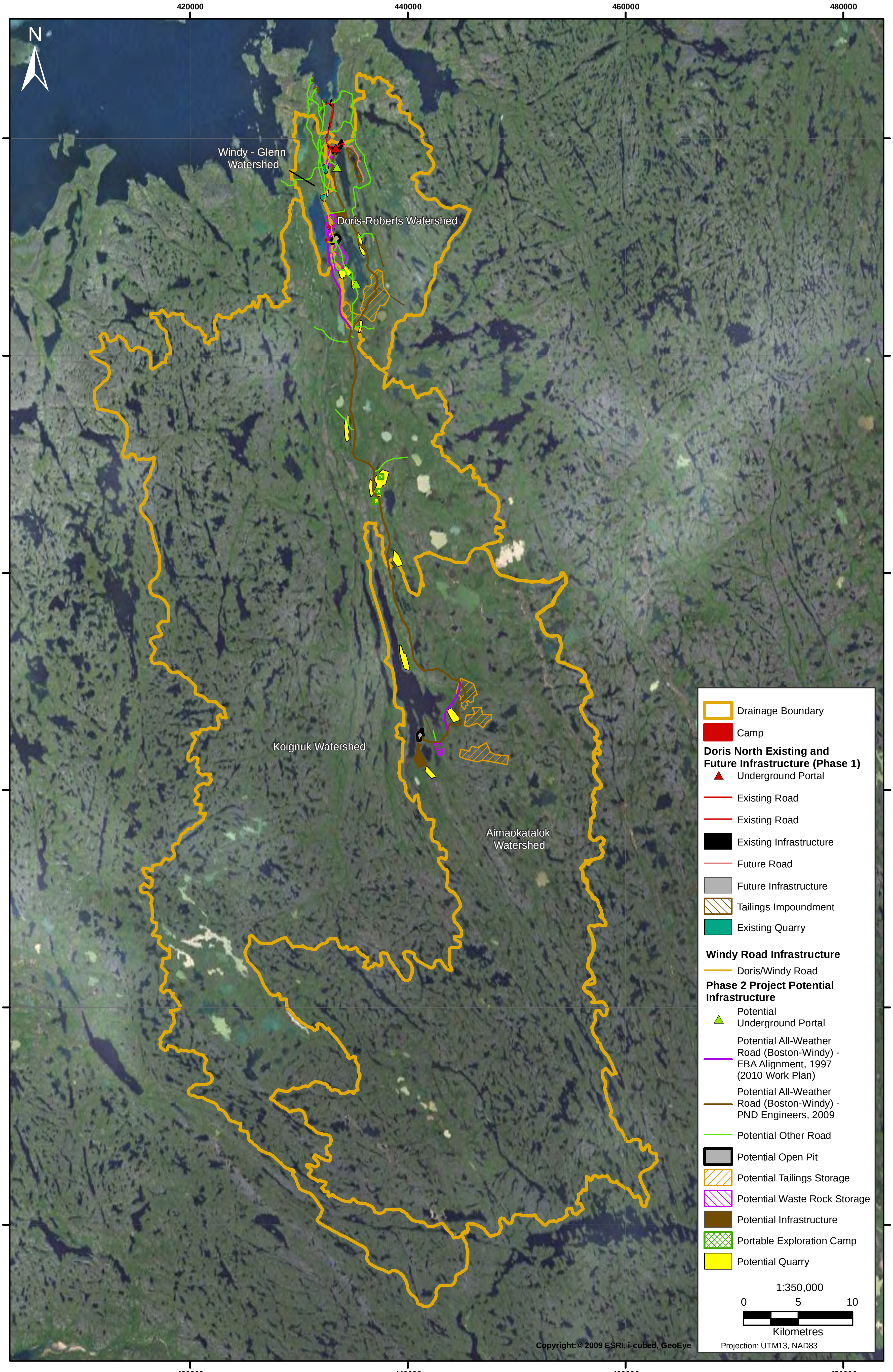

Figure 2.2-1

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Main Drainages in the Study Area

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Table 2.3-1. Summary of Historic Hydrometric Stations in the Doris/Madrid Area

Monitoring Station	Geographic Location [a]		Drainage Area (km^2)	Years of Automated Data Collection
	Easting	Northing		
Doris Lake	433,513	7,558,451	93.1	2004-2010
Doris Lake Outflow	434,063	7,559,507	93.1	1996-1998, 2000, 2003-2010
Glenn Lake Outflow	430,616	7,561,906	31.6	1996-1998, 2000, 2006-2009
Koignuk River	429,739	7,554,336	2,937	2006-2010
Little Roberts Outflow	434,271	7,563,159	198.9	2003-2008
Ogama Inflow	436,617	7,550,891	64.6	1997
Ogama Lake and Outflow	435,648	7,555,130	72.1	1996-1998, 2006-2010
Patch Lake and Outflow	435,993	7,549,169	30	2006-2010
PO Lake	436,584	7,551,126	34.4	2007-2010
PO Lake Outflow	436,565	7,550,014	64.9	2007-2010
Roberts Lake and Outflow	435,289	7,562,800	97.8	2003-2010
Tail Lake	434,899	7,558,494	4.4	2004-2010
Tail Lake Outflow	434,273	7,559,147	4.4	2000, 2004-2010
Windy Lake and Outflow	431,507	7,555,043	13.9	2006-2010
Wolverine Lake and Outflow	435,222	7,545,888	1.97	2006-2010

[a] - UTM Zone 13W, NAD83

Table 2.3-2. Summary of Historic Hydrometric Stations in the Boston Area

Monitoring Station	Geographic Location [a]		Drainage Area (km^2)	Years of Automated Data Collection
	Easting	Northing		
Aimaoktak/Spyder River	441,634	7,499,360	769	2006-2008, 2010
Aimaoktak/Spyder Lake Outflow	438,847	7,509,056	1,224	2006-2008, 2010
Stickleback Outflow	441,934	7,504,127	2.8	1998, 2006-2008
Trout Outflow	442,699	7,503,688	32	2006-2008

[a] - UTM Zone [13W,] NAD83

2.3.2 Regional Data

Table 2.3-3 and Figure 2.3-1 present the locations of regional hydrometric stations operated by the Water Survey of Canada (WSC). Data from these stations was used to supplement the on-site data collected for 2009 in order to calculate annual runoff estimates for the Koignuk River.

Table 2.3-3. Regional Water Survey of Canada (WSC) Stations Relevant to the Study Area

Station Name	Station Number	Geographic Location		Drainage Area (km^2)	Period of Record
Burnside River near the mouth	10QC001	66°43'30" N	108°48'42" W	16,800	1976-present
Tree River near the mouth	10QA001	67°38'6" N	111°54'9" W	5,810	1968-present
Freshwater Creek near Cambridge Bay	10TF001	69°7'52" N	104°59'26" W	1,490	1970-present
Ellice River near the mouth	10QD001	67°42'30" N	104°08'21" W	16,900	1971-present

(continued)

Table 2.3-3. Regional Water Survey of Canada (WSC) Stations Relevant to the Study Area (completed)

Station Name	Station Number	Geographic Location		Drainage Area (km^2)	Period of Record
Back River below Beechy Lake	10RA001	65°11'14" N	106°5'9" W	19,600	1978-present
Contwoyto Lake at Lupin Mine	10QC003	65°46'37" N	111°13'1" W	not provided	1991-present
Fairy Lake River near outlet of Napaktulik Lake	10PC005	66°15'7" N	113°59'7" W	6,442	1993-present
Coppermine River above Copper Creek	10PC004	67°13'44" N	115°53'12" W	46,200	1987-2008
Kendall River near outlet of Dismal Lakes	10PC001	67°12'31" N	116°34'20" W	2,790	1969-2009
Gordon River near the mouth	10QC002	66°48'36" N	107°6'4" W	1,530	1977-1994

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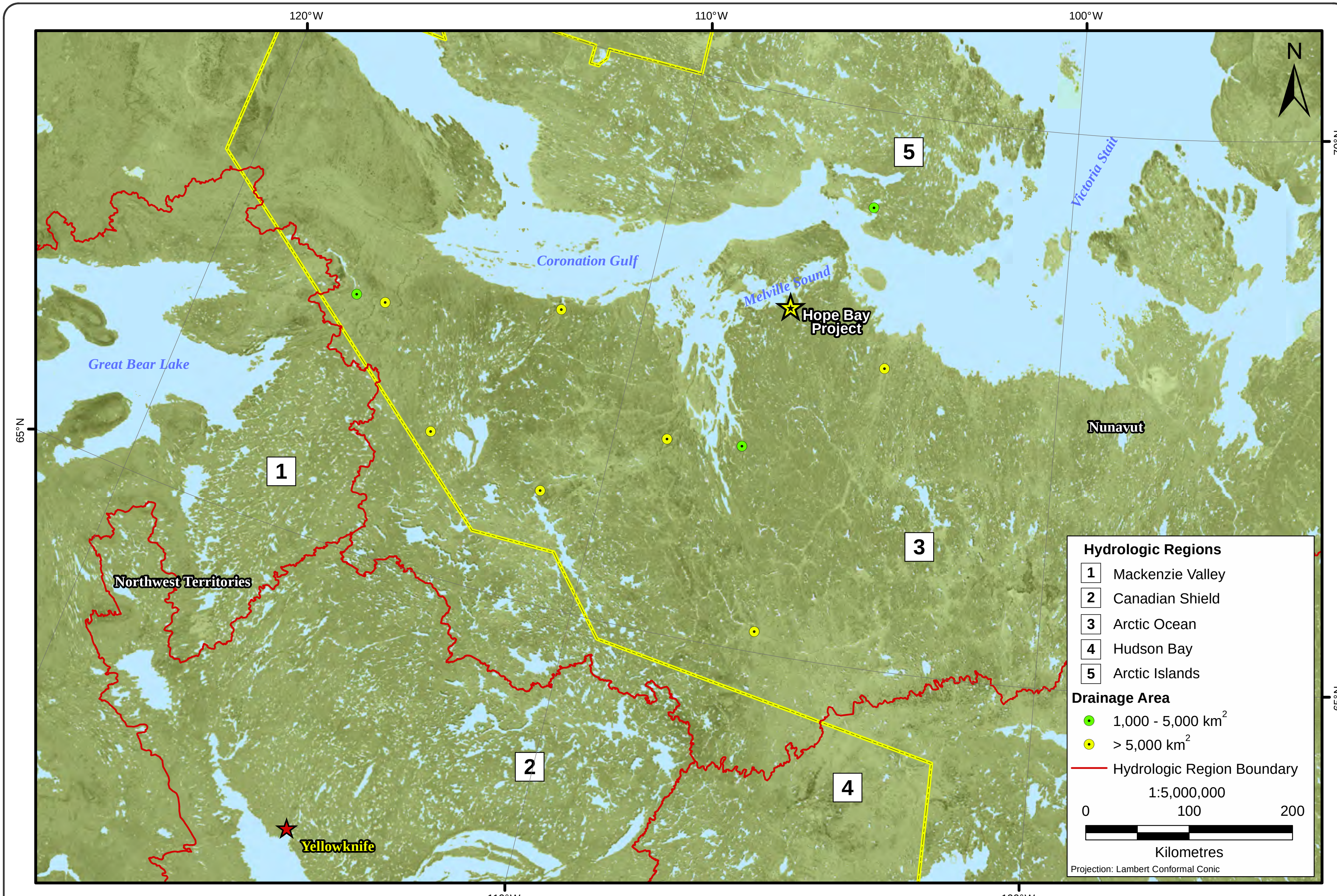

Figure 2.3-1

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WSC Hydrometric Stations Near the Study Area with >5 Year Records

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Figure 2.3-1

3. Methods

3. Methods

This section describes the methods used to collect and analyze hydrometric data in 2010.

3.1 HYDROMETRIC MONITORING NETWORK

A network of 18 hydrometric stations monitoring lake and stream levels was operated during 2010 in the Doris/Madrid and Boston areas.

In the Doris/Madrid area nine hydrometric monitoring stations were remobilized and one new station installed in 2010. Two existing hydrometric stations monitoring lake levels at Doris and Tail lakes were also maintained in 2010 (Table 3.1-1, Figure 3.1-1).

Table 3.1-1. 2010 Hydrometric Monitoring Stations of Streams and Lakes in the Doris/Madrid Area

Basin/Station	Location	Geographic Coordinates [a]		Drainage Area (km^2)	Period of Operation	Monitoring Type
		Easting (m)	Northing (m)			
Doris-Roberts Watersheds						
Doris-Hydro	Doris Lake outflow	434,059	7,559,504	95	June 10 to October 4	stream water level
Doris-Lake	Doris Lake	433,512	7,558,452	95	January 1 to October 5	lake water level
Ogama-Hydro	Ogama Lake outflow	435,501	7,555,173	75	June 10 to October 1	stream water level
Patch-Hydro	Patch Lake	436,062	7,549,169	32	June 14 to September 30	lake water level
PO-Hydro	PO Lake	436,549	7,550,584	68	June 14 to October 1	lake water level
Roberts-Hydro	Roberts Lake	435,310	7,562,560	98	June 14 to October 4	lake water level
Tail-Hydro	Tail Lake outflow	434,300	7,559,158	4	June 10 to October 4	stream water level
Tail-Lake	Tail Lake	434,899	7,558,494	4	January 1 to October 5	lake water level
Wolverine-Hydro	Wolverine Lake	43,4802	7,545,443	3	June 13 to September 30	lake water level
Windy-Glenn Watershed						
Windy-Hydro	Windy Lake	431,481	7,555,089	14	June 10 to September 25	lake water level
Koignuk Watershed						
Koignuk-Hydro	Koignuk River	429,731	7,554,332	2,937	June 6 to October 3	stream water level
Reference-B Watershed						
Reference B-Hydro	Reference Lake outflow	427,077	7,529,965	159	June 11 to September 30	lake water level

[a] - NAD 83, Zone 13 W
[b] - for more details refer to section 3.5
n/a - not applicable

In the Boston area five new hydrometric monitoring stations were installed, and an existing hydrometric station monitoring water levels at Aimaokatalok Lake was maintained in 2010 (Table 3.1-2, Figure 3.1-2).

Table 3.1-2. 2010 Hydrometric Monitoring Stations of Streams and Lakes in the Boston Area

Basin/Station	Location	Geographic Coordinates[a]		Drainage Area (km^2)	Period of Operation	Monitoring Type
		Easting (m)	Northing (m)			
Aimao Out Hydro	Aimaokatalok Lake outflow	438,847	7,509,056	1,224	June 7 to September 26	stream water level
Aimao Lake	Aimaokatalok Lake	438,892	7,508,794	1,224	January 1 to June 15	lake water level
Aimao In Hydro [b]	Aimaokatalok River	441,637	7,499,326	725	June 8 to June 12	stream water level
East Aimao Hydro	Eastern tributary of Aimaokatalok Lake	444,038	7,509,257	363	June 8 to September 29	stream water level
East Tailings Hydro	Eastern tributary of Aimaokatalok Lake draining potential tailings storage	444,385,	7,508,941	8	June 9 to September 27	stream water level
Trout Hydro	Trout Lake inflow	442,599	7,502,024	27	June 9 to September 29	stream water level

[a]- *UTM NAD 83, Zone 13*
[b]- *station was damaged by floating ice. Personnel were able to retrieve the instrumentation on July 22, 2010.*

The monitoring period for the hydrometric stations installed in the spring of 2010 commenced in early-June and continued through to late-September/early-October when the majority of the stations were uninstalled for the winter. Demobilization of the hydrometric stations at the end of the open-water period is necessary because freezing conditions cause damage to the pressure transducer during the winter. Further, outlet channels completely freeze during the winter and discharge levels reach zero.

All hydrometric stations in the Doris/Madrid area were demobilized with the exception of hydrometric stations at Doris Lake and Tail Lake, which had monitoring instrumentation in water deep enough to prevent ice damage to the pressure transducer. These two stations remained in operation as of early-October.

In the Boston area all hydrometric stations were demobilized for the winter. It is important to note that the hydrometric station installed along the banks of the Aimaokatalok River (Aimao Hydro) was damaged by ice and only recorded water level data until June 23, 2010. Personnel were able to retrieve the damaged instrumentation in a subsequent site visit in mid-July, 2010. The existing hydrometric station recording water levels at Aimaokatalok Lake malfunctioned in mid-June. During the installation of hydrometric stations in early-June, 2010 the existing station located along the shores of Aimaokatalok Lake could not be found. Subsequently, the new Aimao Out-Hydro hydrometric station was installed to monitor water levels at the lake outflow. Therefore, when the existing station was located and found malfunctioning during the July 20, 2010 site visit it was deemed unnecessary to replace the instrumentation. The retrieved instrumentation from both stations has been sent to the manufacturer for repairs.

Each station remobilized and installed in 2010 consisted of a 0-5 psi vented Aquistar PT-2X Smart Sensor® (Instrumentation Northwest Inc.). The sensor combines a pressure transducer and data logger in one small diameter unit. The unit recorded water level at ten minute intervals. The sensor and cabling were inserted into a flexible aluminum conduit with one end of the conduit attached to a piece of angle iron 1.5 m long. In rocky substrates, the angle iron was placed directly on the lake or stream bed whereas in fine-grained substrates, the angle iron was attached to a wooden frame to spread the weight evenly and prevent the assembly from sinking into the substrate.

PROJECT #1009-002-03 GIS # HB-10-012 February 02 2011

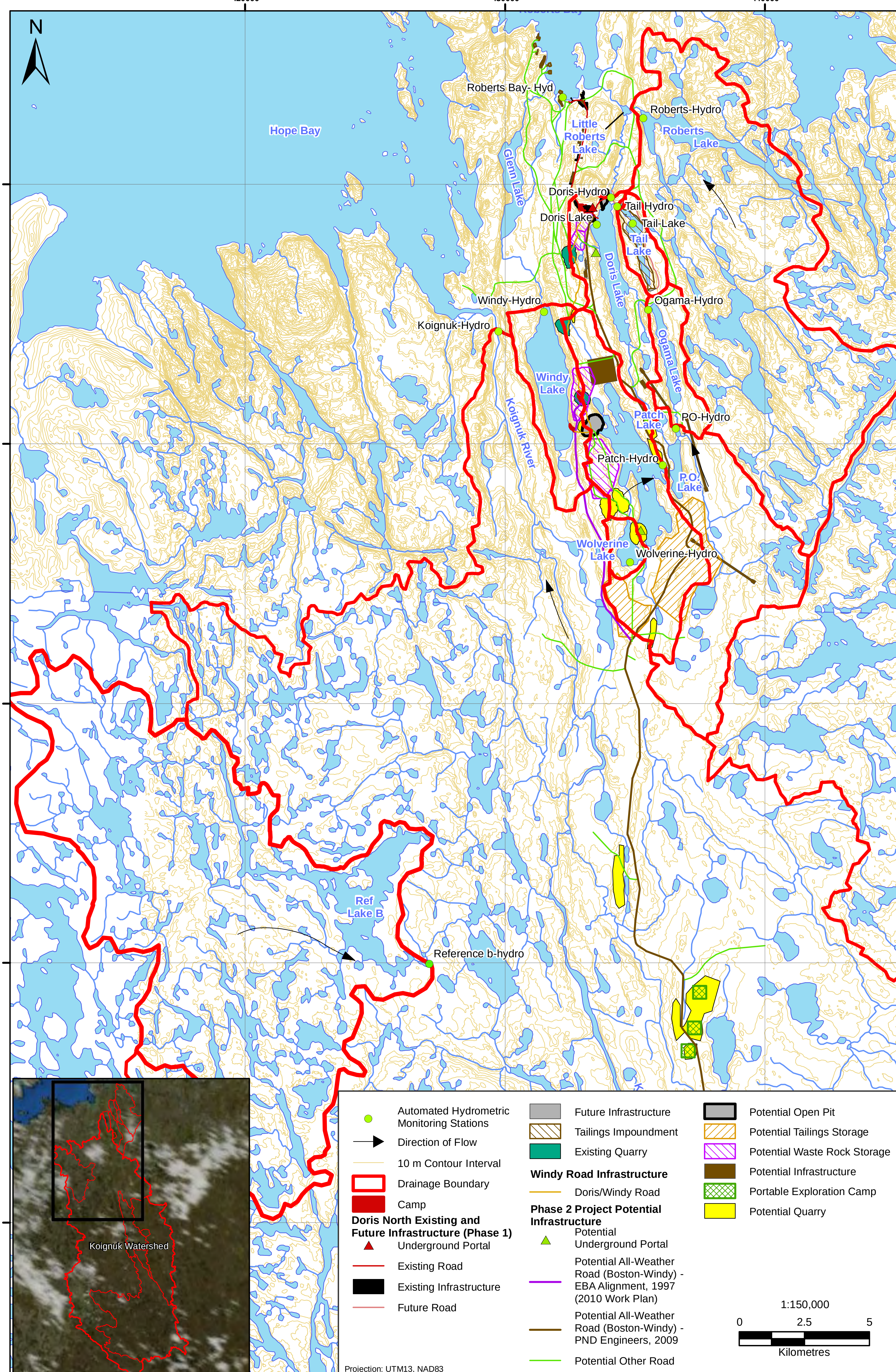

Figure 3.1-1

Figure 3.1-1

Location of 2010 Hydrometric Monitoring Stations within Doris/Madrid Area, Hope Bay Belt Project

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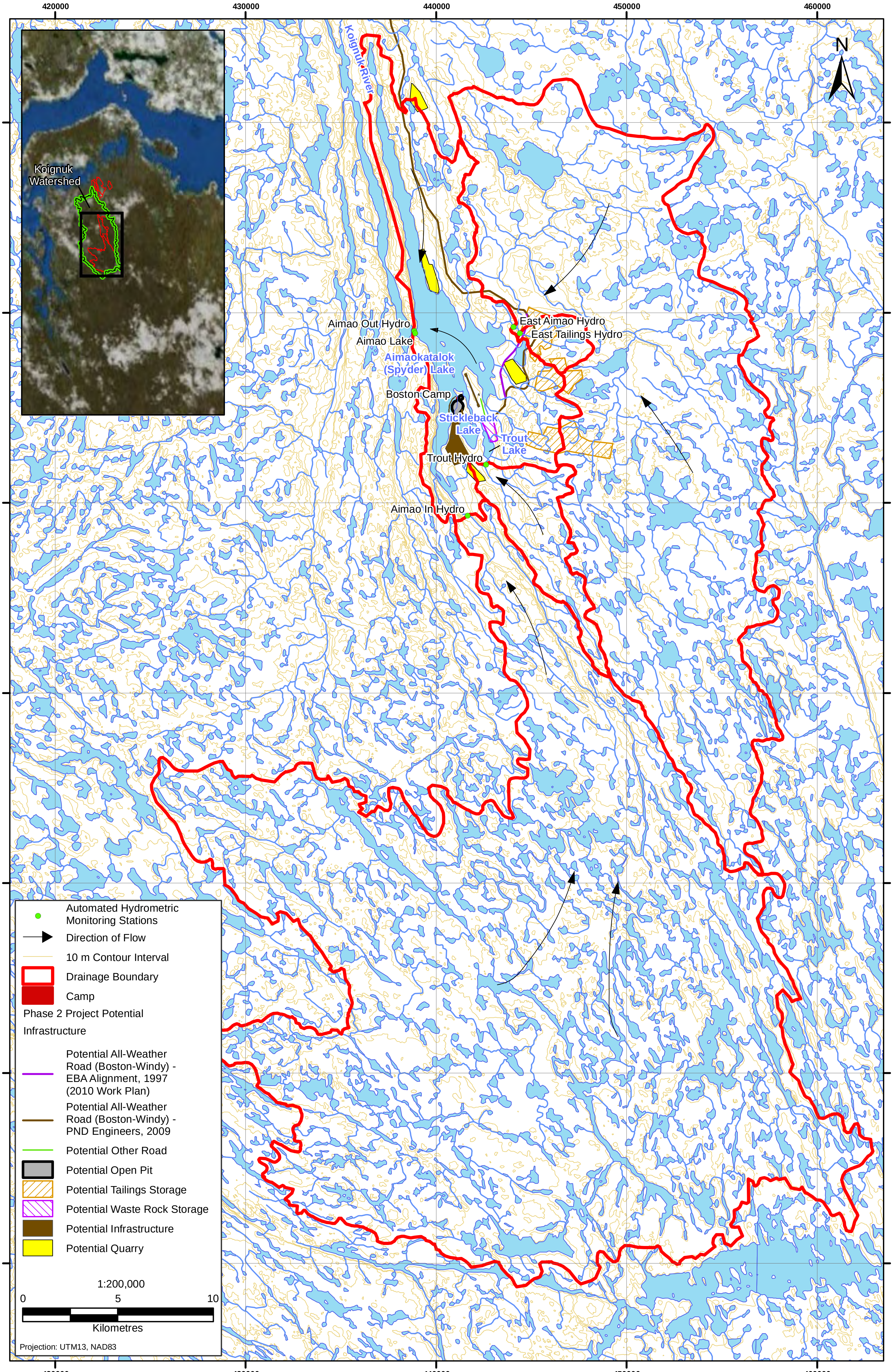

Figure 3.1-2

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Location of 2010 Hydrometric Monitoring Stations within Boston Area

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At the outflow of Ogama Lake, the angle iron was anchored to 1.3 cm diameter pieces of reinforced bar which were drilled into bedrock and anchored in place with rock epoxy. A standard 1 m Water Survey of Canada (WSC) staff gauge graduated to 0.01 m was also installed to allow for visual measurements of stage. The end connector of the sensor was housed in a steel waterproof enclosure located along the adjacent lake shores or channel banks above the high water mark. The angle iron assembly was installed as deep as possible in the water to allow for monitoring of low lake and stream levels. Illustrations of station design are provided in Plate 3.1-1.

Plate 3.1-1. Photographs illustrating hydrometric station design.

Benchmarks established in 2009 were used as survey control points along the channel banks and lake shores at each of the monitoring stations that were reestablished in 2010. During the remobilization of the stations, the elevations of the pressure transducer and water level relative to the station datum were surveyed using an engineer's rod and level. Survey control points were also established at the new stations added to the hydrometric monitoring network in 2010. Pressure transducer and water level elevations relative to the station datum were also surveyed. During subsequent site visits, additional hydrometric leveling surveys were carried out at each station to check and verify pressure transducer readings, as well as to determine the reliability of the water level data that were recorded between site visits.

3.2 CURRENT VELOCITY MEASUREMENTS AND DISCHARGE CALCULATIONS

At each hydrometric station current velocity measurements were performed so that discharges could be determined. Measurements were taken throughout the open water season in order to obtain a range of discharges under different flow conditions. Five site visits were conducted during early-June, mid-June, mid-July, mid-August, late-September, and early-October 2010.

At lake outlets, current velocity measurements were obtained by measuring water velocities using a current velocity meter that has the propeller mounted on a horizontal axis (Swoffer 2100® by Swoffer Instruments Inc.).

Water discharges were computed from the stream velocity measurements using the velocity-area method which determines discharge per unit width for each sounding or vertical. In this method it is assumed that the velocity sampled at each vertical represents the mean velocity in a segment. The segment area extends laterally from half the distance from the preceding vertical to half the distance to the next, and vertically from the water surface to the sounded depth. The partial discharges across the channel are then summed to obtain the estimated total discharge measurement. Typically a minimum of 20 current velocity measurements are taken across the width of a channel with the aim of having each sounding or measurement interval accounting for less than 10% of the total discharge.

At each sounding point across the channel, if the observed water depth was less than 0.75 m, the current water velocities were measured at 60% of the flow depth of water. The measurement was assumed to be the mean velocity for the vertical water section. When water depths were greater than 0.75 m, current velocities were measured at 20% and 80% of the flow depth of water and the average of the two readings was taken as the mean velocity for the vertical. In most cases, two replicate discharge measurements were conducted at each site in order to estimate the precision of the method. The average of the two measurements was taken to be the estimated discharge sample on the day of survey. The value of the two measurements provided the range of error associated with the actual flow measuring technique. In all cases, the adopted methods followed standard WSC operating procedures (Terzi 1981).

At some hydrometric stations water depth or current velocity conditions were too high during the open water season to allow field personnel to safely wade and measure discharge with a handheld current velocity meter. Therefore, discharge was measured at these stations by means of a StreamPro® (Teledyne RD Instruments) acoustic Doppler current profiler (ADCP) following standard operating procedures (Rehmel et al. 2003, WSC 2004).

In the Doris/Madrid area, the ADCP unit was used at the Koignuk River for all discharge measurements during the open water season. The ADCP unit was mounted onto a tethered floating platform and towed by a boat across the channel.

In the Boston area, the ADCP was used for all discharge measurements at the outflow of Aimaokatalok Lake (hydrometric station Aimao Out-Hydro). The ADCP was also employed in June and July at the eastern tributary of Aimaokatalok Lake (hydrometric station East Aimao-Hydro) and at the Aimaokatalok River (hydrometric station Aimao In-Hydro). At these locations the ADCP floating platform was tethered to a cableway that spanned the channel. The cableway was used to draw the ADCP unit across the channel.

In all cases, measurements of current velocity, water depth, and the position of the unit across the channel section were automatically recorded. A single channel section or transect produced one measurement of mean discharge. At least four valid transects were collected during each site visit to reduce the effects of turbulence, directional bias, or other random errors. Results were considered as valid if they were within 5% of the observed mean flow average. The resulting mean discharge value was reported as the estimated discharge for the river. The range of individual measurements was used as the error associated with the average discharge.

3.3 STAGE DISCHARGE RATING CURVES

The 2010 discharge measurements were used to generate stage-discharge relationships for each hydrometric station. Stage-discharge relationships were expressed as rating curves. Stage-discharge rating curves (rating curves) are used to convert water level data (stage) recorded by the hydrometric monitoring stations into a discharge time-series or hydrograph. The quality of a rating curve depends on the number and accuracy of the individual data points used to generate the curve as well as the hydraulic characteristics of the monitoring location. Although a rating curve can be developed with as few as three points, a minimum of six discharge measurements per year is recommended. Each additional point increases the range and robustness of the rating curve at varying discharge levels. Discharge measurements at the higher end of the discharge range are especially important as they help to define the high end of the rating curve. This is important as high flows often require extrapolation beyond the range of the observed data used to generate the rating curve and the rating relationship can change from low flow periods to high flow periods, depending on channel geometry.

Rating curves were developed using Aquarius™ Time Series Hydrologic Software (Aquatics Informatics Inc.). The software uses standard methods outlined by the United States Geological Survey and the International Organization for Standardization (Kennedy 1984, ISO 2010). Plotted on a logarithmic scale, a least-squares regression procedure was used to produce a line of best fit and logarithmic equation for the concurrently measured water level (stage) and discharge data. Taking the antilogarithmic transformation, discharge was determined by a power function of the form:

$$Q = C\,(H - a)^{b}$$

where Q is the discharge [m^3/s], C and b are regression coefficients, H is the stage (water level) [m], and a is the stage at zero flow (datum correction) [m]. A cross-sectional channel survey at most stations provided an approximation to the location of the lowest point on the control; the location was further refined using estimating techniques built into Aquarius™ Software.

3.4 LAKE LEVELS

Sub-hourly water level data (m) were used to calculate a mean daily water level for the eight hydrometric stations that recorded lake water levels in the Doris/Madrid area (Doris Lake, Patch-Hydro, PO-Hydro, Reference B-Hydro, Roberts-Hydro, Tail Lake, Windy-Hydro, and Wolverine-Hydro).

In the Boston area, the pressure transducer that recorded water levels at Aimaokatalok Lake malfunctioned on June 15, 2010. To compensate for the data gap after that date, water level data were estimated using a linear regression model. The model was built using a concurrent period of mean daily water level data recorded from June 7 to June 15, 2010 at the Aimao Lake and the Aimao Out-Hydro hydrometric stations. The resulting model was used with data recorded from June 16 to September 26, 2010 at the Aimao Out-Hydro hydrometric station in order to estimate missing water level data at the Aimao Lake hydrometric station. To assess the validity of the 2010 estimated water level time series at the Aimao Lake hydrometric station, the estimated values were compared to existing historical water level data from 2007 to 2009.

3.5 DISCHARGE HYDROGRAPHS

For the operational period at each station, discharges were calculated by applying the generated rating curves to the recorded stage data. Prior to recorded stage data, rising limbs of the hydrographs were estimated assuming a logarithmic growth function. Based on the daily field updates during the late-May and early-June period, June 1st was assumed as the start date for the freshet period in 2010. After the removal of the pressure transducers in the fall, hydrograph recession limbs were estimated by assuming a stream freeze up date and a linear decay function. Other functions were considered (e.g. logarithmic, polynomial) however the linear function was the most conservative and consistent with results obtained in previous years (Rescan 2009).

For all hydrometric stations located along lakes in the Doris/Madrid area, it was assumed that the outlet streams ceased to flow following a prolonged period of sub-zero temperatures. From previous monitoring years, it was estimated that flows from Tail Lake and Doris Lake ceased following 74 and 252 negative degree-days below a base temperature of 0°C (Rescan 2009). This assumption was applied to the 2010 observed daily mean air temperatures from the Doris meteorological station to provide a date of zero flow of October 27 for Tail Lake and November 13 for Doris Lake. Except for Tail Lake, discharge at all catchments within the Doris-Roberts, Windy-Glenn, and Reference-B Watersheds, were assumed to cease on the same estimated date as Doris Lake. Because Tail Lake has the smallest drainage area, it was assumed that surface water stopped flowing by October 27, 2010.

Due to its larger drainage area the Koignuk River (2,937 km^2) was assumed to stop flowing on December 1, 2010. To confirm, the daily discharge data (2005-2008) from a similarly sized WSC station at Kendall River (2,790 km^2) showed that the river stopped flowing each year between mid-to-late November. In comparison, the Koignuk drainage area is 5% larger than the Kendall Watershed. In addition, the Koignuk River is located farther north and has a climate more influenced by its proximity to the ocean. Thus, the assumption that the Koignuk River stops flowing by December 1st each year was considered to be reasonable. Ice drilling during the 2009 and 2010 winters at the confluence point of the Koignuk at Hope Bay further confirmed that the river does not flow year round. In late April 2009 under-ice water was reached after drilling at the confluence point but no discharge could be measured (Rescan 2010a). Further, salinity samples taken on the same date indicated no evidence of freshwater input from the river into Hope Bay (Rescan 2010b). In April 2010, ice drilling where the Koignuk drains into Hope Bay revealed that the river was frozen all the way to its bed, less than one metre below the ice surface, and that no water was flowing (Rescan 2010c).

The same assumption that uses the concept of negative degree days below a base temperature of 0°C was used for the estimation of freeze up date for streams in the Boston area. When the assumption was applied to the 2010 observed daily mean air temperatures from the Boston meteorological station, negative degree-days 74 and 252 corresponded to October 27th and November 13th respectively.

Using the same rationale, November 13th was assumed as the freeze-up date for water flowing past the hydrometric station East Aimao-Hydro. October 27th was assumed as the freeze up date for the stream draining past the hydrometric station East Tailings-Hydro because of its comparatively small drainage area.

The outflow stream of Aimaokatalok Lake remained open during the 2009/2010 winter. During a site visit on April 25, 2010 personnel measured the depth and width of the open channel as well as performed a visual estimation of the stream current velocity. This information was used to calculate a discharge estimate at this site. This discharge estimate was then used in conjunction with logarithmic growth and decay functions in order to estimate the rising and recession limbs for the 2010 hydrograph respectively.

3.6 HYDROLOGIC INDICES

Calculated annual runoff, mean annual flow, peak flows, and low flows are important hydrologic indices that provide useful information when undertaking a hydrologic assessment for engineering design of mine project infrastructure as well as when managing the water resources once a mine has entered operations.

Calculated annual runoff (as a depth) represents the difference between annual precipitation, snowmelt, and evaporation. It is valuable for obtaining gross estimates of the water available from a basin. Because it is standardized by drainage area it is a useful index for comparing the hydrologic response of basins of different sizes. Annual runoff was expressed as calculated annual runoff and as estimated annual runoff. Calculated annual runoff included runoff values for the period of record at each hydrometric station. Estimated annual runoff was the total runoff for the entire open water season.

The mean annual discharge (MAD), computed as an average discharge over the year, is an additional variable that gives an indication of the potential amount of water a basin can provide as a function of drainage area, geology and climate.

Peak flows represent the maximum flow rate of a catchment during a year in response to precipitation events or snowmelt. Peak flows are used in combination with flood frequency analysis techniques in order to estimate design flows used in the sizing of ditches, diversion channels, or stream crossings. Conversely, low flows provide an estimate of the normal baseflow conditions during the open water season, which is important to the sustained health of a stream's aquatic community.

3.7 TIDE LEVELS

The periodic rise and fall of the ocean was recorded by an automated hydrometric station (tide gauge) that was installed approximately 270 m west of the existing jetty that is located in the southern part of Roberts Bay (Figure 3.1-1 and Table 3.7-1). The tide gauge operated from July 21st to October 2nd when the station was demobilized to prevent winter freeze up.

The station consisted of a Levelogger® M-10 (Solinst Canada Ltd.) pressure transducer/data logger combination. The Levelogger was attached to a floating marker and anchored to the ocean bottom. The unit recorded water levels every 10 minutes. A Barologger® (Solinst Canada Ltd.) was installed on shore and recorded atmospheric pressure to correct the Levelogger absolute pressure readings. The elevation of the tide gauge at Roberts Bay (relative to a geodetic benchmark) was determined using a total station surveying instrument.

Table 3.7-1. Summary of Hydrometric Station at Roberts Bay

Hydrometric Station	Location	Geographic Coordinates[a]		Period of Operation	Monitoring Type
		Easting (m)	Northing (m)		
Roberts Bay - Hydro	Roberts Bay, approximately 270 m of existing jetty	432,212	7,563,352	July 21 to October 2	ocean water level

[a] *- UTM Zone 13W, NAD83*

4. Results

4. Results

4.1 DORIS/MADRID AREA

Results from the 2010 Hydrology Monitoring Program in the Doris/Madrid area are presented as follows: (1) completed discharge measurements, (2) determined stage-discharge relationships, (3) lake water levels, (4) discharge hydrographs, (5) ocean tide levels at Roberts Bay, and (6) additional hydrologic indices for the area.

4.1.1 Discharge Measurements

Discharge measurements were taken during the June freshet period at each hydrometric station with additional measurements conducted in July, August, September, and October 2010, for a total of 46 measurements. The measurements were collected through the open water season in order to obtain a range of discharges at different flow conditions (Table 4.1-1 and Appendix A1).

Surface flows were not measured at the hydrometric station Wolverine-Hydro because there was no defined outlet channel. Negligible amounts of flow were observed spread over marsh-like features on the north and south east ends of the lake although they could not be measured.

Table 4.1-1. Summary of Completed Discharge Measurements in the Doris/Madrid Area in 2010

Hydrometric Station and Drainage Area	Date Measured	Pressure Transducer Stage (m)*	Measured Discharge (m^3/s)	Method (Equipment Used)
Doris-Hydro ($95\ km^2$)	June 10	98.891	0.71	Velocity-Area (Swoffer current meter)
	June 15	99.117	2.34	Velocity-Area (Swoffer current meter)
	July 15	98.919	0.93	Velocity-Area (Swoffer current meter)
	August 19	98.773	0.51	Velocity-Area (Swoffer current meter)
	October 4	98.723	0.45	Velocity-Area (Swoffer current meter)
Koignuk-Hydro ($2,937\ km^2$)	June 13	96.945	118.62	Velocity-Area (ADCP)[†]
	June 16	99.074	187.53	Velocity-Area (ADCP)
	July 22	96.608	24.96	Velocity-Area (ADCP)
	August 18	96.507	7.82	Velocity-Area (ADCP)
	October 5	96.550	8.32	Velocity-Area (ADCP)
Ogama-Hydro ($75\ km^2$)	June 11	98.770	1.86	Velocity-Area (Swoffer current meter)
	June 16	98.867	3.41	Velocity-Area (Swoffer current meter)
	July 16	98.548	0.61	Velocity-Area (Swoffer current meter)
	August 18	98.436	0.40	Velocity-Area (Swoffer current meter)
	October 1	98.413	0.39	Velocity-Area (Swoffer current meter)
Patch-Hydro ($32\ km^2$)	June 11	[a]	0.05	Velocity-Area (Swoffer current meter)
	June 16	99.126	0.53	Velocity-Area (Swoffer current meter)
	July 14	98.995	0.34	Velocity-Area (Swoffer current meter)
	July 18	99.034	0.33	Velocity-Area (Swoffer current meter)
	August 14	98.957	0.26	Velocity-Area (Swoffer current meter)
	October 1	98.843	0.13	Velocity-Area (Swoffer current meter)

(continued)

Table 4.1-1. Summary of Completed Discharge Measurements in the Doris/Madrid Area in 2010 (completed)

Hydrometric Station and Drainage Area	Date Measured	Pressure Transducer Stage (m)*	Measured Discharge (m^3/s)	Method (Equipment Used)
PO-Hydro ($68\ km^2$)	June 14	98.733	3.76	Velocity-Area (Swoffer current meter)
	June 16	99.542	3.37	Velocity-Area (Swoffer current meter)
	July 14	98.600	0.51	Velocity-Area (Swoffer current meter)
	August 18	98.607	0.31	Velocity-Area (Swoffer current meter)
	October 1	98.560	0.30	Velocity-Area (Swoffer current meter)
Reference B-Hydro ($159\ km^2$)	June 11	98.593	2.90**	Velocity-Area (Swoffer current meter)
	July 18	98.317	2.78	Velocity-Area (Swoffer current meter)
	August 17	98.174	0.49	Velocity-Area (Swoffer current meter)
	September 30	98.123	0.24	Velocity-Area (Swoffer current meter)
Roberts-Hydro ($98\ km^2$)	June 14	99.349	3.15	Velocity-Area (Swoffer current meter)
	June 18	99.483	5.60	Velocity-Area (Swoffer current meter)
	July 15	99.184	0.90	Velocity-Area (Swoffer current meter)
	August 19	99.124	0.58	Velocity-Area (Swoffer current meter)
	October 1	99.096	0.41	Velocity-Area (Swoffer current meter)
Tail-Hydro ($4\ km^2$)	June 6	[a]	0.08	Velocity-Area (Swoffer current meter)
	June 10	97.985	0.10	Velocity-Area (Swoffer current meter)
	June 15	98.023	0.18	Velocity-Area (Swoffer current meter)
	July 15	97.906	0.02	Velocity-Area (Swoffer current meter)
	August 19	97.898	0.02	Velocity-Area (Swoffer current meter)
	October 4	97.955	0.02	Velocity-Area (Swoffer current meter)
Windy-Hydro ($14\ km^2$)	June 10	99.369	0.005	Velocity-Area (Swoffer current meter)
	June 16	99.429	0.34	Velocity-Area (Swoffer current meter)
	July 16	99.454	0.20	Velocity-Area (Swoffer current meter)
	August 14	99.437	0.26	Velocity-Area (Swoffer current meter)
	September 25	99.369	0.16	Velocity-Area (Swoffer current meter)

† - Discharge measured by means of an acoustic Doppler current profiler
a- Station not installed
**- Pressure transducer stage referenced to site-specific arbitrary datum*
***- Flow under ice conditions, discharge was underestimated*

4.1.2 Stage-Discharge Relationships

At seven of the nine hydrometric stations, the data collected in 2010 were combined with the data collected in 2009 in order to increase the range and the robustness of the rating curves. In addition, higher flows measured in 2010 helped to better define the upper end of the rating curve at most stations.

Rating equations for each station are summarized in Table 4.1-2; the rating curves are provided in Appendix A2. Survey control points at each lake and stream level station are provided in Appendix A3.

Table 4.1-2. Summary of 2010 Stage-Discharge Rating Equations in the Doris/Madrid Area

Hydrometric Station	Rating Equation $Q = C (h-a)^B$
Doris-Hydro	
low stage	Q = 1.60(h-98.26)1.65
high stage	Q = 4.88(h-98.26)4.28
Koignuk-Hydro	Q = 26.36(h-96.38)2.06
Ogama-Hydro	Q = 5.25(h-98.05)2.68
Patch-Hydro	Q = 1.37(h-98.44)2.53
PO-Hydro	Q = 16.45(h-99.16)2.44
Reference B-Hydro	Q = 44.61(h-98.01)2.39
Roberts-Hydro	Q = 20.99(h-98.94)2.11
Tail-Hydro	Q = 3.98(h-97.81)2.07
Windy-Hydro	Q = 7.08(h-99.2)2.18

Q = discharge [m^3/s]; C= y intercept; h= recorded stage [m]; a= stage at zero flow (datum correction) [m]; B= slope

At the Doris-Hydro hydrometric station, a two-stage (high and low) rating curve was found to provide a better fit to the observed data than a single stage curve and was used to generate a hydrograph for this station. Low flows were well confined by the outlet channel. However, overbank flow during the spring freshet period resulted in a shift in the slope of the rating curve at higher stages (see Appendix A2).

At the Patch-Hydro hydrometric station the channel's hydraulic geometry along the outlet channel changed from 2009 to 2010. This produced a change in the rating relationship, reflected by a change in the slope of the rating curve from 2009 to 2010. As a result of this shift, the rating curve for this site was developed using only data from 2010.

The Reference-B Hydro hydrometric station was installed on June 11, 2010. The discharge measurement taken at the time of station installation was likely underestimated because flow under ice conditions were suspected. This measurement was not used in the development of the stage-discharge relationship. Therefore, it is important to note that the rating relationship developed for this site is preliminary because it was developed using three stage-discharge measurements associated with low-to-medium flow conditions. A more robust rating curve will be generated once additional discharge measurements associated with high flow conditions are taken in 2011.

4.1.3 Lake Levels

Lake levels were recorded at Doris, Patch, PO, Roberts, Tail, Windy, Wolverine, and Reference B lakes. The mean level variation for lakes in the northern part of the belt was 0.34 m, ranging from 0.10 m at Windy Lake to 0.68 m at Doris Lake (Table 4.1-3). Lake water levels decreased after freshet and they were recharged from precipitation events in mid-July, early-August, early-September, and mid-September. Mean daily lake levels are presented in Figures 4.1-1 to 4.1-4 and in tabular form in Appendix A4.

Table 4.1-3. Recorded Lake Water Levels for the 2010 Open Water Season in the Doris/Madrid Area

Lake	Min Water Level (m)	Max Water Level (m)	Water Level Change (m)	Lake Area (km^2)
Doris a	5.44	6.12	0.68	3.4
Tail a	4.95	5.12	0.17	0.8

(continued)

Table 4.1-3. Recorded Lake Water Levels for the 2010 Open Water Season in the Doris/Madrid Area (completed)

Lake	Min Water Level (m)	Max Water Level (m)	Water Level Change (m)	Lake Area (km^2)
Patch	98.84	99.14	0.30	5.7
PO	99.36	99.70	0.34	0.8
Roberts	99.08	99.48	0.40	3.6
Windy	99.38	99.48	0.10	5.3
Wolverine	98.67	98.91	0.24	1.0
Reference B	98.11	98.58	0.47	10.6

[a-] *Water levels are referenced to pressure transducer*

4.1.4 Annual Discharge Hydrographs

Hydrographs were generated for the four hydrometric stations monitoring stream water level (Doris-Hydro, Tail-Hydro, Ogama-Hydro, and Koignuk-Hydro) as well as for the outflow of five of the eight hydrometric stations monitoring lake water level. These are individually presented in Appendix A5. Due to the lack of well defined flows at the Wolverine-Hydro hydrometric station, a rating curve and a hydrograph could not be generated.

It is important to note that there is some degree of uncertainty as to whether the maximum measured discharge at PO-Hydro (3.8 m^3/s on June 14th) was the actual peak flow or whether the maximum flow for the open-water season occurred previous to the site visit on June 14th .

At the Reference B-Hydrometric station, flow under ice conditions likely resulted in the underestimation of the discharge measured on June 11, 2010. This discharge measurement, associated with the highest stage on record for 2010, was not used in the generation of the stage-discharge relationship for this site. Therefore, there is some degree of uncertainty associated with the period of medium-to-high flow conditions shown in the hydrograph between June 11th and July 17th.

Annual hydrographs are presented as mean daily discharge (Figures 4.1-5 and 4.1-6) and as mean daily unit yield (Figure 4.1-7) for the open-water season (June 1st to November 13th). Daily discharge is the average discharge calculated over a 24 hour period. Similarly, the daily unit yield is an index of daily discharge normalized by drainage area. This index allows for direct comparison of the potential volumetric rate of water that can be expected as a function of drainage area.

The mean daily discharge hydrographs show that the onset of the spring freshet occurred in early-June throughout the watersheds in the Doris/Madrid area. Annual peak flows occurred in mid-June in most basins except Windy Watershed where it occurred in late-July. Peak flows resulted from inputs of water from melting snow (between June 14 and June 19, 2010). On average the freshet peak occurred approximately two weeks after streams began to flow. The exception was Windy Watershed where the annual peak occurred approximately seven weeks after the onset of the freshet period and was generated by precipitation events that occurred between July 16th and July 20th.

Following the spring freshet period discharge steadily decreased throughout the Doris/Madrid area until mid-July. After that daily discharges were augmented by rainfall events that occurred between July 14th and July 19th. By the end of July, discharge continued to recede until September when flow discharges increased in response to precipitation events that occurred on September 5th and September 14th.