mm)	54	31	26	15	5	14

(a) Missing data
m^3/s = cubic metres per second; m^3 = cubic metres; mm = millimetres

Station SF10, Tributary to the Northeast Inflow of Pointer Lake

Monitoring Station SF10 was established on the tributary to the Northeast inflow of Pointer Lake on June 15, 2007. The monitoring location consists of a measurement cross section only, because flow is very low or negligible following the brief spring freshet. Evidence of previous hydrological investigations was found downstream of the chosen monitoring location in the form of a fallen wooden weir and pitot tube setup. This channel passes through the Kiggavik ore zones, and consequently may need to be realigned should the proposed development proceed.

The bankfull width at the new monitoring site averaged 1.2 m; however the wetted width during the spring was observed to overflow the channel banks. During spring runoff, discharge was also measured and/or observed in a small side channel that was present approximately 15 m from the right bank of the main channel. The wetted width of this smaller channel was approximately 40 cm, and the measured discharge was less than ten percent of the discharge measured in the main channel. The channel substrate at the monitoring location is organic and grassy; however, immediately upstream there are boulders within the channel (Photos I-43 to I-45). The estimated drainage area to SF10 is 0.62 km^2. There are no upstream lakes to this monitoring location. Table 5.2-22 includes the measured discharges, which ranged from zero to near 0.10 m^3/s (June 2009), and water surface elevations. The discharges and corresponding water surface elevation readings are illustrated in the rating curve in Figure VI-10, Attachment VI. The best fit curve yields the following equation for discharge at a given elevation:

$$Q = (1.2765H - 357.2286)^{3.5100} \quad (20)$$

Table 5.2-22
Measured Water Surface Elevations and Discharges at SF10, Tributary to the Northeast Inflow of Pointer Lake, 2007-2010

Date	Water Surface Elevation (m)	Discharge (m^3/s)
15-Jun-07	98.908	0.05
1-Aug-07	98.813	0.00
18-Sep-07	98.835	0.00
2-Jun-08	98.834	0.01
6-Jun-08	98.791	0.00
10-Jun-08	98.905	0.05
2-Sep-08	98.846	0.01
16-Jun-09	98.897	0.10
20-Jun-09	98.874	0.05
27-Jul-09	98.808	0.00
24-Aug-09	98.860	0.01
17-Jun-10	98.910	0.07

m^3/s = cubic metres per second; m = metres

Station SF11, Northwest Inflow of Pointer Lake

Stream discharge monitoring Station SF11 is located on the northwest inflow of Pointer Lake, downstream of the temporary exploration camp. The estimated drainage area to this station is 3.16 km^2. The monitoring station consists of a measurement cross section only, with no continuous water level recorder. The stream channel at the monitoring location is comprised of an organic bottom and banks (Photos I-46 to I-48). Grass exists within and on the banks of the channel. The maximum stream discharge at SF11 was measured during the spring program in 2007 (Table 5.2-23). The minimum discharge was close to zero during the summer programs in 2008 and 2009. Stage-discharge data are presented graphically in Figure VI-11, Attachment VI. The best fit curve gives the following equation for discharge at a given elevation:

$$Q = (3.7383H - 371.7432)^{2.1381} \quad (21)$$

Table 5.2-23
Measured Water Surface Elevations and Discharges at SF11, Northwest Inflow of Pointer Lake, 2007 -2009

Date	Water Surface Elevation (m)	Discharge (m^3/s)
15-Jun-07	99.758	1.44
18-Sep-07	99.446	0.01
2-Jun-08	99.577	0.11
6-Jun-08	99.520	0.06
8-Jun-08	99.607	0.40
22-Jul-08	99.464	0.00
1-Sep-08	99.547	0.17
17-Jun-09	99.693	0.85
20-Jun-09	99.684	0.79
27-Jul-09	99.477	0.01
25-Aug-09	99.534	0.15

m^3/s = cubic metres per second; m = metres

Station SF12, Outflow of Jaeger Lake

Station SF12 was established during the fall field program on September 20, 2007. This stream drains into Pointer Lake from its west shore (Figure 3.2-2). The channel bottom at this site is comprised of cobbles, and its banks are organic (Photos I-49 to I-51). The monitoring station is located downstream of Jaeger Lake, and the estimated upstream drainage area is 55.1 km^2. The measured discharge during the 2007 fall program was 0.065 m^3/s (Table 5.2-24), and was at a maximum during the fall 2008 program, when it was measured to be 0.34 m^3/s. A spring measurement was not taken in 2008, due to presence of snow and ice cover near the monitoring location at the time of stream surveys. This location proved very difficult for discharge monitoring during the spring runoff period as flow drained from Jaeger Lake from several locations and was dispersed over several channels and as overland flow over the tundra. It was concluded that reliable measurements were not possible in the spring, and discharge monitoring was discontinued in 2009. The stage-discharge relationship is presented in Figure VI-12, Attachment VI.

Table 5.2-24
Measured Water Surface Elevations and Discharges at SF12, Outflow of Jaeger Lake, 2007 and 2008

Date	Water Surface Elevation (m)	Discharge (m^3/s)
20-Sep-07	99.189	0.07
24-Jul-08	99.147	0.13
1-Sep-08	99.266	0.34

m^3/s = cubic metres per second; m = metres

The best fit line through these data points is a linear curve; and as more data are collected this relationship will become reliable over a wider range of stage and discharge measurements. Solving for discharge in the equation presented in Figure VI-12, Attachment VI provides the following equation:

$$Q = 2.8794H - 285.4555 \quad (22)$$

Station SF13, Aniguq River, Downstream of Audra Lake

Station SF13 is located on the Aniguq River, immediately downstream of Audra Lake. Station SF13 is the largest stream in the monitoring program, with an estimated upstream drainage area of 2,740 km^2 (EC2009 b, internet site). Water Survey of Canada (WSC) operated a hydrometric station at this location over the period 1984 to 1994. The site was re-commissioned by AREVA in 2008 for the purpose of linking hydrometric data collected for the Kiggavik Project with the historic record for the region. Thus, the short-term data collected from the LSA could be compared with longer-term data which reflected a broader range of conditions inherent in the 11 year period of record. All runoff generated in the LSA passes though this location prior to discharging to Baker Lake.

This monitoring location is located on a mild bend of the Aniguq River (Photos I-52 to I-54). The thalweg is located near the left bank, and stream substrate is comprised of cobbles and boulders. The river is fast flowing and too deep for wading in the spring. Discharges were not measured directly but rather, calculated from the original stage discharge rating curve that was developed by WSC. Information about the hydrometric station was obtained from WSC (Pippy 2008, pers. comm.). This included the elevation and location of several benchmarks that consist of brass caps cemented in bedrock (Photo I-55). These benchmarks were used as reference elevations for the river stage. WSC also provided the existing stage-discharge rating curve and associated equations. The cross section was considered stable and there was no indication of erosion or channel instability at the site. Consequently the existing rating curve is considered suitable for estimating discharge from water elevations that are tied to the existing benchmarks.

Stream discharge was not measured directly during the 2008, 2009 or 2010 field programs, but a continuous water level sensor was installed during the spring programs in each year and the water levels were surveyed to the benchmarks when the recorder was installed. Because no summer or fall site visits were made in 2010, the water level sensor installed during this time became dry and therefore discharge during most of the open water period cannot be calculated. A summary of monthly discharge data, including water volumes and basin yields, for 2008 2009, and 2010 are presented in Table 5.2-25. The daily discharge data are presented in tables in Attachment VII and as hydrographs in Attachment VIII. Cumulative discharge volumes over the measurement period are also presented in the Figure VIII-9 of Attachment VIII.

Table 5.2-25
Monthly Discharge Summary for SF13, Aniguq River, 2008, 2009 and 2010

	2008			2009			2010
	Jun	Jul	Aug	Jun	Jul	Aug[a]	Jun[a] [b]
Mean (m^3/s)	107.4	53.0	11.5	83.4	38.0	13.9	185.5
Maximum (m^3/s)	170.2	107.5	19.0	128.0	75.3	20.6	283.3
Minimum (m^3/s)	0.0	15.8	4.7	0.0	20.3	7.5	115.6
Volume (10^6 m^3)	213	142	31	137	102	31	144
Basin Yield (mm)	78	52	11	50	37	11	53

[a] Missing data
[b] Missing peak
m^3/s = cubic metres per second; m^3 = cubic metres; mm = millimetres

Station SF14, Qinguq Creek

Station SF14 is located on Qinguq Creek, approximately 8 km upstream of the outlet to Baker Lake. The new stream discharge monitoring station is at the same location as the decommissioned hydrometric station previously operated by WSC from 1969 to 1994. The site was re-commissioned by AREVA in 2008 for the purpose of linking hydrometric data collected for the Kiggavik Project with the historic record for the region. Thus, the short-term data collected from the LSA over the period 2007 to 2010 could be compared with longer-term data, which covers a broader range of conditions inherent in the 26 year period of record. None of the runoff generated from the LSA passes through Quinguq Creek but the drainage area is adjacent to the Aniguq River drainage and would also reflect hydrological conditions similar to those found in the LSA. In addition, the discharge record is longer than the Aniguq River, and the drainage area is similar in size to the Judge Sissons Lake drainage area.

The upstream drainage area to this location is estimated to be 432 km^2 (EC 2009b, internet site). This monitoring location is located on a bend in the stream, upstream of a boulder outcrop (Photos I-56 to I-58). The stream was not wadable in the spring of 2008, 2009, or 2010; however at lower discharges it was possible to wade across the channel. Similar to the hydrometric station on the Aniguq River, a historical benchmark located near the crossing location was used to tie in the data collected during 2008 to 2010 to the stage-discharge rating curve established by WSC (Photo I-59). One direct stream discharge measurement was taken using a current meter in the summer program of 2009 (Table 5.2-26). The resulting discharge was a good fit to that predicted by the historic rating curve for the water elevation measured relative to the benchmark. A continuous water level sensor was installed at SF14 in the spring of

2008, 2009 and 2010. The summary discharge data, including mean, maximum and minimum discharge, discharge volume and basin yields, are presented in Table 5.2-27. Daily discharge data are presented in tabular format in Attachment VII and graphically in Attachment VIII. The hydrograph in 2008 exhibits a sharp peak in early June, followed by a more gradual decline towards the middle of the month. The 2008, 2009, and 2010 hydrographs show secondary small peaks that occur in the fall. The minimum discharges over the periods of record are 1.0 m^3/s in 2008 and 1.2 m^3/s in 2009, both of which occurred in August.

Table 5.2-26

Measured Water Surface Elevation and Discharge at SF14, Qinguq Creek, 2009

Date	Water Surface Elevation (m)	Discharge (m^3/s)
26-Jul-09	33.930	2.00

m^3/s = cubic metres per second; m = metres

Table 5.2-27

Monthly Discharge Summary for SF14, Qinguq Creek, 2008, 2009, and 2010

	2008			2009			2010		
	Jun[a]	Jul	Aug	Jun[b]	Jul	Aug[a]	Jun[b]	Jul	Aug[a]
Mean (m^3/s)	21.67	5.38	2.89	13.99	3.43	2.92	23.49	13.16	6.55
Maximum (m^3/s)	34.75	12.18	11.12	20.61	7.26	9.61	38.69	30.79	10.44
Minimum (m^3/s)	12.39	2.01	1.03	7.96	2.12	1.15	12.41	2.76	2.44
Volume (10^6 m^3)	44.94	14.40	7.73	14.51	9.20	6.55	22.33	35.25	6.22
Basin Yield (mm)	104	33	18	34	21	15	52	82	14

(a) Missing data
(b) Missing peak
m^3/s = cubic metres per second; m^3 = cubic metres; mm = millimetres

SF15, Outflow of Andrew Lake

SF15 is located near the outlet of Andrew Lake. The estimated drainage area to the monitoring location is 33.7 km^2, of which approximately 4.2 km^2 is lake area. This monitoring station is located upstream of SF6 and was established in the spring of 2009. The purpose of this additional station was to obtain further information from Andrew Lake, which may require partial draining given its proximity to the open pit proposed for the Sissons area.

The bankfull width of the channel at the monitoring location is approximately 3.8 m; however during the spring program, the wetted width was measured to be approximately 16.8 m, well outside of the channel banks (Photo I-60). The channel substrate at this location is comprised of sand and cobble, with the occasional boulders (Photos I-61 and I-62).

A total of six measurements were taken at SF15 over the open water period in 2009 and 2010. Discharge ranged from a low of 0.07 m^3/s (summer measurement, 2009) to a high of approximately 5.91 m^3/s (spring measurement, 2010), as presented in Table 5.2-28. The stage-discharge relationship for this cross section is presented in Attachment VI. The equation of the best-fit curve is presented below (Equation 23).

Table 5.2-28
Measured Water Surface Elevations and Discharges at SF15, Outflow of Andrew Lake, 2009-2010

Date	Water Surface Elevation (m)	Discharge (m^3/s)
18-Jun-09	99.705	4.00
6-Jul-09	99.290	0.37
25-Jul-09	99.132	0.07
25-Aug-09	99.165	0.12
17-Jun-10	99.787	5.91
19-Jun-10	99.664	3.59

m^3/s = cubic metres per second; m = metres

$$Q = (1.7889H - 176.8673)^{3.5486} \qquad (23)$$

A continuous water level sensor was placed in this stream during the spring program of 2009 and 2010. In order to determine whether a relationship exists between SF15 and the monitoring station downstream (Station SF6), the 2009 daily data were plotted against each other. These demonstrated a high correlation (R^2 = 0.998). Therefore, using the relationship between SF6 and SF15, a stream discharge record for SF15 was derived for 2007 and 2008. The daily discharge values are presented in Attachment VII, while the daily hydrographs are presented in Attachment VIII. A summary of monthly discharge (mean, maximum, and minimum), discharge volume, and basin yield for 2007-2010 are presented in Table 5.2-29. Peak discharge for SF15 ranged between an estimated 3.97 m^3/s in 2009 to 6.96 m^3/s in 2010. The largest basin yield occurred in 2010 (Table 5.2-29).

Table 5.2-29
Monthly Discharge Summary for SF15, Outflow of Andrew Lake, 2009-2010

	2007				2008			2009			2010		
	Jun	Jul	Aug	Sept[(a)]	Jun	Jul	Aug	Jun	Jul	Aug[(a)]	Jun	Jul	Aug[(a)]
Mean (m^3/s)	3.10	0.43	0.08	0.39	2.63	0.51	0.03	1.86	0.21	0.04	2.78	1.01	0.07
Maximum (m^3/s)	6.25	1.34	0.50	0.51	5.70	1.50	0.34	3.97	0.64	0.08	6.96	3.08	0.15
Minimum (m^3/s)	0.00	0.00	0.00	0.23	0.12	0.00	0.00	0.00	0.04	0.02	0.00	0.17	0.03
Volume (10^6 m^3)	4.82	1.15	0.22	0.61	5.69	1.36	0.07	3.37	0.56	0.10	5.28	2.70	0.14
Basin Yield (mm)	143	34	7	18	169	40	2	100	16	3	157	80	4

(a) Missing data
m^3/s = cubic metres per second; m^3 = cubic metres; mm = millimetres

Station SF16, Outflow of Mushroom Lake

SF16 was established in the spring program of 2009 and continued in 2010. This station is located near the outlet of Mushroom Lake and has an estimated upstream drainage area of 4.03 km^2. The channel substrate at this location is comprised of sand and gravel, and the channel banks are vertical (Photos I-63 to I-65). Five stage and discharge measurements were taken at SF16 over the open water periods in 2009 and 2010, as presented in Table 5.2-30 and illustrated in Figure VI-13 of Attachment VI. The range of measured discharge was between 0.02 m^3/s (summer and fall, 2009) and 0.34 m^3/s (spring, 2010). The stage-discharge relationship is represented by Equation 24.

Table 5.2-30
Measured Water Surface Elevations and Discharges at SF16, Outflow of Mushroom Lake, 2009

Date	Water Surface Elevation (m)	Discharge (m^3/s)
18-Jun-09	99.460	0.14
25-Jul-09	99.216	0.02
25-Aug-09	99.227	0.02
16-Jun-10	99.543	0.34
19-Jun-10	99.497	0.24

m^3/s = cubic metres per second; m = metres

$$Q = (0.2155H - 20.4858)^{34.965} \qquad (24)$$

The mean annual discharge for each of the stream discharge monitoring locations was estimated using Equation (1) and are presented in Table 5.2-31. Mean annual discharge estimates for Qinguq Creek and Aniguq River are based on historical WSC data, as presented previously in Table 5.1-2. Aside from the Aniguq River, estimated mean annual discharge range between near zero values for stations located on the inflows to Pointer Lake (SF3, SF10, SF11) and Outflow of Sik Sik Lake (SF4), to a maximum of 3.89 m^3/s at the Outflow of Judge Sissons Lake. The small estimates for discharge are due to the small contributing drainage areas.

Table 5.2-31
Estimated Mean Annual Discharge for Local Stream Discharge Monitoring Stations around the Project

Station ID	Stream Name	Mean Annual Discharge (m^3/s)
SF1	Outflow of Skinny Lake	0.68
SF2	Outflow of Unnamed Lake Downstream of Cirque Lake	0.09
SF3	Northeast Inflow of Pointer Lake	0.02
SF4	Outflow of Sik Sik Lake	0.01
SF5	Outflow of Pointer Lake	0.48
SF6	Outflow of Shack Lake	0.33
SF7	Outflow of Judge Sissons Lake	3.89
SF8	Outflow of Siamese Lake	0.52
SF9	Outflow of Squiggly Lake	0.43
SF10	Tributary to the Northeast Inflow of Pointer Lake	0.00
SF11	Northwest Inflow of Pointer Lake	0.02
SF12	Outflow of Jaeger Lake	0.34
SF13	Aniguq River	17.1[a]
SF14	Qinguq Creek	2.6[a]
SF15	Outflow of Andrew Lake	0.21
SF16	Outflow of Mushroom Lake	0.03

[a] based on historical WSC data
m^3/s = cubic metres per second

5.2.2.4 Runoff Volume and Yield

Estimated volumes of runoff over the periods of measurement in 2007 and 2008 are presented in Table 5.2-32. Volumes of precipitation over a hydrological year (October to September) are also presented in Table 5.2-32. Precipitation data are from the Baker Lake climate station and were corrected to account for precipitation gauge undercatch in 2007 and 2008 (Mekis 2009, pers. comm.). Adjusted precipitation data were not available for 2009 or 2010 at the time of analysis. The ratios corresponding to uncorrected precipitation data are also presented in Table 5.2-32 for comparative purposes. Runoff ratios for each monitoring location with peak stream discharge data are presented in Table 5.2-32.

Basin yields are presented on a monthly basis in Table 5.2-33. Note that these yields are over the measured periods of record, and that not all months captured a full record of stream discharge data. Basin yields are also presented in Figure 5.2-4. Basin yields are similar for the 2007 and 2008 periods of measurement; however they are lower in 2009.

Table 5.2-32
Kiggavik Local Runoff Volumes and Ratios, 2007-2008

Station ID and Name	Year	End Field Season	Volume of Total Precipitation[a] (10^6 m^3)	Volume of Total Adjusted Precipitation[a] (10^6 m^3)	Estimated Volume of Runoff (10^6 m^3)	Runoff Ratio	Runoff Ratio[b]	Mean Basin Runoff Ratio	Mean Basin Runoff Ratio[a]
SF2, Outflow of Unnamed Lake downstream of Cirque Lake	2007	September 18	3.48	4.88	1.90	0.55	0.39	0.52	0.38
	2008	September 1	3.68	4.79	1.80	0.49	0.38		
SF3, Northeast Inflow of Pointer Lake	2008	July 12	0.537	0.803	0.397	0.74	0.49	0.74	0.49
SF4, Outflow of Sik Sik Lake	2007	September 18	0.576	0.808	0.355	0.62	0.44	0.59	0.44
	2008	September 1	0.609	0.793	0.348	0.57	0.44		
SF5, Outflow of Pointer Lake	2007	September 18	19.8	27.8	16.9	0.85	0.61	0.75	0.55
	2008	September 1	20.9	27.3	13.4	0.64	0.49		
SF6, Outflow of Shack Lake	2007	September 18	13.7	19.1	9.31	0.68	0.49	0.68	0.50
	2008	September 1	14.4	18.8	9.77	0.68	0.52		
SF7, Outflow of Judge Sissons Lake	2007	September 17	165	231	51.5	0.31	0.22	0.34	0.26
	2008	September 1	174	227	65.4	0.38	0.29		
SF8, Outflow of Siamese Lake	2007	September 20	21.6	30.2	c	c	c	c	c
	2008	September 1	22.8	29.7	c	c	c		
SF9, Outflow of Squiggly Lake	2007	September 19	17.4	24.5	c	c	c	c	c
	2008	August 31	18.4	24.0	c	c	c		
SF13, Aniguq River	2008	September 3	727	947	392	0.54	0.41	0.54	0.41
SF14, Qinguq Creek	2008	September 3	115	149	73.9	0.64	0.49	0.64	0.49
SF15, Outflow of Andrew Lake	2007	September 18	8.44	11.8	6.80	0.81	0.57	0.80	0.60
	2008	September 1	8.92	11.6	7.15	0.80	0.62		
Overall mean						0.74	0.47		
2007 Mean						0.64	0.45		
2008 Mean						0.61	0.46		

(a) Precipitation as collected at Baker Lake A climate station (EC 2009c, internet site)
(b) Adjusted precipitation data for Baker Lake (EC 2009c)
(c) A total volume could not be calculated due to the timing of the collection of spring discharge data; therefore annual runoff was not calculated
m^3/s = cubic metres per second

Table 5.2-33
Kiggavik Local Basin Yields, 2007-2010

Year		2007					2008					2009				2010			
Month		Jun	Jul	Aug	Sep	Total	Jun	Jul	Aug	Sep	Total	Jun	Jul	Aug	Total	Jun	Jul	Aug	Total
SF2	Yield(mm)	105	16	12	6	138	125	15	9	1	151	45	11	22	78	-	-	-	-
	Note	-	-	-	MD	-	-	-	-	MD	MD	MP	-	MD	MP/MD	ND	ND	ND	ND
SF3	Yield (mm)	-	-	-	-	-	107	3	0	0	110	61	6	31	98	-	-	-	-
	Note	ND	ND	ND	ND	ND	-	MD	-	ND	-	MP	-	MD	MP	ND	ND	ND	ND
SF4	Yield (mm)	148	6	0	0	154	151	0	0	0	151	29	0	0	29	-	-	-	-
	Note	-	-	-	-	-	-	-	-	-	MD	MP	-	MD	MP	ND	ND	ND	ND
SF5	Yield (mm)	158	47	3	6	214	132	30	2	0	163	91	28	7	126	188	103	11	302
	Note	-	-	-	MD	MD	-	-	-	MD	MD	-	-	MD	MD	-	-	MD	MD
SF6	Yield (mm)	120	29	6	16	171	142	34	2	1	179	84	14	3	101	-	-		-
	Note	-	-	-	MD	-	-	-	-	MD	-	-	-	MD	-	-	-	-	-
SF7	Yield (mm)	47	35	11	4	97	64	45	21	1	130	75	60	27	162	80	63	9	152
	Note	-	-	-	MD	MD	-	-	-	MD	MD	-	-	MD	MD	-	-	MD	MD
SF8	Yield (mm)	-	-	19	12	31	-	10	17	1	28	42	42	16	101	91	107	20	218
	Note	ND	ND	MD	MD	MP/MD	MP/MD	MD	-	MD	MP/MD	-	-	MD	MD	-	-	MD	MD
SF9	Yield (mm)	54	31	26	15	126	-	5	14	-	19	-	-	-	-	-	-	-	-
	Note	MD	-	-	MD	MD	MP	MD	-	ND	MP	ND	ND	ND	ND	ND	ND	ND	ND
SF13	Yield (mm)	-	-	-	-	-	78	52	11	2	143	50	37	11	98	53	-	-	53
	Note	ND	ND	ND	ND	ND	-	-	-	MD	MD	-	-	MD	MD	MP	ND	ND	MP/MD
SF14	Yield (mm)	-	-	-	-	-	104	33	18	6	171	34	21	15	70	7	13	1	22
	Note	ND	ND	ND	ND	ND	MD	-	-	MD	MD	MP	-	MD	MD	MP	-	MD	MP/MD
SF15	Yield (mm)	143	34	7	18	202	169	40	2	1	212	100	16	3	119	157	80	4	241
	Note	-	-	-	MD	MD	-	-	-	MD	MD	-	-	MD	MD	-	-	MD	MD

MP = Missing peak; MD = Missing data; ND = No data; mm = millimetre

5.2.2.5 Flood and Low Flow Frequency

Many factors can influence the magnitude of extreme (flood or low flow) events, including the number of lakes within a drainage basin, lake outlet geometry, topography of the basin, and vegetation. Flood frequencies for the monitoring locations near the Kiggavik Project were estimated using the flood frequency data for Qinguq Creek. Qinguq Creek was selected for flood frequency estimates due to the length of its period of record and size of its drainage basin. Streams associated with smaller drainage areas commonly have higher peak runoff values on a unit-area basis, due to reduced storage within the basin. One method to account for this increase is to apply a factor to the drainage area ratio (Gordon et al. 2004; SaskWater 1993), as follows:

$$Q_1 = Q_2 \left(\frac{A_1}{A_2}\right)^x \qquad (25)$$

Where Q_1 and Q_2 are discharges of the smaller and larger watersheds, respectively; A_1 and A_2 are the drainage areas of the smaller and larger watersheds, respectively; and x is a unitless factor. Using the peak discharge data from the Aniguq River station, assessment of nine years of coincident peak values for Aniguq River and Qinguq Creek results in a median 'x' factor of 0.80. Therefore, estimation of flood discharges for watersheds between the range of Qinguq Creek (432 km^2) and Aniguq River (2,740 km^2) may be accomplished using predicted flood values for Qinguq Creek and the following equation:

$$Q_1 = Q_2 \left(\frac{432km^2}{A_2}\right)^{0.80} \qquad (26)$$

Rearranging Equation (26) gives the following equation:

$$Q_2 = Q_1 \left(\frac{432km^2}{A_2}\right)^{-0.80} \qquad (27)$$

Where Q_1 and Q_2 are flood discharges for Qinguq Creek and the ungauged basin at a given return interval, respectively; and A_2 is the area of the ungauged basin (in km^2). In the case of watersheds that are smaller than Qinguq Creek, a similar approach using the Qinguq Creek data as the larger watershed was employed, as follows. A historical hydrometric station exists near Baker Lake (Akkutuak Creek near Baker Lake). Although technically located within the Northern Arctic ecozone, this station was considered close enough to be used for analysis, due to its location in proximity to the road and the Project. The drainage basin size of Akkutuak Creek (15 km^2) is also in the same order of magnitude as many streams in the LSA and those associated with the proposed access road from Baker Lake. Assessment of eight years of coincident peak values for Akkutuak Creek and Qinguq Creek results in a median 'x' factor of 0.81. Therefore, estimation of discharges for watersheds smaller than Qinguq Creek may be accomplished using predicted flood values for Qinguq Creek and the following equation:

$$Q_2 = Q_1 \left(\frac{A_2}{432km^2}\right)^{0.81} \qquad (28)$$

Flood frequency predictions for monitoring locations around the Kiggavik Project are presented in Table 5.2-34.

5.2.2.6 Ice and Winter Flows

For large open water areas, the physical process of ice formation starts once the surface water temperature reaches its point of maximum density (approximately 4°C). When this happens the process of fall turnover is initiated. As cool air reduces the surface water temperature to near 4˚C, the denser water sinks and is replaced at surface by less dense water upwelling from below. When mixing is complete, and air temperatures are below freezing, the surface water reaches the freezing point and is able to develop an ice cover. The ice cover thickens as the freezing front moves downward into the water column. If ice growth is interrupted by a snowfall of sufficient weight to submerge the ice cover, the lower layers of the snow become wet and limit further heat loss from the ice cover to the atmosphere until the wet snow is frozen. Ice formed this way is called white ice or snow ice, which may form several times in a winter and produce successive layers contributing to the ice thickness.

The decay of lake ice begins with the melting of the snow cover on the ice and the ice near the shore (border ice) that causes loss of its consistency and allows for mechanical degradation. The ice cover is also melted from the bottom by the contact of relatively warm lake water that is vertically mixed by waves and lake currents. The processes of ice melt and mechanical degradation continue until the ice disappears.

An estimation of ice thickness and duration for the lakes at Kiggavik was based on a method that accounts only for heat conduction. This is a reasonable approach under the assumption of minimal solar radiation in winter, which may be expected for the Kiggavik region. The total heat flux upward through the ice and snow is the sum of the heat flux from the warm water below and the latent heat loss as a result of ice formation. The total heat flux was evaluated by the degree-day method using records of daily snow depth and daily air temperature for the period 1953 to 2008 available at Baker Lake (EC 2009e, internet site). Results for Siamese Lake, Mushroom Lake, Judge Sissons Lake and Pointer Lake are presented in Tables 5.2-35 to 5.2-38, respectively. Details of the model used for these evaluations are in Attachment X. Maximum ice thicknesses are estimated to occur in May for each of the modelled lakes. Maximum thicknesses for Siamese, Mushroom, Judge Sissons and Pointer Lakes were 2.48, 1.87, 2.48 and 1.39 m, respectively. Mean values were estimated to be 2.01 m (Siamese Lake), 1.87 m (Mushroom Lake), 2.00 m (Judge Sissons Lake) and 1.39 m (Pointer Lake). In 2009, Golder also measured the ice thickness on a number of lakes near the Project, including Siamese, Mushroom, and Judge Sissons Lakes. Measured values are presented in their respective tables and are generally within the estimated ranges that were modelled.

Table 5.2-34
Flood Magnitude (m^3/s) and Frequency Predictions for Stream Discharge Monitoring Locations near the Project

Station ID	Stream Name	Return Interval (year)						
		1.01	2	5	10	20	50	100
SF1	Outflow of Skinny Lake	3.15	16.2	23.5	27.5	30.8	34.3	36.6
SF2	Outflow of Unnamed Lake Downstream of Cirque Lake	0.58	2.98	4.34	5.09	5.69	6.34	6.75
SF3	Northeast Inflow of Pointer Lake	0.20	1.00	1.46	1.71	1.91	2.13	2.27
SF4	Outflow of Sik Sik Lake	0.14	0.70	1.01	1.19	1.33	1.48	1.57
SF5	Outflow of Pointer Lake	2.38	12.2	17.8	20.8	23.3	25.9	27.6
SF6	Outflow of Shack Lake	1.76	9.03	13.2	15.4	17.2	19.2	20.4
SF7	Outflow of Judge Sissons Lake	13.2	67.7	98.5	115	129	144	153
SF8	Outflow of Siamese Lake	2.54	13.1	19.0	22.3	24.9	27.8	29.5
SF9	Outflow of Squiggly Lake	2.14	11.0	16.0	18.8	21.0	23.4	24.9
SF10	Tributary to the Northeast Inflow of Pointer Lake	0.05	0.24	0.35	0.41	0.46	0.51	0.55
SF11	Northwest Inflow of Pointer Lake	0.17	0.90	1.31	1.53	1.71	1.91	2.03
SF12	Outflow of Jaeger Lake	1.77	9.12	13.3	15.5	17.4	19.4	20.6
SF13	Aniguq River	41.2	212	308	361	404	450	479
SF14	Qinguq Creek	9.4	48.3	70.3	82.3	92.1	103	109
SF15	Outflow of Andrew Lake	1.19	6.12	8.91	10.4	11.7	13.0	13.8
SF16	Outflow of Mushroom Lake	0.21	1.10	1.60	1.87	2.09	2.33	2.48

Table 5.2-35
Modelled and Measured Ice Thicknesses for Siamese Lake (m)

Month	Model Estimate			Measured (2009)
	Minimum	Mean	Maximum	
January	0.65	1.25	1.86	-
February	0.79	1.54	2.12	-
March	0.87	1.78	2.31	-
April	1.02	1.94	2.43	-
May	1.11	2.01	2.48	2.1
June	0.00	1.50	2.47	-
July	0.00	0.09	1.92	-
August	0.00	0.00	0.00	-
September	0.00	0.00	0.06	-
October	0.00	0.13	0.55	-
November	0.09	0.52	1.00	-
December	0.47	0.90	1.46	-

Table 5.2-36
Modelled and Measured Ice Thicknesses for Mushroom Lake (m)

Month	Model Estimate			Measured (2009)
	Minimum	Mean	Maximum	
January	0.65	1.26	1.86	-
February	0.80	1.55	1.87	-
March	0.87	1.78	1.87	-
April	1.03	1.87	1.87	-
May	1.11	1.87	1.87	2.0
June	0.00	1.51	1.87	-
July	0.00	0.09	1.87	-
August	0.00	0.00	0.00	-
September	0.00	0.00	0.10	-
October	0.00	0.14	0.56	-
November	0.09	0.53	1.00	-
December	0.49	0.91	1.46	-

Table 5.2-37
Modelled and Measured Ice Thicknesses for Judge Sissons Lake (m)

Month	Model Estimate			Measured (2009)
	Minimum	Mean	Maximum	
January	0.64	1.24	1.86	-
February	0.78	1.54	2.12	-
March	0.86	1.77	2.31	-
April	1.02	1.93	2.43	-
May	1.11	2.00	2.48	1.80
June	0.00	1.50	2.46	-
July	0.00	0.09	1.91	-
August	0.00	0.00	0.00	-
September	0.00	0.00	0.04	-
October	0.00	0.11	0.54	-
November	0.09	0.51	0.99	-
December	0.45	0.89	1.46	-

Table 5.2-38
Modelled Ice Thicknesses for Pointer Lake (m)

Month	Model Estimate		
	Minimum	Mean	Maximum
January	0.66	1.26	1.39
February	0.80	1.39	1.39
March	0.88	1.39	1.39
April	1.03	1.39	1.39
May	1.12	1.39	1.39
June	0.00	1.39	1.39
July	0.00	0.09	1.39
August	0.00	0.00	0.00
September	0.00	0.00	0.12
October	0.00	0.15	0.57
November	0.09	0.53	1.00
December	0.50	0.91	1.39

The formation of ice on streams and rivers follows similar processes to that of lakes, the main difference being the velocity of the water and potential for turbulence within the stream. As the temperature of a stream decreases, the water has the potential to become supercooled, which results in the formation of small ice crystals called frazil ice (Ryan and Crissman 1990). In shallow streams and rivers, frazil ice may be deposited on channel bottoms, resulting in the formation of anchor ice. This anchor ice can affect the stage-discharge relationship in the spring due to the difference in channel geometry as compared to the open water period. The streams measured in the local Kiggavik project area are assumed to freeze to the bottom over the winter months. In early June of 2007, the stream channel near SF7, Outflow of Judge Sissons Lake, was observed to be frozen completely. Discharge was observed on top of the channel anchor ice during spring field programs at SF7 in 2007, SF8 (Outflow of Siamese Lake) in 2008, and SF9 (Outflow of Squiggly Lake) in 2008. In 2009, lakes that were observed to have ice thicknesses that extended to lake bottoms included Andrew Lake, Rock Lake, Sik Sik Lake, and Willow Lake.

5.3 ALL-WEATHER ROAD CROSSINGS

5.3.1 Regulatory Considerations

In order to minimize risk to aquatic species and to minimize infringement on the public's right to navigate, AREVA will be required to implement mitigation actions and follow practices as per the *Federal Fisheries Act*, the *Territorial Environmental Protection Act*, and the *Navigable Waters Protection Act*. Regulations, which most commonly relate to working around watercourses, are identified under the Federal and Territorial *Acts* indicated in the following sections. In addition to these *Acts*, Indian and Northern Affairs Canada is currently preparing a document entitled Land Use Guidelines for Access: Roads and Trails; however, this document is only available in draft format. The Land Use Guidelines are intended for use on Crown Lands.

5.3.1.1 The *Fisheries Act*

The *Fisheries Act* is federal legislation that dates back to Confederation. It was established to manage Canada's fisheries resource. It applies to all fishing zones, territorial seas and inland waters of Canada, and is binding to the Federal, Provincial, and Territorial governments. As federal legislation, it supersedes Territorial legislation when the two are in conflict. The Sections of the *Fisheries Act* that most frequently apply to watercourse crossings are summarized below:

- Section 20 (1). Requirement for safe passage of fish.
- Section 22 (1). Provisions for minimum flow above and below an obstruction to provide safe passage for fish.
- Section 22 (2). Provision for safe passage of fish during the construction of an obstruction.
- Section 32. Prohibits the killing of fish by means other than fishing (applies to the use of explosives in or near water).
- Section 35 (1). Prohibits harmful alteration, disruption, or destruction of fish habitat.
- Section 36 (3). Prohibits the discharge of deleterious substances (i.e., sediment, hydrocarbons).

Sections 20 (1), 22 (1), and 22 (2) of the *Fisheries Act* apply directly to construction of culvert crossings in fish-bearing streams. Crossings must be designed to ensure that fish passage is not blocked and that discharges through culverts are neither too high nor low to prevent fish passage. An Authorization under the *Fisheries Act* will trigger a review under the *Canadian Environmental Assessment Act* (*CEAA*).

5.3.1.2 Navigable Waters Protection Act

The *Navigable Waters Protection Act* applies to waters that have been deemed to be navigable. If the watercourse is deemed navigable and the crossing requires Ministerial approval under the *Navigable Waters Protection Act*, a review under *CEAA* will be triggered. The section of the *Act*, which relates to construction of works in navigable waters, is Section 5 (1) (a), as follows:

- Section 5 (1). No work shall be built or placed in, on, over, under, through or across any navigable water unless:
  - a. the work and the site and plans thereof have been approved by the Minister, on such terms and conditions as the Minister deems fit, prior to commencement of construction.

5.3.1.3 *Environmental Protection Act* (Nunavut)

The *Nunavut Act* brought Nunavut into being on April 1, 1999. This *Act* stated that the laws made under the Northwest Territories be duplicated for Nunavut. As such the territory of Nunavut's *Environmental Protection Act* became effective on April 1, 1999, as duplicated from the *Northwest Territories Environmental Protection Act* 1988. The section of the *Act* that relates to construction around water courses is Section 5 (1), as follows:

- Section 5.1. Subject to subsection (3), no person shall discharge or permit the discharge of a contaminant into the environment.

5.3.1.4 Northern Land Use Guidelines – Access: Roads and Trails

The Department of Indian Affairs and Northern Development is revising its land use guidelines that are designed to guide land use activity on Crown land and in the Northwest Territories, Nunavut and Yukon. The series of guidelines include several volumes including Access: Roads and Trails. This volume is currently in a draft format dated October 2008; however, it should be complete and published within a year (Gowan 2009, pers. comm.). Section 5.2, Drainage Control, of Access: Roads and Trails reads:

- Section 5.2. Stream crossings must be well planned, as increased erosion and sedimentation near or in-streams can affect water quality and fish habitat. Stream crossings should be planned with the following consideration:
  - Conduct a watershed delineation to determine the design requirements for a high flow, 100 year flood event.

5.3.2 Design Rationale

Recommendations for cross-drainage structures are based largely on cost, constructability, maintenance, and regulatory considerations. From the regulatory perspective, Fisheries and Oceans Canada (DFO) has stated their preferences for cross-drainage structures based on potential impacts to fish and fish habitat (DFO 2003). The preferred type of crossings is characterized by the following:

- maintain ecological connectivity between aquatic life and their preferred habitat;
- maintain hydraulic capacity of the stream;
- retain or replicate streambed characteristics; and
- have minimal impacts on fish and fish habitat.

DFO's order of preference for stream crossing structures is as follows (DFO 2003):

1) clear span bridge with no channel constriction from any component;

2) bridge with piers;

3) open bottom steel arch or concrete box culvert which does not constrict the stream channel;

4) single, closed bottom structure with no channel restriction from any component. Structure may consist of a box culvert, pipe arch, or round culvert which contains natural bottom substrate materials;

5) single closed bottom structure placed essentially flat (<0.5% slope) such as pipe arch, round pipe, or box culvert;

6) multiple culverts with no baffles; and

7) culverts with baffles.

A key consideration in the recommendations for cross-drainage structures is the evaluation of whether or not the structure would create a velocity barrier due to channel constriction or elevated gradient. Most fish in Nunavut are subcarangiform swimmers while burbot and northern pike are considered anguilliform swimmers. The distinction relates to the nature of wave propulsion. Different swimming modes involve differences in the wavelength and amplitude and the portion of the fish's body that is used for generating the wave. For anguilliform swimmers, the amplitude of the wave is larger and the fish tends to use more of its body to generate the wave. With subcarangiform swimmers, the amplitude is smaller and the wave generation is mainly generated from the posterior end of the fish. Subcarangiform fish are typically able to generate greater swimming speeds than are anguilliform swimmers.

Of the anguilliform swimmers, burbot are the only species that are likely to occur in the vicinity of the stream crossings; however they were only observed at Km 129.2, which is a proposed bridge location. The streams located along the all-weather road alignment are assumed to freeze to their channel bottom throughout the winter. Aside from the Thelon River, which has year-round flow, the stream crossing with the largest contributing drainage area is Km 129.2, With an estimated drainage area of 305 km^2, the stream located at Km 129.2 is smaller than Qinguq Creek (drainage area of 432 km^2) and the Aniguq River (drainage area of 2,740 km^2), both of which freeze completely during winter months. Due to the frozen nature of the channels, it is unlikely that burbot or other fish species could use the stream crossings for spawning or overwintering during later winter periods. Therefore, subcarangiform swimmers, arctic grayling in particular, are the target species for fish passage considerations during the freshet.

Flow velocity criteria are a function of the size of fish passing through the structure and the distance the fish is required to swim. For subcarangiform, the accepted fork length is 30 cm (Government of Alberta 2009; Saskatchewan Transportation and Environment Committee 2004). Because the detailed road design in not complete, the distance the fish is required to swim (i.e. the length of the cross drainage structure) is uncertain. At this preliminary assessment stage, a relatively common length of 30 m for a cross-drainage structure, e.g., culvert, has been assumed for all stream crossings. Therefore, based on a 30 m length and a 30 cm long grayling, acceptable fish passage velocity criteria is approximately 0.8 m/s (Katopodis 1992). During the detailed design stage, when the road geometry has been confirmed, the cross drainage structure length and fish passage velocity criterion may require further investigation.

5.3.3 Flood Frequency

Each cross drainage structure was designed to safely pass the 1:100 year flood event (Indian and Northern Affairs Canada 2008). However, fish bearing streams required a second more stringent design discharge, known as the 3Q10 (Katopodis 1992). The 3Q10 is the peak discharge corresponding to a sustained 3-day, 1-in-10 year return period. At the 3Q10, the mean velocity within the crossing structure is to meet the fish passage velocity criteria. Streams that where considered non fish bearing where designed for the 1:100 year flood event only and not the 3Q10.

Flood magnitude predictions for each of the crossings along the Haul Road have been determined for the 3Q10, 1 in 20 year, 1 in 50 year, and 1 in 100 year return intervals using Equation (27 or 28) and flood predictions for Qinguq Creek. These are presented in Tables XI-1 and XI-2 of Attachment XI.

Stream discharge was measured at each of the stream crossings at which flow was measureable and where there was a defined channel. Stream flow measurements are summarized in Table 5.3-1 (2008 data) and Table 5.3-2 (2009 data).

Table 5.3-1
Measured Discharge at Proposed Road Crossing Locations in 2008

Crossing ID	Date	Discharge (m^3/s)
AWR-28	26-Jul-08	0.36
AWR-32	26-Jul-08	0.30
AWR-33	25-Jul-08	3.30
AWR-36	25-Jul-08	1.11

m^3/s = cubic metres per second

Table 5.3-2
Measured Discharge at Proposed Road Crossing Locations in 2009

Crossing ID	Date	Discharge (m³/s)
Km 213.1	31-Aug-09	0.030
Km 212.2	30-Aug-09	0.003
Km 209.4	30-Aug-09	0.006
Km 203.0	29-Aug-09	0.043
Km 197.5	31-Aug-09	0.037
Km 195.1	1-Sep-09	0.019
Km 193.3	2-Sep-09	0.124
Alternate EC 22	28-Aug-09	0.007
Alternate EC 30	29-Aug-09	0.035
Km 157.7	3-Jul-09	0.007
Km 157.3	28-Aug-09	0.892
Km 147.1	2-Jul-09	0.203
Km 154.3	2-Jul-09	0.439
Km 140.0	4-Jul-09	0.001
Km 129.2	28-Jul-09	0.005
Km 127.5	28-Jun-09	0.135
Alternate NC 18	5-Jul-09	0.001
Alternate NC 20	30-Jun-09	0.008
Alternate NC 21	1-Jul-09	0.001
Alternate NC 22	1-Jul-09	0.001
Km 1019.8	26-Jun-09	0.080
Km 108.8	30-Jun-09	0.016
Km 107.8	27-Jun-09	0.022
Km 100.2	27-Jun-09	0.008
Km 17.2	19-Jun-09	0.494
Km 15.6	23-Jun-09	0.094
Km 11.3	24-Jun-09	1.421
Km 6.7	28-Jul-09	0.002
Km 2.0	25-Jun-09	0.109

m^3/s = cubic metres per second

5.3.4 Hydraulic Parameters

The data collected at each stream crossing were averaged to produce typical channel characteristics in the vicinity of each stream crossing, while a surveyed cross section approximately 30 m downstream of the proposed road centreline was used to determine the cross-drainage structure tailwater depth. Crossings that were not topographically surveyed generally had no defined or visible channel. Therefore, a small, insignificant tailwater depth was assumed. Attachment XIII lists the hydraulic parameters including channel slope, Manning's n and tailwater depth that were used in the cross-drainage structure design for each stream crossing.

5.3.5 Preferred Options

The cross-drainage structure options outlined below are preliminary and are intended to demonstrate the approximate size and shape that would satisfy the given fish and hydraulic criteria. Culvert shapes and sizes were taken from the *Handbook of Steel Drainage & Highway Construction Projects (CSPI 2002)*. Arches were not considered at this preliminary stage due to the additional cost and construction effort required for the footings. Further analysis should take place at the detailed design stages to confirm the most appropriate crossing configuration.

Where multiple large pipes are required to meet fish passage criteria, bridges may be considered if shown to be cost effective. At the detailed design stage, where road geometrics are known, consideration can be given to design options which can reduce the required number or size of culverts at a crossing where fish passage criteria must be met. For example, installing large offset boulder pairs at intervals through the length of the culvert may provide velocity refuges for fish, thus the fish may move from boulder pair to boulder pair, with the opportunity to rest, and not be required to swim the entire length of the culvert in one continuous effort. This may allow a culvert design with higher overall velocity (i.e., smaller and/or fewer culverts) without creating a velocity barrier for fish.

The preferred option at some of the fish bearing streams produces mean velocities within the culvert barrel of 0.8 m/s or less; however, the inlet and/or outlet velocities may exceed the fish passage design criteria of 0.8 m/s. The reason for this is that inlet velocities tend to be higher than culvert barrel velocities because of an acceleration of flow into the culvert. The acceleration zone is typically small allowing fish to use their burst speed to traverse this zone. Outlet velocities are higher due to the lack of well defined channels in the tundra. Channels tend to be shallow and small with the majority of the flow spilling over the banks and spreading out on the tundra during peak flows. This spreading out of flow reduces the culvert tail water depth resulting in a slight drop in water elevation as the water flows out of the culvert. This drop produces another small acceleration zone. Several options exist to reduce this acceleration zone. For example, small culvert outlet pools can be constructed to maintain a certain water elevation. This constant tail water elevation can significantly reduce the outlet velocities. Outlet pools and other similar modification were not considered for these preliminary cross-drainage structure options. Such modifications can be considered during the detailed design stages.

The location of each potential stream crossing along the proposed north all-weather road is shown in Figure 3.3-1. Although all stream crossings are shown for the eastern portion of the all-weather road, the focus of the hydrological investigation was on the two routes furthest from the community of Baker Lake. Plan, profile and cross section view of each topographically surveyed stream crossing can be found in Attachment XII. As mentioned in Section 4.2.4, four crossing locations were surveyed in 2008, prior to the road re-alignment undertaken in the winter of 2008/2009. These were identified as AWR locations and are no longer under consideration as stream crossing locations. However, the location of these stream crossings is shown on Figure 3.3-1 and plan view and cross section drawings for each of these locations were prepared and are provided in Appendix XII, though no further hydraulic assessments were undertaken.

Alternate EC 1

The stream crossing at Alternate EC 1_is located east of the community of Baker Lake, on the north shore of Baker Lake. It is the most eastern stream crossing. A topographic survey was not completed; however, an aerial inspection was conducted and a photograph is shown in Figure 5.3-1. From the air, the upstream channel appeared to be overland flow, while the downstream appeared to have a small channel. The upstream drainage area is approximately 0.44 km^2 and the estimated 1:100 year peak discharge is 0.41 m^3/s. Due to its small drainage area and seasonality, this stream is assumed to not have fish. Therefore, the preferred culvert option is one 600 mm diameter corrugated steel pipe (CSP) placed at grade. The hydraulic characteristics associated with this and other design alternatives are listed in Table XIII-1.

Km 213.1

The stream crossing at Km 213.1 has an upstream drainage area of approximately 4.70 km^2 and is located within an incised valley on the north shore of the waterbody of Baker Lake. The stream is braided before being reduced to a single channel near the proposed road centerline. The stream substrate is sand, cobble and boulders, and the banks have shrubs, as shown in Figure XII-1. Fish were observed in this stream; therefore, the cross drainage structure must accommodate fish passage. The 1:100 year peak discharge and 3Q10 are estimated at 2.80 and 1.77 m^3/s, respectively. Of the options listed in Table XIII-2, the preferred cross drainages structure is two 3000 mm diameter CSP placed at an embedment depth of 50% of the culvert diameter and zero slope.

Km 212.2

The stream crossing at Km 212.2 is located east of the community of Baker Lake. The stream channel is along a steep slope draining towards the waterbody of Baker Lake. The channel has cobble and boulder substrate with organic banks, as shown in Figure XII-2. The estimated upstream drainage area is 1.43 km^2 and the 1:100 year peak discharge is 1.07 m^3/s. Because of its steep slope and seasonality, this stream is considered non fish bearing. Of the options considered and listed in Table XIII-3, the preferred cross drainage structure is one 1000 mm diameter CSP placed without embedment. In order to reduce the outlet velocities the culvert will require a slope of approximately 2.0% which is less than the existing stream bed slope of 8.6%.

Km 209.4

The stream crossing at Km 209.4 occurs on a drainage path to the waterbody of Baker Lake. It is located near an all-terrain vehicle (ATV) trail east of the community of Baker Lake. Overland flow exists with some channelization, as shown in Figure XII-3. The channel substrate is sand

and gravel with grass and organics. The estimated upstream drainage area is 2.74 km², with a 1:100 year peak discharge of 1.81 m³/s and a 3Q10 discharge of 1.14 m³/s. Because this stream drains into Baker Lake, it is assumed to be fish bearing. The preferred cross drainage structures are two 2200 mm diameter CSPs placed at zero slope with 30% embedment. The hydraulic results from this option and other are listed in Table XIII-4.

Km 207.6, Alternate EC 6, and Alternate EC 7

A topographic survey was not conducted on the stream crossings at Km 207.6, Alternate EC 6 or Alternate EC 7 because of their seasonality and small drainage areas. However, aerial inspections were done and photographs are shown in Figure 5.3-1. Overland flow was visible at all three crossing locations. The estimated upstream drainage areas for Km 207.6, Alternate EC 6, and Alternate EC 7 are 0.82, 1.66, and 0.09 km², respectively, resulting in 1:100 year peak discharges of 0.68, 1.2, and 0.11 m³/s, respectively. Assuming non fish bearing streams, the preferred cross drainage structures are circular CSP culverts with diameters of 800, 1,200 and 600 mm for Km 207.6, Alternate EC 6, and Alternate EC 7, respectively, installed without embedment at the existing stream channel slope. Tables XIII-5, XIII-6 and XIII-7 list the considered options.

Km 203.0

The stream crossing at Km 203.0 has an upstream drainage area of 4.59 km² and is located north of the community of Baker Lake between two small waterbodies, as shown in Figure XII-4. The stream does not have a well defined channel; however, fish were observed in this drainage path. The stream substrate is cobble and boulders overlain with organics, while the floodplains are dominated by grass and some boulder outcrops areas. The 3Q10 and 1:100 year peak discharge are approximately 1.74 m³/s and 2.75 m³/s, respectively. Of the options considered and listed in Table XIII-8, the preferred cross drainage structure is two 2,200 mm diameter CSPs placed at an embedment of 50% and zero slope.

Alternate EC 11, Alternate EC 12, and Alternate EC 13The stream crossings at Alternate EC 11, Alternate EC 12, and Alternate EC 13 are located on the road route that is the second farthest from the community of Baker Lake (Figure 3.3-1). They have upstream drainage areas of 1.22 km², 2.12 km² and 2.15 km², respectively. A topographic survey was not conducted on these stream crossings because of their seasonality and small drainage areas. Overland flow with some channels and ponded water were visible at all three crossing locations. It is assumed that Alternate EC 11 is not fish bearing due to its smaller drainage area. However, it is assumed that Alternate EC 12 and Alternate EC 13 are fish bearing due to their direct connection to Baker Lake. The preferred cross drainage structure for Alternate EC 11 is one 1,000 mm diameter circular CSP installed at grade. For Alternate EC 12 the preferred structures are two 2,400 mm diameter CSPs with 480 mm embedment and zero slope. For Alternate EC 13 the preferred structures are two 1800 mm diameter CSPs with 50% embedment and zero slope. Tables XIII-9, XIII-10 and XIII-11 list the hydraulic characteristics associated with these and other options.

Km 197.5

The stream crossing at Km 197.5 is located between two waterbodies on the road route that is the farthest from the community of Baker Lake. Much of the flow is through the grassed wetland area, as shown in Figure XII-5. The channel has cobble substrate and grass floodplains. The estimated upstream drainage area is 5.44 km². Fish were located in the stream. The 3Q10 and 1:100 year peak discharge are estimated to be 1.99 and 3.16 m³/s, respectively. Of the options considered for cross drainage structures listed in Table XIII-12, the preferred option is two 2,800 mm diameter circular CSPs embedded 50% and placed at zero slope.

Km 195.1

The stream crossing at Km 195.1 is located between two waterbodies on the road route that is the farthest from the community of Baker Lake. The upstream drainage area is approximately 2.60 km². Although no fish sampling was conducted on this stream (as outlined in Appendix X Fish and Fish Habitat Baseline), it is assumed that fish exist as found in stream crossings at Km 197.5 and Km 193.3 that drain into the same lake. The 3Q10 and 1:100 year peak discharge are estimated to be 1.10 and 1.74 m³/s, respectively. Of the options considered and listed In Table XIII-13, the preferred option is two 1,800 mm diameter circular CSPs placed at zero slope and an embedment of 50%.

Km 193.3

The stream crossing at Km 193.3 is located on the road route that is the farthest from the community of Baker Lake. The stream is braided with cobble substrate (refer to Figure XII-7). The upstream drainage area is the largest of the stream crossings assessed east of the Thelon River estimated at 8.16 km². Fish were found in the stream near the proposed road crossing. The 3Q10 and 1:100 year peak discharge are estimated to be 2.77 and 4.39 m³/s, respectively. The preferred cross drainage structures are three 3,200 mm diameter circular CSPs placed at an embedment of 50% and zero slope. Table XIII-14 lists the hydraulic characteristics associated with this and other options.

Alternate EC 22

The stream crossing at Alternate EC 22 is located on the road route that is the second farthest from the community of Baker Lake. The upstream drainage area is estimated to be 1.11 km². The stream is braided and is located in grassy low area, as shown in Figure XII-8. The main channel has cobble and sand substrate, while the floodplain has low lying shrubs. Fish were located in the stream; therefore, the cross drainage structure will require fish passage considerations. The 3Q10 and 1:100 year peak discharge is estimated at 0.55 and 0.87 m³/s, respectively. The preferred cross drainage option is one 1,800 mm diameter CSP placed at an embedment of 360 mm and zero slope. The hydraulic characteristics for this option and others are listed in Table XIII-15.

Alternate EC 30

The stream crossing at Alternate EC 30 is located near the outlet of a small waterbody midway between the community of Baker Lake and the Thelon River. The stream is braided with sand

and gravel substrate, as shown in Figure XII-9. The main channel is box-like while the other channels are grassy and bowl-like. The stream channel is disturbed by an ATV trail. Its estimated upstream drainage area is 5.66 km², and the 3Q10 and 1:100 year peak discharge is estimated at 2.06 m³/s and 3.26 m³/s, respectively. For fish passage, the preferred cross drainage option, among several options, as listed in Table XIII-16, is two 3,000 mm diameter circular CSPs embedded to 50% and installed at zero slope.

Km 174.8

Stream crossing Km 174.8 is located across the Thelon River. The Thelon River is the one of the largest river in the Nunavut Territory flowing into Hudson Bay. At the stream crossing location, the estimated drainage area is 153,000 km² and the mean annual discharge is approximately 757 m³/s. Fish are found in this river. A bridge has already been considered by AREVA for this crossing. Because of this, the Thelon River crossing was not part of the detailed assessment by Golder. In other words, a topography survey and a stream discharge measurement were not conducted.

Km 174.3

The stream crossing at Km 174.3 is a small seasonal tributary to the Thelon River with an upstream drainage area of approximately 1.14 km² and a 1:100 year peak discharge of 0.89 m³/s. Due to the seasonality of the stream, fish passage is not a concern for the culvert design. This crossing was not topographically surveyed. The slope and tailwater depth were assumed to be 0.5% and 0.1 m, respectively. Among several options considered, as listed in Table XIII-17, the preferred option is one 900 mm diameter CSP culverts placed at the existing channel slope and grade.

Km 172.2

The stream crossing at Km 172.2 is located on a small tributary approximately 1 km upstream of its confluence with the Thelon River. The small main channel meanders through grass with some overland flow, as shown in Figure XII-10. The upstream drainage area is approximately 3.78 km². The stream does not contain fish; therefore fish passage is not a concern. The estimated 1:100 year peak discharge is 2.35 m³/s. Four different sizes of CSP culverts were evaluated for this crossing and are shown in Table XIII-18. The preferred option is one 1,400 mm diameter CSP installed without embedment at the existing bed slope of approximately 1.2%.

Km 171.2

A topographic survey was not conducted on stream crossing at Km 171.2 because of its seasonality and small drainage area of 0.53 km². Crossing at Km 171.2 is located approximately 1 km upstream of Km 172.2 and has a 1:100 year peak discharge of 0.48 m³/s. During an aerial inspection, there was no evidence of a stream channel, as shown in Figure 5.3-2. This stream is considered non fish bearing. The preferred culvert option is one 800 mm diameter CSP placed at grade. The hydraulic results from this option and other are listed in Table XIII-19.

Km 168.0

The stream crossing at Km 168.0 has an upstream drainage area of 3.00 km^2 and occurs between two small water bodies. Fish passage is not a concern for this stream. The estimated 1:100 year peak discharge is 1.95 m^3/s. A topographic survey was not completed on this stream crossing; however, an aerial inspection was conducted and a photograph is shown in Figure 5.3-2. A small channel was evident from the air. A culvert slope and tailwater depth of 0.5% and 0.1 m were assumed during the preliminary culvert design, resulting in a preferred culvert option of one 1,400 mm diameter CSP placed without embedment. Refer to Table XIII-20 for hydraulic characteristic associated with all options considered.

Km 163.2

The stream crossing at Km 163.2 is a small channel with overland flow; therefore, this stream is considered non fish bearing. It has an upstream drainage area of 1.07 km^2 and a 1:100 year peak discharge of 0.84 m^3/s. A topographic survey was not done on stream crossing; however, an aerial inspection was conducted and a photograph is shown in Figure 5.3-2. A culvert slope and tailwater depth of 0.5% and 0.1 m were assumed during the preliminary culvert design. Among the options considered listed in Table XIII-21, the preferred culvert option of one 900 mm diameter CSP placed without embedment and at the existing channel slope.

Km 161.5

The stream crossing at Km 161.5 occurs in a wetland area between two small water bodies that drain south into Qikittalik Lake. The upstream drainage area is approximately 2.79 km^2. At the time of the field survey, no channelized flow was present upstream of the wetland, but a small channel with trace flow was located downstream which flows into a small pond approximately 80 m downstream of centreline. Because of the size and configuration of the drainage path, as shown in Figure XII-11, it was assumed that no fish would be passing during higher freshet flows. Using the estimated 1:100 year peak discharge of 1.84 m^3/s, three different sized circular CSP culverts were evaluated for this crossing and are listed in Table XIII-22. The preferred option for the crossing at Km 161.5 is one 1,200 mm diameter CSP installed with no embedment at the existing stream bed slope of approximately 0.72%.

Km 159.5

The stream crossing at Km 159.5 has an upstream drainage area of 0.96 km^2 and occurs on a small tributary that drains to Qikittalik Lake. The estimated 1:100 year peak discharge is 0.78 m^3/s. A topographic survey was not done on this stream crossing. From the air, the stream appears channelized near an upstream waterbody but spreads out into overland flow at the proposed road crossing. Because of this, fish passage is not a concern. A culvert slope and tailwater depth of 0.5% and 0.1 m were assumed during the preliminary culvert design, resulting in a preferred culvert option of one 800 mm diameter CSP placed without embedment. Refer to Table XIII-23 for hydraulic characteristic associated with all options considered.

Km 157.7

The stream crossing at Km 157.7 is located approximately 150 m upstream of Qikittalik Lake and has an upstream drainage area of 3.90 km². The channel becomes spread out and undefined at approximately the proposed road centerline, as shown in Figure XII-12. The floodplain has low lying shrubs and grass. Several species of fish were located in this stream; therefore, the cross-drainage structure must allow fish passage. The proposed arrangement for the crossing at Km 157.7 consists of three 3,000 mm diameter CSP culverts embedded 600 mm at zero slope. Table XIII-24 lists the hydraulic characteristics associated with all options. The average velocity through the pipe would be approximately 0.77 m/s during the 3Q10 discharge.

Km 157.3

The upstream drainage area of stream crossing Km 157.3 is estimated at 56.7 km². The stream channel is approximately 30 m wide with cobble and boulder substrate overlain with a layer of organics. The banks have grass and low laying shrubs. Small riffle and rapids are present upstream, while Qikittalik Lake is just downstream of the proposed road centerline. Fish are present in this stream. The 1:100 year peak discharge is estimated at 21.1 m³/s, while the 3Q10 is approximately 13.3 m³/s. Because of these large discharges, the preferred cross drainage structure is a bridge. Figure XII-13 shows the plan view of this crossing including several photographs.

Km 154.8

The stream crossing at Km 154.8 occurs on a stream draining west into Qikattalik Lake. It has an upstream drainage area of 10.4 km² and a 1:100 year peak discharge of approximately 5.34 m³/s. A topographic survey was not done on stream crossing; however, an aerial inspection was conducted and a photograph is shown in Figure 5.3-2. During the time of the aerial survey, there was no evidence of water; therefore, fish is not a concern. A culvert slope and tailwater depth of 0.5% and 0.1 m were assumed during the preliminary culvert design, resulting in a preferred culvert option of one 1,800 mm diameter CSP placed without embedment. All considered options are listed in Table XIII-25.

Km 147.1

The stream crossing at Km 147.1 has an upstream drainage area of approximately 5.29 km^2. The channel meanders slightly and has gravel, cobble and sand substrate with grassy organic banks, as shown in Figure XII-14. Fish are present in this stream. The 1:100 year peak discharge and 3Q10 are estimated at 3.09 and 1.95 m³/s, respectively. Three cross drainage structures were considered and are listed in Table XIII-26, with the preferred arrangement being three 2,400 mm diameter circular CSP culverts with 50% embedment placed at zero slope. The average velocity through the pipes during a 3Q10 event is approximately 0.77 m/s.

Km 145.3

The stream crossing at Km 145.3 is located about 80 m downstream of a small waterbody and has an upstream drainage area of 43.2 km². The stream channel is well defined and straight at the proposed road centerline. The channel substrate is sand, gravel and cobble with grassy banks and some low lying shrubs in the floodplain. The upstream waterbody has vertical organic banks and a sandy lake bottom. The 1:100 year peak discharge is estimated at 16.9 m^3/s, while the 3Q10 is approximately 10.7 m^3/s. Because of these large discharges, the preferred cross drainage structure is a bridge. Refer to Figure XII-15 for a plan view of the crossing with photographs.

Km 140.0

The stream crossing Km 140.0 occurs approximately 5 km northwest from Km 145.3 along the proposed road alignment. The stream channel is relatively well defined with sand and cobble substrate, as shown in Figure XII-16. The crossing at Km 140.0 is located in an area with many low lying shrubs and bedrock outcrops with some subsurface flow. Because of the small size and characteristics of the drainage path, it was assumed that no fish would be passing during higher freshet flows. Several options were evaluated to pass the 1:100 year peak discharge estimated at 1.86 m^3/s, as listed in Table XIII-27. The preferred option for the crossing at Km 140.0 is one 1200 mm diameter CSP installed with no embedment. In order to reduce the outlet velocities the culvert will require a slope of approximately 2.0% which is less than the existing stream bed slope of 3.2%.

Km 131.3

The stream crossing at Km 131.3 occurs within the Kavisilik Lake sub-basin and has an upstream drainage area of 4.34 km^2. A topographic survey was not done on the stream crossing; however, an aerial inspection was conducted and a photograph is shown in Figure 5.3-3. This stream is not considered fish bearing. The 1:100 year peak discharge is estimated to be 2.63 m^3/s. A culvert slope and tailwater depth of 0.5% and 0.2 m were assumed during the preliminary culvert design, resulting in a preferred culvert option of one 1,600 mm diameter CSP placed without embedment. All considered options are listed in Table XIII-28.

Km 130.1

The stream crossing at Km 129.2 has the largest upstream drainage area of the assessed stream crossing estimated at 305 km^2. The crossing at Km 129.2 is a significant sized channel that is approximately 30 m wide with cobble and boulder substrate. The stream channel is generally straight with organic banks and low lying shrubs in the floodplain, as shown in Figure XII-17. Fish are present in this stream. The 1:100 year peak discharge and 3Q10 are estimated at 82.4 m^3/s and 52.0 m^3/s, respectively. Due to the size of the channel and the magnitude of the discharges, the preferred option for this crossing is a bridge.

Km 127.5

The stream crossing at Km 127.5 is located in the northeast part of the Siamese Lake sub-basin and has an upstream drainage area of approximately 16.5 km^2. The channel is somewhat straight and well defined near the proposed crossing, as shown in Figure XII-18. It has cobble and sand substrate with organic grassy banks and a gently sloping floodplain. This stream is considered fish bearing and has an estimated 3Q10 of 4.91 m^3/s, while the 1:100 year peak discharge is 7.77 m³/s. Several cross drainage structures were considered including circular, horizontal ellipse and pipe arch structural plate culverts. The preferred option is four circular culverts with diameters of 3,000 mm, embedded to a depth of 1,500 mm and placed at zero slope. During the 3Q10, the average velocities within the pipes are approximately 0.79 m/s, as listed in Table XIII-29.

Alternate NC 17

The stream crossing at Alternate NC 17 occurs approximately 1.3 km upstream of a relatively large waterbody within the Siamese Lake sub-basin (Figure XII-19). Alternate NC 17 has an upstream drainage area of approximately 2.69 km^2. At the proposed road centerline, the channel curves around a rocky ridge where a small channel joins the main channel. No fish were found in this stream; therefore, the cross drainage structure is not designed for fish passage, and instead, designed for the estimated 1:100 year peak discharge of 1.78 m³/s. Several sized circular CSP were considered and are listed in Table XIII-30. The preferred option is one 1,000 mm diameter CSP that is not embedded and has a slope of 3.3% similar to the stream channel.

Alternate NC 18

The stream crossing at Alternate NC 18 is located east of Siamese Lake on a small tributary to an unnamed lake. The flow is channelized upstream of the study area but, as illustrated in Figure XII-20, becomes braided with several channels through hummocky terrain in the study area. The right floodplain is characterized by large boulders and rugged terrain, while the left floodplain contains grass and low shrubs. It was assumed that no fish would be passing during higher freshet flows because of the characteristics of the drainage path. The 1:100 year peak discharge is estimated at 4.62 m³/s. Several circular CSP culverts of different sizes were considered for this crossing and are listed in Table XIII-31; however, the preferred option is one 1,600 mm diameter installed at grade. In order to reduce the outlet velocities the culvert will require a slope of approximately 1.5% which is less than the existing stream bed slope of 3.2%.

Km 112.9

The stream crossing at Km 112.9 is a small seasonal drainage occurring near the boundary of the Kavisilik Lake and Siamese Lake sub-basins. The upstream drainage area is 0.15 km², the smallest of all the crossings, and the 1:100 year peak discharge is 0.17 m³/s. A topographic survey was not done on the stream crossing. The preferred culvert option is one 600 mm diameter CSP placed without embedment, as listed in Table XIII-32.

Alternate NC 20

The proposed road centerline at stream crossing Alternate NC 20 is located at a ponded water area just east of Skinny Lake, as shown in Figure XII-21. The main inflow channel to the ponded area is located in the southeast of the pond and has cobble, gravel substrate. A small north outlet channel has a grassy bed, while main south outlet has organic bed with grass. The upstream drainage area is relatively small at approximately 0.72 km². This stream is not fish bearing; therefore, culvert options were designed only for the 1:100 year peak discharge of

0.61 m³/s. Of the several options consider and listed in Table XIII-33, the preferred option is one 800 mm diameter CSP that installed at grade with a slope similar to the existing channel bed of 0.70%.

Alternate NC 21 and Alternate NC 22

The stream crossings at Alternate NC 21 is a relatively well defined channel located along a west facing ridge east of Skinny Lake, while the stream crossing at Alternate NC 22 is located closer to Skinny Lake in the lowland area. Both are shown Figure XII-22. At Alternate NC 22, there is no well defined channel and it is very hummocky terrain with ponded water. The upstream drainage area for Alternate NC 21 and Alternate NC 22 are 1.24 and 0.24 km², respectively. These small channels do not have fish; therefore, culverts were designed only for the 1:100 year peak discharges of 0.95 and 0.25 m³/s for Alternate NC 21 and Alternate NC 22, respectively. Tables XIII-34 and XIII-35 list the considered options. The preferred options for Alternate NC 21 and Alternate NC 22 are one 900 mm diameter and one 600 mm diameter CSP culverts that are installed at grade with slopes similar to the existing channel beds.

Km 109.8

The stream crossing at Km 109.8 is located at the south end of Skinny Lake and has an upstream drainage area of 2.40 km². As shown in Figure XII-23, the proposed road alignment goes through a relatively large waterbody, and the stream that was assessed is essentially a small connection between two sides of Skinny Lake. The lake shores and stream bottom are cobbles. The channel has a uniform width and slope and is fish bearing. The 1:100 year peak discharge and 3Q10 are estimated at 1.63 and 1.03 m³/s, respectively. For this proposed road alignment, the preferred cross drainage structure is two circular CSP culverts with diameters of 2,000 mm and embedment depths of 1,000 mm placed at zero slope. During the 3Q10, the mean velocity in the culvert is approximately 0.79 m/s. Refer to Table XIII-36 for hydraulic characteristic associated with all options considered. However, it is likely that the road alignment will shift south to avoid Skinny Lake.

Km 108.8

The stream crossing at Km 108.8 is a well defined channel with cobble and gravel substrate, as shown in Figure XII-24. The stream is located at the base of a ridge and flows east into Skinny Lake. It has an upstream drainage area of 0.89 km² and an estimated 1:100 year peak discharge of 0.73 m³/s. Due to the upstream channel characteristics, the stream is considered non fish bearing. The preferred cross drainage structure, among the ones listed in Table XIII-37, is one 800 mm diameter CSP placed at grade with a slope matching the existing channel slope of approximately 1.9%.

Km 107.8

The stream crossing at Km 107.8 occurs approximately 1 km west of Skinny Lake. The relatively well defined stream meanders slightly and has an upstream drainage area of 1.09 km². As shown in Figure XII-25, the channel has an organic bottom with grassy banks. No fish were found in this stream; therefore, the cross drainage structure was designed for solely for the 1:100 year peak discharge of 0.86 m^3/s. The preferred option is one 800 mm diameter CSP placed at grade with a slope matching the existing channel slope of approximately 0.88%. Refer to Table XIII-38 for hydraulic characteristic associated with all options considered.

Km 103.4

The stream crossing at Km 103.4 has a small seasonal drainage without a well defined channel. During the field survey, no flow was present, only ponded water. The upstream drainage area is 0.16 km^2 and the 1:100 year peak discharge is estimated at 0.18 m^3/s. There are no fish is this stream, and the preferred cross drainage structure option is one 600 mm diameter CSP placed at grade with a slope matching the existing channel slope of approximately 0.19%. Refer to Figure XII-26 for a plan view of the crossing and Table XIII-39 for the list of hydraulic characteristics associated with the considered cross drainage structures.

Km 100.2

The upstream drainage area for the stream crossing at Km 100.2 is estimated to be 2.57 km^2. It is located approximately 1.4 km northeast of the Kiggavik camp. At the crossing area, water passes through a large boulder outcrop, as shown in Figure XII-27. There is no well-defined channel until approximately 15 m downstream of the proposed road centreline. Flow was not measureable through the boulder outcrop. The channel substrate 50 m downstream of the centreline is fine sand with some grass. This is not fish bearing; therefore, the cross drainage structures were designed using only the 1:100 year peak discharge estimated at 1.72 m^3/s. Of the several options considered and listed in Table XIII-40, the preferred option is a 1,200 mm diameter CSP placed at grade. In order to reduce the outlet velocities the culvert will require a slope of approximately 1.5% which is less than the existing stream bed slope of 2.2%.

Km 19.6

The stream crossing Km 19.6 is a small seasonal drainage just north of the Kiggavik camp. It occurs near the drainage boundary of the Caribou Lake and Willow Lake sub-basins, resulting in a small upstream drainage area of 0.35 km^2. The 1:100 year peak discharge is estimated at 0.35 m^3/s. A topographic survey was not done on the stream crossing; however, an aerial inspection was conducted and a photograph is shown in Figure 5.3-3. The preferred culvert option is a 700 mm diameter CSP placed without embedment, as listed in Table XIII-41.

Km 17.2

the stream crossing at Km 17.2 occurs approximately 1.6 km west of the Kiggavik camp and is located within the Caribou Lake sub-basin. It has an upstream drainage area estimated at 12.3 km^2. The stream is braided at the location of the proposed road study area, as shown in Figure XII-28. The channel has cobble substrate and organic grassy banks. Fish were located in this stream; therefore, the cross drainage structures were designed using the 3Q10 estimated at 3.85 m^3/s and the 1:100 year peak discharge estimated at 6.10 m^3/s. The preferred option is three 3,000 mm diameter circular CSPs. The culverts would be installed with an embedment depth of 1,500 mm and zero slope. At the 3Q10, the mean velocity within the pipes is approximately 0.81 m/s, as listed in Table XIII-42.

Km 15.6

The stream crossing at Km 15.6 is located just downstream of a small waterbody with two outlets, as shown in Figure XII-29. One outlet is smaller and carries less flow but is quite incised. The second channel is larger and carries more flow but is grassy and much of the flow is overland with many branches. The stream crossing at Km 15.6 has an upstream drainage area of 4.66 km². Fish were found in this stream. The 3Q10 and 1:100 year peak discharge are 1.76 m³/s and 2.79 m³/s, respectively. Of the options considered and listed in Table XIII-43, the preferred option is two 3000 mm diameter CSP culverts placed at an embedment depth of 1,500 mm and zero slope. At the 3Q10, the mean velocity in the culvert is approximately 0.79 m/s.

Km 147.1

The stream crossing at Km 147.1 is located on a seasonal drainage with no defined channel. The upstream drainage area is 1.04 km² and the 1:100 year peak discharge is 0.82 m³/s. A topographic survey was not done on the stream crossing. The preferred culvert option is one 900 mm diameter CSP placed without embedment. Refer to Table XIII-44 for the hydraulic characteristics of the considered cross drainage structures.

Km 11.3

The upstream drainage area of the stream crossing at Km 11.3 is estimated at 32.8 km². The stream channel is straight with a uniform width of approximately 15 m throughout the study area. Refer to Figure XII-30 for a plan view and photographs of the proposed crossing which occurs approximately 100 m downstream of Sleek Lake. Channel substrate consists of cobble and boulder, with grassy organic banks shrubs in the floodplain. Fish are present in this stream. The 1:100 year peak discharge and 3Q10 are estimated at 13.5 and 8.54 m³/s, respectively; therefore, the preferred cross drainage structure is a bridge.

Km 6.7

The stream crossing at Km 6.7 is located between two smaller water bodies that eventually drain into Boulder Lake, as shown in Figure XII-31. It has a well defined channel with cobble substrate and vertical grassy banks. The floodplain has some low lying shrubs. The upstream drainage area is approximately 17.9 km². Fish are present in this stream. The 3Q10 and 1:100 year peak discharge are 5.23 and 8.27 m³/s, respectively. Due to the large drainage area and presents of fish, the preferred cross drainage structure for Km 6.7 is a bridge.

Km 2.0

The stream crossing at Km 2.0 is just downstream of Mushroom Lake and has an upstream drainage area of 4.23 km². The stream channel is incised and meanders through a grassy floodplain, as shown in Figure XII-32. It has a sandy bottom with some vegetation and gravel. There is a small waterbody approximately 50 m downstream of the proposed road centreline. Most of the channel is box-like with vertical banks. Fish are present in this stream. Of the options considered for this crossing, the preferred option is one 2,600 mm diameter circular CSP culvert with an embedment depth of 1,300 mm and zero slope. At the 3Q10, the mean velocity in the culvert is approximately 0.75 m/s. Refer to Table XIII-45 for the hydraulic characteristics of the considered cross drainage structures.

Cross Drainage Preferred Option Summary

A summary of the preferred cross drainage structures for each assessed stream crossing based upon the assumptions presented throughout Section 5.3 are outlined in Table 5.3-3. The cross-drainage structure preferred options are preliminary and are intended to demonstrate the approximate size and shape that would satisfy the given fish and hydraulic criteria. Further analysis should take place at the detailed design stages to confirm the most appropriate crossing configuration.

Table 5.3-3
Summary of Preferred Cross Drainage Along the Kiggavik All-Weather Road

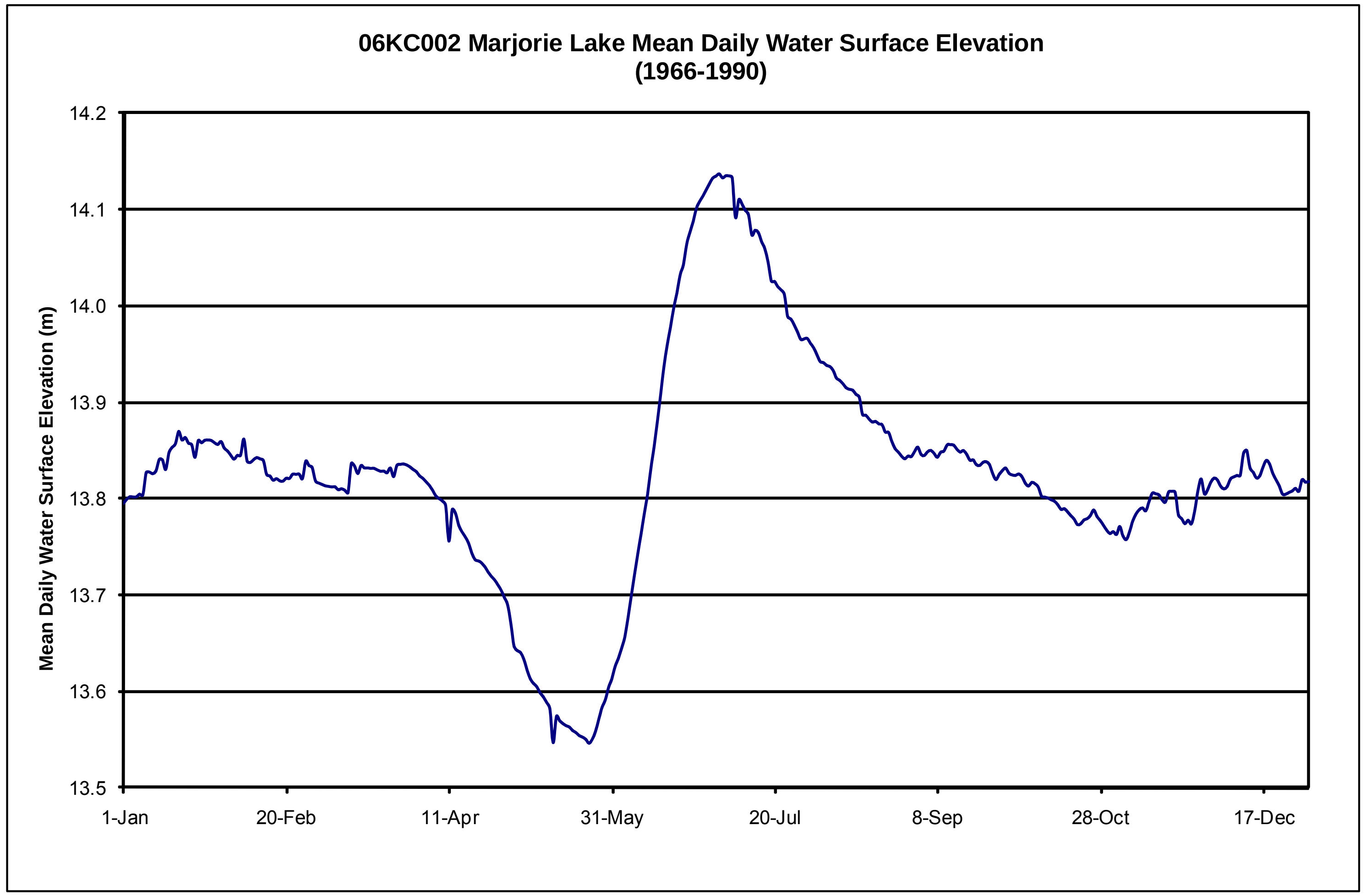
Crossing ID	Option	Fish Bearing	Design Discharge (m^3/s)	Number of Culverts	Shape	Diameter (mm)	Embedment Depth (mm)
Alternate EC 1	2	no	0.41 (1:100yr)	1	circular	600	0
Km 213.1	5	yes	1.77 (3Q10)	2	circular	3,000	1,500
Km 212.2	2	no	1.07 (1:100yr)	1	circular	900	0
Km 209.4	5	yes	1.14 (3Q10)	2	circular	2,200	660
Km 207.6	1	no	0.68 (1:100yr)	1	circular	800	0
Alternate EC6	3	no	1.21 (1:100yr)	1	circular	1,000	0
Alternate EC7	2	no	0.11 (1:100yr)	1	circular	600	0
Km 203.0	5	yes	1.74 (3Q10)	2	circular	2,200	1,100
Alternate EC 11	2	no	0.94 (1:100yr)	1	circular	9,000	0
Alternate EC 12	1	yes	0.93 (3Q10)	2	circular	2,400	480
Alternate EC 13	4	yes	0.94 (3Q10)	2	circular	1,800	900
Km 197.5	5	yes	1.99 (3Q10)	2	circular	3,000	1,500
Km 195.1	5	yes	1.10 (3Q10)	2	circular	1,800	900
Km 193.3	5	yes	2.77 (3Q10)	3	circular	3,200	1,600
Alternate EC 22	3	yes	0.55 (3Q10)	1	circular	1,800	360
Alternate EC 30	4	yes	2.06 (3Q10)	2	circular	3,000	1,500
Km 174.3	3	no	0.89 (1:100yr)	1	circular	800	0
Km 172.2	4	no	2.35 (1:100yr)	1	circular	1,200	0
Km 171.2	4	no	0.48 (1:100yr)	1	circular	600	0
Km 168.0	3	no	1.95 (1:100yr)	1	circular	1,200	0
Km 163.2	3	no	0.84 (1:100yr)	1	circular	800	0
Km 161.5	2	no	1.84 (1:100yr)	1	circular	1,000	0
Km 159.5	3	no	0.78 (1:100yr)	1	circular	800	0
Km 157.7	1	yes	1.52 (3Q10)	3	circular	3,000	600

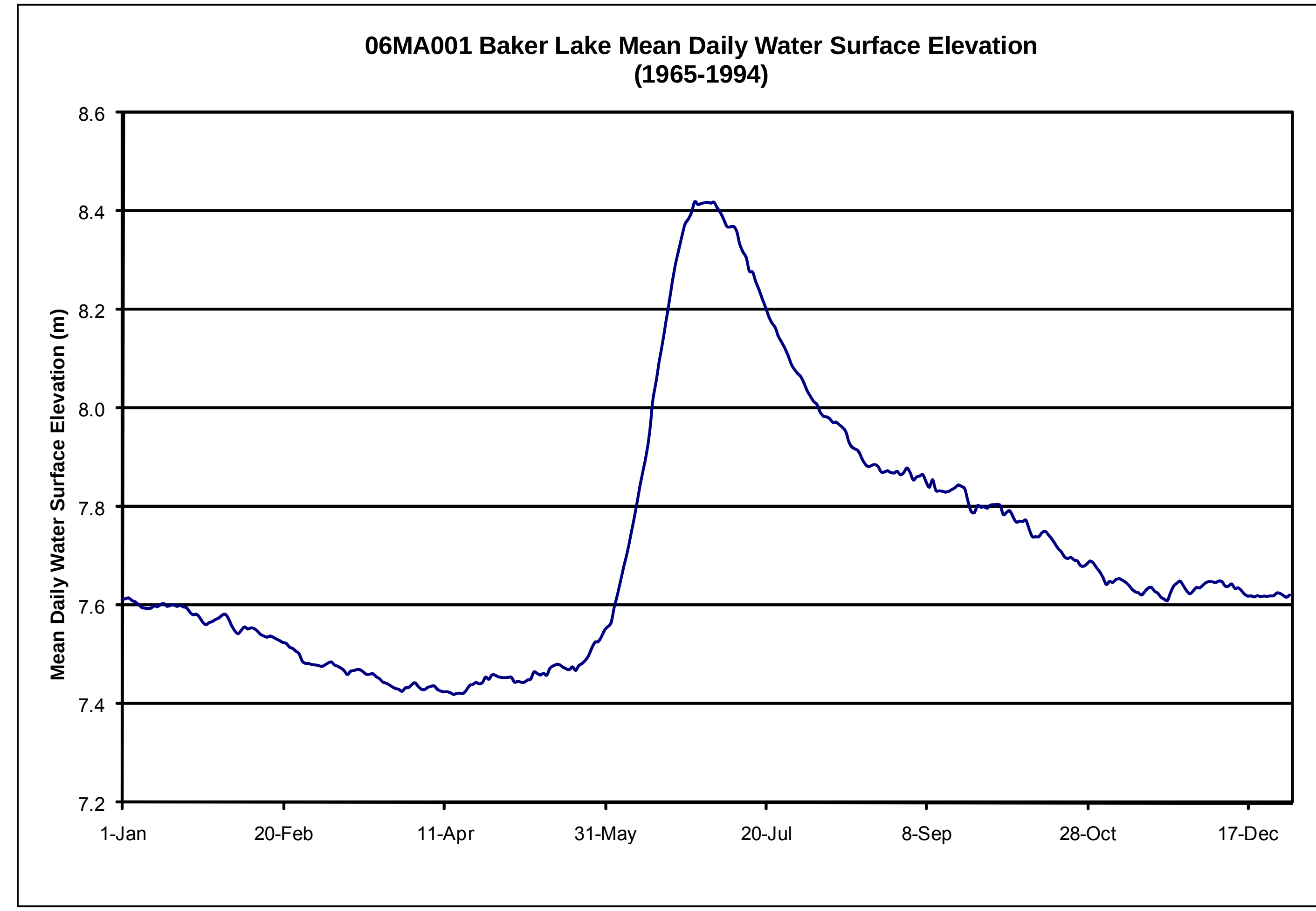
Table 5.3-3
Summary of Preferred Cross Drainage Along the Kiggavik All-Weather Road (continued)

Crossing ID	Option	Fish Bearing	Design Discharge (m^3/s)	Number of Culverts	Shape	Diameter (mm)	Embedment Depth (mm)
Km 157.3		yes	13.31 (3Q10)	BRIDGE			
Km 154.8	2	no	5.34 (1:100yr)	1	circular	1,800	0
Km 147.1	5	yes	1.95 (3Q10)	3	circular	2,400	1,200
Km 145.3		yes	10.67 (3Q10)	BRIDGE			
Km 140.0	1	no	1.86 (1:100yr)	1	circular	1,000	0
Km 131.3	2	no	2.63 (1:100yr)	1	circular	1,400	0
Km 129.2		yes	52.02 (3Q10)	BRIDGE			
Km 127.5	5	yes	4.91 (3Q10)	4	circular	3,000	1,500
Alternate NC 17	2	no	1.78 (1:100yr)	1	circular	1,000	0
Alternate NC 18	4	no	4.62 (1:100yr)	1	circular	1,600	0
Km 112.9	3	no	0.17 (1:100yr)	1	circular	600	0
Alternate NC 20	2	no	0.61 (1:100yr)	1	circular	800	0
Alternate NC 21	1	no	0.95 (1:100yr)	1	circular	900	0
Alternate NC 22	2	no	0.25 (1:100yr)	1	circular	600	0
Km 109.8	5	yes	1.03 (3Q10)	2	circular	2,000	1000
Km 108.8	2	no	0.73 (1:100yr)	1	circular	800	0
Km 107.8	3	no	0.86 (1:100yr)	1	circular	800	0
Km 103.4	2	no	0.18 (1:100yr)	1	circular	600	0
Km 100.2	3	no	1.72 (1:100yr)	1	circular	1,000	0
Km 19.6	3	no	0.35 (1:100yr)	1	circular	600	0
Km 17.2	5	yes	3.85 (3Q10)	3	circular	3,000	1,500
Km 15.6	5	yes	1.76 (3Q10)	2	circular	3,000	1,500
Km 14.1	2	no	0.82 (1:100yr)	1	circular	900	0
Km 11.3		yes	8.54 (3Q10)	BRIDGE			
Km 6.7		yes	5.23 (3Q10)	BRIDGE			
Km 2.0	4	yes	1.63 (3Q10)	1	circular	2,600	1,300

m^3/s = cubic metres per second; mm = millimetres

List of Figures





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Creator: MGD/MK
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Data Sources: *Water Survey of Canada*

FIGURE 5.1-1
MEAN DAILY WATER ELEVATIONS FOR MARJORIE LAKE AND BAKER LAKE

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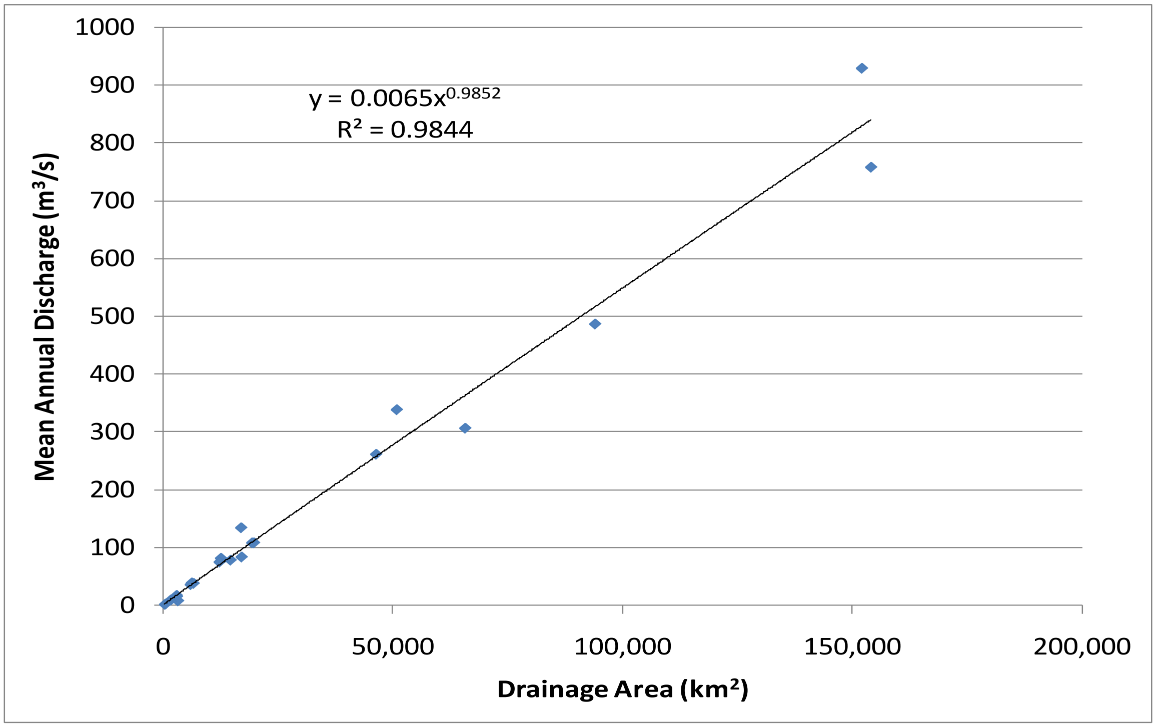
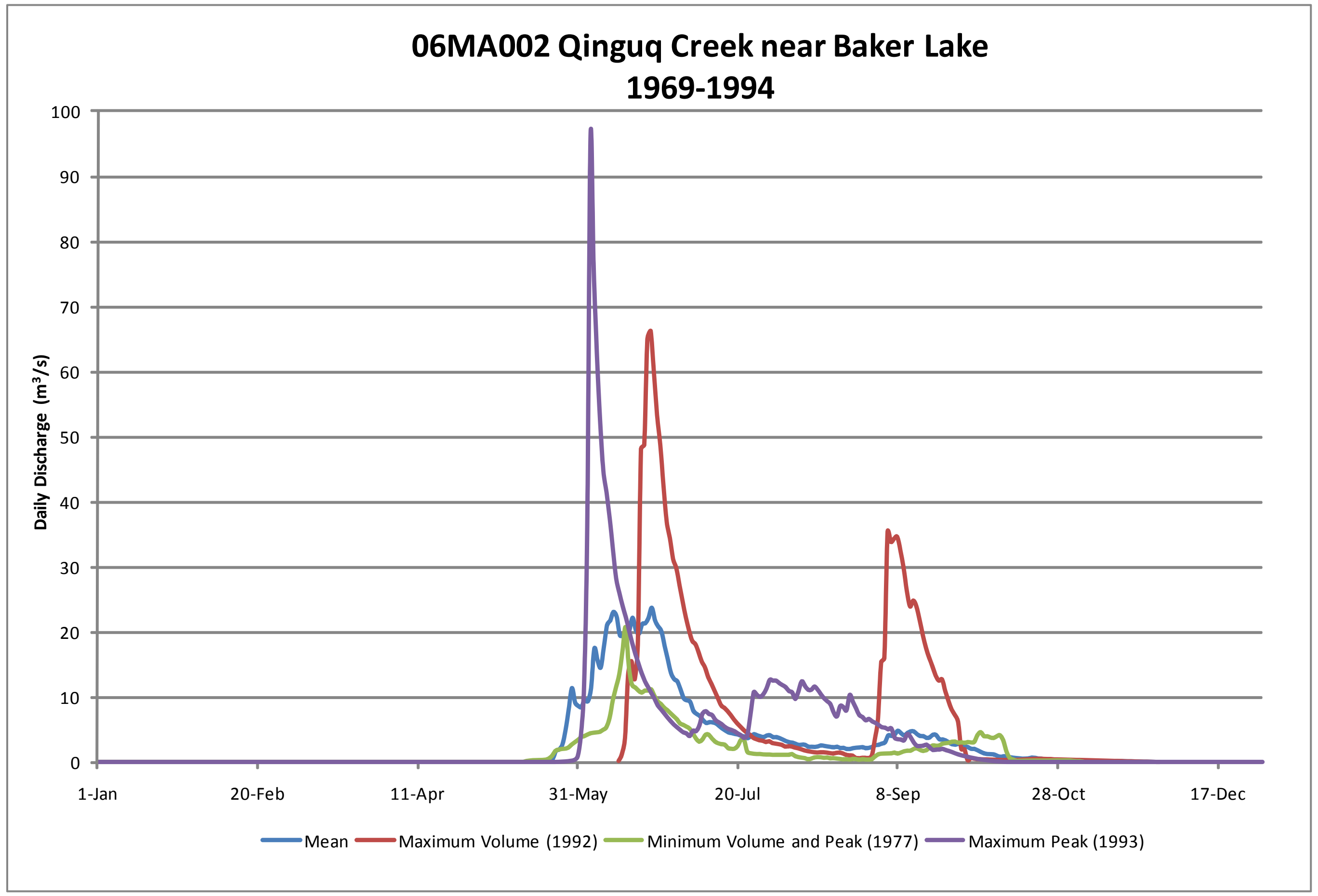
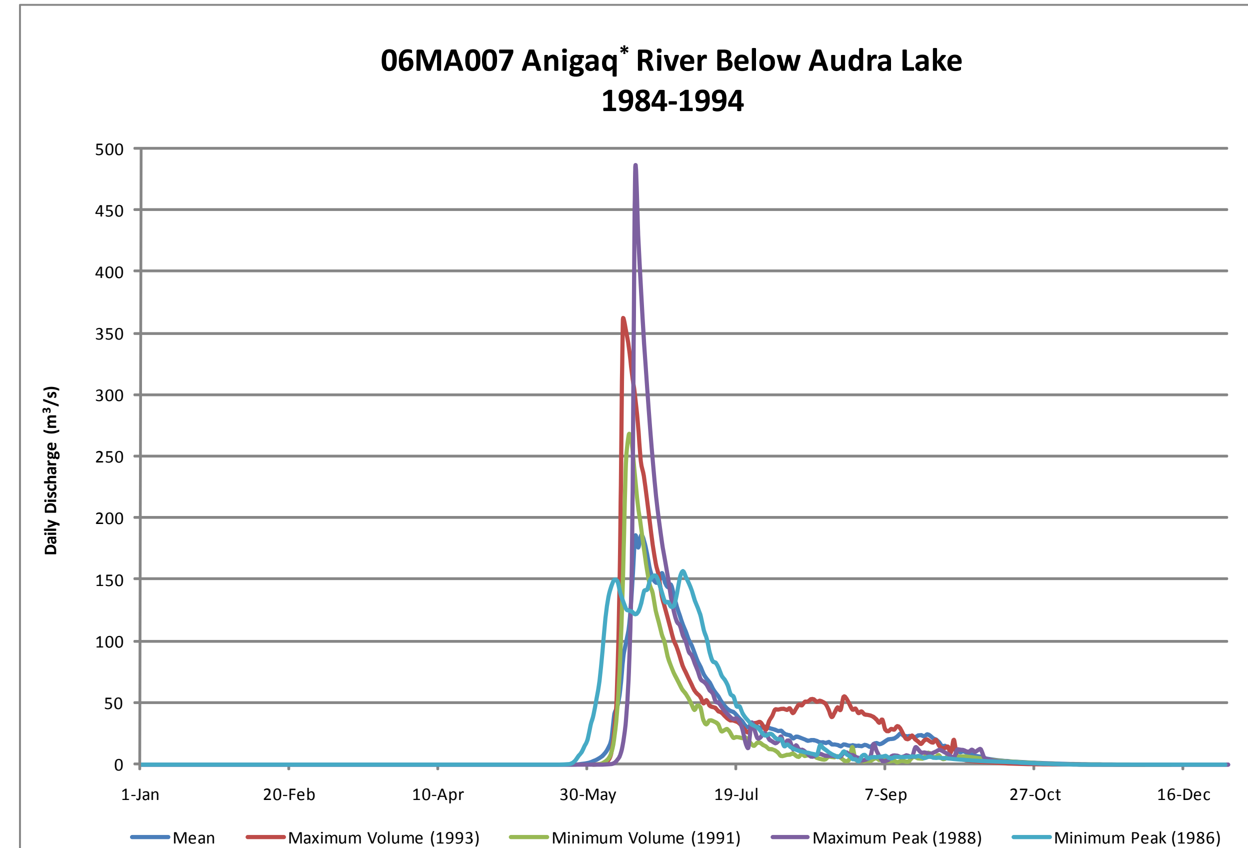
Figure 5.1-2 Mean Annual Discharge versus Drainage Area for Nunavut Streams Located in the Southern Arctic Ecozone







*WSC refers to this station as Anigaq River; however, geographic references to this River have it named Aniguq River (NRCAN 2009, internet site)

Projection: NAD 1983 UTM Zone 14N
Creator: MGD/MK
Date: 12/31/2009
File: KI08D103
Data Sources: *Water Survey of Canada*

FIGURE 5.1-3
MEAN, MAXIMUM AND MINIMUM DAILY HYDROGRAPHS FOR ANIGUQ RIVER AND QINGUQ CREEK

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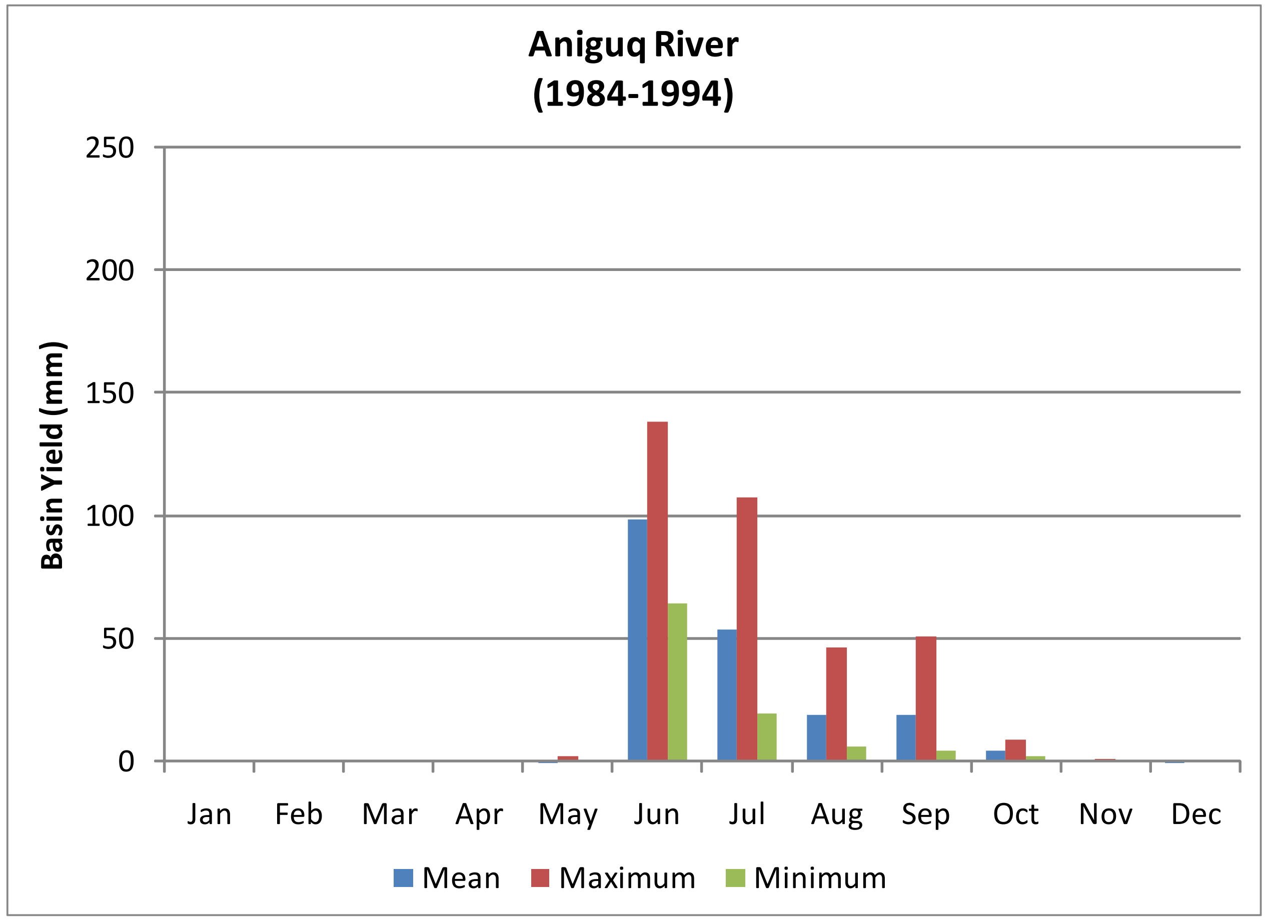

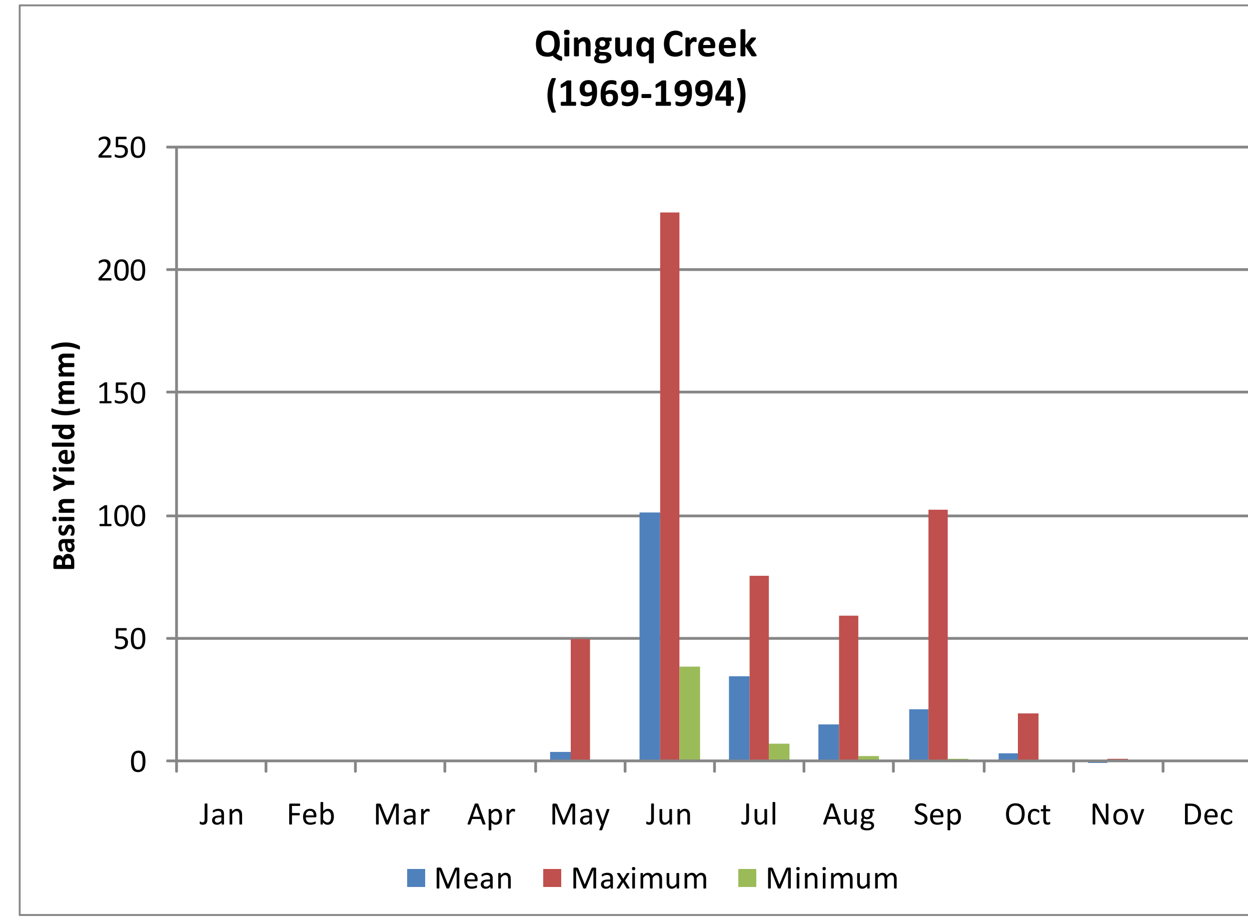

Projection: NAD 1983 UTM Zone 14N
Creator: MGD/MK
Date: 12/31/2009
File: KI08D116
Data Sources: *Water Survey of Canada*

FIGURE 5.1-4
MEAN, MAXIMUM AND MINIMUM MONTHLY BASIN
YIELDS FOR QINGUQ CREEK (1969-1994) AND ANIGUQ RIVER (1984-1994)

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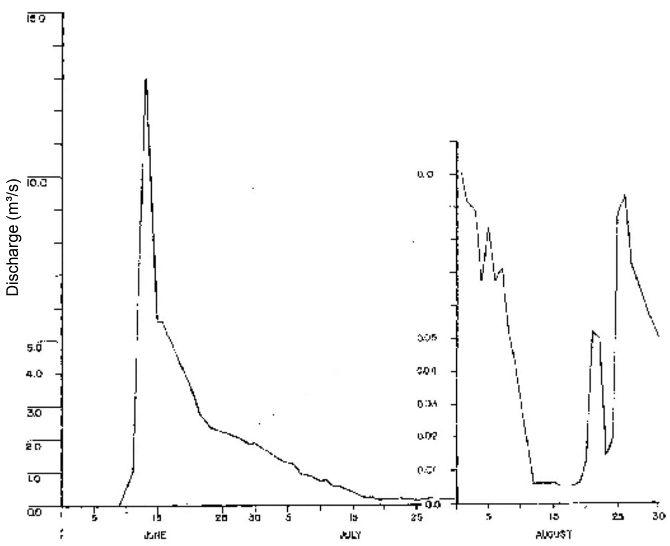
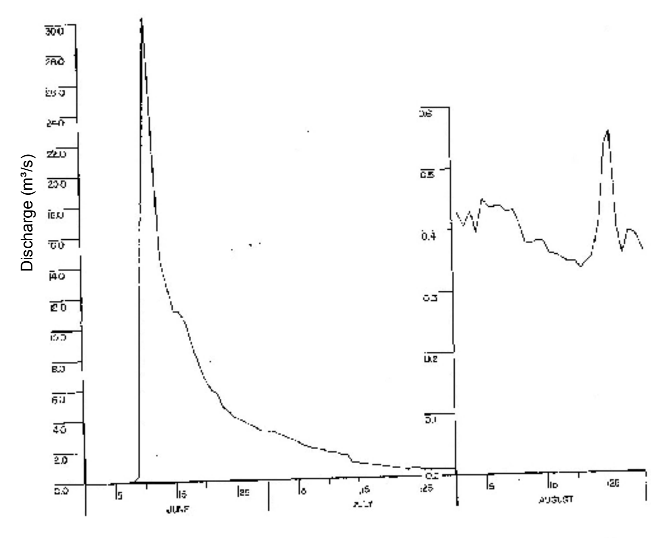
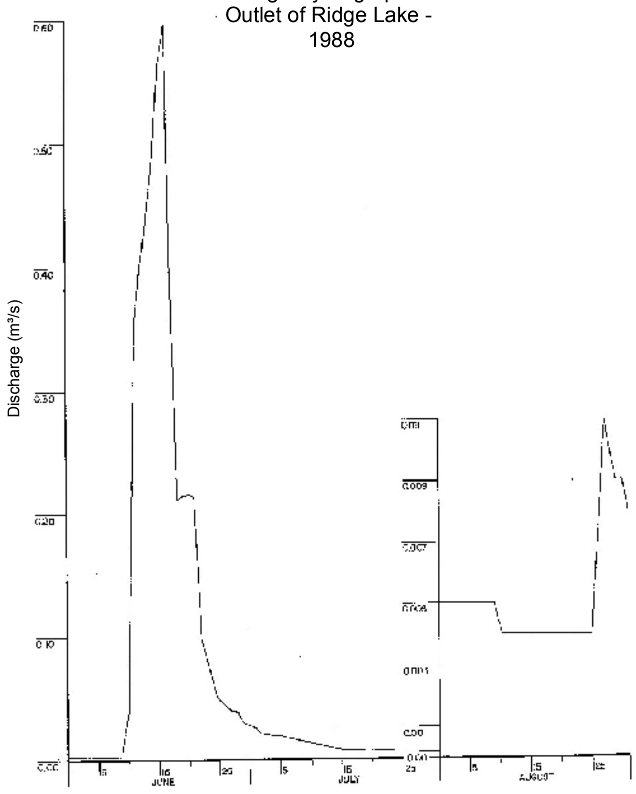
Discharge Hydrograph at the
Outlet of Jaeger Lake
1988



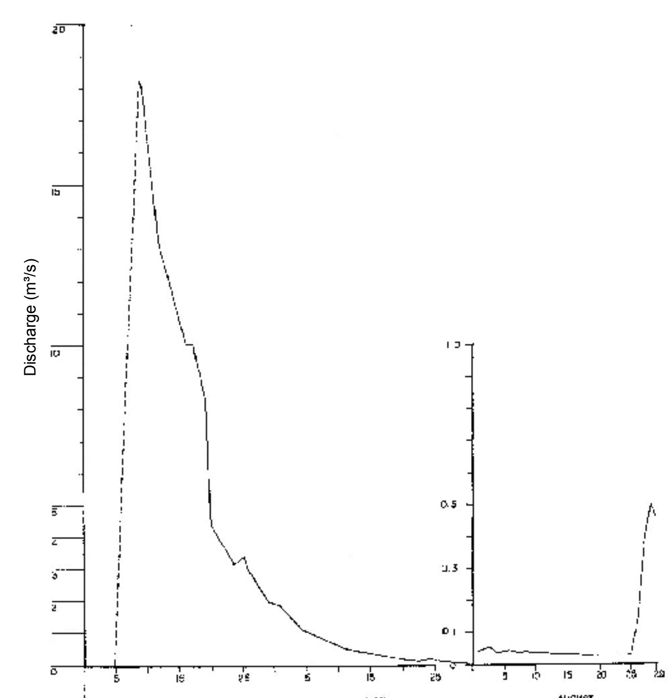
Discharge Hydrograph at the
Outlet of Pointer Lake
1988



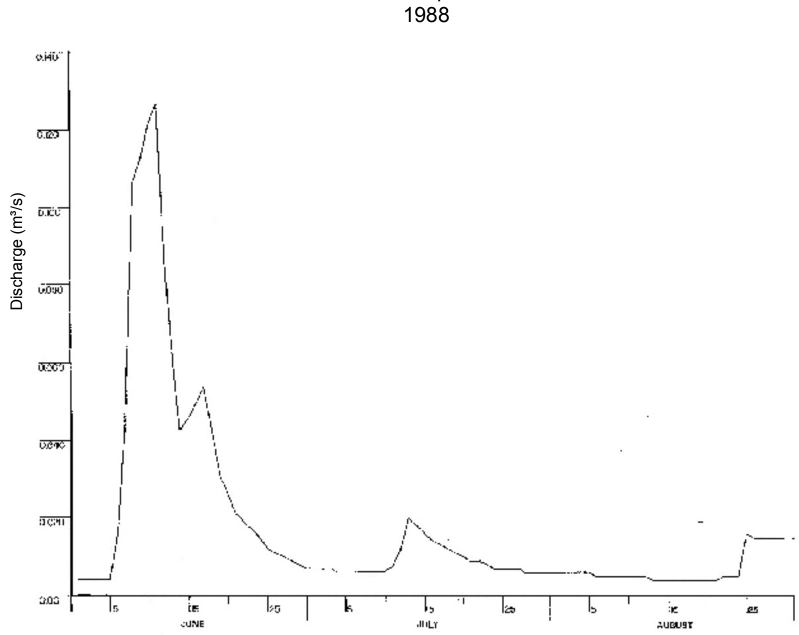
Discharge Hydrograph at the
Outlet of Ridge Lake -
1988



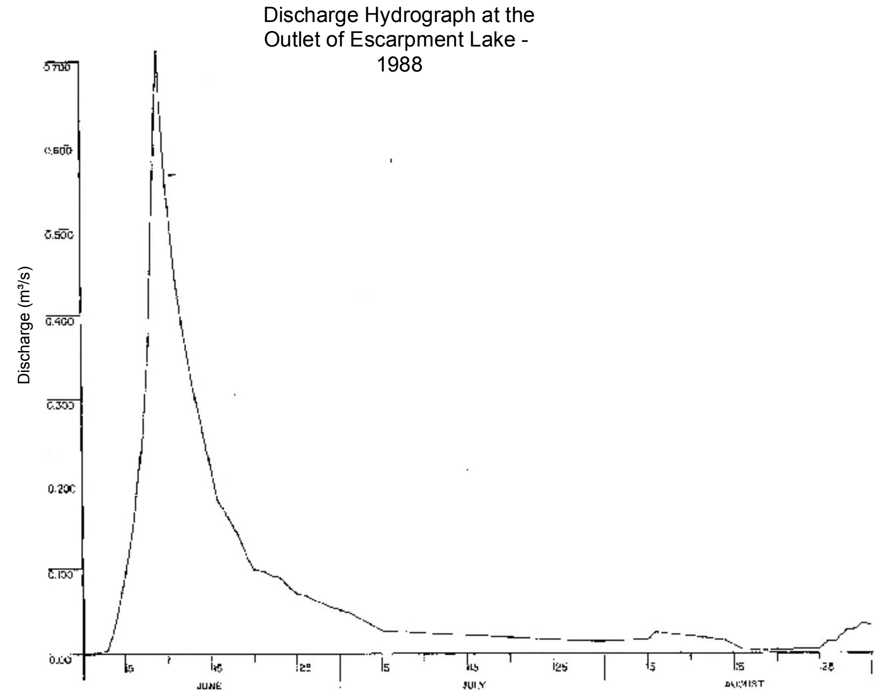
Discharge Hydrograph at the
Outlet of Skinny Lake -
1988



Discharge Hydrograph at the
Outlet of Cirque Lake -
1988



Discharge Hydrograph at the
Outlet of Escarpment Lake -
1988



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Data Sources: *BEAK, 1990*

FIGURE 5.2-1
LOCAL HYDROGRAPHS

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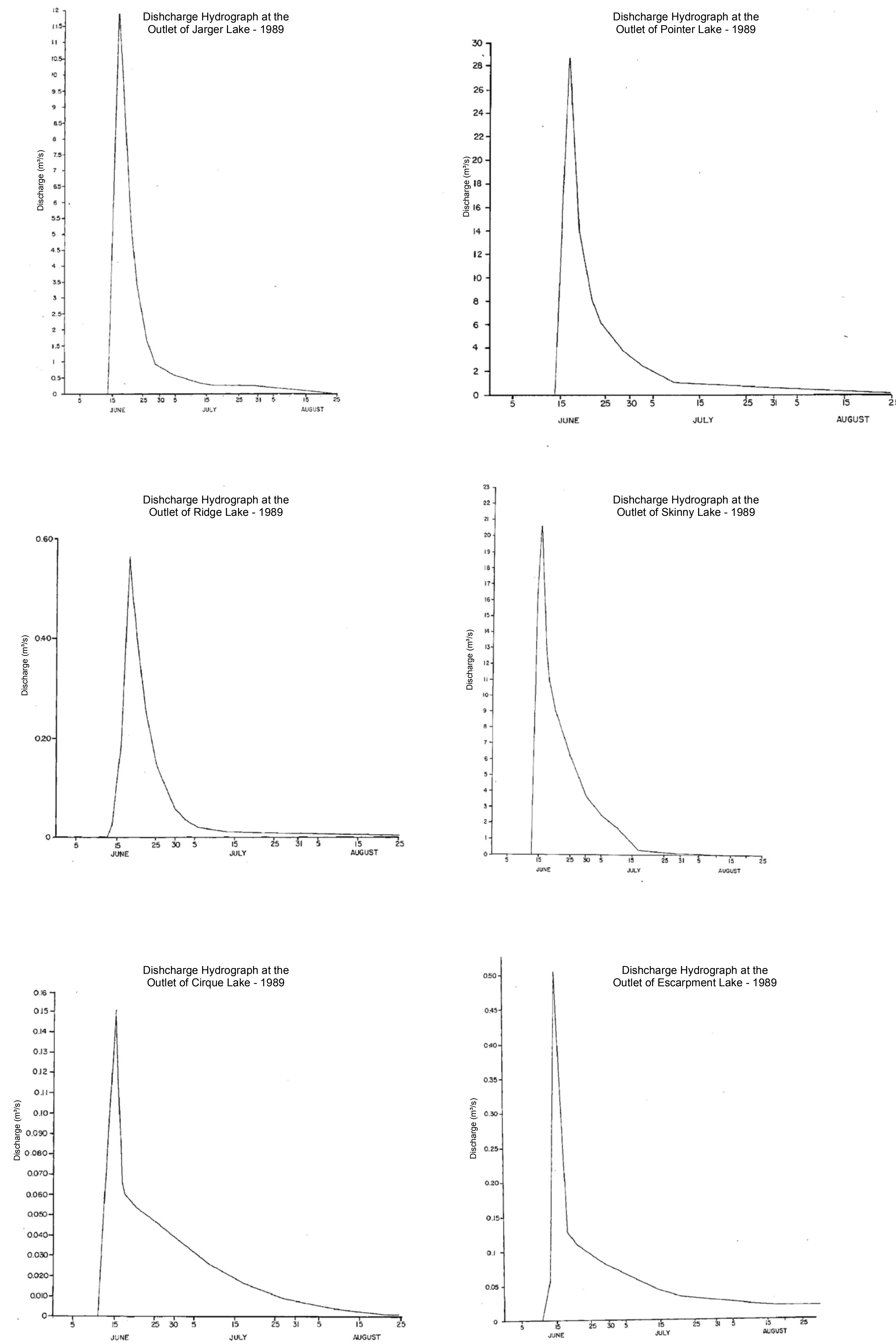

Projection: NAD 1983 UTM Zone 14N
Creator: MGD/MK
Date: 31/12/2009
File: KI08D107
Data Sources: *BEAK, 1990*

FIGURE 5.2-2
LOCAL HYDROGRAPHS, 1989

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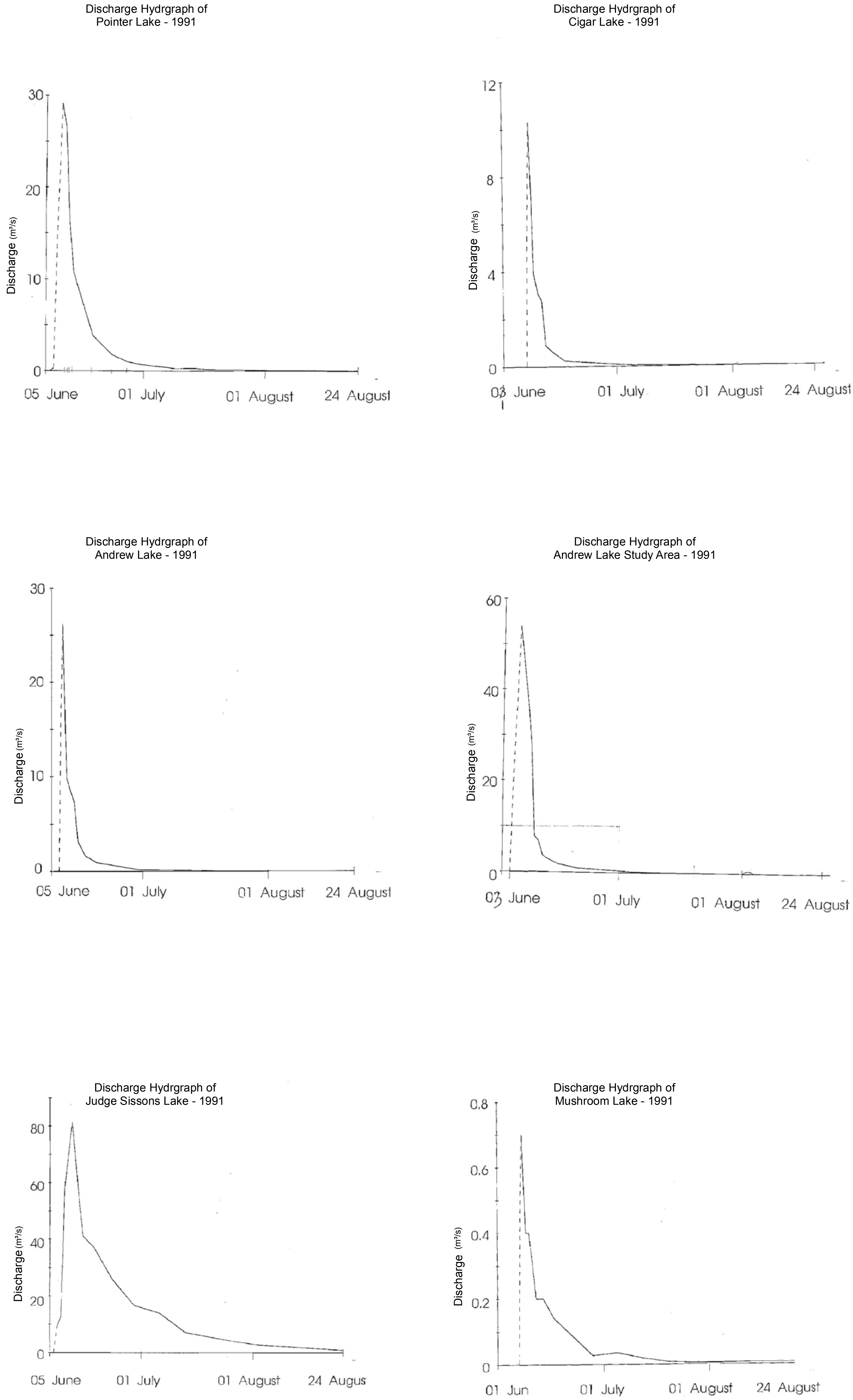

Projection: NAD 1983 UTM Zone 14N
Creator: MGD/MK
Date: 31/12/2009
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Data Sources: *BEAK, 1992*

FIGURE 5.2-3
LOCAL HYDROGRAPHS, 1991

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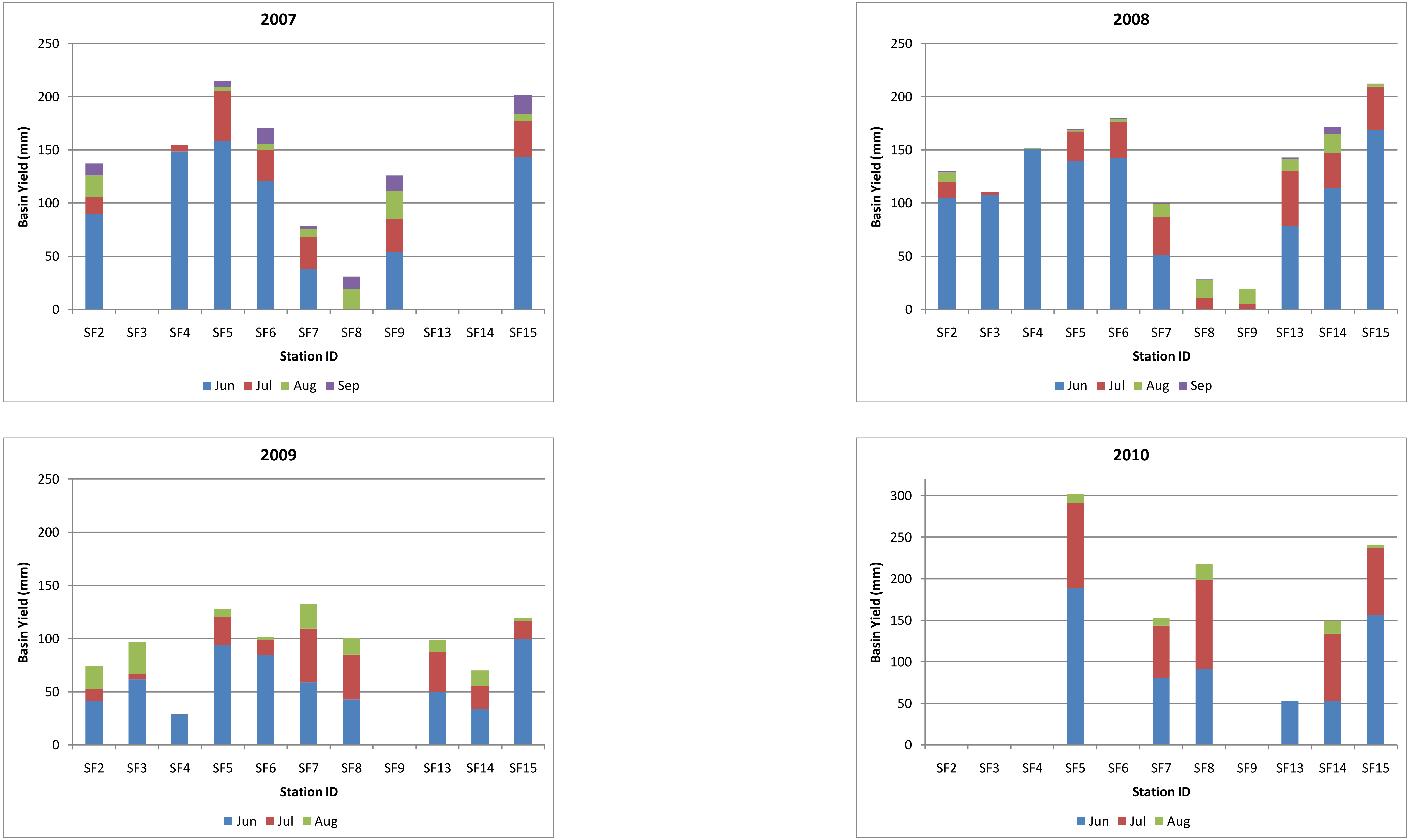

Projection: NAD 1983 UTM Zone 14N
Creator: MGD
Date: 12/29/2010
File: KI08D117
Data Sources: *Water Survey of Canada*

FIGURE 5.2-4
MONTHLY BASIN YIELDS (2007, 2008, 2009, 2010)

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Projection: NAD 1983 UTM Zone 14N
Creator: MGD
Date: 01/31/2011 Scale: 1:100,000
File: KI08D109
Data Sources: *NTS Mapsheet 56D, 66A, 66B, AREVA Resources Canada Inc.*

FIGURE 5.3-1
UNSURVEYED NORTH ROAD STREAM CROSSINGS
(ALTERNATE EC 1, KM 207.6, KM 206.6, KM 205.2)

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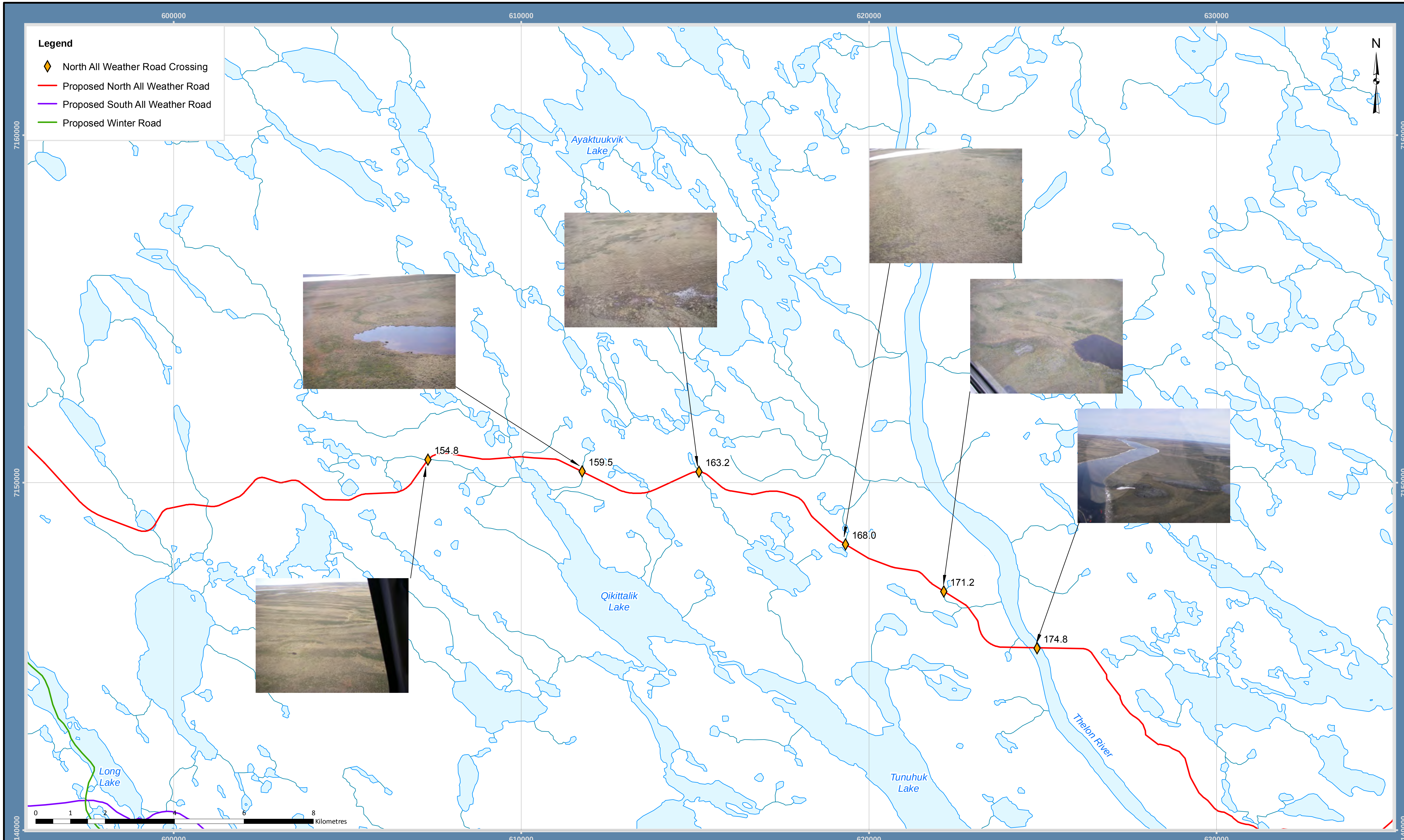

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Creator: MGD
Date: 01/31/2011 Scale: 1:100,000
File: KI08D110
Data Sources: *NTS Mapsheet 56D, 66A, 66B, AREVA Resources Canada Inc.*

FIGURE 5.3-2
UNSURVEYED ALL-WEATHER ROAD STREAM CROSSINGS
(KM 174.8, KM 171.2, KM 168.0, KM 163.2, KM 159.5, KM 154.8)

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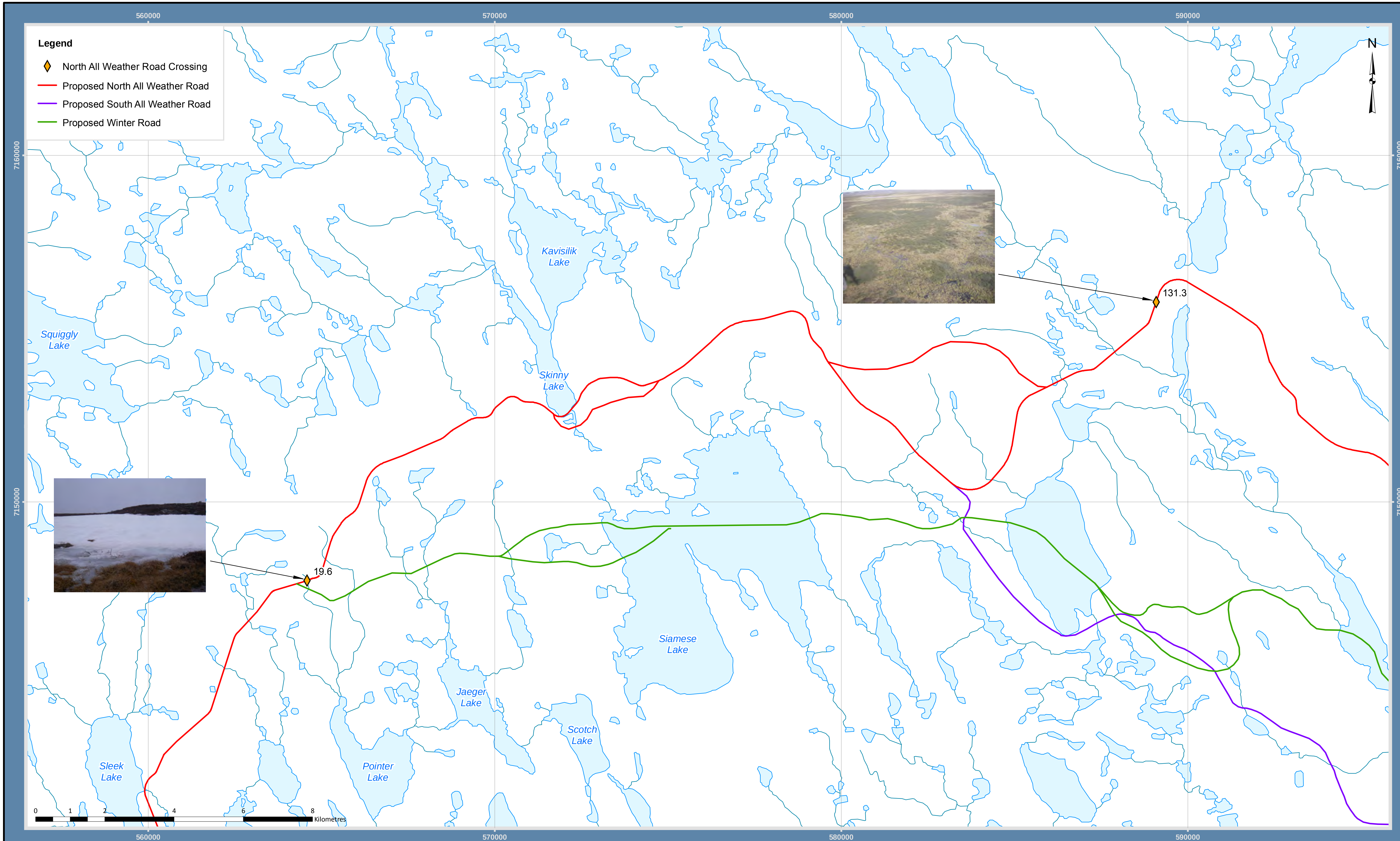

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Creator: MGD
Date: 01/31/2011 Scale: 1:100,000
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Data Sources: *NTS Mapsheet 56D, 66A, 66B, AREVA Resources Canada Inc.*

FIGURE 5.3-3

UNSURVEYED ALL-WEATHER ROAD STREAM CROSSINGS
(KM 131.3 AND KM 19.6)

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6 SUMMARY

Hydrological assessments were undertaken in support of the development of the proposed Kiggavik Project (the Project). Results of recent field investigations along with past studies in the local area were used in combination with long-term regional hydrological and climatic regional data to characterize hydrological conditions in the local study area (LSA). Information compiled for the Project will be used as a basis for environmental impact assessment, engineered designs for water management and supply, and for decommissioning. In addition to hydrological data collected for the proposed mine development, field investigations were also undertaken in support of the proposed access road from the Kiggavik Projects to the community of Baker Lake.

The LSA for hydrology includes four sub-basins draining to Judge Sissons Lake along its northern and western shoreline, and two sub-basins which occur north and east of the Project site. All of the sub-basins related to the Project are drained to the Aniguq River system which flows eastward and discharges to Baker Lake. Lakes, wetlands and streams are common in the LSA. Water is abundant at times, particularly during the freshet, when permafrost strongly limits infiltration and when eight months of precipitation that has accumulated on the landscape melts over a period of several weeks. However, in winter there is little or no flow and only the deeper lakes contain significant water.

Annual runoff in the Nunavut Southern Arctic ecozone region is quite consistent among hydrometric stations with long-term historic records. The mean unit area runoff value among regional hydrometric stations with drainage areas ranging from 217 to 152,000 km^2 is 0.0058 $m^3/s/km^2$, with 50% of 23 stations reporting values between 0.0054 and 0.0062 $m^3/s/km^2$. The Aniguq River and Qinguq Creek are the nearest hydrometric stations to the Project (less than 65 km) and report mean annual runoff values of 0.0060 and 0.0062 $m^3/s/km^2$, respectively.

Based on precipitation data from Baker Lake, the proportion of precipitation which becomes runoff was assessed for nine hydrometric stations monitored on the Project site over the open water period of 2007 to 2010. The range among runoff ratios calculated at these stations was from 0.26 to 0.60. The Aniguq River reported a runoff ratio of 0.41 and Qinguq Creek reported a runoff ratio of 0.49 over the same period. For small drainages with little storage capacity, nearly all the runoff is over the freshet period (June), with runoff outside this period occurs only following substantial precipitation. In other larger basins with large storage capacity, such as Judge Sissons Lake outflow, approximately 50% of the runoff may occur in June, with the remainder draining over the balance of the open water period.

Many of the streams in the region cease to flow over the winter period until spring melt in late May or early June. The largest stream monitored as part of the Kiggavik Project hydrometric program (Judge Sissons Lake Outlet) drains an area of 658 km^2 and is believed to freeze to the base in winter, as inspection of that lake outlet in early June 2007 indicated that the stream was completely frozen. Streams in the LSA do not carry any flow for approximately 60% of the year. Very large rivers in the regional study area, such as the Thelon River, continue to flow year-round.

Lake ice is thickest in late winter and can reach a thickness of more than 2 m. For many of the shallower lakes, most of the liquid volume will be frozen. Siamese Lake is the second largest lake in the LSA and is being considered as a water supply source. Siamese Lake is a strong candidate as a water supply lake and has a surface area of approximately 28 km^2 and a volume of 1.15×10^8 m^3. When ice thickness is greatest, nearly 43% of the lake volume will be frozen.

Flood magnitude and frequency assessments were carried out for selected streams in the LSA. Calculated values are based on regional data and compare favourably to measured values collected over the period 2007 to 2010, and older historical data collected on the site in the late 1980s and early 1990s.

Using data collected in the field, cross drainage structure options were considered for the proposed all-weather road stream crossings. In total, 16 stream crossings were assessed east of the Thelon River and 34 crossings were assessed west of the Thelon River. Fish passage was a concern for 17 of the stream crossings requiring a mean culvert velocity of approximately 0.8 m^3/s or less. The options presented are preliminary and are intended to demonstrate the approximate size and shape that would satisfy the given fish and hydraulic criteria. Further analysis should take place at the detailed design stages to confirm the most appropriate crossing configuration for each location.

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8 GLOSSARY

3Q10 – The peak discharge corresponding to a sustained 3-day, 1-in-10 year return period

7Q10 – The low flow discharge corresponding to a 7-day, 1-in-10 year return period

Barologger – a pressure transducer manufactured by Solinst Canada; measures barometric pressure

Boulder moraine – unconsolidated boulder debris left behind by a glacier

Esker – gravel deposit left by a glacial stream

Evapotranspiration – the combined process that moves water from both land surfaces and plants into the atmosphere

Hummock – a low mound or ridge of ground associated with frost heave

Hydrograph – the plot of discharge versus time

Levelogger – a pressure transducer manufactured by Solinst Canada, measures total (water and barometric) pressure

Runoff ratio – the ratio between the volume of stream flow and volume of total precipitation

Thalweg – the lowest (deepest) point along a given cross section in a stream